APPLYING NETWORK ANALYSIS
METHODS TO EFFICIENT VEHICLE USE
FOR MILK ASSEMBLY

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APPLYING NETWORK METHODOLOGY TO EFFICIENT VEHICLE USE
FOR MILK ASSEMBLY

Introduction

Using readily available network analysis methods, a study was undertaken to: 1) estimate the potential savings in resources which could be realized if assemblers of raw milk used mathematical techniques to schedule their assembly vehicles and to 2) quantify the magnitude and cost of route duplication and scheduling inefficiency present in a milk assembly system operated in a region of New York state.

This paper briefly discusses network methods and, in particular, those network methods used in this analysis and why they offer advantages over other equivalent methods. The data used in the analysis and the heuristic use of the optimizing methods as well as procedures used by the authors to overcome complexities present in the actual milk assembly system studied are described. Characteristics of the redesigned milk assembly system are presented and estimates of the magnitudes of inefficiencies derived.

Network Methods

The study and use of network methods increased dramatically between the early 1960's and late 1970's and continues to receive increased attention in both the theoretical and applied areas of operations research (Bradley, and Golden and Magnanti). This has resulted because network models 1) accurately represent many actual systems
which are encountered in applied studies, 2) are more easily explained
to nonanalysts, 3) allow for the low-cost solution of large-scale
problems, 4) can solve some problems with significantly more
variables and constraints than other equivalent optimization tech­
niques. Also, many large-scale optimization problems have embedded
subproblems which can be efficiently solved as networks.

Many naturally occurring systems can be expressed as networks with
a nodes/arcs/flows structure:

airports/airlanes/aircraft,
switch points/telecommunications lines/messages,
pumping stations/pipelines/fluids and gases,
work centers/materials handling/jobs, and
dairy farms and plants/roads/milk and
milk assembly vehicles.

Classic network problems include the minimum spanning tree prob­
lem, the maximum flow problem, the shortest path problem, the transpor­
tation, assignment, or transshipment problems, the postman problem
(Bradley), and the traveling salesman problem (Christofides 1975).

Three of these generic problems are represented in this analysis--the
shortest path, transportation and traveling salesman problems. A
shortest path algorithm was used to calculate the necessary distance
information from the network representing the detailed road system
connecting the farms, garages, and plants. A transportation algorithm
was used to assign farms to processing plants or garages. And, the
actual vehicle routing problem is a variation of the traveling salesman
problem.
Shortest Paths

In a directed network with lengths (distances, costs, times, etc.) assigned to the arcs, this problem is to find the minimum total length (total distance, cost, time, etc.) path 1) from one node to another, 2) from one node to all other nodes, or 3) from all nodes to all other nodes. Many very obvious applications for calculating shortest paths exist as well as some not-so-obvious applications (e.g. Phillips et al., pp.95-101 and Pang and Yu). Moreover, highly efficient algorithms exist for solution of large-scale problems (e.g. Gilsinn and Witzgall).

In the study area there were 507 (n) points of interest (nodes), farms, garages, plants, resulting in a total of 128,271 distances (n(n-1)/2). Manual measurement of each of these distances would be impractical because of the time required and the tremendous potential for error. Measuring each distance would also require the selection of the best path to follow between any two points, clearly a formidable task in such a large problem. Instead, the farms, plants, haulers' locations, road intersections and connecting roads were defined as a network and a shortest path algorithm (Gilsinn and Witzgall) was used to derive the 128,271 shortest distances needed. To enumerate all shortest paths, only distances between each node and its adjacent nodes were needed. As a result, only 4,097 distances needed to be measured on United States Geological Service 1:24,000 scale maps. This is still a formidable task, but it is clearly a much easier procedure than attempting to measure all 128,271 distances and more accurate than
using an approximating grid procedure. The actual computations costs were less than $8 on Cornell University's IBM 3081.

**Transportation**

Unnecessary route duplication was defined as the miles and minutes, and thereby cost, which could be saved by reassigning farms to haulers' locations so that farm assignment overlap would be reduced. Farms were reassigned to haulers based on minimized total farm to hauler distances. As a result of this reassignment, areas of farm assignment overlap were virtually eliminated. The farm reassignment problem was formulated as a transportation problem and solved using, GNET, the network algorithm developed by Bradley et al. (1977). This transportation problem could be represented as a matrix with 484 rows and 2,868 columns. Each farm reassignment was solved for less than $5.

Computational studies of transshipment and transportation algorithms (Bradley 1975, p.229) have shown the primal simplex special purpose network algorithms to be 30-40% faster than out-of-kilter algorithms for solving these problems and up to 150 times as fast as general linear programming programs. In addition, the storage requirements are less than those of the out-of-kilter and general LP algorithms.

**Traveling Salesman**

Given a network with nonnegative arc lengths (distances, cost, time, etc.), the traveling salesman problem is to find the minimum cost "walk" through the network that starts at a node, covers each node at
least once, and returns to the starting node. This problem would have applicability to such activities as delivering newspapers to newsstands and assembling milk at farms. While linear, integer, and dynamic programming algorithms have been used to solve small-scale traveling salesman problems, algorithms capable of optimally solving large-scale problems have not been developed. Additionally, theorists do not expect that an efficient optimizing algorithm for this problem will ever be found, but they cannot be certain (Karp, p.60). The reason for the pessimism is that the traveling salesman problem belongs to a class of problems which are called NP-complete (Non-deterministic Polynomial) (Christofides, Chap.9; Karp; Kolata). Problems such as the minimum spanning tree, maximal flow, shortest path, and capacitated transshipment problems can be solved in polynomial time (P-class), the worst case computational time needed to solve one of these problems is of the order $n^k$, where $k$ is some integer constant (Karp). NP-complete problems, such as the traveling salesman problem, however, are problems which can, in the worst case, only be solved in exponential time, i.e., the computational time needed to solve one of these is of the order $k^n$. For instance, if the salesman had to visit only four cities, he could easily consider the 12 possibilities manually. If he had to visit 10 cities, the problem would require a little more time since there would be 1.8 million possibilities. If there were 18 cities, it could take a modern computer hundreds or even thousands of years to enumerate all the possibilities. Theorists do retain hope that a polynomial algorithm can be constructed, since no one has yet demonstrated that such an algorithm does not exist, whereas
for some kinds of games, it has been proved that such an algorithm does not exist.

The traveling salesman problem is important because of its close relationship to the various forms of difficult routing problems. An alternative approach to solving this NP-complete problem is to use an approximating algorithm, or "heuristic" (Zanakis and Evans).

There are many reasons to use heuristic methods to solve problems. For the vehicle routing problem, the most compelling justification is that no efficient optimizing method for large-scale problems is available. Even if one were discovered, the cost of using it could well be prohibitive. As Bradley states, "often heuristics are developed for small computer or hand calculation. It should be recognized that the cost and accuracy of data is often a more pressing issue than computing the optimal solution" (Bradley, 1975, p.226).

Many heuristic algorithms for solving vehicle routing problems have been suggested (Golden and Magnanti). Among these, the savings approach first suggested by Dantzig and Ramser, and later modified by Clarke and Wright, the sweep method used by Gillett and Miller, and the generalized assignment approach used by Fisher and Jaikumar, have received the most attention and are frequently used as standards of comparison for other algorithms or as starting points for further analysis (Russell).

For the analysis reported here, the savings approach to vehicle routing was used. The computer implementation of the Clarke and Wright (CW) algorithm used was a program named ROUTE, which was written by Hallberg and Kriebel. The savings approach is a relatively inexpensive
method which yields good results when compared to other algorithms. In a study of five routing heuristics, Fisher and Jaikumar found that for eight routing problems in the size range of the routing problems encountered in our analysis, i.e., 100 stops or less, that, while their implementation of the CW algorithm attained the highest average solution value, this value was only 6.4% higher than the algorithm with the lowest average solution value. Additionally, the algorithm with the lowest average solution value took an average of 8.3 times as much computer time to find these lower values. Clarke and Wright use the concept of a savings coefficient. The savings coefficient is the distance saved by serving two stops on the same route rather than serving them separately.

\[ S_{ij} = d_{io} + d_{oj} - d_{ij} \]

where, \( S_{ij} \) is the savings coefficient for the \( i,j \) pair of stops,
\( d_{io} \) is the distance from stop \( i \) to the depot,
\( d_{oj} \) is the distance from the depot to stop \( j \),
and \( d_{ij} \) is the distance from stop \( i \) to stop \( j \).

The \( n(n-1)/2 \) savings coefficients are calculated and ranked in descending order. A route is constructed by linking stops with the largest savings coefficients (i.e., proceeding down the savings array) until a set of stops is combined into a route which encounters a vehicle capacity or other constraint. The process continues until all stops are assigned to feasible routes.
Data, Procedures and Results

It has been hypothesized that gains in technical efficiency of raw milk assembly can be realized as a progressively larger proportion of the milk assembly function is brought under central coordination. This would result: 1) from a reduction in the amount of route duplication, that is, duplication in the roads actually traversed by assembly vehicles (Nolte and Koller, p.35), and 2) from superior vehicle scheduling management, which is also hypothesized to be available to the coordinators of the larger assembly operations (Cropp and Graf, p.10; Nolan). Others have studied this issue (e.g., Babb and Newell, Karpoff et al., Lamb, and Strang), but they have had to make simplifying assumptions to accommodate computational limitations of the techniques they used or they have not had actual route information to which comparisons could be made.

State and federal milk marketing specialists who provided partial funding for this project expressed a desire to have the study completely cover all the farms in a specific geographic area, Cortland County, in central New York. Six hauling firms, operating 63 routes which had at least one farm in Cortland County were studied. These haulers served a total of 478 farms on these 63 routes and delivered milk to ten plants in May of 1980. Using the drivers’ daily weigh slips, the following information was collected about each actual route for an eight-day period:

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

Eight days were studied to include a complete weekly cycle for farms served every-other-day (EOD) and to allow for study of daily fluctuations. All haulers operated sided routes, i.e., one set of farms was served on odd numbered days and another set was served on even days. Some drivers collected more than one load of milk per day, and each of these loads was considered to be a route in this study. Cortland County routes were of two types, routes which delivered milk directly to local plants and routes which returned to the haulers' garages in order to switch tractors and/or drivers for a trip to a New York City plant, approximately 230 miles away, see Table 1.

In addition to the route characteristics obtained from the weigh slips, it was necessary to identify a road system over which pickup vehicles could travel and from which distances linking all points of interest could be derived. Once the road network was defined and shortest distances were calculated, standards for driving and farm service times were used along with the network information to calculate a number of performance variables for the actual weigh slip (WS) routes.

The WS routes were rescheduled for each hauler using the vehicle routing heuristics. On the rescheduled weigh slip (RWS) routes, haulers served exactly the same set of farms they served on the WS routes. In calculating RWS routes with the routing heuristic, several complicating factors had to be handled. First, while it is possible to store milk on farms for two days, 35 of the 478 farms studied in May of 1980 did not have sufficient storage capacity to be served EOD and required every-day (ED) service. The ROUTE program allows a number of
different vehicle types to be input as available. It also allows a
vehicle restriction at each stop, such that vehicle Type X may not
serve a particular stop. To insure that each ED stop was scheduled on
a different route, two vehicle types were assumed to be available,
Type X and Type Y. These truck types actually had identical capacities
but defining them as Type X and Y trucks created an odd day and an even
day fleet. One ED stop was then restricted to vehicle Type X only, the
other to vehicle Type Y only, and all EOD stops were unrestricted.
Routes could then be sequenced so that the two ED stops were assured to
be on the proper days.

Second, whereas the general vehicle routing problem has a single
depot from which vehicles depart and to which they return, the problem
we studied has multiple depots from which vehicles depart and the
delivery points do not necessarily coincide with these points. Addi-
tionally, when a vehicle runs more than one route, the first delivery
point serves as the second departure point. The heuristic used to
schedule these garage-to-plant routes involved the development of
"super" routes. The depot was the plant location, and the hauler's
garage was treated as a dummy farm stop. A truck which was large
enough to hold all the milk assigned to the plant over the two-day
cycle was assumed to be available. ROUTE was then used to sequence one
"super" route which included all the farms and the hauler's garage.
Routes were manually created by beginning at the garage's location in
the super route and adding farms in sequence toward the plant, con-
sidering vehicle type restrictions, until actual truck capacities were
reached. These routes were properly scheduled to begin at the garage
and end at the plant with a full load. Two routes from the garage were created for each super route, and new, smaller super routes were created with the remaining unassigned farms until a sufficient number of first trips were scheduled. By employing this rule to create route systems for haulers delivering to plants, it was not necessary to assume that the trucks were housed at the plants. For subsequent routes which actually would begin and end at the plant, ROUTE could be used without modification.

Third, the vehicles actually used by the haulers were of two types, straight-chassis and tractor-trailers, and were not of a standard size. Straight-chassis trucks ranged from 30,100 pounds capacity to 38,700 pounds. Tractor-trailers ranged from 48,160 pounds to 52,850 pounds. Combined with the procedure that ROUTE uses to construct routes, there was a tendency for ROUTE to underutilize vehicles. ROUTE schedules stops by examining the savings coefficients in descending order. Therefore, the candidate stops to be added to a route are limited by their placement in the savings matrix. In essence, only stops that are geographically close to the last stop added to the route are considered as candidates, but if those farms' production is too large for the truck being considered or if they have previously been assigned to another route, the route construction ends. Existing links cannot be broken, such that if a candidate stop is already assigned to a route, that entire route must be added to the route being scheduled. This procedure often leaves a subset of stops which are close to the depot (at the bottom of the savings list) that are not considered until relatively late in the scheduling process. Because these stops are
close to the depot, they are often situated such that they could be added to one of the other routes with little or no increase in total distance. In most cases these residual stops can be added or swapped from one route to another until they are eliminated. In practice, we wrote a computer program which had access to all the data on vehicle capacities, stop volumes, and distances to quickly and inexpensively evaluate various scheduling permutations to refine the vehicle schedules determined by ROUTE.

Others (Russell) have suggested more formalized approaches to improving initial starting point solutions obtained from heuristics such as CW. By combining computer and manual heuristic procedures, it was possible to capitalize on the ROUTE program's strength in sequencing farm stops and accommodate the above complications to calculate efficient routes (RWS). For details of the specific manual procedures used, see Sehulster, Chap. 2.

A comparison of the WS routes and RWS routes is presented in Table 2. Using budgeted vehicle costs (Lesser and Wasserman), these reductions of 14.7 percent in two-day mileage and 4.8 percent in two-day total time would result in total annual savings of $54,000 or 1.2 per hundred pounds. In addition, two routes would be saved. These savings measure the potential benefit of more efficient vehicle scheduling before considering route duplication.

Using the transportation algorithm described above, farms were reassigned to haulers on the basis of minimized total farm to hauler distance.
Under the reassignment scheme, a farm might be served by a different hauler and milk would be comingled, that is, milk from patrons of the various cooperative and proprietary firms would be loaded on the same truck and plants would receive some milk that had previously gone to another plant. Haulers would collect approximately the same volume of milk, use the same fleet, and ship to the same plants as under the WS routes. Further, plants would receive approximately the same volume of milk and all the milk would be picked up. Under our reassignment scheme, 45% of the farms would be served by a different hauler than had actually served them.

Comparing RWS routes to routes generated for the set of farms assigned to haulers so as to minimize overlap (NO) isolates the inefficiency attributable to route duplication. Table 3 shows the operating characteristics of RWS versus NO routes. Four hundred and fifty-six miles every two days (17.6%) were attributable to duplication in farm pickup. Although duplication caused haulers to travel more miles and to spend more time, 3.9% more than RWS routes, it did not cause them to operate more routes, because tank capacity, rather than time or route length, was the limiting factor in the dense Cortland area. The fully-allocated cost of route duplication was estimated to be $49,000 annually or 1.1_ per hundred pounds.

By comparing NO routes with WS routes, one can estimate the potential savings if farms were reassigned and if the improved routing techniques used in this study were implemented. The full impact every two days would be an estimated reduction of 1403 minutes (8.6%) and 901 miles (29.7%), saving approximately 32,000 gallons of fuel annually.
and the elimination of 2 routes. Long-run annual hauling costs could be reduced $104,000 or 2.3 per hundred pounds. This would represent approximately a -1% increase in net farm income.

While participating in a farm reassignment scheme to eliminate route overlap would save the group of haulers substantial mileage in the long-run, the impact on each individual hauler due to rescheduling or reassignment varied. The predicted savings in mileage from each of the two sources—improved routing techniques and improved farm assignments—is compared in Table 4. The two-day mileage reductions predicted for RWS versus WS routes indicates the relative efficiency of each hauler’s operations. The relative benefits of NO versus RWS routes indicates the ‘rationality’ of selecting each hauler’s farms relative to his own location. By these measures, hauler C operated the most efficient routes, but served the most poorly located group of farms. Conversely, hauler E had the most rational set of farms, but operated the least efficiently designed routes. Hauler A also had an irrational set of farms to serve and would not serve Cortland County farms at all under reassignment.

While the efficiencies gained by individual haulers with respect to route design and route duplication varied substantially, the combined gains were large and quite similar for every hauler. For local assembly, we estimate that total dollar savings from both reassignment and rescheduling would be approximately 10% of total hauling costs. These savings would be achieved in an area where farm density is high, limiting the penalty for inefficient route design on the part of haulers and inefficient farm assignment, so that this level of savings
may be thought of as something of a lower bound in cases where like numbers of farms, haulers, and plants are operating in a similar geographic area. In cases of cooperative or proprietary consolidations, mergers, or acquisitions, these hauling cost savings would be in addition to other savings generated in the course of marketing and/or processing producer receipts or marketing final products.

Conclusions

The results and experience of this study have implications for industry practitioners, researchers interested in similar questions relative to transportation efficiency, and federal order administrators. For the practitioner who confronts, perhaps daily, the problems of vehicle scheduling and routing, this study demonstrates that computerized vehicle scheduling procedures can be used to gain efficiency and lower costs. These techniques require a considerable overhead cost in developing the necessary data. One can expect that computer generated solutions may well require manual manipulation to accommodate the complexities of an actual routing problem, but computerized techniques can, when used sensibly, improve upon strictly manual procedures. Implementing improved routing strategies may require additional or unusual management practices, as is definitely the case when a hauler comingles the milk of farmers who are not all patrons of the same cooperative. Finally, although the magnitude of the potential gains in assembly efficiency will vary with the characteristics of a particular market and the management skills of a particular firm, this study (and others before it) confirm that a sizeable savings in milk
assembly resources could be realized by more efficient vehicle scheduling and the reduction of route overlap.

For the researcher interested in problems of this type, this study demonstrates that it is possible to address large-scale problems having a level of scope and detail that makes few compromises for computational difficulties through the use of heuristics and optimization. Although the familiar procedures of mathematical programming are powerful tools, they have limited agricultural economists who have studied transportation related problems in the past. Well-documented operations research techniques are available that considerably expand the capabilities of agricultural economists interested in large-scale problems involving efficiency issues or optimization.
Footnotes

1/For some types of problems, special purpose network algorithms have consistently been shown to be 50-200 times faster than general linear programming computer codes (Bradley, Brown, & Graves, Mgt. Sci. p.2).

2/Other reassignment schemes were tried (see Sehulster, Chapter 4), and still others have been suggested (e.g., Hardy).
Table 1. Description of Hauling Patterns, May, 1980

<table>
<thead>
<tr>
<th>Haulers</th>
<th>Routes</th>
<th>Producers</th>
<th>Hauling Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>21</td>
<td>1 Route to local plant (1 Route returns to hauler)</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>55</td>
<td>6 Routes return to hauler</td>
</tr>
<tr>
<td>C</td>
<td>7</td>
<td>63</td>
<td>2 Routes to local plants (5 Routes return to hauler)</td>
</tr>
<tr>
<td>D</td>
<td>13</td>
<td>88</td>
<td>13 Routes to local plants</td>
</tr>
<tr>
<td>E</td>
<td>10</td>
<td>92</td>
<td>10 Routes return to hauler</td>
</tr>
<tr>
<td>F</td>
<td>25</td>
<td>152</td>
<td>25 Routes return to hauler</td>
</tr>
</tbody>
</table>

6 haulers 63 routes 478 farms 16 Routes to local plants 47 Routes return to hauler

NOTE: These are only routes operated by each hauler which include at least one Cortland County farm. All six firms operated other routes which were not included in this study.
Table 2. Operating Characteristics for All Haulers with Rescheduled Weigh Slip (RWS) and Weigh Slip (WS) Routes, May 1980, 2 Days of Operation

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>RWS</th>
<th>WS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Farms</td>
<td>478</td>
<td></td>
</tr>
<tr>
<td>Number of Farms Served Every Day</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Pounds of Milk Picked Up</td>
<td>2,477,516</td>
<td></td>
</tr>
<tr>
<td>Number of Routes</td>
<td>61</td>
<td>63</td>
</tr>
<tr>
<td>Total Miles</td>
<td>2,588</td>
<td>3,033</td>
</tr>
<tr>
<td>Total Minutes</td>
<td>15,530</td>
<td>16,320</td>
</tr>
<tr>
<td>Routes Returning to Hauler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Miles</td>
<td>1,690</td>
<td>2,008</td>
</tr>
<tr>
<td>Number of Routes/Truck/Day:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight Chassis</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Tractor-Trailer</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Standard Time/Truck/Day:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight Chassis</td>
<td>5 hours 48 min.</td>
<td>7 hours 8 min.</td>
</tr>
<tr>
<td>Tractor-Trailer</td>
<td>4 hours 47 min.</td>
<td>4 hours 37 min.</td>
</tr>
<tr>
<td>Routes Delivering to Plants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(straight chassis trucks only)</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Total Miles</td>
<td>898</td>
<td>1,025</td>
</tr>
<tr>
<td>Number of Routes/Truck/Day</td>
<td>1.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Standard Time/Truck/Day</td>
<td>8 hours 56 min.</td>
<td>8 hours 26 min.</td>
</tr>
<tr>
<td>Overall Fullness/Trip (%)</td>
<td>96.0*</td>
<td>93.6</td>
</tr>
<tr>
<td>Farm Density (on-route miles/stop)</td>
<td>2.6</td>
<td>3.1</td>
</tr>
</tbody>
</table>
The RWS routes would be 96.0% full based on the average of the pickup volumes recorded for each farm on the weigh slips. This is higher utilization than other researchers have "budgeted" for routes. The variation in actual daily production was analyzed and very little day-to-day fluctuation was found; therefore, these routes should be feasible for actual operations.
Table 3. Operating Characteristics for All Haulers with Non-Overlapping (NO) and Rescheduled Weigh Slip (RWS) Routes, May 1980, 2 Days of Operation

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>NO</th>
<th>RWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Farms</td>
<td>478</td>
<td></td>
</tr>
<tr>
<td>Number of Farms Served Every Day</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Pounds of Milk Picked Up</td>
<td>2,477,516</td>
<td></td>
</tr>
<tr>
<td>Number of Routes</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>Total Miles</td>
<td>2,132</td>
<td>2,588</td>
</tr>
<tr>
<td>Total Minutes</td>
<td>14,917</td>
<td>15,530</td>
</tr>
<tr>
<td>Routes Returning to Hauler</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Total Miles (Routes Returning to Hauler)</td>
<td>1,275</td>
<td>1,690</td>
</tr>
<tr>
<td>Number of Routes/Truck/Day:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight Chassis</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Tractor-Trailer</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Standard Time/Truck/Day:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight Chassis</td>
<td>5 hours 38 min.</td>
<td>5 hours 48 min.</td>
</tr>
<tr>
<td>Tractor-Trailer</td>
<td>4 hours 35 min.</td>
<td>4 hours 47 min.</td>
</tr>
<tr>
<td>Routes Delivering to Plants (straight chassis trucks only)</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Total Miles</td>
<td>857</td>
<td>898</td>
</tr>
<tr>
<td>Number of Routes/Truck/Day</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Standard Time/Truck/Day</td>
<td>8 hours 33 min.</td>
<td>8 hours 56 min.</td>
</tr>
<tr>
<td>Overall Fullness/Trip (%)</td>
<td>96.0</td>
<td>96.0</td>
</tr>
<tr>
<td>Farm Density (on-route miles/stop)</td>
<td>2.1</td>
<td>2.6</td>
</tr>
</tbody>
</table>
Table 4. Efficiency Comparisons and Incentives

<table>
<thead>
<tr>
<th>Hauler</th>
<th>Savings Due to Rescheduling (Savings as % of WS Miles)</th>
<th>Savings Due to Reassignment (Savings as % of RWS Miles)</th>
<th>Combined Savings (Savings as % of WS Miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.7</td>
<td>30.7</td>
<td>34.9</td>
</tr>
<tr>
<td>B</td>
<td>14.6</td>
<td>11.2</td>
<td>24.1</td>
</tr>
<tr>
<td>C</td>
<td>4.1</td>
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<tr>
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<td>All Six Haulers</td>
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<td>17.6%</td>
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References


