The Computerized Routing of Meter Readers over Street Networks: New Technologies Turn Old Problems into New Opportunities

by

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# **Outline of Lecture**

- The close enough traveling salesman problem (CETSP)
- The CETSP over a street network
- Heuristics for solving this problem
   Greedy Approaches
   IP Formulations
- Computational Results
- Conclusions

#### **The CETSP over a Street Network**

- Until recently, utility meter readers had to visit each customer location and read the meter at that site
- Now, radio frequency identification (RFID) technology allows the meter reader to get close to each customer and remotely read the meter
- Our models are based on data from a utility and use an actual road network with a central depot and a fixed radius r for the hand held device
- Our goal is to minimize distance traveled or elapsed time

#### **The CETSP over a Street Network**

- We used RouteSmart (RS) with ArcGIS
  - Real-world data and constraints
  - >Address matching
  - Side-of-street level routing
  - > Solved as an arc routing problem
- Our heuristic selects segments to exploit the "close enough" feature of RFID
- RS routes over the chosen segments to obtain a cycle
- Currently, RS solves the problem as a Chinese (or rural) Postman Problem

## **Heuristic Implementation**

- How do we choose the street segments to feed into RS?
- We tested several ideas
- Greedy procedures
  - ➢ Greedy A: Choose the street segment that covers the most customers, remove those customers, and repeat until all customers are covered
  - Greedy B: Same as above, but order street segments based on the number of customers covered per unit length
- IP Formulations

## **IP Formulation**

• We also experimented with formulating the problem as an IP:  $\sum_{i=1}^{N}$ 

Minimize  $\sum_{j} c_{j} x_{j}$ 

subject to

 $\sum_{j} a_{ij} x_{j} \ge 1 \text{ for all } i$  $x_{j} \in \{0,1\}$ 

where  $a_{ij} = 1$  if customer i is covered by road segment j 0 otherwise

and  $x_j = 1$  if road segment j is traversed 0 otherwise

## **IP Variants**

• We tested several choices for the objective function

IP1: Minimize the number of road segments chosen
c<sub>i</sub> = 1 for all j

IPD1: Minimize the distance of the road segments chosen
c<sub>j</sub> = the distance of road segment j

## **Each Color is a Separate Partition**



## **A Single Partition**



## A Closer Look at a Partition



## **The Area Covered with RFID**



#### The Area Covered by the Entire Partition



### **Dense Partition Results**

|               |              | 500 foot radius        |      |                             |                          |
|---------------|--------------|------------------------|------|-----------------------------|--------------------------|
| <u>Method</u> | <u>Miles</u> | Number ofHoursSegments |      | Miles of<br><u>Segments</u> | Deadhead<br><u>Miles</u> |
| RS            | 204.8        | 9:22                   | 1099 | 97.5                        | 107.3                    |
| Greedy A      | 160.5        | 7:06 470               |      | 64.4                        | 96.1                     |
| Greedy B      | 166.5        | 7:27                   | 577  | 64.2                        | 102.3                    |
| IP1           | 165.8        | 7:25                   | 458  | 62.4                        | 103.4                    |
| IPD1          | 161.6        | 7:15                   | 470  | 59.1                        | 102.5                    |
| Essential     | _            | _                      | 342  | 43.3                        | _                        |

### **Dense Partition Results**

|               |              | 350 foot radius        |      |                             |                          |
|---------------|--------------|------------------------|------|-----------------------------|--------------------------|
| <u>Method</u> | <u>Miles</u> | Number ofHoursSegments |      | Miles of<br><u>Segments</u> | Deadhead<br><u>Miles</u> |
| RS            | 204.8        | 9:22                   | 1099 | 97.5                        | 107.3                    |
| Greedy A      | 171.9        | 7:45 621               |      | 78.1                        | 93.8                     |
| Greedy B      | 179.3        | 7:55                   | 610  | 78.0                        | 101.3                    |
| IP1           | 169.8        | 7:39                   | 608  | 77.6                        | 92.2                     |
| IPD1          | 168.1        | 7:40                   | 609  | 76.9                        | 91.2                     |
| Essential     | —            | _                      | 451  | 61.9                        | _                        |

## **Sparse Partition Results**

|               |              | 500 foot radius        |     |                             |                          |
|---------------|--------------|------------------------|-----|-----------------------------|--------------------------|
| <u>Method</u> | <u>Miles</u> | Number ofHoursSegments |     | Miles of<br><u>Segments</u> | Deadhead<br><u>Miles</u> |
| RS            | 213.6        | 9:26                   | 405 | 98.4                        | 115.2                    |
| Greedy A      | 189.9        | 8:22 217               |     | 79.6                        | 110.3                    |
| Greedy B      | 197.0        | 8:56                   | 236 | 84.7                        | 112.3                    |
| IP1           | 188.2        | 8:18                   | 216 | 78.5                        | 109.7                    |
| IPD1          | 188.4        | 8:18                   | 216 | 78.3                        | 110.1                    |
| Essential     | -            | _                      | 212 | 78.0                        | -                        |

## **Sparse Partition Results**

|               |              | 350 foot radius        |     |                             |                          |
|---------------|--------------|------------------------|-----|-----------------------------|--------------------------|
| <u>Method</u> | <u>Miles</u> | Number ofHoursSegments |     | Miles of<br><u>Segments</u> | Deadhead<br><u>Miles</u> |
| RS            | 213.6        | 9:26                   | 405 | 98.4                        | 115.2                    |
| Greedy A      | 200.1        | 8:34                   | 379 | 91.2                        | 108.9                    |
| Greedy B      | 203.1        | 8:41                   | 391 | 93.3                        | 109.8                    |
| IP1           | 200.5        | 8:36                   | 378 | 91.6                        | 108.9                    |
| IPD1          | 201.0        | 8:37                   | 380 | 91.0                        | 110.0                    |
| Essential     | _            | _                      | 325 | 85.9                        | _                        |

### **Results for all 18 Partitions**

|               |              | 500 foot radius        |       |                             |                          |
|---------------|--------------|------------------------|-------|-----------------------------|--------------------------|
| <u>Method</u> | <u>Miles</u> | Number ofHoursSegments |       | Miles of<br><u>Segments</u> | Deadhead<br><u>Miles</u> |
| RS            | 3798.1       | 165:41                 | 16509 | 1545.1                      | 2253.0                   |
| Greedy A      | 3045.2       | 140:05 9895            |       | 1498.9                      | 1546.3                   |
| Greedy B      | 3140.3       | 144:41                 | 11483 | 1528.6                      | 1611.7                   |
| IP1           | 3055.6       | 140:37                 | 9857  | 1492.8                      | 1562.8                   |
| IPD1          | 3039.1       | 140:02                 | 9907  | 1491.8                      | 1547.3                   |
| Essential     | _            | _                      | 7777  | 1399.6                      | _                        |

### **Results for all 18 Partitions**

|               | -            |              |             |                 |
|---------------|--------------|--------------|-------------|-----------------|
|               | Best         |              |             | Best            |
| <u>Method</u> | <u>Miles</u> | <u>Hours</u> | <u>Time</u> | <b>Distance</b> |
| RS            | 3798.1       | 165:41       | 0           | 0               |
| Greedy A      | 3045.2       | 140:05       | 7           | 7               |
| Greedy B      | 3140.3       | 144:41       | 0           | 0               |
| IP1           | 3055.6       | 140:37       | 4           | 5               |
| IPD1          | 3039.1       | 140:02       | 7           | 8               |

#### Redundancy

To provide redundancy, we test how serving each customer by at least two different road segments effects the costs

In terms of the IP, change  $\sum_{i} a_{ij} x_j \ge 1$  to  $\sum_{i} a_{ij} x_j \ge 2$ 

|               |              | 500 foot radius        |     |                             |                          |
|---------------|--------------|------------------------|-----|-----------------------------|--------------------------|
| <u>Method</u> | <u>Miles</u> | Number ofHoursSegments |     | Miles of<br><u>Segments</u> | Deadhead<br><u>Miles</u> |
| IP2           | 192.3        | 8:23                   | 250 | 81.2                        | 111.1                    |
| IPD2          | 193.1        | 8:26                   | 251 | 79.9                        | 113.2                    |
| IP1           | 188.2        | 8:18                   | 216 | 78.5                        | 109.7                    |
| IPD1          | 188.4        | 8:18                   | 216 | 78.3                        | 110.1                    |

Sparse Partition

## Conclusions

- We have shown several heuristics for solving this new class of problems
- The best heuristics seem to work well
- RFID travel paths have a 15% time savings and 20% distance savings over the RS solution
- As the technology improves (i.e., the radius increases) the savings will increase dramatically<sub>20</sub>