Some Interesting and Important Vehicle Routing Research Topics

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Outline of Talk

- Some opening remarks
- The CETSP over a street network
- Arc routing with meanderable streets
- Vehicle routing with customer preference for visit order
- Additional topics of interest
- Conclusions

Opening Remarks

- I have worked on vehicle routing problems since 1974
  - As a researcher
  - As an owner of RouteSmart from 1980 to 1998
- Remarkable advances since 1974
- This represents a major success story for OR

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
- In previous work (Shuttleworth et al., 2008), our models were based on data from a utility and used an actual road network with a central depot and a fixed radius r for the hand-held device
- Our goal was 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 selected segments to exploit the "close enough" feature of RFID
- RS routed the meter reader over the chosen segments to obtain a cycle
- RS solved the problem as a CPP or a RPP

Heuristic Implementation

- How did we chose the street segments to feed into RS?
- We tested several heuristic ideas
  - Greedy Approaches
  - IP Formulations
- The focus was on exploiting the power of RFID in order to find a shorter route

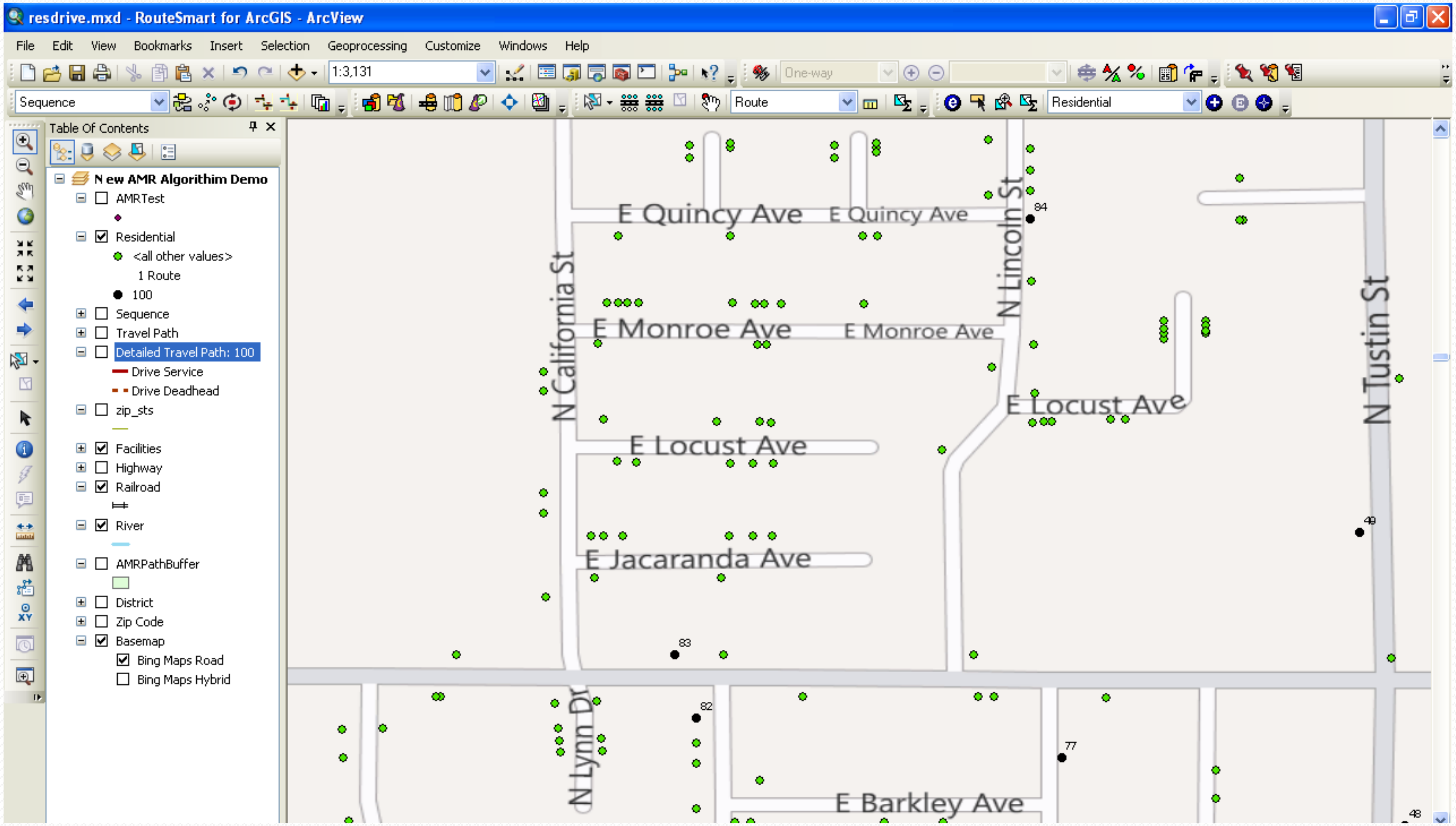
Shuttleworth et al. Results

- We presented several heuristics for solving this new class of problems
- The best heuristics seemed to work well
- RFID travel paths had a 15% time savings and 20% distance savings over the RS solution
- As the technology improves (i.e., the radius increases) the savings will continue to increase

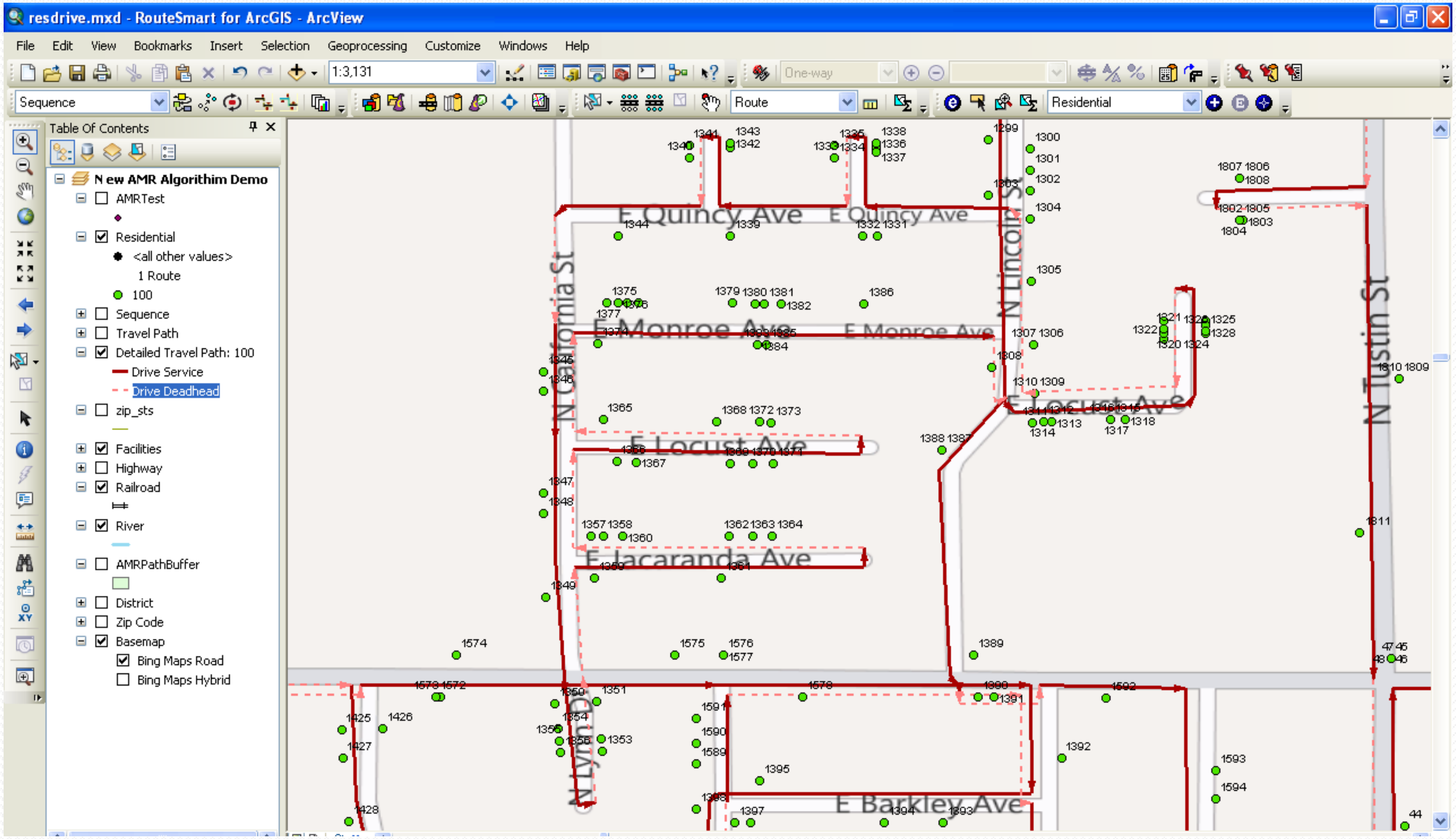
An Example from RouteSmart

- Shortly after our work on this topic, RS developed its own commercial capability
- An illustration is provided on the next few slides
- So far, the focus has been on improving one route at a time, but partitioning a region into routes is also important

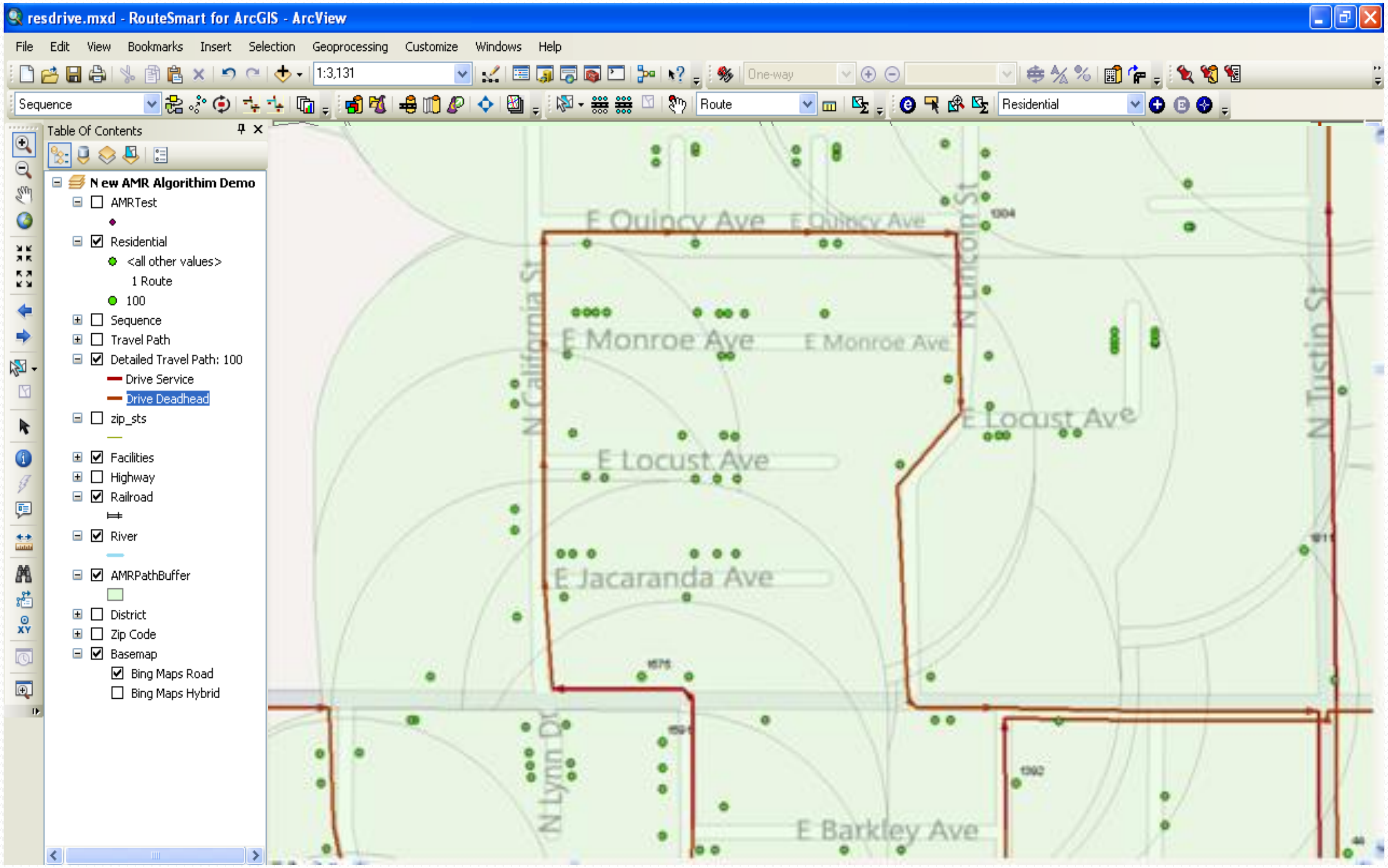
A Neighborhood on a Route



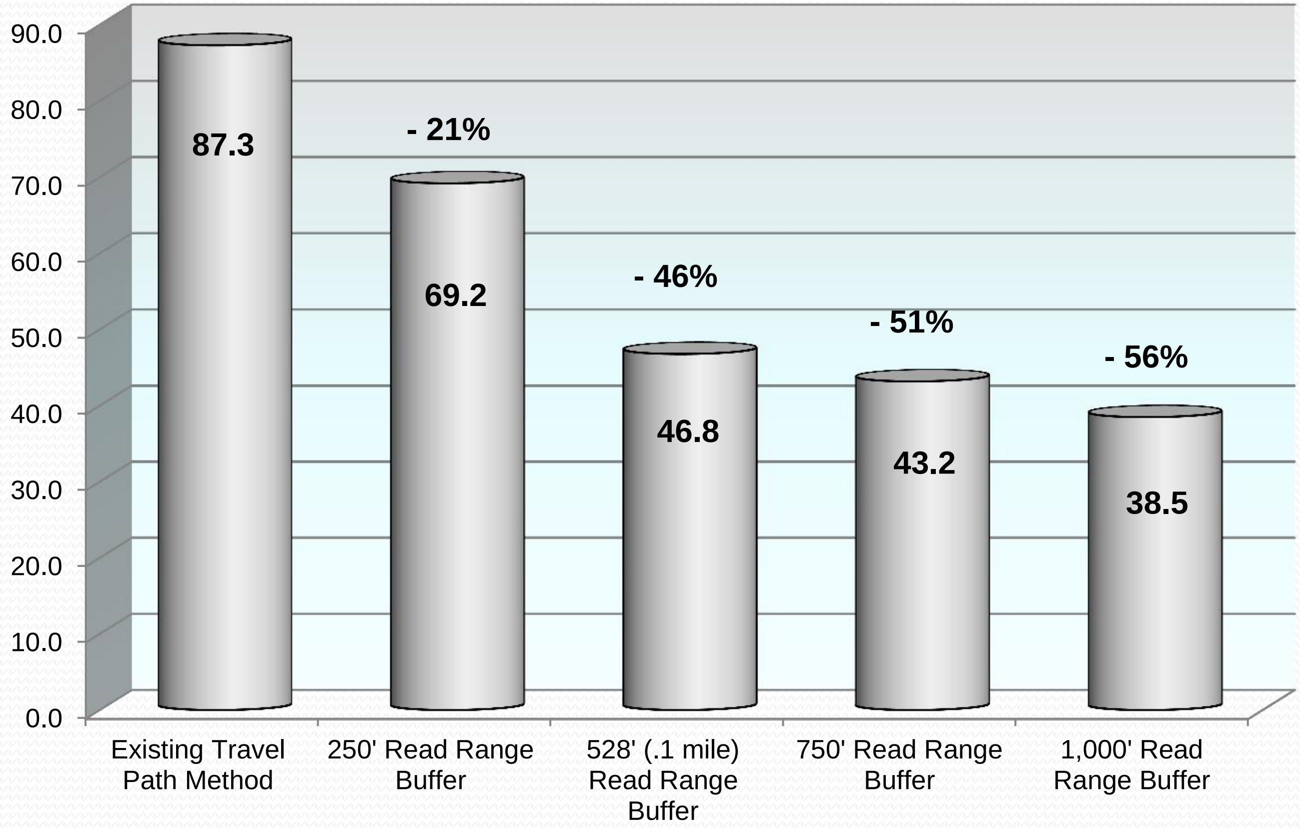
A Traditional Route through a Neighborhood



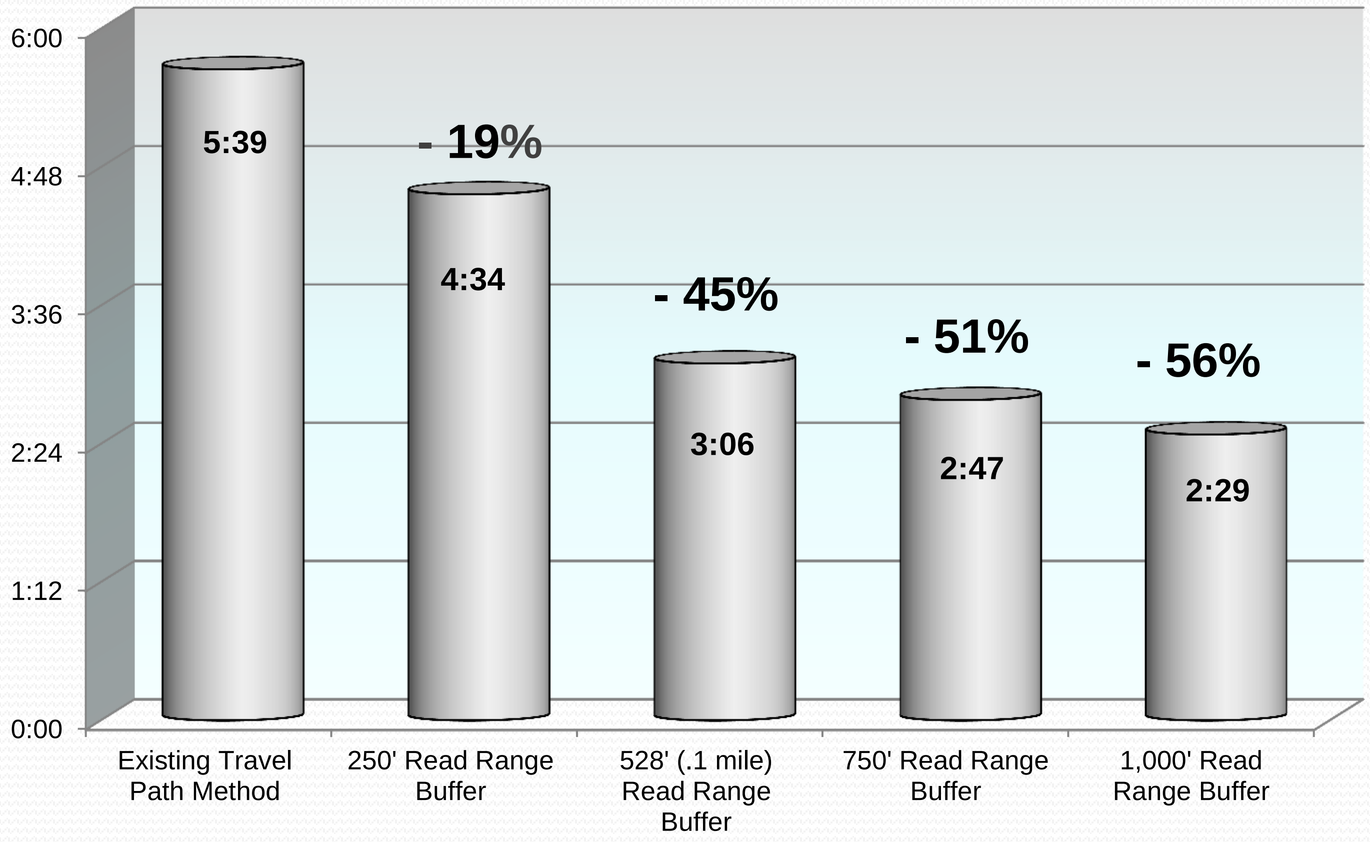
An *RFID* Route through the same Neighborhood



RFID Impact on Route Miles

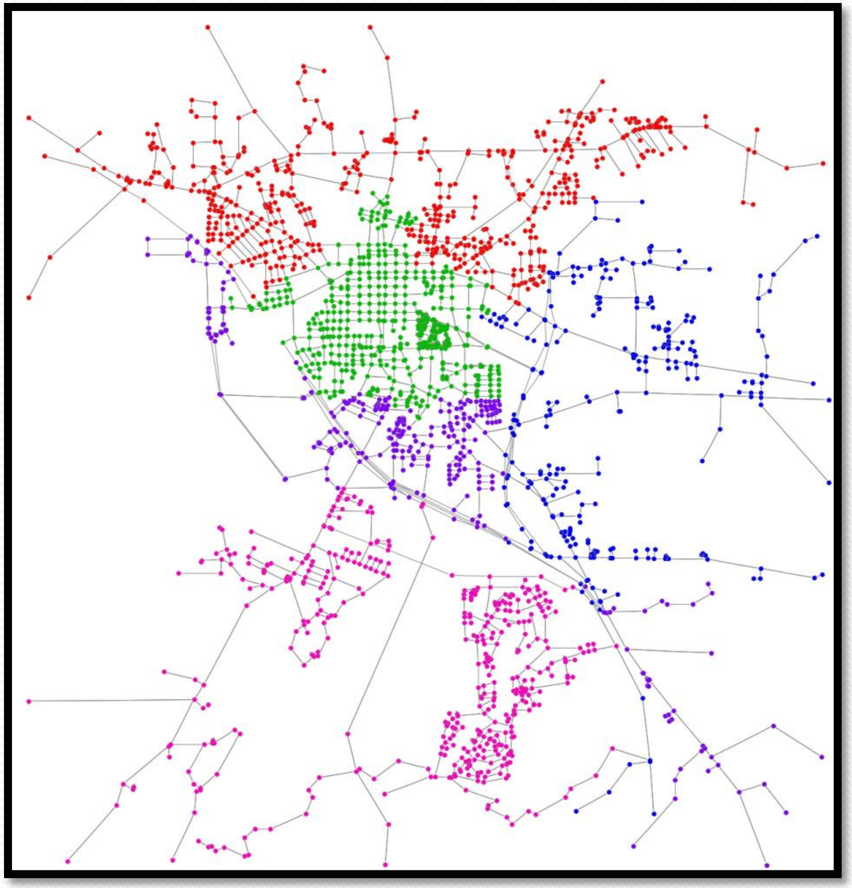


RFID Impact on Route Time

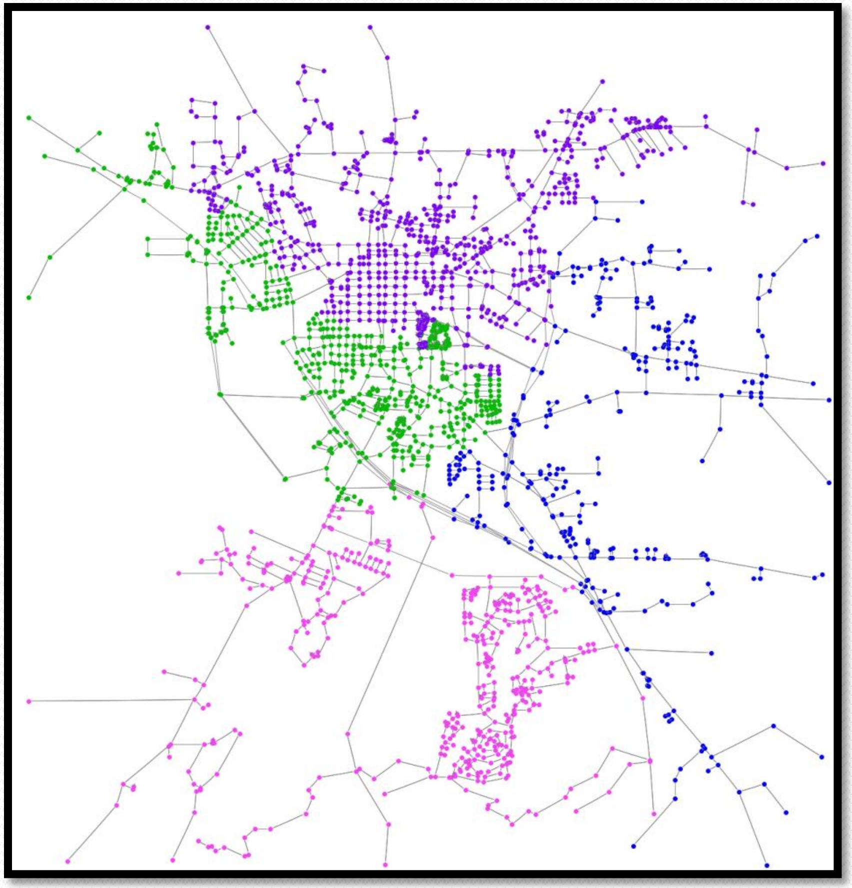


Designing Partitions

Partitions with r=100

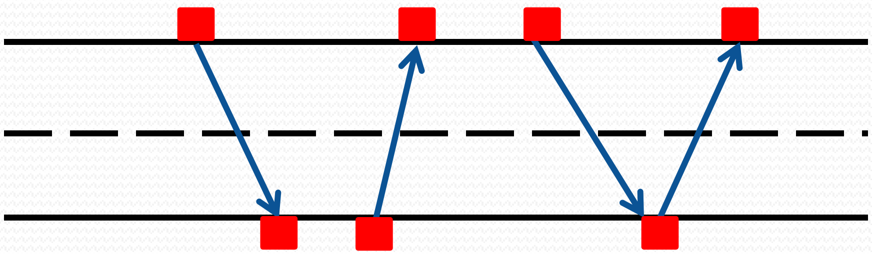


Partitions with r=150



Arc Routing with the Meander Option

- Suppose there is demand for service at homes on a street
- If the street is narrow and the traffic is light, it is possible (and often desirable) to service both sides of the street in a single pass (i.e., meander in one direction)



- If the street is wide and traffic is heavy, we must service each side on a different pass (i.e., meandering is not allowed)

Meanderable Streets

- In intermediate cases, we can ask the algorithm to decide which option is best – these streets are called meanderable
- This is an important real-world issue
  - Home delivery of newspapers
  - Trash collection
  - Local delivery (e.g., UPS & Fedex)
  - Meter reading (for now)
  - Maybe USPS delivery
- Irnich (2005, 2008, 2008) has studied this problem and transformed it to an asymmetric traveling salesman problem, but, otherwise, it has attracted little attention

Mixed Windy RPP with the Meander Option

- Consider a street connecting *a* and *b*
- Streets on which there is no demand are not required
- For streets where there is demand on only one side, a single pass over a directed arc is required

Mixed Windy RPP with the Meander Option

- For streets where there is demand on both sides, there are three possibilities
  - If Meander = No, we have two directed arcs between *a* and *b*
  - If Meander = Yes, we have one undirected edge between *a* and *b*
  - If Meander = Maybe, we have one of the above two scenarios

Solving the Problem Using IP

- Zhang & Ming (2013) formulated this problem as an IP
- It differs from Irnich's IP, but takes about the same amount of time to solve small instances
- Real-world instances were provided by RouteSmart
- Zhang & Ming solved an instance with 684 nodes, 4938 arcs, 20 components, and 240 meanderable streets in 145 seconds using CPLEX 12.5

Sensitivity Studies

- In general, we expect
  - $M_{ij} + T_{ij} > \text{Max}\{S_{ij} + T_{ij}, S_{ji} + T_{ji}\}$ and
  - $M_{ij} + T_{ij} < (S_{ij} + T_{ij}) + (S_{ji} + T_{ji})$

- Zhang & Ming studied the impact of the number and costs of meanderable streets
- As the number of meanderable streets increases, total cost tends to decrease
- As the meander cost to service cost ratio increases, we meander less

The Importance of Meandering

- We observe that even when the ratio R is large, it still might make sense to meander

$$R = \frac{M_{ij} + T_{ij}}{(S_{ij} + T_{ij}) + (S_{ji} + T_{ji})}$$

- On a real-world instance that we solved, we found one meander with R = 1.2112 and another with R = 1.3523
- So, the meander cost can be relatively high and yet still offer cost saving opportunities

Future Work

- There is much work to be done on both exact and heuristic approaches
- A commercial sanitation client asked whether we can design algorithms that take time of day into account
  - It may be desirable to meander some streets in the early morning (4 to 5 am), but not later

Vehicle Routing with Customer Preference for Visit Order

- Service companies visit customer's homes for inspections, installations, repairs, etc.
  - E.g., cable TV companies
- A customer is informed that he will be visited on Tuesday, between 9 am and 5 pm
  - For some customers, that is fine
  - Other customers might be willing to pay an extra amount to be visited early or late in the day

Customer Preference for Visit Order

- Given that it may be impossible to estimate the duration of a service call with precision, it makes more sense to ask customers to pay extra to be visited first, second, last, next to last, etc. on a route
- Two approaches
  - Set a price in advance (e.g., $25, $15, and $5) for first, second, and third on a route
  - Allow customers to bid (or not) for visit order
- The goal is to minimize {travel cost – revenue}

Initial Progress on this Problem

- Sahin, Golden, Raghavan (2013) have begun to study this problem
- We start with a TSP version
  - One service technician can visit *n* customers per day
- We considered two MILP formulations

MILP Formulation

- A modified Dantzig (1963) formulation
  - It has on the order of n^3 binary variables
  - $$x_{ijt} = \begin{cases} 1 & \text{if the technician travels from } i \text{ to } j \text{ and visits } j \text{ in order } t \\ 0 & \text{otherwise} \end{cases}$$
  - It is rarely used to solve the TSP
- A modified Miller-Tucker-Zemlin (1960) formulation
  - It has on the order of n^2 binary variables

Numerical Study

- 10 instances of 20 customers (n=20) each
- Coordinates generated randomly in a 100 x 100 square
- Distances are Euclidean
- 20%, 30%, or 40% of the customers place bids
- They bid for the first and last 3 or 5 positions
- Bids are generated using a Normal distribution
- The two formulations are solved using CPLEX 12.5

Formulation Comparison

Bids	20%		30%		40%	
Formulation	Dantzig	MTZ	Dantzig	MTZ	Dantzig	MTZ
B & B Nodes	2624	371,279	545	1,105,837	2449	9,871,894
CPU Time (s)	6.9	82.3	2.8	225.1	6.7	2401.4
Average LP-IP Gap	13.02%	46.51%	12.62%	58.48%	9.91%	63.44%

- The MTZ formulation seems sensitive to the percentage of customers bidding
- The Dantzig formulation shows no such sensitivity

Future Work

- We have managed to solve (to optimality) instances with 50 customers for the TSP version and 80 customers for a VRP version (both with bidding)
- The VRP version assumes there are K vehicles and that each vehicle services exactly Q customers (i.e., $KQ = n$)
- There is much work to be done on both exact and heuristic approaches

Conclusions

- We have witnessed enormous progress in vehicle routing over the past 40 years
- We can all take pride in the many successful implementations of vehicle routing software
- Still, there is so much more work for us to do