VEHICLE ROUTING - A CASE STUDY

by

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CHAPTER I

Introduction

Delivery and pick-up of a commodity or a group of commodities by trucks is an important activity at many firms engaged in "agri-business." In the formula-feed industry, delivery trucks are used extensively to transport feed from the feedmill to many geographically dispersed farms. Delivery trips often involve serving two or more stops where the sequencing of stops is important in determining lengths of the routes. Thus, any procedure which will result in driving a shorter distance or spending less time per trip, while providing the same services, can contribute to lower delivery costs and improved distribution.

The purpose of the study was to apply an already developed algorithm to an existing problem and perform a comparative study between the solution thus obtained and the data available from currently used system.

Background

Most formula feeds for the poultry industry are formulated, manufactured, and distributed by large feed manufacturers. The volume of primary feed manufactured in the United States in 1973 amounted to an estimated 73.2 million tons.

By type of animal, the poultry industry consumes approximately a third (31%) of the total primary feed and more than 60% of this feed is distributed in bulk form.[1]

A typical feed manufacturing company employs a fleet of trucks to deliver feed from the feedmill to farms in the surrounding region. Mostly, large manufacturers own their fleet of trucks. It has been reported that more than 50% of the total feed tonnage was hauled by privately owned trucks [15]. The primary reasons feed manufacturers give for operating their own fleet are:

1. To reduce hauling costs.
2. To provide faster delivery.
3. To reduce inventory.
4. To provide better control of distribution.

However, a U.S.D.A. study [19] reports that the trend is towards leasing a very large percentage of the feed-trucks required for delivery operations.

The following two types of trucks are generally used: 1) A "Straight Hauling" truck (10-wheeler), and 2) a Tractor Trailer. These trucks have compartments and are equipped with a suitable unloading system. Typical configurations for the above two truck-types are shown in Figure 1 and Figure 2. As depicted in the figures, compartments may differ in con-

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[1] As reported by Feedstuffs in [19].

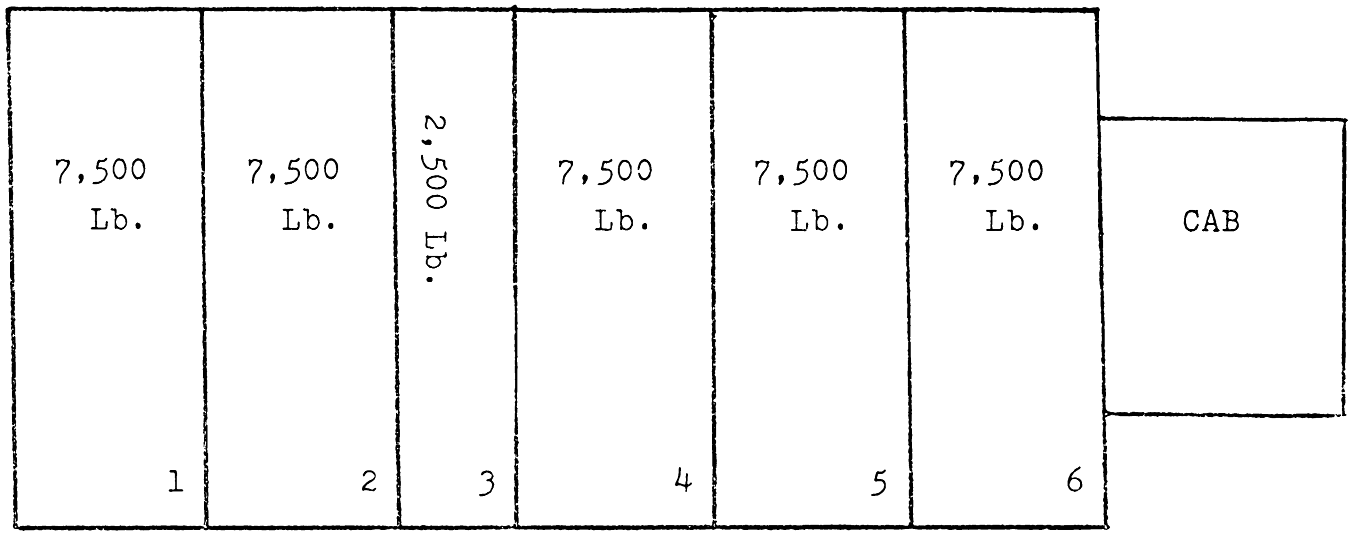

Figure 1

Total Capacity = 20 Tons

Bulk Feed Truck Body - Straight 10 Wheeler

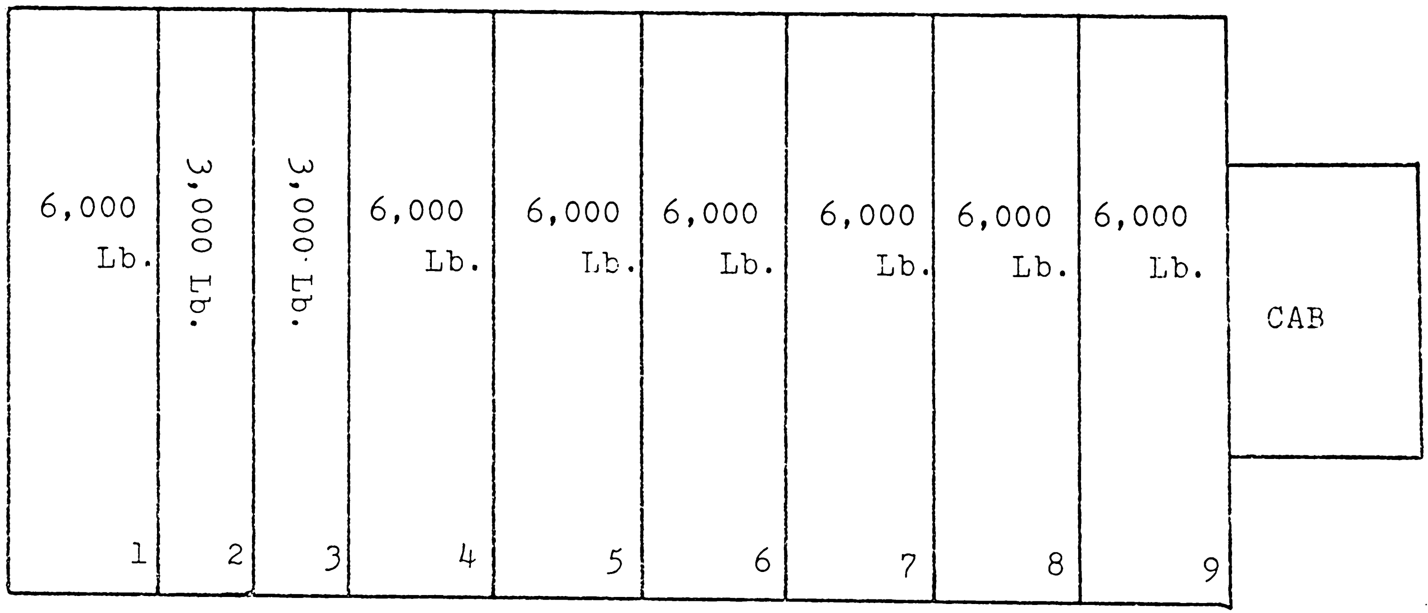

Figure 2

Total Capacity = 24 Tons

Bulk Feed Truck Body - Trailer Type

figuration and size. However, the size of a compartment, once fixed by design, cannot be altered. Consequently, the number of compartments in a given truck remains unchanged. The selection of truck body and unloading system depends on such factors as:

1. The unloading rate desired.
2. The type of feed hauled.
3. The farmers' holding bin configuration.
4. Geographical location of the farm and local delivery customs.
5. Legal tonnage and compartment loading requirements.
6. Product handling, cleanout, and contamination.
7. Initial capital investment in the equipment and the fuel economy.

The formulation, production, storage, and handling of feeds have to comply with various standards and specifications set by the state and federal regulatory agencies. Also, feed ingredients and drug additives for medicated feed have to meet the dietary requirements of poultry in accordance with the type of poultry, and their life-stage. Therefore, it is very important that the quality and required specifications of formulated feed remain unaltered during transporting. As a result, it is not permissible to mix two orders in a given compartment.

Orders for feed are received by the dispatching unit of a particular feed manufacturer from "servicemen." These personnel, employed by the manufacturer, pay weekly visits to farms assigned to them and assess dietary requirements of the poultry grown on each farm. The orders are then placed in accordance with this assessment. Each order specifies the farm, type of feed, amount required, and delivery deadline (in some cases, preferred time of delivery).

Orders received at the dispatching unit are assigned priorities based on several factors such as: urgency of the order, amount to be delivered, availability of feed, availability of trucks, payload per trip achieved by dispatching the order, weather conditions, etc. Usually, both the dayshift and nightshift are used to make deliveries. The vehicle scheduling is done by a full-time dispatcher in cooperation with the production personnel.

As soon as orders are processed, the truck drivers are given dispatch invoices with proper location and directions. Mostly, drivers plan their own routes. Each delivery truck returns to the feedmill after completing the assigned deliveries. On the average, a truck makes five or six trips per day and travels a total distance of approximately 450 miles. In preparing vehicle schedules, emphasis is placed on high loading efficiency or high tonnage hauled per trip. Normally, the objective is to maximize the payload per trip. Other key factors which influence schedules are:

1. Maximize the tonnage delivered per stop.

2. Minimize the feed delivery stops per trip.

3. Reduce truck "dead-time" by using both first and second shift deliveries.

Description of the Problem

In light of this background, the specific problem of this investigation is described as follows:

A set of poultry farms, each with a known location and known order (type of feed and quantity required), is to be supplied from a single feedmill by delivery trucks of known capacity. The objective is to produce a set of routes that minimize the total distance traveled by all trucks employed in satisfying the demands in a given day. In accomplishing this objective, the following conditions serve as constraints that must be met:

a. The number of available trucks is a small finite number.

b. The capacity of the trucks may not be exceeded.

c. The total distance traveled by a truck in a given day to make assigned deliveries may not exceed some predetermined value. However, the truck may make more than one trip if necessary.

d. No two orders may be mixed in a given compartment.

e. The requirements of all farms must be satisfied in a given day provided that sufficient trucks are available.

Reason For the Study

The cost of delivery is a major expense of operating any feedmill business. Direct cost reduction in bulk-feed transportation can contribute toward improving overall plant efficiency and, more importantly, can increase the net profit of the feed manufacturing and feeding operation. Figure 3 shows an approximate breakdown of the costs associated with the delivery operation. A systematic vehicle-routing procedure can help reduce distribution costs by reducing total distance traveled. Also, this complex and expensive logistical task is commonly handled by dispatchers who do not have the aid of scientific techniques capable of accommodating the many constraints a delivery system must meet. A vehicle-routing technique may greatly increase the ability and efficiency of the dispatcher to carry out this task.

This study examines the problem in light of data obtained from Purdue, Inc. of Salisbury, Maryland (hereafter referred to as Purdue, Inc.) and attempts to present a solution procedure which is feasible, simple to apply, and efficient. A solution procedure is proposed in Chapter II and was applied to the actual data obtained from Purdue, Inc. The routes designed by using the recommended computer algorithm are compared with the routes designed by the dispatcher at Purdue, Inc. and the results are discussed in Chapter IV.

Assumptions and Approach

The problem of delivering finished poultry feed is a rather complex problem. In order to obtain a workable solution procedure, the following simplifying assumptions were made:

Direct Costs (80%)	Per Mile	Per Ton
Drivers Wages and Expenses	$0.16	$1.00
Fuel and Oil	0.07	0.42
Tires and Maintenance	0.07	0.42
Sub Total	0.30	1.84
Indirect Costs (20%)		
Depreciation	0.06	0.35
Taxes, License, and Registration	0.02	0.14
Insurance	0.01	0.07
Interest on Investment	0.01	0.05
Sub Total	0.10	0.61
Total Cost	$0.40/mile	$2.45/ton

Figure 3

Average Delivery Costs

(*Ref*. American Feed Manufacturers Association Feed Production Council)

1. All farm locations are known.

2. All farms have the necessary space and facilities to accommodate incoming trucks and unload the feed.

3. There are no restrictions regarding the time of delivery.

4. The number of available trucks for delivery operations is known in advance of making a schedule.

5. A truck may remain idle part of the time or all the time if demands for the given day do not require its services.

6. Each vehicle begins and terminates all trips at the feed mill.

7. Complete information about every order is available before a schedule is made.

8. Each order is from one farm, for one feed type, and for a single quantity.

9. All available trucks are identical with respect to size, capacity and capability and these trucks are the straight-hauling (or 10-Wheeler) type.[2]

10. The number of compartments in each available truck is the same and all compartments are equal in capacity.[3]

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[2]The complexity, and therefore scope of the problem is significantly reduced by these two assumptions. Further, the simplifying assumptions approximate the actual conditions at Purdue, Inc.

[3]Ibid.

The problem may be formulated in various ways. These various possible formulations, and the advantages and disadvantages of each formulation, are discussed in Chapter II. Then, based on this discussion, the algorithm by Gillett and Miller [8] was selected. This heuristic algorithm is based on minimizing the total of distances traveled in all the routes. The system of vehicle routing at Purdue, Inc., is then examined in Chapter III and a solution obtained to demonstrate the recommended approach.

CHAPTER II

Vehicle Routing: A Survey

For the general vehicle dispatch problem, a fleet of trucks is to be deployed from a single depot in order to supply customers located at different locations with a certain quantity of goods. The trucks have limited capacity and possibly a distance constraint. The usual objective is to design a set of routes and paths in each route that will minimize the total distance traveled by all trucks in supplying all demands.

Many researchers have modelled the routing problem as an extension of the multi-traveling salesman problem, with capacity constraints. Optimal seeking algorithms, as well as heuristic algorithms, have been developed and applied to solve the routing problem.

Optimal seeking procedures guarantee an exact solution after a finite number of iterations. However, the computer time required grows exponentially with the number of locations [14]. A rule of thumb used by Little et al. [14] suggests that adding 10 locations to the problem increases the computer time ten-fold. Bellmore and Nemhauser [1] have reported that, using dynamic programming methodology to solve the routing problem, the computer time and storage required become prohibitive if 20 locations are to be served. For a medium or large size feed manufacturing business, the number of farms served in one shift usually exceeds fifty. Thus, optimal seeking procedures are not appropriate for solving such a real world routing problem. As a result, in surveying the extensive literature published on the vehicle-routing problem, concentration was focused on heuristic procedures.

In 1959, Dantzig and Ramser [4] first considered the vehicle-dispatch problem. Later, Clarke and Wright [3] modified the Dantzig and Ramser approach and since then, heuristic procedures have been developed by Christofides and Elion [2]. Hayes [10], Gaskell [7], and Tillman and Cochram [16]. Recently, Krolak, Felts and Nelson [12] and Gillett and Miller [8] have independently developed heuristics that are claimed more efficient than the heuristics developed prior to their work.

Heuristic procedures are generally faster and more capable of obtaining optimum or near optimum solutions to large size problem, where it is necessary to trade off precision for computational efficiency.

The following four heuristic approaches were therefore considered as possible solution procedures for the routing problem of this particular study:

a. The Savings Approach: Clarke and Wright [3],

b. The Man-Machine Approach: Krolak, et al [12],

c. The Variable Swapping Approach: Lin and Kernigham [13],

d. The Sweep-Algorithm Approach: Gillett and Miller [8].

The Savings Approach: Clarke and Wright [3]

This algorithm, a modification of the Dantzig and Ramser approach, is one of the simplest heuristics and provides a fast, feasible solution to the routing problem. However, the solution can be substantially different from the optimal solution in many cases [17].

The algorithm developed by Clarke and Wright can be described by the following procedure:

a. Consider that N locations (each on individual routes) are served by one vehicle so that the initial solution consists of N independent routes.

b. Calculate the savings, S_{ij}, from making a link between location i and location j. If D_{ij} is the distance between locations i and j (for symmetric distances), the savings are:

$S_{ij} = 2 \times (D_{oi} + D_{oj}) - D_{oi} - D_{ij} - D_{oj} = \underline{D_{oi} + D_{oj} - D_{ij}}$ and, for asymmetric distances, the savings are:

$S_{ij} = \underline{D_{oi} + D_{oj} - D_{ij}}$,

where the zero subscript represents the source, feed mill.

c. Arrange the savings in a descending order of magnitude or the greatest savings

d. Then, beginning at the first value, perform the following:

1. If making a link results in a feasible route in accordance with the constraints on the problem, then add this link to the solution, otherwise reject it.

2. Continue in this fashion until all links in descending order of savings have been considered.

e. The links which have been selected form the solution to the problem.

The Savings Approach, one of the original heuristics, offers the following advantages:

1. It is simple to apply and to program on a digital computer.

2. It requires only a small amount of computer time and storage.

3. It provides a good starting solution for other more complex algorithms.

The major disadvantage of the algorithm lies in the sub-optimabity of the solutions and, in cases where the constraints on the problem are tight, the solution can be far from optimal. Also, a link once added to the solution is never removed. As a result, the present solution can not be altered by replacing some links by others to improve on total savings. The selection of the link with the largest savings thus does not guarantee the best total savings.

The Man Machine Approach: Krolak, Felts, and Nelson [12]

This is one of the more recent approaches to the solution of the vehicle routing problem. In this approach, the authors suggest a man-machine interactive solution procedure where the human dispatcher participates in the development of a solution. A general overview of the approach, with details following, consist of the following steps:

a. The dispatcher defines the problem.

b. The computer organizes the data in a fashion that isolates the important parameters of the problem and gives several alternate solutions to show how the data can be arranged as a whole.

c. The dispatcher attempts to organize the data into a solution.

d. The dispatcher makes a comparison between the computer solution, his solution and the computer's organization of the data, and then creates a composite solution.

e. The dispatcher uses the computer to re-evaluate the composite solution and to produce better solutions by investigating various local and regional problems isolated by step b.

f. Using this judgement and other information, the dispatcher continues steps (d) and (e) until he has exhausted all the potential benefits to be derived or until further efforts will be only of marginal benefit.

The heuristic portion of the solution begins by collecting farms based on their proximity. This will divide all farms into "aggregations" or sets consisting of farms close to one another. Those aggregations whose centers of gravity (or average coordinates in the case of a Euclidian distance problem) are closest to each other are then joined pairwise, subject to the constraints on the problem, until the number of aggregations is equal to the specified number of routes. A set of heuristics which include the Traveling Salesman and Transportation subroutines is used next to obtain a starting solution.

The interactive phase displays the solution to the dispatcher (graphically, when possible) along with a suggested checklist for improvements. The dispatcher can then make necessary changes in the solution based on his intuition, judgement, and past experience. He continues to do so until a satisfactory routing is achieved. The routes thus obtained can be stored in the computer to be retrieved when needed.

The advantages of this approach, as reported by the authors, can be summarized as follows:

1. Accurate results have been obtained for problems up to two hundred locations and the computer time required varies almost linearly with the number of locations.

2. The dispatcher is allowed to interact with the machine in the development of a solution and hence does not have to "blindly" accept the computer solution.

3. The computer helps the dispatcher gain insight into solution procedures for future problems.

The approach has the following disadvantages:

1. The time required of both the computer and the dispatcher, especially, for the problem solution is large.

2. A pictorial display for problems other than dimensional and Euclidian is difficult to obtain, if possible

at all.

3. Time consuming procedures, such as Traveling Salesman or Transportation solution routines are required to obtain an initial solution.

4. The solution approach is interesting but difficult to describe specifically. This can lead to a vague understanding on behalf of the user (dispatcher) in a real-world environment.

The Variable Swapping Approach: Lin and Kernighan [13]

This heuristic basically solves the Traveling Salesman problem. By incorporating the design constraints into the problem, this procedure can be used to solve the vehicle-routing problem.

This method uses the same interchange philosophy as many of the other heuristics and employs a rationale very similar to the r-optimal concept of Elion, et al [2]. The r-optimal algorithm starts with a feasible solution satisfying all the constraints. Then, r-links of the solution are replaced by another set of r links (subject to the constraints) if this results in an improved solution. Increasing values of r result in a better solution, but increase the computational time rapidly. Therefore, it is difficult to select the value of r offering the best compromise between computer time and quality of the solution.

The procedure developed by Lin and Kernigham treats r as a variable. The value of r is determined iteratively at each stage to maximize the improvement. The algorithm stops when no further improvement can be achieved or satisfactory answers are obtained.

The algorithm also offers the following features that increase its efficiency substantially without significant extra cost. After a local optimal solution S is found, the time spent to investigate all possible improvements over S can be avoided whenever S reoccurs. Also, in choosing links to be replaced, trivial selections (like, choosing links between nearest-neighbor locations) can be avoided by a "look-ahead" feature of the algorithm. Moreover, some local optima might share common links which seem likely to be present in the optimal solution. The "reduction" phase attempts to retain these links when considering further investigations. This reduces the computational effort involved considerably.

The algorithm has the following advantages:

1. Computer time varies with N^2 (N is the number of locations) which, according to the authors, is highly promising, especially for large problems. The authors have reported improvements in three out of five problems when compared with the Man-Machine Interactive procedure of Krolak, Felts and Nelson [12], with substantially less machine time and no dispatcher time required.

2. On small problems (up to fifty locations), the probability of obtaining an optimal solution is close to unity.

The disadvantages of this extremely efficient and effective algorithm are:

1. It provides good results for symmetrical problems only.

2. It requires a feasible, starting solution.

The Sweep-Algorithm: Gillett and Miller [8]

In this approach, the problem is broken into a number of sub-problems which are solved individually. The sweep-algorithm divides the locations into feasible sets of routes according to their polar coordinates with respect to the source (on the feed mill in this study), subject to the design constraints. Then, "sweeping" counter-clockwise (forward sweep) or clockwise (backward sweep) around the source point, locations are systematically added or deleted from sets of routes as improvements are found. Distance reductions are determined by using a Traveling Salesman routine which determines the sequencing of deliveries and the optimal distance associated with any selected route.

The Forward Sweep algorithm can be described by the following steps where the notations given by the authors are retained:

a. Let 1 represent the source (or feedmill) and let (X(I), Y(I)) be the rectangular coordinates of the Ith location with respect to the feedmill. Define the polar coordinate angle S(I) of the Ith location as:

$$S(I) = \text{Arctan}\ \frac{Y(I) - Y(1)}{X(I) - X(1)}$$

where, $-\pi \leq S(I) \leq 0$ if $(Y(I) - Y(1)) < 0$

and $0 \leq S(I) \leq \pi$ if $(Y(I) - Y(1)) \geq 0$

b. Renumber the locations (farms) according to the magnitude of their polar coordinate angle. That is, $S(I) \leq S(I + 1)$ for all I. If there exist two locations, I and J, such that $S(I) = S(J)$, then $I < J$ if $R(I) < R(J)$, where R is the radius from location 1 (the feedmill). This procedure will determine a unique ordering for all locations.

c. Beginning with the location that has the smallest angle (that is, location 2), partition locations into routes. The first route consists of locations 2, 3, . . ., J, where J is the last location that can be added to the first route without violating the constraints. The second route will consist of locations J + 1, J + 2, . . ., L, where L is the last location that can be added to the second route without violating the constraints. The remaining routes are formed in the same manner to cover all N locations (farms).

d. Use a Traveling Salesman routine to determine the optimal solution for each route. The total distance traveled will be the sum of all distances for individual routes.

e. Consider replacing one location in route K with one or more locations in route K + 1 for K = 1, 2, . . ., M - 1 where M is the number of routes formed. If this improves the solution, the replacement is made and the replaced location is left unassigned to be included in a later formed route.

This process is continued until no further improvement is achieved.

f. Rotate the X and Y axes counter-clockwise so that location 3 becomes location 2, location 4 becomes location 3, . . ., and location 2 becomes the last location. Repeat steps (c), (d), and (e). Each time, the minimum total distance of all routes is evaluated.

g. Repeat step (f) until all possibilities have been exhausted or a satisfactory solution obtained. The smallest of all total distance values provides a good heuristic solution.

The backward-sweep algorithm is exactly like the forward-sweep except the routes are formed in reverse order. Initially, route 1 consists of locations N, N - 1, . . ., L; route 2 consists of locations L - 1, L - 2, . . ., J and so on. In most cases, the two algorithms produce different routes and, consequently, different values of minimum total distance. Of course, the smallest of these is the best approximate solution.

The sweep-algorithm has the following advantages:

1. For problems with a small number of locations per route, the algorithm works very efficiently and effectively, requiring little computer time. A 250-location problem, with an average of 10 locations per route, has been solved in 9.7 minutes on a IBM 360/67 computer using this algorithm.

2. If the number of locations per route remains

constant, the computer time increased linearly with the total number of locations[4], which is very promising.

3. The algorithm produces solutions which are competitive to those produced by the Man-Machine approach of Krolak, et al. [12] and furthermore, it is a completely computerized algorithm requiring no Man-Machine interaction.

4. For small problems, the algorithm is comparable to any other heuristic with respect to both time and accuracy.[5]

5. The algorithm can accomodate various large number of constraints effectively.

The algorithm suffers from the following disadvantages:

1. The algorithm requires a Traveling Salesman subroutine to solve individual routes.

2. The number of "sweeps" or passes executed by the algorithm is set equal to the largest number of locations found in any one route during the first pass.

Selection of the Algorithm

The problem of routing feed-delivery trucks usually consists of more than fifty farms to be supplied in one working shift. As the size of the problem gets larger, present

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[4]As cited by Gillette and Miller [8]

[5]The authors claim to have obtained the best solutions to the vehicle-dispatch problem.

optimal seeking procedures are judged inappropriate due to excessive computer time and storage space and attention is focused on heuristic procedures.

The "Sweep" algorithm by Gillett & Miller was selected as a solution procedure for the feed-delivery system because of the reasons discussed below:

Generally, large scale vehicle-routing problems can be of two types. Those that change frequently and those that do not. The routing of feed-trucks falls in the former category. In this problem, the deliveries vary from day to day, and, generally, the use of both the first and second shift is required. The sweep algorithm, with its high computational efficiency, can be effectively used with very little computer time cost.

According to the general heuristic decision rule [8] when there are many routes to be created, with few delivery points on each route, forming routes first generally gives better results. In the problem of routing feed-trucks, due to the important constraint that no two orders can be mixed, the number of farms supplied on each route is less than or equal to the number of loading compartments in a truck. For the problem of this study, this number seldom exceeds ten. The sweep algorithm therefore was judged appropriate. Furthermore, the sweep algorithm is quite applicable to single-feed-mill problems. Also, design constraints on both truck capacity and distance traveled can be easily incorporated into the program.

The next chapter discusses, in detail, the system of distribution presently used at Purdue, Inc. and the acquisition of various data used to demonstrate the proposed solution procedure.

CHAPTER III

A Case Study

The system of distribution (Figure 4) of poultry feed followed at Purdue, Inc. is based on the same general guidelines as described in Chapter 1. This system can be summarized as follows:

1. Production and storage of various types of formula feed is carried out at the feedmill located on the outskirts of Salisbury, Maryland.

2. The servicemen employed by Purdue, Inc. pay periodic visits to a number of customer farms spread out in the DELMARVA area (consisting of parts of Delaware, Maryland, and Virginia) east of the Chesapeake Bay peninsula. These servicemen assess the dietary requirements of the poultry grown on each farm visited. After consulting with farm owners, orders are placed for a particular type and quantity of feed with the dispatching department of Purdue, Inc.

3. The incoming orders are assigned priorities by the Dispatching Department, according to type of feed ordered, availability of feed, quantity required, availability of trucks, etc. in cooperation with the Production Department.

4. Orders are dispatched according to the assigned priorities in such a way as to maximize the overall loading efficiency. Truck drivers are given dispatch invoices, com-

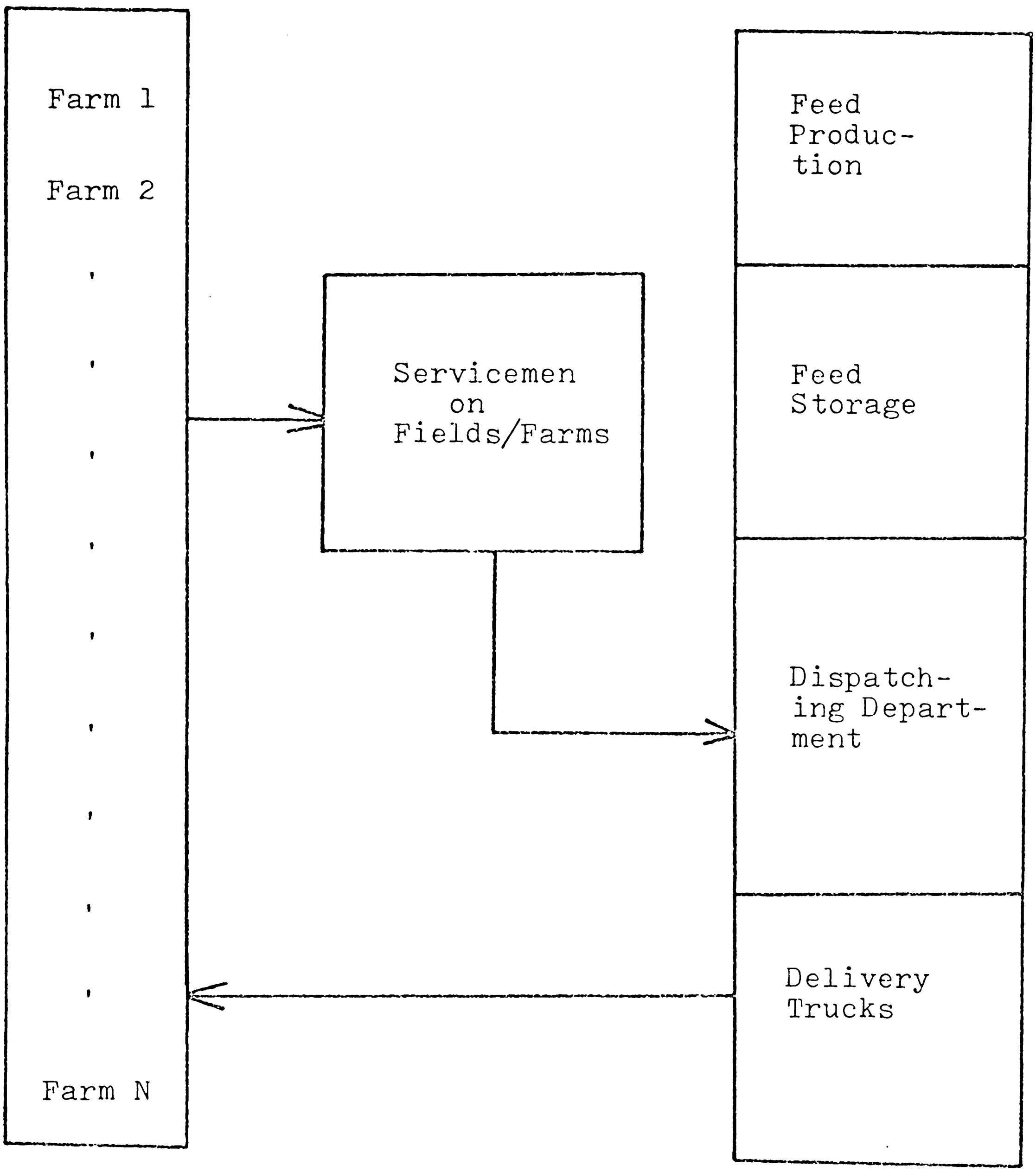

Figure 4

Block Diagram Showing Present System

plete with exact farm location and proper directions to each location.

5. The truck drivers delect their own sequence of routes to visit assigned farms and return to the feedmill after completing the deliveries.

Purdue, Inc. currently operates a fleet of fifteen trucks to include both the straight hauling and trailer type (Figures 1 and 2). The former type is designed to haul a total load of about 20 tons and the latter type has a capacity of 24 tons. On an average day, these trucks visit a total of 130 farms in a total of 80 trips.

Most of the farms are visited for feed deliveries. However, occasionally, feed is picked up. Pickups are generally assigned during night-shifts. According to Mr. Royce White of Purdue, Inc., each truck is loaded an average of 6 times every day and travels a total average distance of 500 miles.

In light of the solution approach, the entire data preparation was divided into two phases. The first phase consisted of data aquisition and data translation was achieved in the second phase.

Data Acquisition

All the necessary data was collected with the cooperation of the management of Purdue, Inc. and the truck operators.

The following information was collected through a system of three data forms (Figures 5, 6, 7) designed especially for this study:

1. Truck Data Data Form (2)
    a. Truck Type
    b. Truck identification number
    c. Nominal capacity of each truck
    d. Number of tanks/compartments in each truck
2. Daily Summary Data Form (3)
    a. Total miles traveled by each truck
    b. Fuel consumption by each truck
    c. Total tonnage delivered
    d. Number of trips made by each truck
    e. Number of farms visited by each truck
    f. Total number of deliveries and pickups made by each truck
3. Trip Record Data Form (1)
    a. Exact location and directions of each farm visited
    b. Quantity delivered and/or picked up
    c. Feed type delivered to each location

The necessary data was recorded over a period of one full week. Data described in 1 and 2 above was compiled by the Dispatching Department of Purdue, Inc. The data described in 3 was recorded by the dispatcher on duty at the time of a particular trip and the truck operator.

The data, acquired through the system described above, Data Form 3 (Daily Summary)

Date ____________ Recorded by____________

Truck Number	ODOMETER RECORD		DAILY TOTALS			
	Start	Ending	Fuel (gals)	Total Load Delivered (units)	Trips (no)	Farm Visited

Instructions & Suggestions

1. Total load carried may be given in pounds or tons (indicate units).
2. Farms visited daily for deliveries and pickups need to be recorded under separate headings as shown above.
3. If necessary use a continuation sheet.

Department of Agricultural Engineering, VPI & SU

Figure 5

Data Form I (Trip Record)

Date ______ Truck No. ______ Recorded by ______ Trip No. ______

Loading Time ______ Starting Odometer Reading ______ miles

Location and/or Directions	Delivery			Pickup		
	Qty. (units)	Type (no.)	Unloading Time	Qty. (units)	Type (no.)	Loading Time

Time to unload returned feed ____ mins. Ending Odometer Reading ______ miles

<u>Instructions & Suggestions</u>

1. Use company trip code, if any.
2. Units of quantity may be lbs. or tons. (indicate units)
3. All the stops need to be recorded in the actual order.
4. If at a certain stop delivery is made, omit the columns under pickup and vice-versa.
5. Loading and unloading times may be rounded off to the nearest minute.

Figure 6

Data Form 2 (Truck Data)

Truck Number	Truck Type	Nominal Capacity (units)	No. of Tanks

Instructions & Suggestions

1. Under column 'Truck Type' specify trailer: straight, etc.
2. Specify nominal capacity in tons or pounds (indicate units).

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Figure 7

required translation in order to suit the input requirements by the 'Sweep Algorithm' computer program of Gillett and Miller.

Also, in light of the simplifying assumptions discussed in Chapter I, screening of the collected data was necessary. The trucks used to deliver feed varied in their carrying capacity. Only trucks with identical carrying capacity and compartment configuration were therefore chosen. On certain days of the particular week over which data was collected, pick ups were made by some of the trucks selected. Since the proposed approach considers only deliveries, and no pick ups, days on which feed was picked up from customer farms were deleted from the sample. Thus, representative data consisted of two days with identical trucks and all deliveries.

Data Translation

In order to use the Gillette & Miller routing algorithm, the input data and coding required is as follows:

1. The number of locations, N, including the feedmill (the feedmill being Location 1).

2. The rectangular coordinates of each location, X(I), Y(I).

3. The quantity of feed to be delivered at each location, Q(I).

4. The maximum distance that can be traveled by a truck on a given day, XD.

The data as collected met the requirements 1 and 4. These values were available from Phase I of the study as discussed previously. In order to satisfy requirements 2 and 3, it was necessary to transform the data as discussed below:

2. In obtaining the rectangular coordinates of each farm location, the locations were plotted on a DELMARVA peninsula road map. Initially county maps were referred to obtain exact farm locations. This was then transferred to an approximate location on the road map. The X and Y coordinates were recorded in miles, as illustrated in Figure 8.

3. It was assumed in Chapter I that every farm order to be supplied is for a single type of feed and for a single quantity. This is, in fact, true for virtually all orders. Even though two orders may be for the same type of feed and a single compartment has the capacity for both orders, no two orders can be mixed in any given compartment. This constraint was handled by a very simple approach, namely, "unitizing every order." It was assumed that all the truck compartments have identical capacity. Thus, if C is the capacity of each truck in tons and K is the number of compartments in each truck, all the compartments have a capacity of C/K tons. Thus, a unit of C/K was defined and orders from all farms were redefined in terms of this unit. The approach proved useful for two reasons:

First, this approach provides a very simple solution to a major constraint on the problem. Secondly, by changing the value of C/K (varying K, given C or varying C, given K), a simulative study could be made to provide additional insight into the problem.

Thus following the procedure described above, a total of four data sets were prepared as input to the computer program listed in Appendix I. The four data sets were as follows:

1. Based on 11/17/76 trip information: A ratio of C/K = 3.333 tons was used, where C = 20 tons and K = 6. (This data set was used for Cases A and B of Chapter IV)

2. Based on 11/24/76 trip information: A ratio of C/K = 3.333 tons was used, where C = 20 tons and K = 6. (This data set was used for Cases A and B of Chapter IV.

3. Based on 11/17/76 trip information: A ratio of C/K = 2.5 tons was used, where C = 20 tons and K = 8. (This data set was used for Cases C and D of Chapter IV)

4. Based on 11/24/76 trip information: A ratio of C/K = 2.5 was used, where C = 20 tons and K = 8. (This data set was used for Cases C and D of Chapter IV)

The results of processing the four data sets above by the computer algorithm were compared with the actual routing used by Purdue, Inc. on the same dates. The results are discussed as Cases A, B, C and D in Chapter IV.

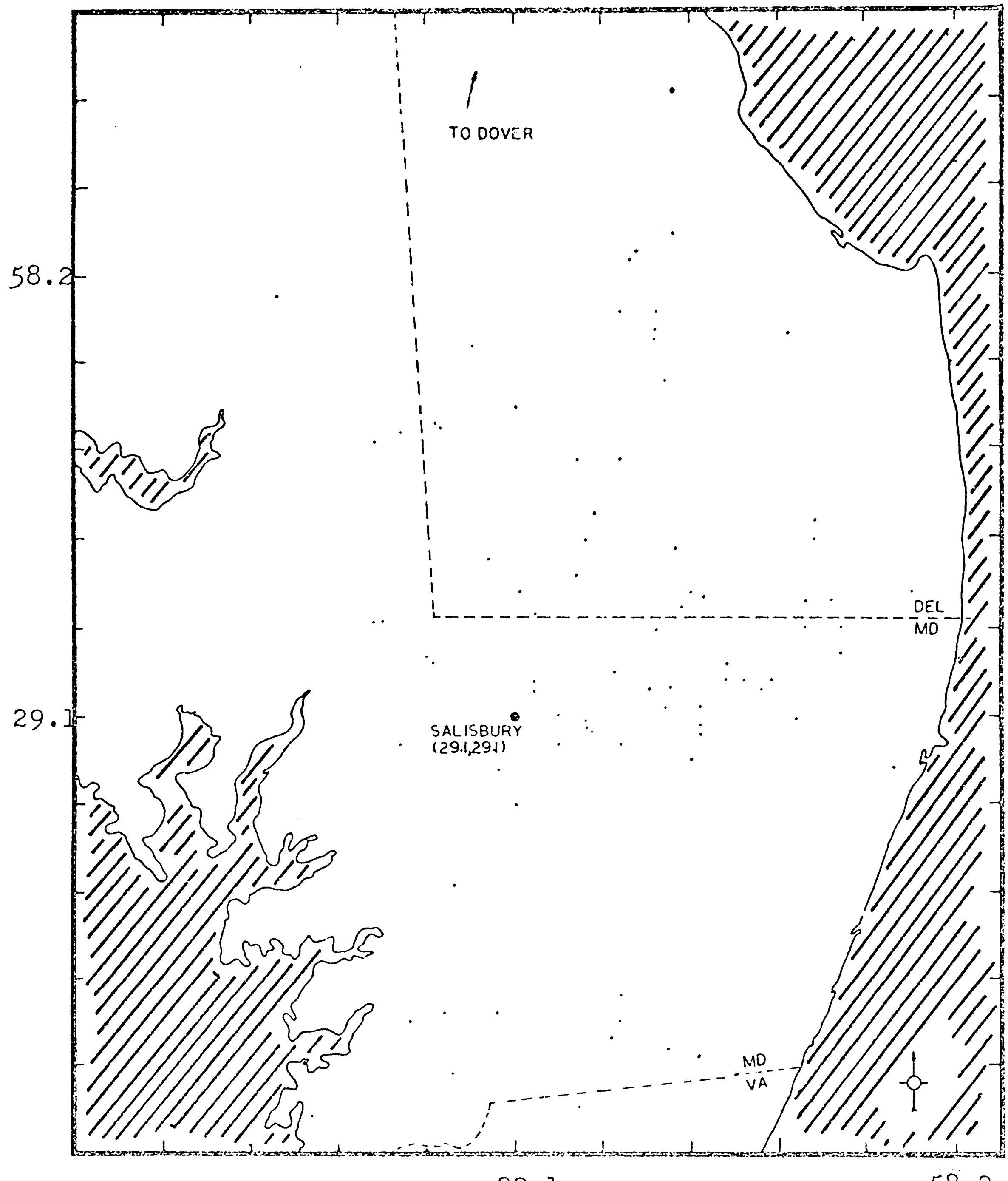

Figure 8

Mapping of Farm Locations

CHAPTER IV

This chapter discusses the results obtained by using the recommended solution procedure for routing feed trucks. The computer program developed by Gillett and Miller was used. A complete listing of this program is included in Appendix I of this report. The chapter also compares the results of this study and the routing data already available from Purdue, Inc.

Before presenting the results, it is necessary to again discuss the major constraints which are involved in this study.

Discussion of Constraints

1. Nominal load capacity and compartment configuration: As discussed in Chapter III, trucks selected for this study were of identical capacity and compartment configuration. Nominal load capacity of each truck was 20 tons and the compartment configuration was given in Figures 1 and 2. The simplifying assumption (10) made in Chapter I that all compartments are of equal capacity is not, as seen from these figures, far from reality.

In the data preparation phase of Chapter III, the capacity of each compartment was defined to be a unit capacity, ratio C/K. The data was prepared using two values of C/K, namely, C/K = 3.333 tons and C/K = 2.5 tons. The ratio C/K = 3.333 tons where C = 20 tons and K = 6 most closely approximate the actual situation at Purdue, Inc. The unit capacity of 2.5 tons and total number of 8 compartments were values used for the purpose of simulating the routing problem.[6] The nominal load capacity, C, of each truck was maintained at 20 tons. Further, the simulation was also carried out by using a unit capacity of 2.5 tons and the total number of 10 compartments in each truck. This resulted in a higher nominal load capacity of 25 tons. Results obtained by using the above data are discussed further in this chapter under Case D.

2. <u>Total allowed distance of travel per day per truck</u>: The value of this constraint was arrived at by examining the entire data obtained from Purdue, Inc. for maximum distance traveled by any truck during a given working day of 22 hours (consisting of two eleven-hour shifts).

According to Mr. Royce White of Purdue, Inc., trucks travel about 22 miles in a given hour. This average, Mr. White informed, was arrived at by allowing for average loading and unloading times, lunch breaks and other pertinent allowances. Thus, the average of 22 miles per hour given a total distance of 484 miles traveled per truck per working day.

Pythagorean Vs. Actual Traveled Distance

The computer program of Gillett and Miller uses Pythagorean (straight-line) distances between two locations to calculate the distance traveled on a given route. In real-

---

[6]This formed Data Sets (3) and (4) as described in Chapter III.

ity, however, actual shortest road distance between two locations is generally greater than the straight line distance between them. Fletcher [6] reported the actual road distance between two locations to be approximately 16 percent greater. This may vary depending upon the geographical nature of the area covered through delivery routes. In urban areas, due to systematic layout of roads, the value may be less than 16 percent, while in mountainous terrain, a higher value may be realistic. In the DELMARVA region, where the land is mostly flat, 16 percent is judged to be appropriate. Thus, the total of distances traveled by all trucks in making scheduled deliveries was multiplied by a factor of 1.16 to recognize the real situation.

Added Distance Per Location Visited

Another approach to estimate the actual traveled distance for all trucks on all routes is to add a constant distance for every farm visited. This approach assumes that highway distances are approximately rectilinear and secondary road distances can be accounted for by adding a predetermined distance for every location visited on a given route. This value can be determined by acquiring suitable data and performing necessary analysis. In this study, an added distance of 5 miles for every location visited was judged to be appropriate.

The following sections of this chapter discuss the results obtained by using the data described earlier. The Computer program was run on the IBM 370 Model 158 Computer at

Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Discussion of the Results

The results of this study are classified under the four cases A, B, C and D. This classification is shown in Tables 1 and 2 for the data sets 11-17-76 and 11-24-76, respectively, as discussed in Chapter III. With respect to nominal load capacity and compartment configurations, each case (A, B, C, and D) is identical for each data set.

In Case A and Case B, an attempt was made to simulate the actual situation of Purdue, Inc. The only difference between these two cases is that, in the former, total distance traveled on all routes is obtained by multiplying the computed value by a factor of 1.16. For Case B, the 'added distance per location visited' approach described earlier is used. In Case C, the nominal load capacity of 20 tons is distributed in 8 compartments of 2.5 ton capacity each. This reduction in the compartment capacity was made to achieve increased loading flexibility. Case D was formulated to examine the effect of higher nominal load capacity of each truck. In this case, the nominal capacity of each truck was increased to 25 tons and distributed equally among 10 compartments.

Table 3 and 4 summarize the results of the study. Table 5 is an example of routes formed for Case A (11-17-76 data) by the Gillette and Miller program. From the results given in Tables 3 and 4, it is seen that the total distance traveled to

Table 1

Data Set 11-17-76

Total Number of Available Trucks = 8

Total Tonnage Delivered = 930.77 Tons

Number of Farms Visited = 78

	Purdue, Inc.	Case A	Case B	Case C	Case D
Nominal Capacity (Tons)	20	20	20	20	25
No. of Compartments	6	6	6	8	10
Capacity of Each Compartment (Tons)	Not Equal	3.333	3.333	2.5	2.5

Table 2

Data Set 11-24-76

Total Number of Available Trucks = 8

Total Tonnage Delivered = 890.63 Tons

Number of Farms Visited = 77

	Purdue, Inc.	Case A	Case B	Case C	Case D
Nominal Capacity (Tons)	20	20	20	20	25
No. of Compartments	6	6	6	8	10
Capacity of each Compartment (Tons)	Not Equal	3.333	3.333	2.5	2.5

Table 3

Solution: 11-17-76

	Purdue, Inc.	Case A	Case B	Case C	Case D
Total Distance Traveled (Miles)	2684.00	2455.40	2497.15	2418.62	2087.31
Total No. of Trips/routes	53	60	60	59	48
Average Miles Traveled Per ton	2.88	2.64	2.68	2.60	2.24
Average tons Delivered Per Trip	17.56	15.51	15.51	15.78	19.40
*Average Loading Efficiency Per Trip	0.87	0.78	0.78	0.79	0.78

*Ratio = Average tons delivered per trip / Nominal truck capacity in tons.

Table 4

Solution: 11-24-77

	Purdue, Inc.	Case A	Case B	Case C	Case D
Total Distance Traveled (Miles)	2751.00	2277.31	2351.85	2204.58	2004.44
Total No. of Trips/Routes	51	56	56	54	49
Average Miles Traveled Per ton	3.09	2.56	2.64	2.48	2.25
Average tons Delivered Per Trip	17.46	15.90	15.90	16.49	18.18
*Average Loading Efficiency Per Trip	0.87	0.80	0.80	0.82	0.72

*Ratio = Average tons delivered per trip / Nominal truck capacity in tons.

Table 5

Example: Route formation for data set 11/17/76, Case A.
(C = 20 tons, K = 6)

Route No.	Location Visited	Load Carried (Units)	Traveled Distance (Miles)
1	1-23-24-1	5.00	13.66
2	1-21-1	6.00	12.35
3	1-63-1	4.00	22.60
4	1-11-1	6.00	21.65
5	1-16-15-1	6.00	42.23
6	1-33-1	6.00	39.82
7	1-36-1	6.00	49.23
8	1-22-1	5.00	40.93
9	1-70-1	4.00	34.73
10	1-13-78-1	6.00	85.01
11	1-74-1	6.00	55.33
12	1-72-1	6.00	67.01
13	1-52-1	4.00	54.22
14	1-77-1	4.00	48.46
15	1-2-1	4.00	28.83
16	1-61-1	6.00	25.08
17	1-71-1	6.00	36.53
18	1-65-1	6.00	19.26
19	1-6-1	4.00	61.71
20	1-43-1	4.00	5.21
21	1-64-1	6.00	4.20
22	1-51-50-1	6.00	61.32
23	1-28-1	6.00	30.47
24	1-69-1	6.00	47.70
25	1-79-1	6.00	26.16
26	1-75-1	6.00	25.56
27	1-46-1	4.00	27.76
28	1-4-1	5.00	14.59
29	1-8-1	4.00	29.48
30	1-47-32-1	5.00	43.65
31	1-68-1	6.00	44.55
32	1-45-12-1	6.00	54.86
33	1-58-1	5.00	43.82
34	1-27-1	4.00	28.80
35	1-76-1	5.00	17.81
36	1-56-41-1	6.00	44.79
37	1-60-1	6.00	20.13
38	1-26-67-1	6.00	34.11

Table 5, continued

39	1-31-1	5.00	30.62
40	1-66-44-1	5.00	32.82
41	1-42-10-1	6.00	24.48
42	1-55-1	4.00	25.19
43	1-3-49-1	6.00	52.84
44	1-34-35-1	6.00	24.00
45	1-7-18-1	4.00	54.10
46	1-37-1	6.00	6.79
47	1-5-1	6.00	48.76
48	1-40-1	6.00	39.77
49	1-30-1	6.00	44.92
50	1-17-1	6.00	39.65
51	1-9-1	5.00	11.64
52	1-20-38-1	3.00	53.52
53	1-57-1	6.00	43.07
54	1-54-1	2.00	23.57
55	1-19-1	5.00	7.38
56	1-39-1	6.00	48.41
57	1-53-1	5.00	59.86
58	1-25-1	5.00	15.53
59	1-14-1	4.00	15.53
60	1-29-1	6.00	43.39

deliver the same tonnage is considerably reduced. However, the total number of trips made has increased. This is due to identical capacity of each compartment and consequent loss of flexibility in vehicle-loading. It can be observed that in Case D less trips are made because of higher nominal capacity of each truck.

Both tables indicate that average miles traveled per ton delivered is reduced progressively in Cases A through D. Higher values of average trips made by each truck are directly related to lower average loading efficiency. It can be observed that Case C shows a slight improvement in average miles traveled per ton and average loading efficiency when compared with Cases A and B. This indicates that reduction in compartment capacity has a favorable effect on both total distance traveled and loading efficiency.

Due to the limited scope of this study, it was not possible to compile the necessary data to perform a cost comparison of the proposed routing plans versus the actual routing used by Purdue, Inc. However, results indicate a potential saving of at least 0.20 miles for every ton delivered. If an estimate 1,000 tons were hauled every day, 200 less miles will be traveled. Assuming that cost of delivery is directly proportional, the average miles per ton (Figure 9) savings achieved by using the proposed solution procedure may indeed be substantial. Also, less miles traveled may be favorable in view of long term maintenance costs.

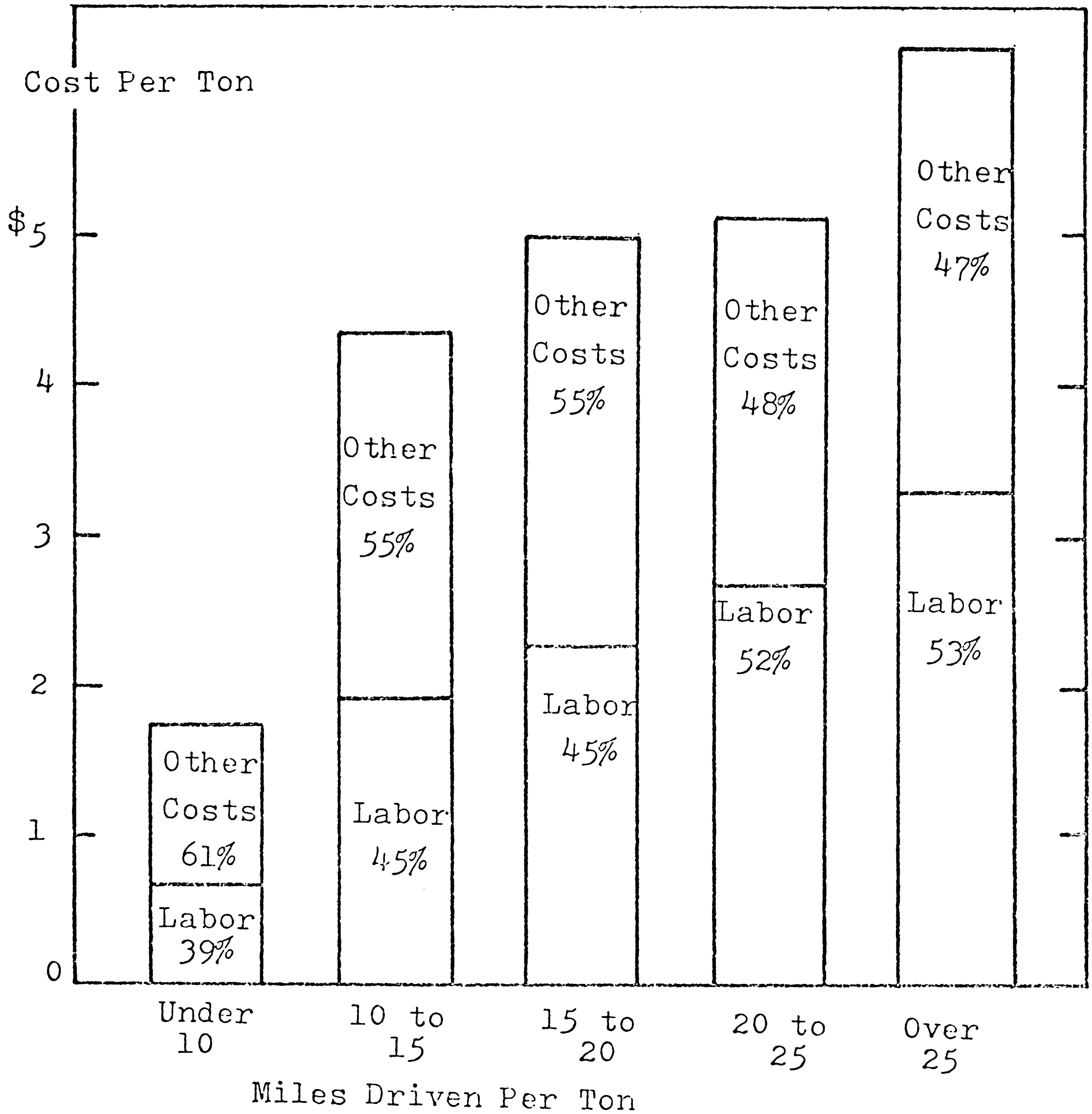

Figure 9

Relationship Between Cost Per Ton and Miles Traveled Per Ton

CHAPTER V

In this chapter, a summary of this study is provided. Some thoughts about areas for further study are also discussed.

Summary

The purpose of the study was to apply an already developed algorithm to an existing problem and perform a comparative study between the solution thus obtained and the data available from currently used system.

Chapter I described and defined the problem in light of an overview of the formula-feed industry. Certain simplifying assumptions and the approach proposed to resolve the problem were also discussed in Chapter I. In Chapter II, a survey of the literature pertaining to the vehicle-routing problem was presented and the method used in the study was discussed. Chapter III was devoted to a discussion of the data preparation required for the study and involved two phases: data acquisition, and data translation. In Chapter IV, as a continuation of the case study, results obtained by using the recommended approach for solving the problem were discussed. The chapter concluded with a brief discussion about potential savings achievable through use of the proposed solution procedure.

The problem was solved on the IBM 370 model 158 computer. Average computer running time was 25 seconds. Appendix I lists the 'Sweep Algorithm' program by Gillett and Miller.

The solution procedure presented in this study is applicable to any feed delivery problem with a single feed mill supplying many geographically dispersed farms. The same procedure can be used to resolve the problem when the system under study undergoes any future expansion in terms of farms visited, number of available trucks, or the frequency of deliveries made.

Areas For Future Research

This study deals specifically with the problem of delivery routing. In reality, there are many instances where excess feed is picked up by trucks after completion of assigned deliveries. A study incorporating this situation would be worthwhile. Also, one of the simplifying assumptions made in the study was that all compartments of every delivery truck have identical carrying capacity. As discussed earlier in the study, this results in a lower loading efficiency and waste of truck space. Removal of this restriction and the consideration of unequal compartment capacities, with their effect on the overall efficiency, is a possible project of interest. An economic analysis of the entire feed delivery operation in light of increased fuel costs, inflation, and the possibility of leasing vehicles versus owning them, poses another area for future research.

A study of different solution procedures discussed in Chapter II and their effectiveness as compared to one another in solving this particular problem would make a worthwhile topic for further study.

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APPENDIX I

PROGRAM LISTINGS FOR THE GILLETTE AND MILLER SWEEP ALGORITHM

APPENDIX I

PROGRAM LISTINGS FOR THE GILLETTE AND MILLER SWEEP ALGORITHM

Limitations

The program can handle routing problems with up to 250 locations with an average of 10 locations per route or 1000 locations with an average of 5 locations per route. The program handles only single depot problems.

Input Data

Card #	Variable	Format	Description
1	N	I5	Number of locations including the feed mill.
	C	F10.2	Load Capacity for each truck (in UNITs)[7]
	XD	F10.2	Maximum distance of travel allowable for each truck in miles
	XLD	F10.2	Added distance per location visited.
2	X(I)	F10.5	X coordinate of location I (in miles)

---

[7] In this report UNIT has been defined as C/K rounded off to the next higher integer value, where

C = Load capacity of each truck in tons
K = Number of compartments in each truck

Card #	Variable	Format	Description
	Y(I)	F10.5	Y coordinate of location I (in miles)
	Q(I)	F10.5	Demand for location I (in UNITs).

Repeat card 2 for each location including feed mill (location 1).

Output Data

Number of locations.

Load Capacity of each truck.

Maximum distance allowable for each truck.

Added distance per location visited.

Feed mill coordinates

	Rectangular Coordinates		Polar Coordinates
Location #	X coordinate Y coordinate	Demand	Radius Angle

Solution:

1. Best Solution: Forward Sweep Algorithm

   Route # Total Load Carried Total Distance Traveled
   No.'s of locations forming route

   Total distance over all routes

2. Best Solution: Backward Sweep Algorithm

   Format as in Solution 1

3. Best Solution: Forward Sweep Algorithm Checking J +2 location

   Format as in solution 1

4. Best Solution: Backward Sweep Algorithm checking J + 2 location.

   Format as in Solution 1

```
C
C*********************************************************************C
C                                                                     C
C      THIS IS A PROGRAM TO SOLVE VEHICLE ROUTING PROBLEMS USING      C
C      THE 'SWEEP' ALGORITHM DEVELOPED BY GILLETT AND MILLER. THIS    C
C      PROGRAM, DESIGNED TO SOLVE MEDIUM AS WELL AS LARGE SCALE       C
C      VEHICLE ROUTING PROBLEMS, CAN HANDLE UP TO 250 LOCATIONS       C
C      INCLUDING THE CENTRAL POINT OR SOURCE.                         C
C                                                                     C
C*********************************************************************C
C
C
      COMMON A(101,101), IROUT(101)
      DIMENSION R(250),S(250), K(250),SS(250), MK(250),NT(250),KK(250)
     *,X(250),Y(250),Q(250),IT(300),ITT(300),QQZ(100),DQZ(100),
     * KKZ(100),BQD(100),BQZ(100),KZ(100)
      ILM = 1
C
C*********************************************************************C
C                                                                     C
C      INPUT DATA:                                                    C
C      READ IN :     N = NUMBER OF LOCATIONS INCLUDING FEEDMILL       C
C                    C = LOAD CAPACITY FOR EACH TRUCK                 C
C                   XD = MAXIMUM ALLOWABLE DISTANCE IN MILES          C
C                  XLD = ADDED DISTANCE PER LOCATION VISITED.         C
C                                                                     C
C*********************************************************************C
C
      READ (5,255) N,C,XD,XLD
  255 FORMAT (I5,3F10.2)
      AVQ = 0
      DO 1 I = 1,N
```

```
C
C*******************************************************************C
C                                                                   C
C              X(I),Y(I) = RECTANGULAR COORDINATES OF LOCATION (I)  C
C               Q(I) = FEED DEMAND AT LOCATION (I)                  C
C               THE FEEDMILL IS AT LOCATION (1)                     C
C                                                                   C
C*******************************************************************C
C
      READ (5,256) X(I), Y(I), Q(I)
  256 FORMAT (3F10.5)
    1 AVQ = AVQ + Q(I)
      AVQ = AVQ/(N-1)
      XX= X(1)
      YY = Y(1)
      WRITE (6,258) N,C,XD,XLD,X(1), Y(1)
  258 FORMAT (' NUMBER OF POINTS IS  ',I5/' LOAD CAPACITY IS  ',F12.6/
     C' DISTANCE CONSTRAINT IS  ',F12.6/' EXTRA DISTANCE PER STOP IS  '
     C,F12.6/' DEPOT AT  ',F12.6,'  AND  ',F12.6)
      KLN = 1
      KV = 0
C
C*******************************************************************C
C                                                                   C
C     CHANGE TO POLAR COORDINATES WITH FEEDMILL AT ORIGIN.          C
C                                                                   C
C*******************************************************************C
C
      WRITE (6,200)
  200 FORMAT (' ',18X,'X(I)', 7X,'Y(I)', 5X,'DEMAND', 4X,'RADIUS',
     1  4X,'ANGLE')
  538 MM = 1
```

```
      BSTD = 10000000.
      RMAX = 0
      SUMR = 0
      DO 2 I = 2,N
      R(I) = SQRT((X(I) - XX)**2 + (Y(I) - YY)**2)
      S(I) = ATAN2(Y(I) - YY,X(I) - XX)
      SUMR = SUMR + R(I)
      IF(ILM.GT.1) GO TO 5001
      WRITE (6,257) I,X(I), Y(I), Q(I), R(I), S(I)
  257 FORMAT (8X,I3,5(2X,F10.4))
 5001 IF(RMAX- R(I)) 66,2,2
   66 RMAX = R(I)
    2 CONTINUE
      GO TO (1000,2000,3000,4000),ILM
 1000 WRITE (6,1001)
 1001 FORMAT ('1 FORWARD SWEEP ALGORITHM')
      GO TO 5000
 2000 WRITE (6,2001)
 2001 FORMAT ('1BACKWARD SWEEP ALGORITHM')
      GO TO 5000
 3000 WRITE (6,3001)
 3001 FORMAT ('1FORWARD SWEEP ALGORITHM CHECKING J+2 LOCATION')
      GO TO 5000
 4000 WRITE (6,4001)
 4001 FORMAT ('1 BACKWARD SWEEP ALGORITHM CHECKING J+2 LOCATION')
 5000 CONTINUE
      AVR = SUMR/(N-1)
      DO 81 I = 1,N
      DO 81 J = I,N
      A(I,J) = SQRT (1.*((X(I) - X(J))**2 + (Y(I) - Y(J))**2))
   81 A(J,I) = A(I,J)
      K(1) = 1
```

```
      K(N+1) = 1
C
C*********************************************************************C
C                                                                     C
C     ARRANGE LOCATIONS IN AN ASCENDING ORDER WITH RESPECT TO         C
C     THEIR POLAR COORDINATES.                                        C
C                                                                     C
C*********************************************************************C
C
   21 J = N
      KOU = 0
      SUMD = 0
      DO 67 I = 2,N
      K(I) = I
   67 SS(I) = S(I)
    5 XMAX = -1000000. * (-1) ** ILM
      DO 3 I = 2,J
      IF(ILM .EQ.2 .OR. ILM .EQ. 4) GO TO 551
      IF(SS(I) - XMAX) 4,3,3
  551 IF(SS(I) - XMAX)3,3,4
    4 XMAX = SS(I)
      II = I
    3 CONTINUE
      IB = K(II)
      K(II) = K(J)
      K(J) = IB
      B = SS(II)
      SS(II) = SS(J)
      SS(J) = B
      J = J - 1
      IF(J-2) 6,6,5
    6 CONTINUE
```

```
C
C*********************************************************************C
C                                                                     C
C      FORM ROUTES.                                                   C
C                                                                     C
C*********************************************************************C
C
   11 J = 2
      M = 1
      KCECK = 0
      N1 = 0
      N2 = 0
      LX = 0
      JJ = 2
      SUM = Q(K(2))
      MM = MM + 1
   12 J = J + 1
   45 IF(SUM + Q(K(J))- C) 13,13,14
   13 SUM = SUM + Q(K(J))
      KCECK = 0
      IF (J .EQ. N)  SUMQ = SUM
  792 IF(J-N) 12,27,27
   14 CONTINUE
      IF(ILM .LE. 2) GO TO 714
      IF( J+1 .GE. N) GO TO 714
      IF(SUM + Q(K(J+1)) - C) 713,713,714
  713 IB = K(J+1)
      K(J+1) = K(J)
      KCECK = 0
      K(J) = IB
      SUM = SUM + Q(K(J))
      J = J + 1
```

```
  714 JJJ = J - 1
C
C**********************************************************************C
C                                                                      C
C     CHECK NEXT LOCATION.                                             C
C     FIND TWO NEAREST POINTS.                                         C
C     KII IS LOCATION IN ROUTE WITH SMALLEST RADIUS AND LARGEST ANGLE  C
C     JJX IS IN ROUTE CLOSEST TO JJI NOT IN ROUTE.                     C
C                                                                      C
C**********************************************************************C
C
  328 F = 1000000
      DO 40 I = JJ,JJJ
      EFG = R(K(I)) - S(K(I)) * AVR
      IF(F - EFG) 40,40,48
   48 F = EFG
      KII = I
   40 CONTINUE
      RX = 100000000
      DO 346 I = 1,4
      JX = J - I
      IF(JX .LT.2) GO TO 346
      IF(R(K(JX))/AVR - .7) 346,346,347
  347 J5 = J + 6
      IF(J5 - N) 363,363,364
  364 J5 = N
  363 DO 348 II = J,J5
      IF (A(K(JX),K(II)) - RX) 349,348,348
  349 RX = A(K(JX),K(II))
      JJX = JX
      JII = II
  348 CONTINUE
```

```
  346 CONTINUE
      IF(KCECK .GT. 0) GO TO 374
      KOUNT = 1
      DO 320 I = JJ,JJJ
      KOUNT = KOUNT + 1
  320 IROUT(KOUNT) = K(I)
      IROUT(1) = 1
      IROUT(KOUNT+1) = 1
      CALL TRAVS (KOUNT,DIST)
      DIST = DIST + (KOUNT - 1) * XLD
      IF(DIST .GT.XD) GO TO 76
      DO 716 I = 1,KOUNT
  716 KK(I) = IROUT(I)
  374 CONTINUE
      SUMQ = SUM
      IF(RX .GT. 100000) GO TO 75
C
      RRX = R(K(JII))
      JIX = JII
      DO 334 I = J,JIX
      IF(R(K(I)) - RRX) 334,334,335
  335 RRX = R(K(I))
      JII = I
  334 CONTINUE
   42 IF(SUM + Q(K(JII)) - Q(K(KII)) - C) 44, 44,75
C
   44 JY = 5
      IF(JY-(N-JJJ))  324,322,322
  322 JY = N - JJJ
  324 JZ = JY + 1
      IF(KCECK .EQ. 1) GO TO 375
      DO 321 I = 2,JZ
```

```
  321 IROUT(I) = K(JJJ+I-1)
      IROUT(1) = 1
      CALL BTS (JY, DIST2)
  375 CONTINUE
      KCECK = 0
C
      IF(JII -JJJ + 1  .GT. JY) GO TO 443
      DO 332 I = 2,JZ
  332 IROUT(I) = K(JJJ+I-1)
      IROUT(1) = 1
      IROUT(JII-JJJ+1) = K(KII)
      CALL BTS (JY, DIST3)
C
      KOUNT = 1
      DO 331 I = JJ,JJJ
      KOUNT = KOUNT + 1
  331 IROUT(KOUNT) = K(I)
      IROUT (1) = 1
      IROUT(KOUNT+1) = 1
      IROUT(KII - JJ + 2) = K(JII)
      CALL TRAVS (KOUNT,DIST1)
      DIST1= DIST1+ (KOUNT - 1) * XLD
      IF(DIST1 .GT. XD) GO TO 443
C
      EFG = AVR  * (Q(K(JII)) - Q(K(KII))) / AVQ
      IF(EFG+DIST + DIST2 - DIST1 - DIST3)443,443,326
  326 DIST = DIST1
      DO 717 I = 1,KOUNT
  717 KK(I) = IROUT(I)
      SUMQ = SUM
      JJ1 = JJJ - 1
      SUM = SUM + Q(K(JII)) - Q(K(KII))
```

```
      JI = K(KII)
      DO 51 I = KII,JJ1
   51 K(I) = K(I+1)
      IF(JII .NE. JJJ + 1) GO TO 274
      K(JJJ) = K(JJJ + 1)
      K(JJJ + 1) = JI
      GO TO 275
  274 K(JJJ) = K(JII)
      K(JII) = JI
  275 J = J - 1
      DIST2 = DIST3
      KCECK = 1
      GO TO 12
C
  443 MAX = 1000000
      IF(J5 - J .LT. 3) GO TO 75
      DO 420 I = J,J5
      IF(I - JII) 421,420,421
  421 IF(MAX- A(K(I),K(JII)))420,422,422
  422 JKK = I
      MAX = A(K(I),K(JII))
  420 CONTINUE
      IF(SUM + Q(K(JII)) + Q(K(JKK)) - Q(K(KII)) .GT. C) GO TO 75
C
      KOUNT = 1
      JZ = 6
      IF(JII - JJJ + 1 .GE. JZ) GO TO 75
      IF(JKK - JJJ + 1 .GE. JZ) GO TO 75
      IF(JZ -(N -JJJ+ 1)) 435,436,436
  436 JZ = N - JJJ
  435 DO 431 I = 2,JZ
      IF(I .EQ.JKK - JJJ + 1) GO TO 431
```

```
      KOUNT = KOUNT + 1
      IROUT(KOUNT) = K(JJJ + I - 1)
  431 CONTINUE
      IROUT(JII - JJJ + 1) = K(KII)
      IROUT(1) = 1
      JT = KOUNT - 1
      CALL BTS (JT,DIST5)
C
      KOUNT = 1
      DO 430 I = JJ,JJJ
      KOUNT = KOUNT + 1
      IROUT(KOUNT) = K(I)
  430 CONTINUE
      IROUT(1) = 1
      KOUNT = KOUNT + 1
      IROUT(KOUNT + 1) = 1
      IROUT(KII - JJ + 2) = K(JII)
      IROUT(KOUNT) = K(JKK)
      CALL TRAVS (KOUNT,DIST4)
      DIST4= DIST4+ (KOUNT - 1) * XLD
      IF(DIST4 .GT. XD) GO TO 75
C
      IF(DIST + DIST2 - DIST4 - DIST5) 75,433,433
  433 DIST = DIST4
      DO 718 I = 1, KOUNT
  718 KK(I) = IROUT(I)
      SUM = SUM + Q(K(JII)) + Q(K(JKK)) - Q(K(KII))
      SUMQ = SUM
      M5 = JJJ + 4
      JI = K(KII)
      JM = K(J)
      IF(KII .EQ. JJJ) GO TO 794
```

```
      JJ1 = JJJ - 1
      DO 434 I = KII,JJ1
  434 K(I) = K(I+1)
      K(JJJ) = K(JII)
      JJJ = JJJ + 1
      K(JJJ) = K(JKK)
      K(JKK) = JI
      IF(JII .EQ. J) GO TO 793
      K(JII) = JI
      K(JKK) = JM
      GO TO 793
  794 K(J) = K(JII)
      K(KII) = K(JKK)
      JJJ = JJJ + 1
      K(JII) = JM
      K(JKK) = JI
  793 CONTINUE
      KCECK = 2
      GO TO 12
C
C**********************************************************************C
C                                                                      C
C      DELETE ONE FROM ROUTE.                                          C
C                                                                      C
C**********************************************************************C
C
   76 JJJ = JJJ - 1
      KOUNT = KOUNT - 1
      J = J - 1
      SUM = SUM - Q(K(J))
      GO TO 328
C
```

```
C**********************************************************************C
C                                                                      C
C     ACCEPT THE ROUTE.                                                C
C                                                                      C
C**********************************************************************C
C
   75 SUMD = SUMD + DIST
      KT = JJJ - JJ + 2
      DQZ(M) = DIST
      QQZ(M) = SUMQ
      KZ(M) = KT
      DO 536 I = 1,KT
      KOU = KOU + 1
  536 IT(KOU) = KK(I)
  719 FORMAT (/' ROUTE',I5,'   HAS LOAD',F10.2,'  WITH DISTANCE ',F10.2,
     1 '  IS' / 28(1X,I3))
      LX = 0
      M = M + 1
      SUM = Q(K(J))
      JJ = J
   20 IF(KLN-1) 30,31,30
   31 IF(KV-KOUNT) 32,30,30
   32 KV = KOUNT
   30 CONTINUE
      IF(J-N) 12,27,27
   27 KOUNT = 1
      JJJ = J
      IROUT(1) = 1
      DO 82 I = JJ,J
      KOUNT = KOUNT + 1
   82 IROUT(KOUNT) = K(I)
      IROUT(KOUNT + 1) = 1
```

```
      CALL TRAVS (KOUNT, DIST)
      DIST = DIST + (KOUNT - 1) * XLD
      IF(DIST - XD) 83,83,97
   97 J = J + 1
      GO TO 76
   83 CONTINUE
      QQZ(M) = SUMQ
      KZ(M) = KOUNT
      DQZ(M) = DIST
      DO 537 I = 1,KOUNT
      KOU = KOU + 1
  537 IT(KOU) = IROUT(I)
      SUMD = SUMD + DIST
   84 FORMAT(//' TOTAL DISTANCE IS',F15.5)
      IF(BSTD - SUMD) 530,531,531
  531 NM = N + M
      BSTD = SUMD
      DO 532 I = 1,NM
  532 ITT(I) = IT(I)
      DO 533 I = 1,M
      BQD(I) = DQZ(I)
      BQZ(I) = QQZ(I)
  533 KKZ(I) = KZ(I)
      MZ = M
  530 CONTINUE
C
C***********************************************************************C
C                                                                       C
C     INCREMENT THE ANGLE.                                              C
C                                                                       C
C***********************************************************************C
C
```

```
      KLN = 2
      IF(MM      - KV) 61,50,50
   61 XMIN = 100000000.
      DO 62 I = 2,N
      IF(S(K(I)) - XMIN) 63,62,62
   63 XMIN = S(K(I))
      MI = K(I)
   62 CONTINUE
      S( MI ) = 3.14529 - ABS(S( MI )) + 3.14529
      GO TO 21
   50 CONTINUE
      WRITE (6,5002)
 5002 FORMAT (///' BEST SOLUTION IS')
      IB = 0
      DO 534 I = 1,MZ
      IA = IB + 1
      IB = IB + KKZ(I)
  534 WRITE (6,719) I,BQZ(I),BQD(I),    (ITT(J),J=IA,IB)
      ILM = ILM + 1
      WRITE (6,84) BSTD
      IF(ILM .LE. 4) GO TO 538
  521 CONTINUE
      STOP
      END
      SUBROUTINE TRAVS (N,DIST)
      COMMON A(101,101), K(101)
      DIMENSION KK(101), KKK(101)
      N1 = N + 1
      DO 34 I = 1,N1
   34 KKK(I) = K(I)
   51 IF(N-3) 54,54,53
   53 N1 = N - 1
```

```
      N3 = N - 3
    5 DO 12 KOUNT = 1,N
      DO 32 IK = 1,N3
      K1 = IK + 1
      DO 32 IJ = K1,N1
      D1 = A(K(IK),K(IJ+ 1)) + A(K(1),K(IJ))
      D = A(K(1),K(IJ+1)) + A(K(IK), K(IJ))
      IF(D1 - D) 6,6,7
    6 IA = 8
      D = D1
      GO TO 17
    7 IA = 2
   17 IF(D+A(K(IK+1),K(N))-A(K(1),K(N))-A(K(IK),K(IK+1)) - A(K(IJ),K(IJ+
     11)) + .001) 9,32,32
   32 CONTINUE
      IB = K(N)
      N1 = N - 1
      DO 13 I = 1,N1
   13 K(N-I+1) = K(N-I)
      K(1) = IB
   12 CONTINUE
      GO TO 2
    9 DO 19 I = 1,N
   19 KK(I) = K(I)
      IJ2 = IJ+2
      K1 = IK+1
      K(N) = KK(IJ+1)
      KO = 0
      IF(IJ2 - N) 36,36,37
   36 DO 20 I = IJ2,N
      KO = KO + 1
   20 K(KO) = KK(I)
```

```
37 DO 21 I = K1,IJ
   KO = KO + 1
21 K(KO) = KK(I)
   K(N) = KK(IJ+1)
   IF(IA - 8) 18,15,18
15 DO 22 I = 1,IK
   KO = KO + 1
22 K(KO) = KK(I)
   GO TO 14
18 DO 25 I = 1,IK
   KO = KO + 1
25 K(KO) = KK(IK+1-I)
14 CONTINUE
   DO 35 I = 1,N
35 KKK(I) = K(I)
   GO TO 5
 2 CONTINUE
54 CONTINUE
   DIST = A(KKK(N),KKK(1))
   DO 30 I = 2,N
30 DIST = A(KKK(I-1),KKK(I)) + DIST
   RETURN
   END
   SUBROUTINE BTS (N,BOUND)
   COMMON A(101,101), K(101)
   DIMENSION MM(10,10), T(10,10), IT(10), KK(10)
   DO 21 I = 1,N
   DO 22 J = 1,N
22 MM(I,J) = 0.
21 IT(I) = 0.
   IT(N+1) = N+1
   T(1,1) = 0
```

```
      IT(1) = 1
      BOUND = 100000.
C
      JJ = 1
      I = 1
    1 I = I + 1
      II = I - 1
      DO 25 L = 1,II
      IF (IT(L)) 25,25,26
   26 MM(I,IT(L)) = 1
   25 CONTINUE
   12 DX = 100000
      DO 2 J = 2,N
      IF (MM(I,J) .EQ. 1) GO TO 2
      T(I,J) = T(I-1,JJ) + A( K(JJ), K(J))
      IF(T(I,J) .GT. BOUND) GO TO 8
      IF(DX .LT. T(I,J)) GO TO 2
      DX = T(I,J)
      KZ = J
    2 CONTINUE
C
      IF(DX .GT.10000) GO TO 24
   11 IT(I) = KZ
      JJ = KZ
      MM(I,JJ) = 1
      IF(I .LT. N  ) GO TO 1
      GO TO 28
C
   24 I = I - 1
      IF (I .EQ. 1) GO TO 13
      DX = 100000
      DO 27 L = 2,N
```

```
      IF (MM(I,L) .EQ.1) GO TO 27
      IF (T(I,L) .GT.DX) GO TO 27
      DX = T(I,L)
      JJ = L
   27 CONTINUE
      DO 29 L = 1,N
   29 MM(I+1,L) = 0
      IF(DX .GT. 10000) GO TO 24
      IT(I) = JJ
      MM(I,JJ) = 1
      IF(I .LT. N  ) GO TO 1
C
   28 I = I + 1
      T(I,1) = T(I-1,JJ) + A( K(JJ), K(I))
      IF(T(I,1) .GT. BOUND) GO TO 24
      J = I
      BOUND = T(I,1)
      IF(N+1 - I) 36,35,36
   35 DO 34 L = 1,I
   34  KK(L) =  K(IT(L))
   36 CONTINUE
    8 IT(I) =    J
      GO TO 24
   13 DO 342 I = 1,N
  342 K(I) = KK(I)
      RETURN
      END
```

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VEHICLE ROUTING - A CASE STUDY

by

Suhas G. Sathe

(ABSTRACT)

This report presents a solution procedure to accomplish efficient routing of vehicles. Specifically, the routing of delivery trucks to transport bulk poultry feed from a single feed mill to various customer farms located in the surrounding region at nearly 50 miles radius was studied. The goal was to minimize the total distance traveled for all routes.

The project was divided into two phases. In the first phase, truck delivery records were developed through a system of forms over a period of one week at Purdue, Inc. of Salisbury, Maryland. These records were used for preparation of the data required in the second phase of the project. In the second phase, the 'Sweep' Algorithm by Gillette and Miller was used to generate truck routes on a digital computer.

The results obtained through the recommended solution procedure were compared with the routes designed by the dispatcher at Purdue, Inc. These results showed significant savings in total distance traveled over all routes.