A Minimal Technology Routing System for Meals on Wheels*

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A novel routing system based on a new travelling salesman heuristic was successfully implemented to handle the efficient daily routing of a varying number of vehicles to more than 200 delivery points whose locations change daily. The system had to be easily mantained by one person and require no resources (for example, no computer). Our system achieved these objectives, cost less than $50, and, moreover, shortened average travel times by 13% compared to previous performance.

Routing problems — where vehicles visit many delivery points distributed over a geographical region and return to the depot within minimal time — are notoriously difficult to solve. Even the most powerful computers available today would require years to exactly solve routing problems of moderate size. Consequently recent research has focused on heuristic methods, simple procedures that enable computers to generate good (but not optimal) solutions.

Unlike computers, humans have a knack for generating good routes, but they get bogged down in details when the problem is large. With our colleagues at the Production and Distribution Research Center of the Georgia Institute of Technology, we have been investigating interactive computer methods, in which a computer with color graphics is used as an "intelligent scratchpad" by a human operator who designs the routes. In the course of these activities we unexpectedly discovered a heuristic so simple that a computer is not even required [Bartholdi

*This research was supported by The New Faculty Research Development Program of the Georgia Institute of Technology and The Office of Naval Research under Contract No. N00014-80-k-0709.

0092-2102/83/1303/0001$01.25

TRANSPORTATION — ROUTE SELECTION
NETWORKS/GRAPHS — TRAVELING SALESMAN
PROGRAMMING — INTEGER ALGORITHMS, HEURISTIC

and Platzman 1982].

We recognized that our idea applies wherever routing must be performed quickly without computers or technically trained personnel. From previous experience we knew of a charitable organization that faced routing problems of this type. To validate our method and to help a worthy cause, we worked with the charity to implement a routing system based on our idea.

Meals on Wheels

Senior Citizen Services, Inc. is a private, nonprofit corporation in Atlanta, Georgia whose purpose is to provide social services for the elderly, especially the elderly poor, in Fulton County. One of their major services is the "Meals on Wheels" program (MOW), which delivers prepared lunches to people who are unable to shop or cook for themselves. As for many charitable organizations, the funding for MOW is unstable, chronically insufficient, and occasionally desperate. Any additional resources are used to purchase more food for needy people, so the administrative facilities of MOW remain the bare minimum necessary to function.

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MOW operates Monday through Friday each week. At 8:30 a.m. the prepared meals are delivered by an institutional caterer to Senior Citizen Services in mid-Atlanta. There they are heated in a holding oven until about 9:15 a.m. when four paid, part-time employees arrive. They load the meals into insulated bulk containers and then into their four vehicles. Each driver is given a "route manifest" which lists all of his delivery locations in a suggested order of visitation. Each then drives his route, delivering 40-50 meals to 30-40 locations between 10 a.m. and 2 p.m.

Because the delivery vehicles are usually station wagons, they can easily carry sufficient meals, so vehicle capacity is not an effective limitation. The only constraint is that all meals must be delivered within four hours, the length of time the insulated containers will keep the meals properly warm. However, drivers complete their routes within the limit so time constraints are usually not active. In fact, neither vehicle capacity nor delivery time is likely to become an active constraint unless the system grows considerably, an unlikely event for a charitable organization during lean times.

MOW maintains two lists of clients: an *active* list of those to whom meals are currently delivered, and a *waiting* list of those hoping to join the system when space or additional resources become available. A special feature of this delivery problem is that the lists are quite volatile (Table 1). In fact, the lists change at a rate of about 14% each month because of the nature of the clients: most are elderly or ill. They may die, or recover from illness, or receive care elsewhere (in a hospital, nursing home, or family) and so leave whichever list they are on. Clients may be added to the active list either from the waiting list, or as emergency special cases (perhaps referred to MOW by a social worker).

Month	People Served	People Added	People Lost
July 1981	159	—	—
August	167	15	7
September	169	8	6
October	195	29	3
November	225	40	10
December	256	37	6
January 1982	?	?	?
February	273	31	?
March	299	41	15
April	327	36	8
May	341	26	12
June	353	22	10
July	358	5	20
August	278	2	62
September	240	2	40
October	227	8	21
November	246	40	21

Table 1. Changes in the Meals on Wheels active client list from August 1981 through November 1982. About 80% of these clients received their meals through the routing system; the rest were served by volunteers.

The volatility of the active list is further increased by the special way in which MOW is funded. Senior Citizen Services receives operating revenues from three primary sources, the federal government, the state of Georgia, and United Way. Unfortunately, all three administer their grants under different fiscal calendars. The federal government begins its fiscal year on October 1, the State of Georgia on July 1, and United Way on January 1. The multiple fiscal years cause continuous turmoil at MOW because each grant must be spent during its respective fiscal year. Consequently it is not unusual for a large number of people to be added to the active list during the close of a fiscal year and then to be removed to the waiting list during the beginning of a new fiscal year.

MOW is managed by a devoted, energetic woman who is a full-time employee of Senior Citizen Services. As in many charitable organizations, the manager tends to be overworked. Her responsibilities are many, and include management of the MOW budget, and responsibility for all technical aspects of meals: planning menus, ordering meals from the caterer, monitoring the quality of meals, maintaining the insulated containers for the meals, and supervising part-time employees. In administering the delivery of meals she maintains the list of delivery locations, maintains routes to be followed by the delivery trucks, and supervises the four part-time drivers. She also recruits and trains volunteers, and coordinates her services with social workers. The manager has little time (and essentially no resources) to devote to routing.

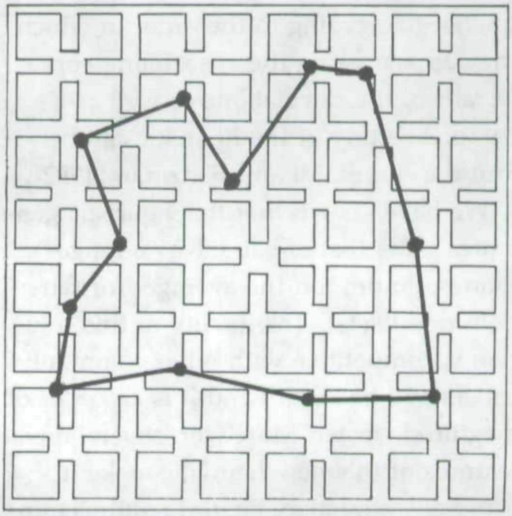


Figure 1. The spacefilling curve is an infinitely crinkly version of the pattern above. The heuristic tour visits the points as they appear along the spacefilling curve.

We set out to design a method to help the busy manager quickly generate efficient routes from a volatile list. This method could not rely on a computer, nor even on appreciable clerical effort, for such resources are not within the means of MOW.

The New Heuristic

The routing system we implemented is based on a new travelling salesman heuristic [Bartholdi and Platzman 1982] which is extremely simple and yet provides good tours on the average. The idea behind this algorithm is a "spacefilling curve" (Figure 1), which may be imagined to visit all the points of the unit square. The algorithm has the following structure:

Step 1. For each location (x,y) calculate its relative position, θ, along the spacefilling curve.

Step 2. Sort the locations from the smallest to largest θ.

Thus the points to be visited are sequenced according to the order in which they appear along the spacefilling curve. Details of the calculations as well as a complete study of the heuristic can be found in Bartholdi and Platzman [1982].

We have shown that this heuristic generates tours that are about 25% longer than optimum (on the average, for random point sets). The quality of this solution is competitive with other commonly considered heuristics and it is an order of magnitude faster. Moreover, several novel features of this new heuristic make it especially attractive. First, it requires minimal data: to route to n locations requires only the $2n$ values of the coordinates (x,y). In fact, the $O(n^2)$ distances between points are never required! Second, points may be easily inserted into or removed from the heuristic tour. There is no need to re-solve the entire problem. In contrast, tours generated by other methods are not so easy to modify. It is the minimal requirements of this algorithm together with the ease of insertion and removal that suit it so well to the MOW routing problem.

The Routing System

The routing system we built for MOW consists of a map, a table of θ values, and two Rolodex™ card files.

The map is a standard Department of Transportation street map of Atlanta. It is mounted under a plastic grid so that one can read the (x,y) coordinates for any location.

We pre-computed a table for MOW so that they do not need to calculate θ . It allows one to enter with values for (x,y) and read a corresponding θ value. It fits easily on six sheets of paper.

Each of the two card files contains a complete list of active clients. A card lists a client's name, address, and telephone number, together with miscellaneous notes, such as special handling required for meals, etc. In addition, each card has the client's θ number. Each client is represented by two identical cards, one for each file. The first file is sorted alphabetically by name, and the second is sorted numerically by θ.

The card files permit simple insertion and removal of clients so that the system can easily handle the volatility of the lists. To remove a client, one just looks up his name in the alphabetical list, notes his θ value, and removes the card, then looks up his θ value in the route list and removes that card also. To insert a client, one simply goes to the map and measures the (x,y) coordinates of the client's location, then enters the table with (x,y) and reads the corresponding θ value. Two

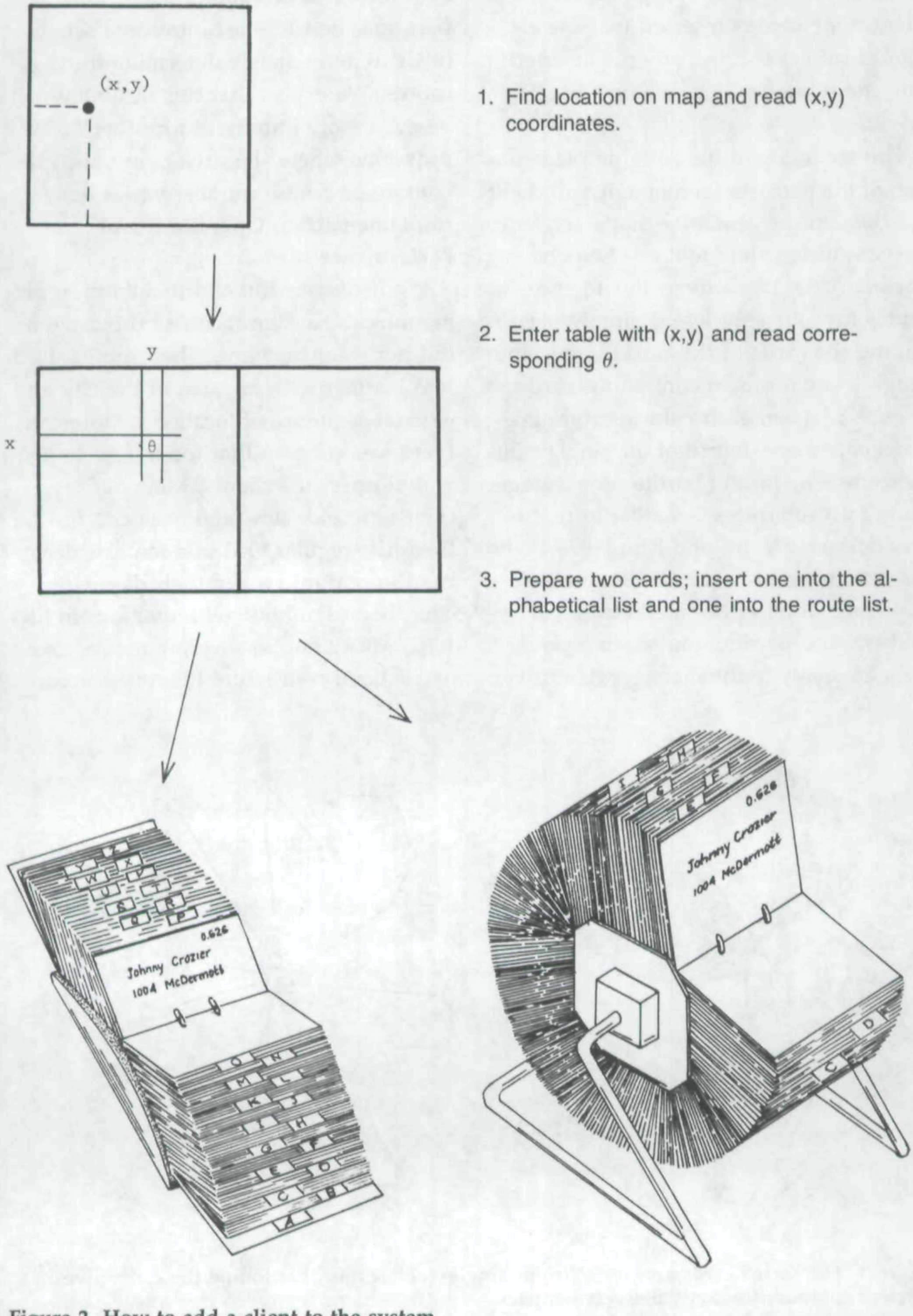


Figure 2. How to add a client to the system.

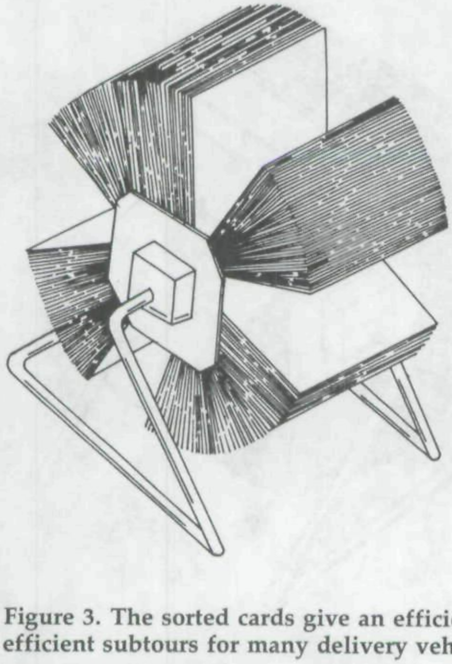
identical file cards are prepared for the client. One card is inserted into the alphabetical list and the other is inserted into the numerically sequenced list (Figure 2).

The second card file is the implementation of the heuristic. It maintains all client locations in the sequence that a *single* delivery vehicle would follow when obeying our heuristic. We convert this to subroutes for four vehicles by simply partitioning the cards of the card file into four roughly equal sets of contiguous cards (Figure 3). Then each vehicle drives approximately one-fourth of the single vehicle route. The idea of partitioning a single route into subroutes is similar to that of Fredrickson, Hecht, and Kim [1978], who prove nice worst-case bounds for a stricter implementation of the method.

This route-partitioning scheme gives great flexibility to the manager. If a driver or vehicle is unavailable, it is simple to partition the route list into three sets of cards to immediately determine three routes. We expect that this flexibility will be even more important for other MOW programs where the drivers are unpaid volunteers whose number varies daily.

Implementation, Operation, and Performance

We had some initial difficulty in implementing the system because the drivers did not want to change their routes. Each was familiar with his area of the city and general sequence of locations. Moreover, there was concern that too much change would upset the clients. Most of the clients are old, sick, and isolated, and for them the regular visit of a familiar driver is an important part of their day. However, because of budget reductions in July 1982, MOW had to severely reduce its active list and restructure the routes accord-



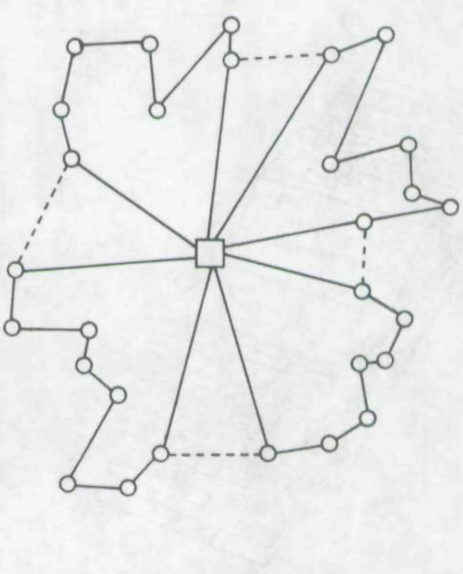


Figure 3. The sorted cards give an efficient single-vehicle tour. Partioning the cards gives efficient subtours for many delivery vehicles.

ingly. Since major changes had to be made anyway, we implemented our system at that time.

Because the routing algorithm is a heuristic, we expected it to occasionally choose sequences that could easily be improved. Accordingly we advised drivers to consider their sequence a suggestion to which they should make local improvements if possible. In fact no clear improvements were found and we had trouble with drivers erroneously thinking they knew an improvement to the sequence. After that we recommended that the sequence be maintained exactly as determined by the heuristic.

We discovered that partitioning the single route into subroutes caused some concern. The manager naturally wanted "ideal" routes, that is, those that look efficient on a map *and* balance total delivery time among the drivers. She was worried because the routes derived by partitioning tend to have somewhat large travel times to each first or from each last delivery. It seemed more reasonable, she felt, to go to someplace close first. But when we measured the routes, the relatively long initial and final legs of each were generally found to be an insignificant part of total delivery time. This was partly because the heuristic reduced total driving time to only 30-40% of total delivery time for each route. Thus occasional travel time aberrations from imperfectly partitioned routes are unimportant. However, the MOW manager preferred to hunt and make adjustments until she determined an acceptable partition. Since repartitioning is done only occasionally, this seemed satisfactory.

The routing system is generally used as expected, with one exception. In practice, the manager tends to make additions to the active list by "eyeballing" the map, and not by looking up θ immediately. She does this because daily changes are small and she is rushed. Later, when time permits, she looks up the θ values and files them appropriately. But there is a danger of our system degenerating if the θ values are not maintained.

The manager tries to balance the work of the four drivers. Because they are paid by the hour, none wants an unusually short route, and trading routes among the drivers is not acceptable because that would disrupt the driver-client relationship. Fortunately, the partitioning scheme works quite well in this regard. Because travel time is only 30-40% of total delivery time, the total delivery time depends mostly on how many meals are to be delivered. Consequently, partitioning the route file into equal sets of cards tends to produce routes for which the total delivery times (although not travel times) are nearly equal. Table 2 summarizes the routes as of November 1982.

	Routes			
	1	2	3	4
Meals	48	47	55	45
Locations	25	35	38	36
Approximate miles	23	28	41	37
Approximate total delivery time (hours)	3½	3½	4	4

Table 2. Summary of the routes as of November 1982.

Because the client list changes so quickly, it was not possible to directly compare the driving times and distances of our routes with previous routes. We did, however, submit a previous client list to our heuristic and determined that our routes were about 13% shorter as measured by Euclidean distance.

The most important improvement, however, is the facility with which the system may now incorporate changes in the client list or the number of drivers.

Future Work

There are other programs similar to MOW in several counties immediately surrounding Atlanta. While their active lists are smaller (typically half that of MOW) they cannot afford paid deliverers. Consequently they are dependent on volunteer drivers, whose number may vary from day to day. We expect a system like ours to help these organizations too. Accordingly, we are preparing a booklet describing how to implement such a system, giving θ tables, and so forth. We hope to make the booklet available to Meals on Wheels organizations throughout the country.

Our method may also be useful to various profitable delivery ventures as well, especially if it is not possible to justify a major investment in computer equipment and appropriately trained personnel. Potential application areas might include package, parts, or newspaper deliveries.

References

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Barbara M. Dimorier at Senior Citizen Services of Atlanta writes that, "With this new method, we were able to reduce the number of miles driven and to consolidate five routes into four. Because of the method we now have an easy, inexpensive, and quick way to adjust our drivers' routes as we remove and add new clients."