Improving Vertical Coordination from Farm-To-Plant Using A Cooperative

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Abstract: The drive to make the food delivery system more efficient is affecting milk marketing cooperatives. This paper analyzes ways to improve the vertical coordination between the farm and the processing level via a cooperative through a more efficient transportation system.

Keywords: Cooperative, dairy, milk, vertical coordination

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In 1992, firms in food retailing became aware of a new competitor, Wal-Mart. Wal-Mart arrived on the food retailing scene with a very cost efficient inventory, warehouse, and trucking system that allowed them to reduce operating costs five percentage points below the food retailing industry average (Kinsey, 1998). In reaction to Wal-Mart, supermarket chains through their trade associations started an initiative called the Efficient Consumer Response (ECR) with an objective of designing a food delivery system that was more efficient (Kinsey and Senauer, 1997).

The drive to make the food delivery system more efficient started affecting the Florida milk marketing cooperatives (MMC) in the late 1990's. Florida fluid milk processors and Florida dairy farmers belonging to the MMC asked the MMC to become more efficient. The MMC told processors and farmers that the standard operating procedures of the processors and farmers were inhibiting the MMC from becoming more efficient. For example, instead of each processor receiving the same number of loads of milk each day of the week, they order a different number of loads of milk each day. Furthermore, processors will cancel loads of milk the day before delivery. This action by a processor raises the cost of delivering milk to the processor. On the farmer side, a dairy farmer will have a small bulk tank that requires the cooperative to make two or more collections from the farm per day. This action by the farmer increases the cost of collecting milk from the farmer. Therefore, there needs to be an increased awareness about how the actions of each member of the vertical market system influence the business operation of the others. There needs to be an increased commitment by the three entities to 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 market place is forcing the MMC to perform the job better. Farmers and processors want milk collected and delivered on a time schedule. It is the MMC's job to insure that 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 marketing margin between the processor's price and the farm price. If a reduction occurs,a higher price farmers receive obtained by farmers and a gain in farmer return. In the longer run, the savings will be divided among the processors and farmers.

Methodology

According to the 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 only solve small problems (e.g., the integer-programming computer program written by Sutcliffe and Board, 1990). The ArcLogistics algorithm was used in this study and is an example of an algorithm that can solve large problems (i.e., 203 dairy farms and 13 fluid milk processing plants served by eight truck terminals). However, ArcLogistics can only insure a local optimum.

ArcLogistics Route (ALR) is the routing-scheduling software distributed by the Environmental Systems Research Institute, Inc. (ESRI). 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 first groups, or clusters, demand nodes into routes. It 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 Routes (ALR) is not exactly those classical procedures. ALR was created based on ESRI's experience gained from the Sears projects, Sears logistics services and Sears product services (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, including (1) the resource-assignment algorithm, and then (2) 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 by the multiple-insertion algorithm (MI). 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) $$C = Min\left(\beta_1 \sum d + \beta_2 \sum v + \beta_3 \sum w\right)$$

where d is the total traveling distance, v is total time window violations (e.g., hours), and w represents total waiting times (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, which are the initial-route building, the stop assignment, and the optimal post-insertion improvement (Weigel and Cao, 1999).

The MI procedure begins with an initial-route building. This step constructs an initial route to each available truck. The initial route includes only the starting and ending points. Second, the MI procedure adds unassigned stops into the routes. 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 (Weigel and Cao, 1999)

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

where C_{ijk} 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) $$C_{xyz} = Min\{C_{irk} \mid \text{for all } i, r, \text{ and } k\}.$$

[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 processes are attempts to improve the initial route constructed from the first MI algorithm. The sequence-and-route improvement procedure consists of two heuristic procedures, which are the intraroute and interroute 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), in order to obtain an outcome beyond the local optima. This outcome cannot be achieved solely by using the interroute- and intraroute improvement procedures.

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

A transferring move is a procedure that moves a stop from the original route and inserts it in 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 either any existing constraint is violated or the stop was 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 that will be presented next.

The intraroute-improvement procedure. According to 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 precedure (1976) was proven to be effective for solving the TSPTW (Cao and Rinderle, 1992 and 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 the later position within the sequence. The same is true for backward insertions except a stop is inserted in the 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) $$\Delta d_{ij} = d_{i-1,i+1} + d_{j,i} + d_{i,j+1} - d_{i-1,i} - d_{i,i+1} - d_{j,j+1},$$

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

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

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

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

Procedures

The analysis was performed using the ArcLogistics Route 2.0 software (ALR) provided by the Environmental System Research Institute (ESRI) in 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 fluid milk processing plants' time windows. 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 processing plant time window last[2]. The "specialty" option in ALR restricted a truck to a processing plant time window. Trucks destined to deliver farm milk loads to processing plant A

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

in Lakeland could not visit the 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 processing plant time windows, some trucks visited the processing plant before visiting a farm to pick up milk. This happened because the solver wanted trucks to meet the time window constraints at the processing plant even if they had no milk to deliver. This problem was solved by using the following procedures. First, run the ALR solver. Second, investigate all routes. If the plant time windows are the last orders on all truck routes (i.e., all farms were visited before the plant time window), the procedure was finished. If not, then (1) lock in (i.e., keep) the routes which had plant time windows as the last orders on the routes and (2) rerun the solver. Perform (1) and (2) until all routes have a plant time window as the last stop.

Data and Assumptions

Truck scheduling data was provided by the MMC during the period of October 3-9, 1999, involving 203 dairy farms, 13 fluid milk processing plants, 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, Jacksonville, Okeechobee, Tallahassee, Tampa, and Unadilla, respectively (MMC unpublished paper (1999). Milk supply is assumed equal to demand (i.e., no imported milk) during the studied 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 places). All farm milk loads stored at terminals were sent directly to fluid milk processing plants before farm milk loads that were picked up on that day. However, milk could only be stored up to 72 hours (3 days) at 40 degrees Fahrenheit before delivered to the fluid milk processing plants.

Each terminal served farms in its own area and performed first in first out policies (FIFO). All terminals were open 24 hours a day.

Tank trailers had a capacity of 55,000 pounds (550 hundredweight) in Okeechobee and Avon Park terminal areas, 53,000 pounds (530 hundredweight) in Belleview, Jacksonville, Mayo, Tallahassee, and Unadilla areas, and 50,000 pounds (500 hundred weight) in Tampa area (MMC dispatch sheet). Tractors and trailers began a route at a MMC terminal and finished at a fluid milk processing plant or finished at the same terminal from which they left. The empty load miles traveled after unloading farm milk at the fluid milk processing plant was not considered in this analysis. The average truck speed was assume to be 55 miles per hour for highways with limited access, 40 miles per hour for the local highways, 35 miles per hour for primary and secondary streets, and 25 miles per hour for local streets. Cost per mile used in this analysis was $1.29 (the MMC's report), which included the cost of fuel, maintenance and depreciation. Cost per hour was assumed to be $15.00[3], which included the hourly wage of the driver both in regular time and over-time.

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[3] Average wage for Florida Truck Drivers, Heavy and Tractor-Trailer in 1999 reported by U.S. Department of Labor statistic is $14.42.

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 square. 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 the service areas of (1) Okeechobee and Avon Park, (2) Tampa, (3) Belleview and Mayo, (4) Jacksonville, (5) Tallahassee, and (6) Unadilla.

The benchmark run was the actual milk collection and delivery performed from Sunday, October 3 through Saturday, October, 9, 1999 by the MMC. All information was put in 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 and 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 and minus 2 hours from the scheduled pickup (allowing flexibility in the scheduling and routing process by ALR). The plus and minus 30 minutes for processing 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 scenarios were performed and compared in all service areas.

Empirical Results

The truck cost of $1.29 per mile is used to generate cost per mile in the benchmark and alternative runs. Therefore, savings corresponding to mile reduction (switching from benchmark to alternative run) in all service areas were $7,387.26, October 3-9, 1999 (Table 1).

The total mileage reduction (October 3-9) between the benchmark and alternative runs ranged from 284.44 miles for the Unadilla area to 1,627.16 for the Belleview-Mayo area (Table 1). However, the mileage reduction percentage ranged from a low 0.74 percent for the Avon Park-Okeechobee area to a high 14.01 percent for the Tampa area (Table 1).

Most farms (96.9 percent) in the Avon Park-Okeechobee area provided a full load of milk. More than 95 percent of the trucks had only one stop. Conversely, the Tampa service area had 7.29 one-stop routes on average, or 53.2 percent 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 finishing the pickup process. There were no time window restrictions, unlike the processing plants.

The 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 a cost savings of $4,095.88 by decreasing the hours for the October 3-9, 1999 period (Table 2).

Processing plant time window violations (hours) and the total number of time window violations are important components of overall dispatching efficiency for handling milk at fluid milk processing plants. For the benchmark run, the plant time window violations (hours) in total (October 3-9) ranged from 12.21 hours for the Jacksonville area to 180.82 hours for the Avon Park-Okeechobee area; whereas, they ranged from 0.07 hours for the Jacksonville area to 17.15 hours for the Belleview-Mayo area in the alternative run (Table 3). The reduction in plant time window violations (hours) in total (October 3-9) between the benchmark and alternative runs ranged from a low 55.14 percent (21.07 hours) for Belleview-Mayo area to a high 99.43 percent (12.14 hours) hours for the Jacksonville area (Table3).

Total number of plant time violations (October 3-9) for the benchmark run ranged from six for the Jacksonville area to 60 for the Avon Park-Okeechobee area. They ranged from one for the Jacksonville area to 29 for the Belleview-Mayo area for the alternative run (Table 4). The reduction in total number of plant time window violations between the benchmark and alternative runs ranged from a low 19.44 percent for Belleville-Mayo area to a high 83.33 percent for the Jacksonville area (Table 4).

Farm time window violations associated with hours in total (October 3-9) ranged from 20.47 hours for the Avon Park-Okeechobee area to 125.18 hours for the Belleview-Mayo area in the benchmark run; while they ranged from none for the Unadilla area to 3.22 hours for the Belleview-Mayo area in the alternative run (Table 5). The total number of farm time violations (October 3-9) for the alternative run ranged from none for the Unadilla area to seven for the Belleview-Mayo area in the benchmark run, and they ranged from 29 for the Avon Park-Okeechobee area to 142 for the Belleview-Mayo area in the benchmark run (Table 6).

Sensitivity Analysis

Sensitivity analysis shows how sensitive the results are if some constraints are relaxed. It was performed in three cases. In the first case, imported milk loads were added in the analysis when all constraints remained unchanged. In the second case, there were no time window constraints at the dairy farms (milk loads can be picked up any time). In the last case, there were no time window constraints at both the dairy farms (milk loads can be picked up anytime) and the processing plants (milk loads can be delivered anytime).

Imported Milk Procurement

The imported milk loads are the milk loads brought from external supply sources (non-members of MMC) to the processing plants in the system. Sensitivity analysis results involving imported milk procurement indicate little effect on the transportation system resulting from inclusion of the imported milk loads. Most imported milk loads arrived at the processing plants at times that did not have an impact on the system.

No Farm Time Constraints and No Time Farm-No Time Plant Constraints

The mileage reduction was 854.69 miles (3.71 percent) between the alternative and the sensitivity run associated with no farm and plant time window constraints (Table 8). Whereas, a 106.04-mile reduction, or 0.48 percent, was obtained through comparison between the sensitivity run associated with no farm and plant time constraints and the sensitivity run associated with no farm time constraints (Table 8). In terms of total route time, 22.36 hours (2.98 percent) and 1.34 hours (0.18 percent) are gained when comparing the alternative run and the sensitivity run with no farm time constraints to the sensitivity run with no farm and plant time constraints (Table 8). A truck cost of $1.29 per mile and $15 per hour was used to generate total route expenses. Relaxing the farm time constraints leads to a savings of $1,281.14 correlated to mileage and hour reduction (Table 8). Further savings through relaxing plant time constraints (relative savings of the sensitivity run associated with no farm and plant time constraints and the sensitivity run associated with no farm constraints) were $156.88 (Table 8). The sensitivity run associated with no farm time constraints and the sensitivity run with no farm and plant time constraints are identical for the Tallahassee and Unadilla service areas due to no direct shipments from farm to plant in these service areas.

Unlike the benefit received from the alternative run, the small mileage and hour reduction for the sensitivity run with no farm time constraints and the sensitivity run with no farm and plant constraints indicates a small benefit ($156.88) to the MMC. As a result, the MMC should retain the current plant delivery schedule, so as to maintain the processors' satisfaction. Furthermore, MMC should focus on savings through its members' coordination (dairy farmers for $1,438).

Summary

Scheduling and routing are important activities for distributing highly perishable agricultural commodities in the vertical market system. This is especially true for fluid milk, which requires virtually instantaneous transportation from producers to processing plants in order to maintain the quality of the product. The objective of this article is to determine the most efficient way for scheduling and moving farm milk from producers to the processing plants for the MMC. The literature review points out that the scheduling and routing problem is very complex. As the number of producers increase, the possible ways to route and schedule trucks increases. The problem increases in complexity when farm and processing-plant time windows are added. The scheduling and routing software, ArcLogistics Route 2 (ALR), is used to achieve results. ALR seeks efficient routes by using data about farms, trucks, and processing plants with its built-in street network database.

Truck scheduling data were provided by the MMC for the period of October 3-9, 1999. The benchmark run was the actual milk collection and delivery routes used by the MMC. The MMC had a scheduled pickup time for each farm and a delivery time schedule for each plant. A plus and minus 30-minute processing-plant time window was included in the benchmark model. On the other hand, the alternative run was routed and scheduled by ALR with a plus and minus two-hour farm time window and a plus and minus 30-minute processing-plant time window.

The number of miles and number of time window violations are two key results. The number of miles is directly related to the MMC's cost of scheduling and routing milk from producers to processors. In contrast, the number of time window violations (number and hours) implies the time schedule performance of the MMC's dispatchers. Fewer farm time window violations improve the satisfaction of milk producers. The processing-plant managers are more satisfied with the lower processing-plant time window violations (a time window is violated if a truck visits a farm or processing plant before or after its time window). The benchmark and alternative runs were performed and compared in all service areas (Avon Park-Okeechobee, Tampa, Belleview-Mayo, Jacksonville, Tallahassee, and Unadilla).

The total mileage reduction (October 3-9) between the benchmark and alternative runs range from a low 0.74 percent for the Avon Park-Okeechobee area to a high 14.01 percent for the Tampa area. The Tallahassee area was second highest behind Tampa with 13.62 percent. The percentage reduction dropped to 8.92 percent for Unadilla, 7.12 percent for Jacksonville, and 2.15 percent for the Belleview-Mayo area. For all service areas, 5,726 miles, or 3.36 percent, 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 all service areas was $7,387.26 (October 3-9).

One reason for different mileage reductions might be the nature of the service areas. More multiple-stop routes allow for more combinations in the route construction process and results in the potential for mileage reduction. For example, most farms in the Avon Park-Okeechobee area (96.9 percent) provided a full load of milk for each truck. Thus, more than 95 percent of the trucks in this area made only one stop. The mileage reduction between the benchmark and the alternative run was 0.74 percent. For the Belleview-Mayo area, 84 percent of the routes were one-stop routes, and the mileage reduction in this area was 2.15 percent. Next is the Jacksonville area, which had 73.8 percent one-stop routes and a 7.12 percent mileage reduction. For the Tampa area, which had the highest mileage reduction (14.01 percent), 53.2 percent of the total routes were one-stop routes. Thus, the correlation between the mileage reduction percentage and the percentage of multiple-stop routes applied to the Avon Park-Okeechobee, Tampa, Belleview-Mayo, and Jacksonville areas. In other words, the more multiple-stop routes, the more potential mileage reduction. However, these findings were mixed in the Tallahassee and Unadilla areas where there are no direct milk load deliveries from dairy farms to processing plants. All trucks in the Tallahassee and Unadilla areas returned to their terminals after finishing the pickup process; there were no time window restrictions, unlike the processing plants. Tallahassee adhered to the correlation between the mileage reduction percentage and the percentage of multiple-stop routes; Unadilla did not.

The hours of plant time window violations and the total number of time window violations (frequency) are important components of overall dispatching efficiency for moving milk to the fluid milk processing plants. The reduction in hours of total plant time window violations (October 3-9) between the benchmark and alternative runs started from a low 55.14 percent for the Belleview-Mayo area (70.38 percent for Tampa and 92.35 percent for Avon Park-Okeechobee) to a high 99.43 percent for the Jacksonville area. The reduction in hours of plant time window violations between the benchmark and alternative runs was 83.71 percent for all service areas (October 3-9). Meanwhile, reduction in the number of plant time window violations between the benchmark and alternative runs began with a low 19.44 percent for the Belleview-Mayo area (66.67 percent for Avon Park-Okeechobee and 73.91 percent for Tampa) to a high 83.33 percent for the Jacksonville area. The reduction in the number of plant time window violations between the benchmark and alternative runs was 55.20 percent for all service areas (October 3-9).

The reduction in hours of farm time window violations (October 3-9) between the benchmark and alternative runs ranged from a low 90.62 percent for the Avon Park-Okeechobee area (96.52 percent for Jacksonville, 97.43 percent for Belleview-Mayo, 99.70 percent for Tallahassee, and 99.90 percent for Tampa) to a high 100 percent for the Unadilla area. The reduction in hours of farm time window violations between the benchmark and alternative runs was 98.00 percent for all service areas. Meanwhile, the reduction in the number of farm window violations between the benchmark and alternative runs started from a low 83.33 percent for the Avon Park-Okeechobee area (91.67 percent for Jacksonville, 95.30 percent for Belleview-Mayo, 96.43 percent for Tallahassee, and 98.57 percent for Tampa) to a high 100 percent for the Unadilla area. The reduction in the number of farm window violations between the benchmark and alternative runs was 95.69 percent for all service areas.

Sensitivity analysis shows how the results change if some constraints are relaxed. Constraints on the alternative run were relaxed in three scenarios. First, non-MMC farm milk loads (imported milk loads) were added to the MMC farm milk loads in order to meet processor demand (imported milk loads were included in the alternative run). Second, the alternative run was changed so there were no time window restrictions at the dairy farms. Third, the alternative run was altered so that time windows were eliminated from farms and processing plants (results from sensitivity runs were compared with those from the originally constrained alternative run). In the first case, the sensitivity analysis results involving imported milk indicates little effect (less than a 0.4 percentage reduction in all categories) on the transportation system resulting from inclusion of the imported milk loads. In the second case, the reduction between the alternative and sensitivity runs was 3.25 percent in terms of mileage and 69.49 percent in terms of hours of plant time window violations. The reduction in mileage was small, but the plant time window reductions were large. This indicates that if MMC were allowed to pick up milk loads without farm time window restrictions, the processing-plant time window violations would be reduced by almost 70 percent. Moreover, results from the third sensitivity run (no farm and plant time window constraints) showed little further improvement from the second sensitivity run (less than a 0.5 percentage reduction in mileage and total used time).

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Table 1. Total mileage comparisons between the benchmark and alternative runs for the Avon Park-Okeechobee, Tampa, Belleview-Mayo, Jacksonville, Tallahassee, and Unadilla service areas, October 3-9, 1999.

Service Areas	Benchmark	Alternative	Reduction		
	Total Weekly Miles			Percent	Dollar[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	1156.61	7.12	$1,492.03
Tallahassee	9,732.11	8,406.85	1325.27	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/mile.

Table 2. Total route time comparisons between the benchmark and alternative runs for the Avon Park-Okeechobee, Tampa, Belleview-Mayo, Jacksonville, Tallahassee, and Unadilla service areas, October 3-9, 1999.

Service Areas	Benchmark	Alternative	Reduction		
	Total weekly hours			Percent	Dollar[a]
Avon Park-Okeechobee	1729.26	1718.69	10.57	0.61	$158.55
Tampa	340.38	319.30	21.08	6.19	$316.20
Belleview-Mayo	2259.87	2161.42	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)	5594.66	5321.60	273.06	(4.88)	$4,095.88

[a]Cost reduction is based on cost of $15/hours.

Table 3. Total processing plant time window violations (hours) for the benchmark and alternative runs for the Avon Park-Okeechobee, Tampa, Belleview-Mayo, Jacksonville, Tallahassee, and Unadilla service areas, October 3-9, 1999.

Service Areas	Benchmark	Alternative	Reduction	
	Total Weekly 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)

Table 4. Number of processing plant time window violations for the benchmark and alternative runs for the Avon Park-Okeechobee, Tampa, Belleview-Mayo, Jacksonville, Tallahassee, and Unadilla service areas, October 3-9, 1999.

Service Areas	Benchmark	Alternative	Reduction	
	Total Weekly 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)

Table 5. Total farm time window violations (hours) for the benchmark and alternative runs for the Avon Park-Okeechobee, Tampa, Belleview-Mayo, Jacksonville, Tallahassee, and Unadilla service areas, October 3-9, 1999.

Service Areas	Benchmark	Alternative	Reduction	
	Total Weekly 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 (number) for the benchmark and alternative runs for the Avon Park-Okeechobee, Tampa, Belleview-Mayo, Jacksonville, Tallahassee, and Unadilla service areas, October 3-9, 1999.

Service Areas	Benchmark	Alternative	Reduction	
	Total Weekly 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)

Table 7. Mileages, processing plant time violations, and total route time between the alternative and sensitivity runs (imported milk) for all service areas on Thursday, October 6, 1999.

	Number of Miles	Plant Time Window Violations (hours)	Number of Plant Time Violations	Total Route Time (hours)
Alternative run	23,035.08	4.95	4	749.45
Sensitivity run	22,949.43	4.93	4	747.46
Change	85.65	0.02	-	1.99
Change (percent)	0.37	0.40	-	0.27

Table 8. Mileage and total route time comparisons of the alternative run, sensitivity run associated with no farm time constraints, and sensitivity run associated with no farm and plant time constraints for the Avon Park-Okeechobee, Tampa, Belleview-Mayo, and Jacksonville service areas, October 7, 1999.

	Number of Miles	Total Route Time (hours)	Total Cost[a] (dollars)
Alternative run	23,035.08	749.45	40,957.00
Run with no farm time constraints	22,286.42	728.43	39,675.87
Run with no farm and plant time constraints	22,180.39	727.09	39,518.99
Reduction from alternative run (percent)	854.69 (3.71%)	22.36 (2.98%)	1,438.02
Reduction from run with time windows at farms (percent)	106.04 (0.48%)	1.34 (0.18%)	156.88

[a]Total cost was calculated using a vehicle cost of $1.29 per mile and $15 per hour.