Some Interesting Vehicle Routing Research Topics: Suggestions from an Oldtimer

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Outline of Talk

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

My Dissertation Research

- Involved large-scale vehicle routing
- Partially supported by the American Newspaper Publishers Association (from January 1974 to June 1975)
  - Develop a computer code for specifying vehicle routes for bulk newspaper deliveries
  - Determine if these computerized approaches look promising
- We worked with the Worcester Telegram (WT)
  - Evening circulation of 92,000, approximately 600 drop points
  - We located the depot and drop points on a large map with pins
  - We used Euclidean distances and generated routes quickly

From Student to Consultant

- We compared our routes to existing WT routes
- WT re-examined their routes and altered several
- The experiment was of limited real-world value
- Assad, Ball, Bodin, and Golden founded RouteSmart in 1980
- In the 1980s, we consulted with large companies on vehicle routing
- Starting in 1989, we designed and sold vehicle routing software
- In 1998, we sold the business to a large NY civil engineering company
- We remained connected to RouteSmart until early 2004
- Let's focus on RouteSmart's work in newspaper distribution

Some of RouteSmart's Newspaper Clients

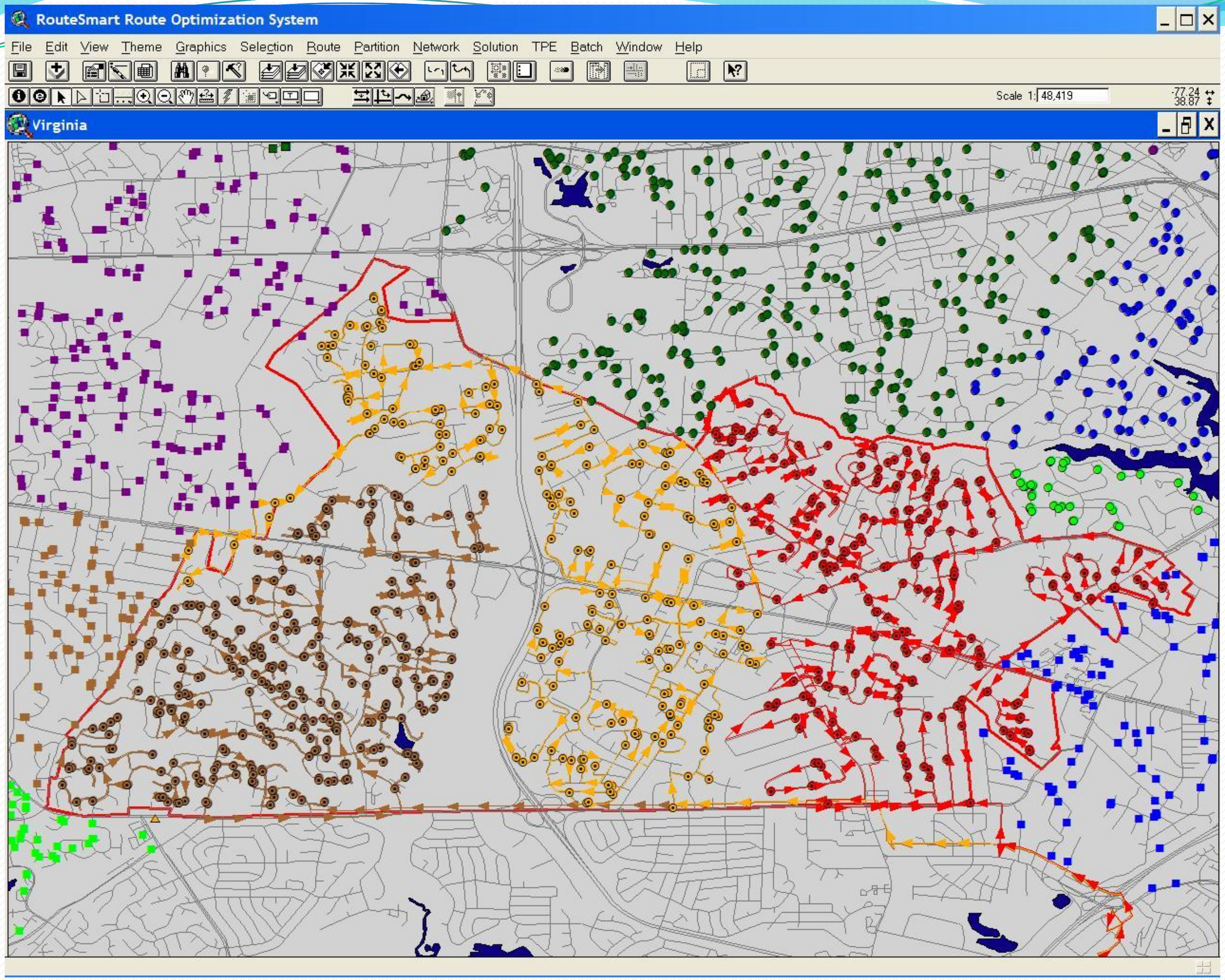
- Washington Times
- The (Toronto) Globe and Mail
- Dow Jones & Company
- Orlando Sentinel
- Pittsburgh Tribune-Review
- The Baltimore Sun
- Newsday
- San Francisco Chronicle
- Chicago Sun-Times
- The Seattle Times
- Chicago Tribune
- St. Louis Post-Dispatch
- The New York Post
- Detroit News
- San Diego Union Tribune
- Miami Herald
- The Washington Post
- Winnipeg Free Press

Recent Developments

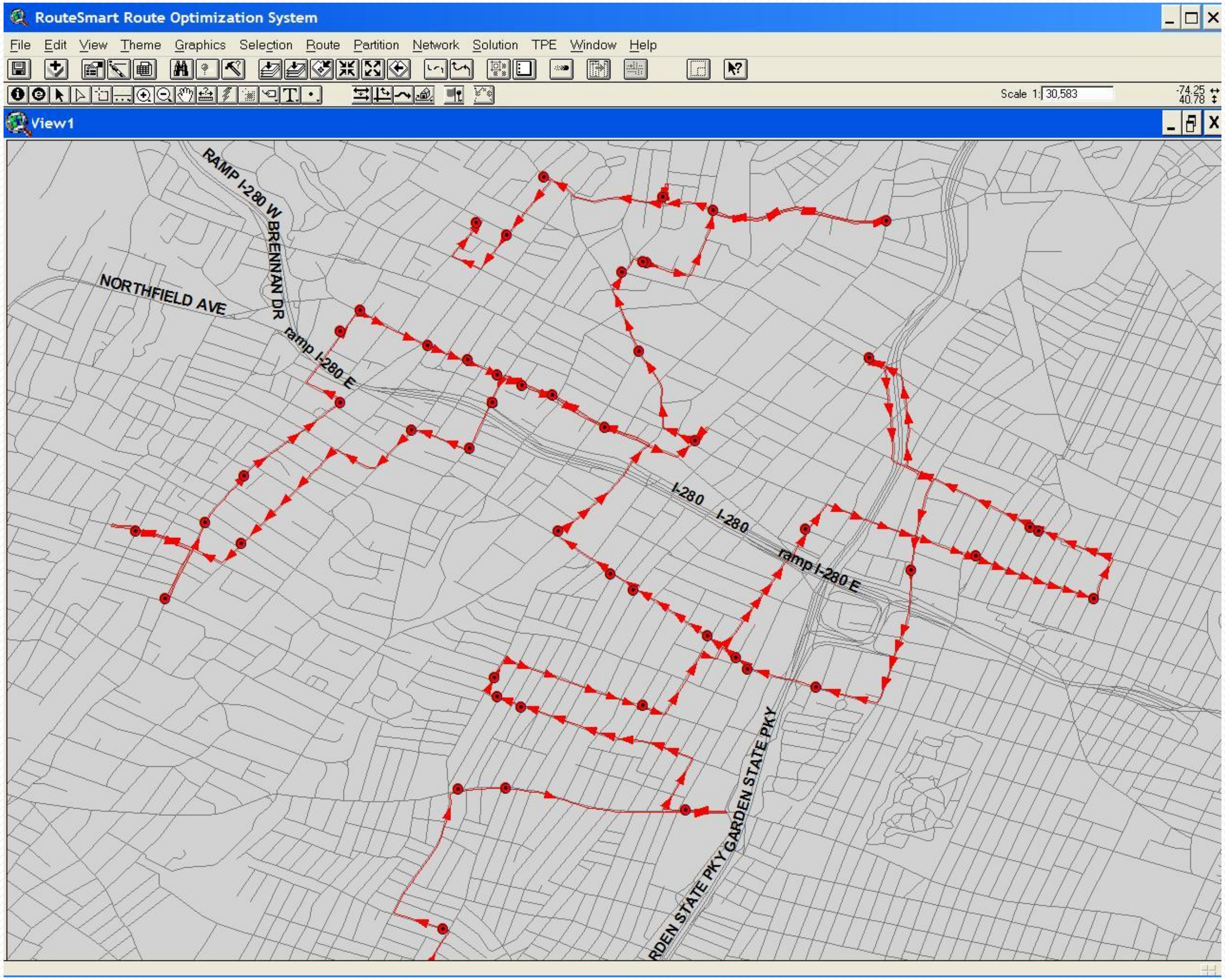
- RouteSmart began its new hosted, managed service for newspaper distribution – RouteSmart Online in 2010
  - No required hardware acquisition
  - No large up-front fees for licensing
  - Detailed travel paths provided each day
  - Uses the Amazon EC2 Cloud Computing environment
- RouteSmart Online processes approximately 25,000 newspaper routes encompassing 5.2 million subscribers on a nightly basis
- Bottom line: Remarkable advances from 1974 to 2013

Key Observations

- This represents a major success story for OR
- Essentially all major newspapers in the U.S. use vehicle routing software
  - Home delivery (arc routing)
  - Delivery of bundles (node routing)
- It is critically important for us to continue to focus on research motivated by real-world problems



Travel Paths over the Street Network
Home Delivery



Travel Path over the Street Network
Delivery of Bundles

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

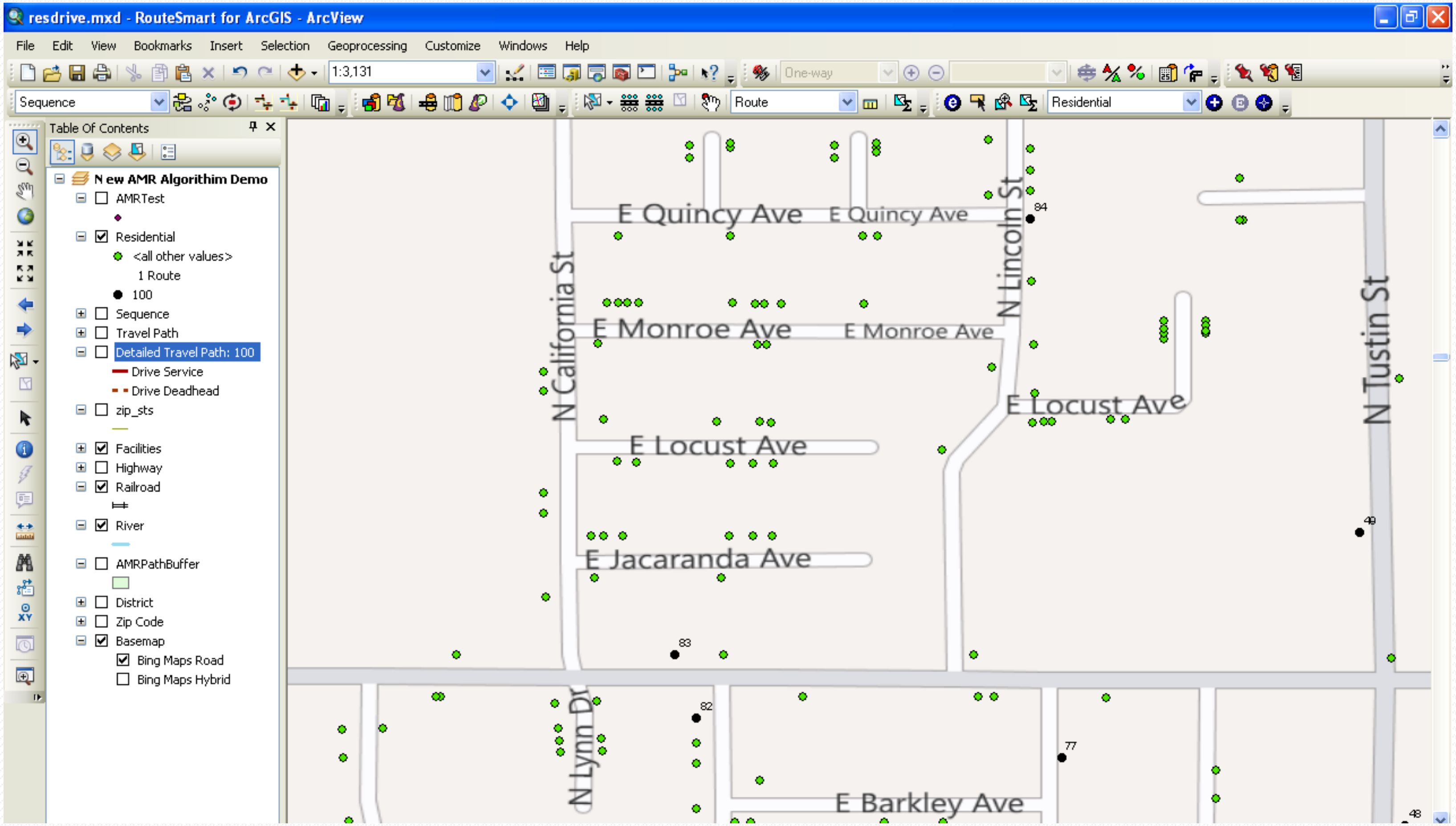
Shuttleworth et al. Results

- 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

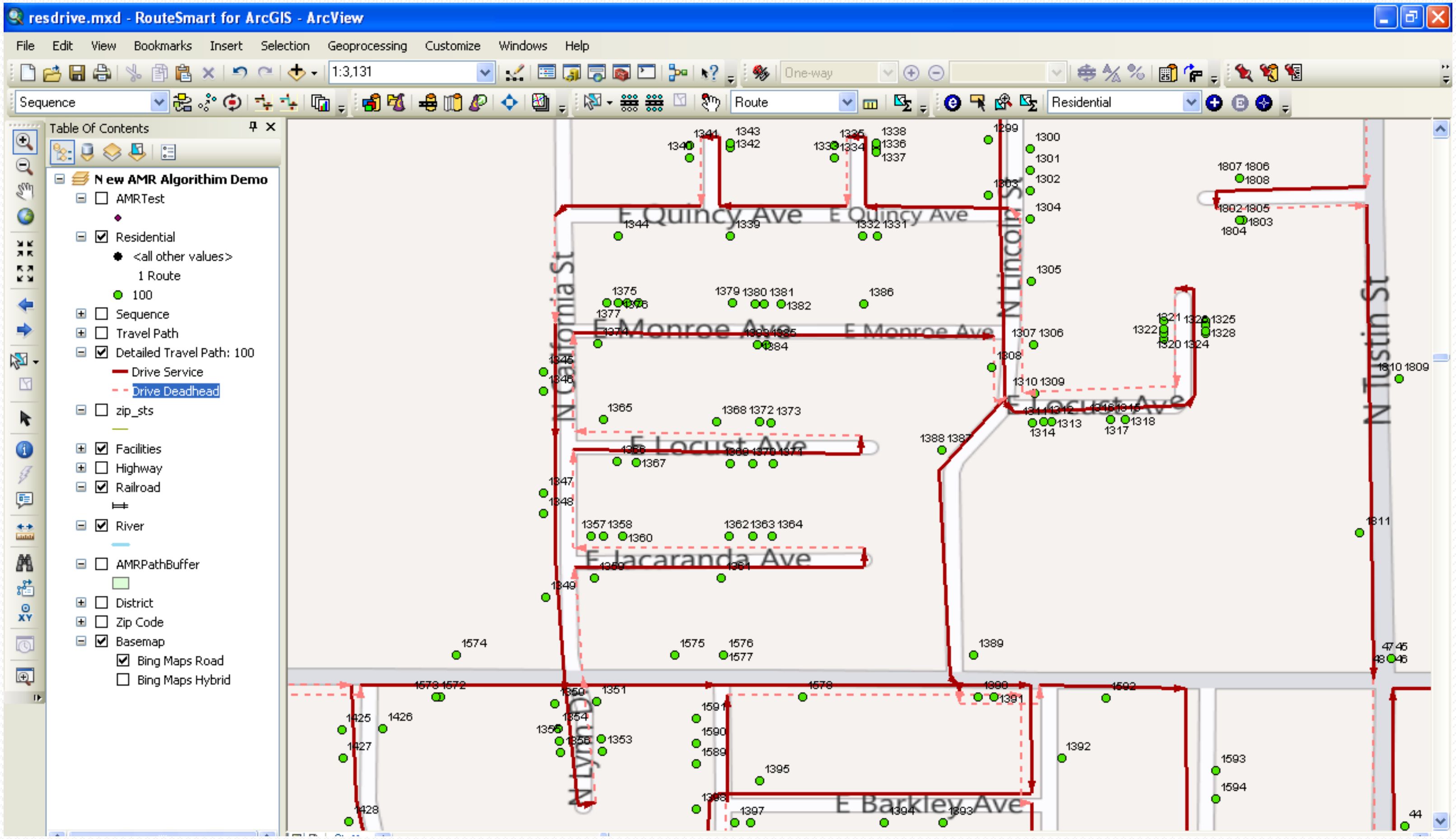
An Example from RouteSmart

- 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

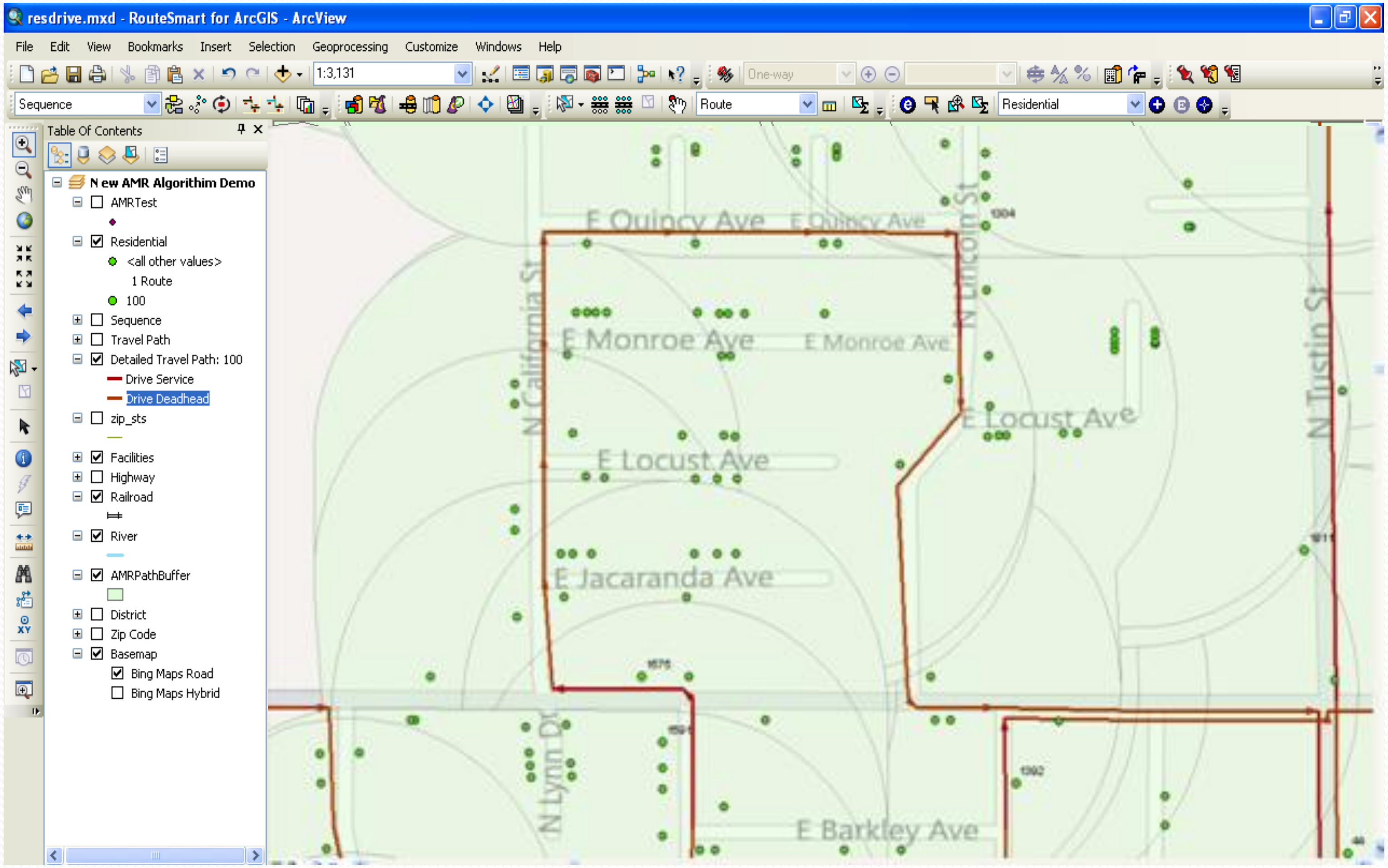
A Neighborhood on a Route



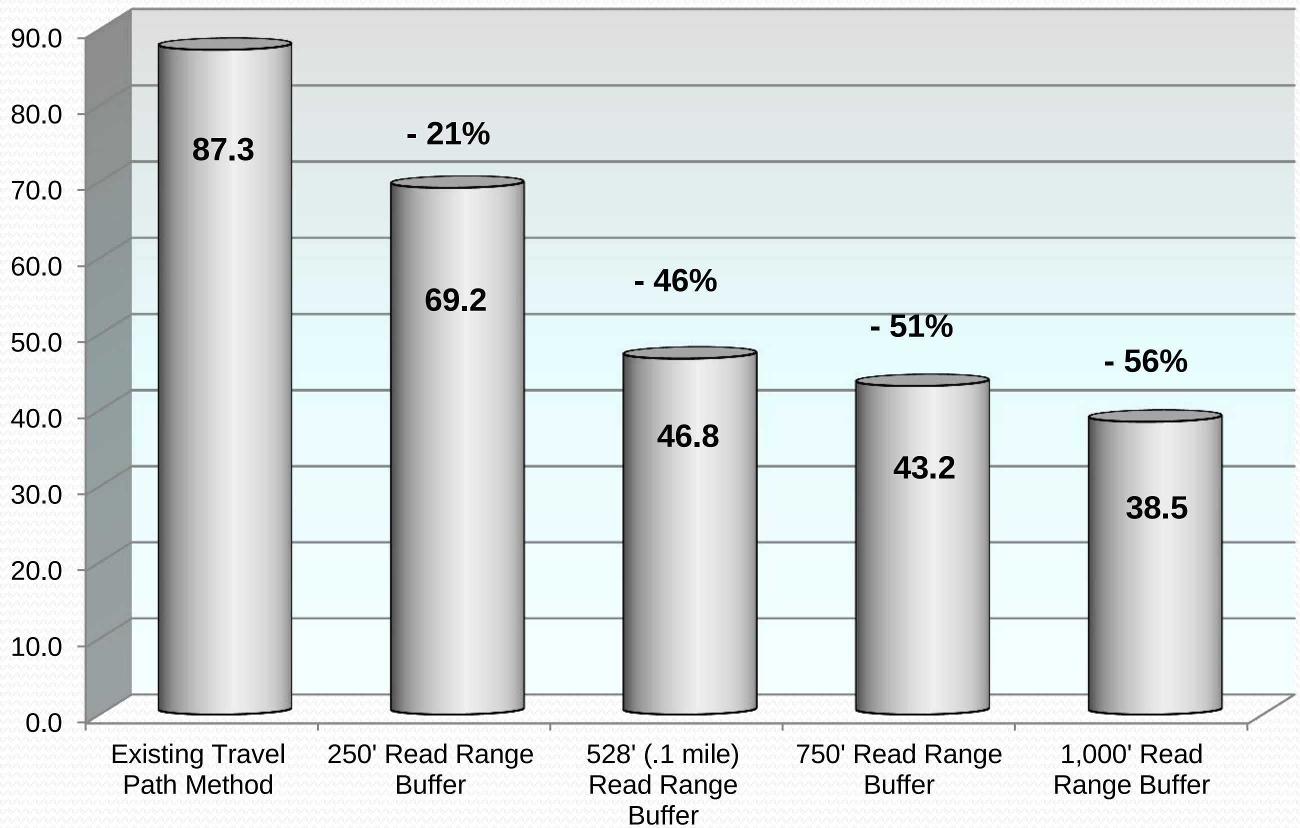
A Traditional Route through a Neighborhood



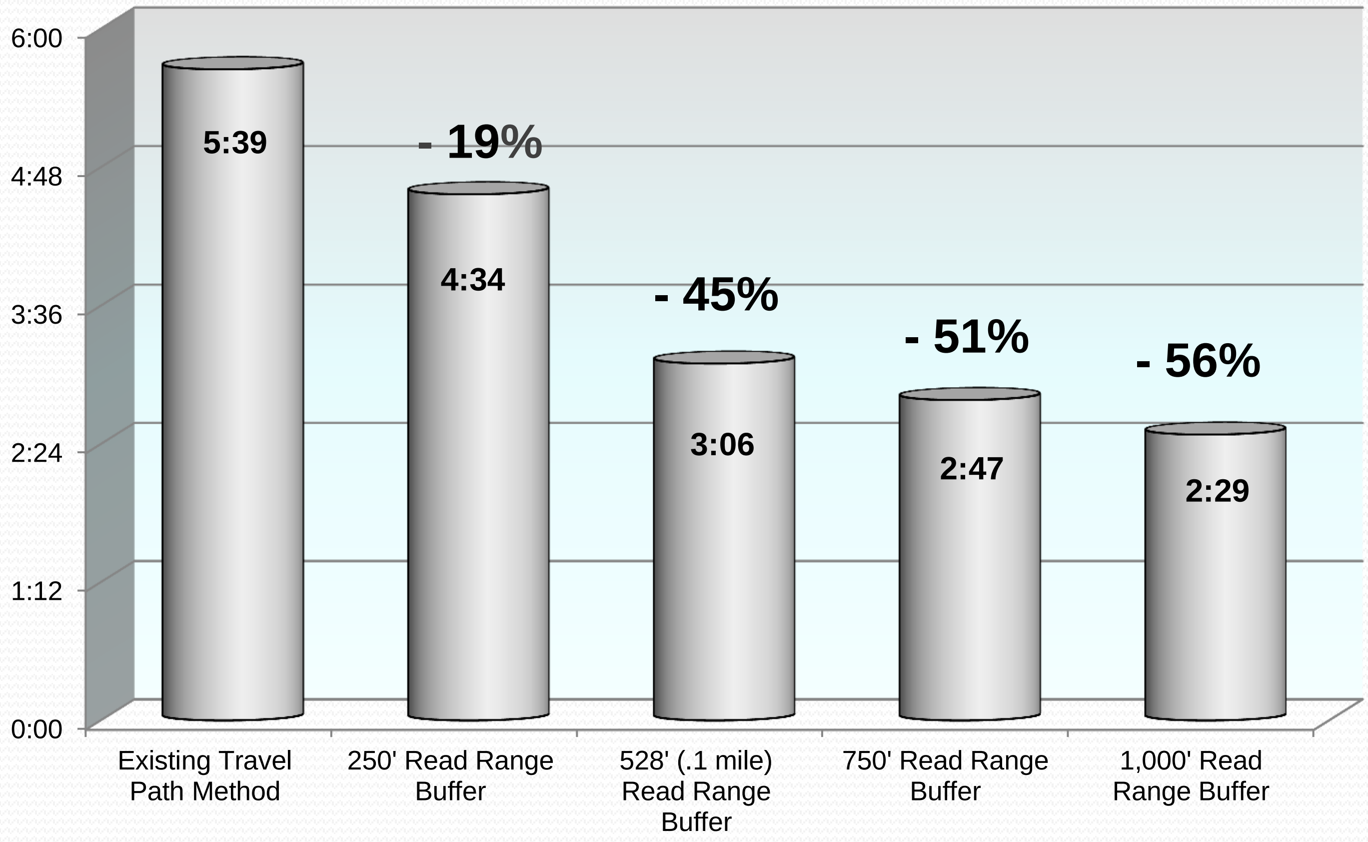
An *RFID* Route through the same Neighborhood



RFID Impact on Route Miles

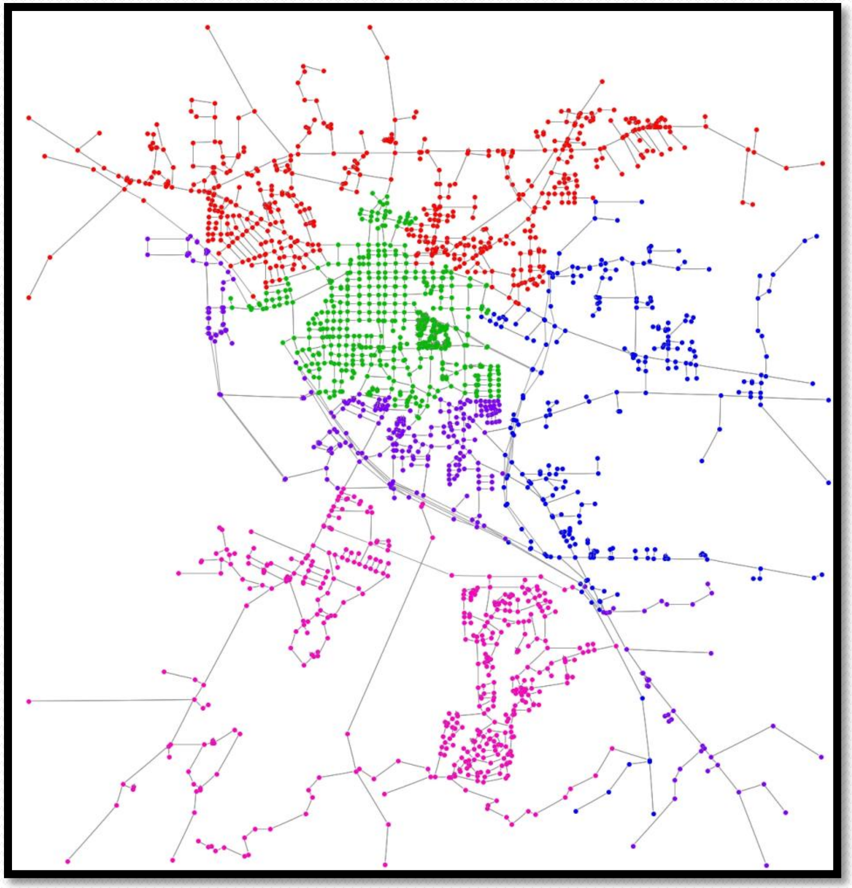


RFID Impact on Route Time

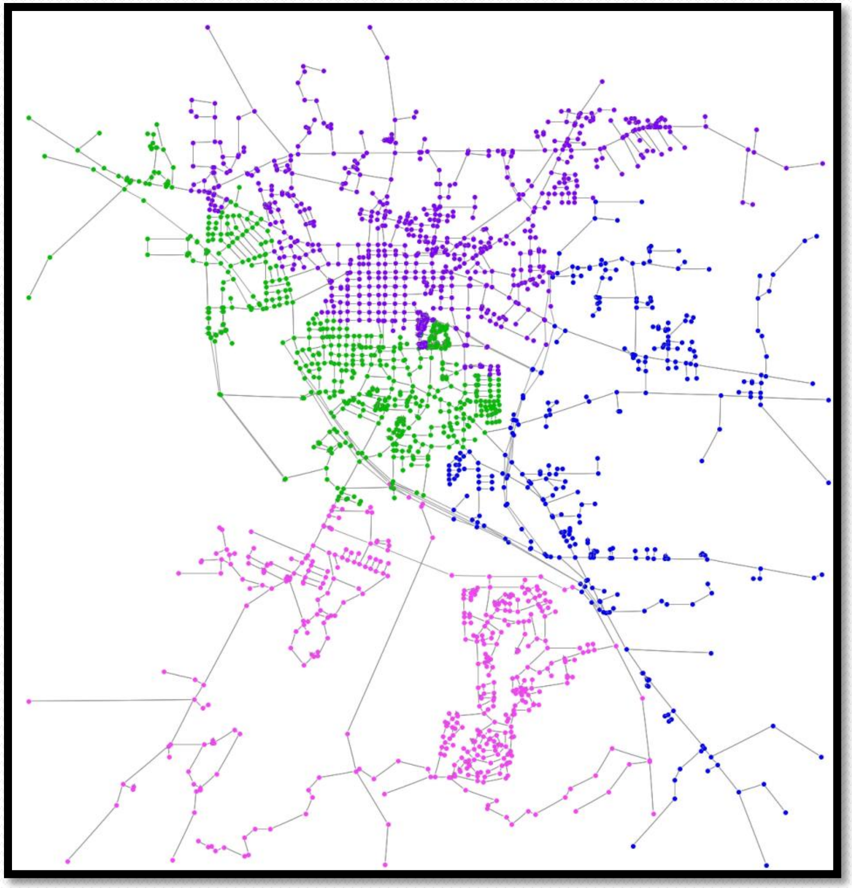


Designing Partitions

Partitions with r=100



Partitions with r=150

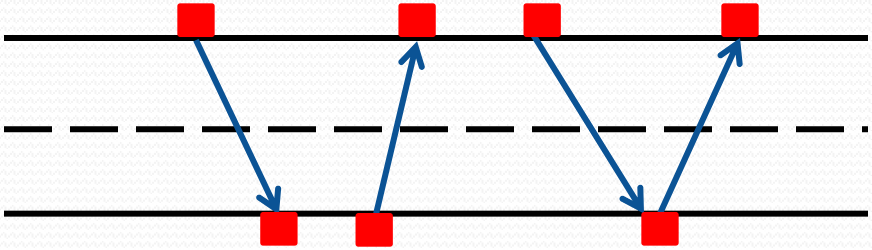


New Technologies Turn Old Vehicle Routing Problems into New Ones

- RFID and the CETSP over a street network
- Telemetry and vehicle routing (Verma and Campbell, 2012)
- Alternative fuel-powered trucks and vehicle routing (Erdogan and Miller-Hooks, 2012)
- It would be nice to see a paper that collects and surveys a variety of examples of new technology that has impacted traditional vehicle routing models, as above

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

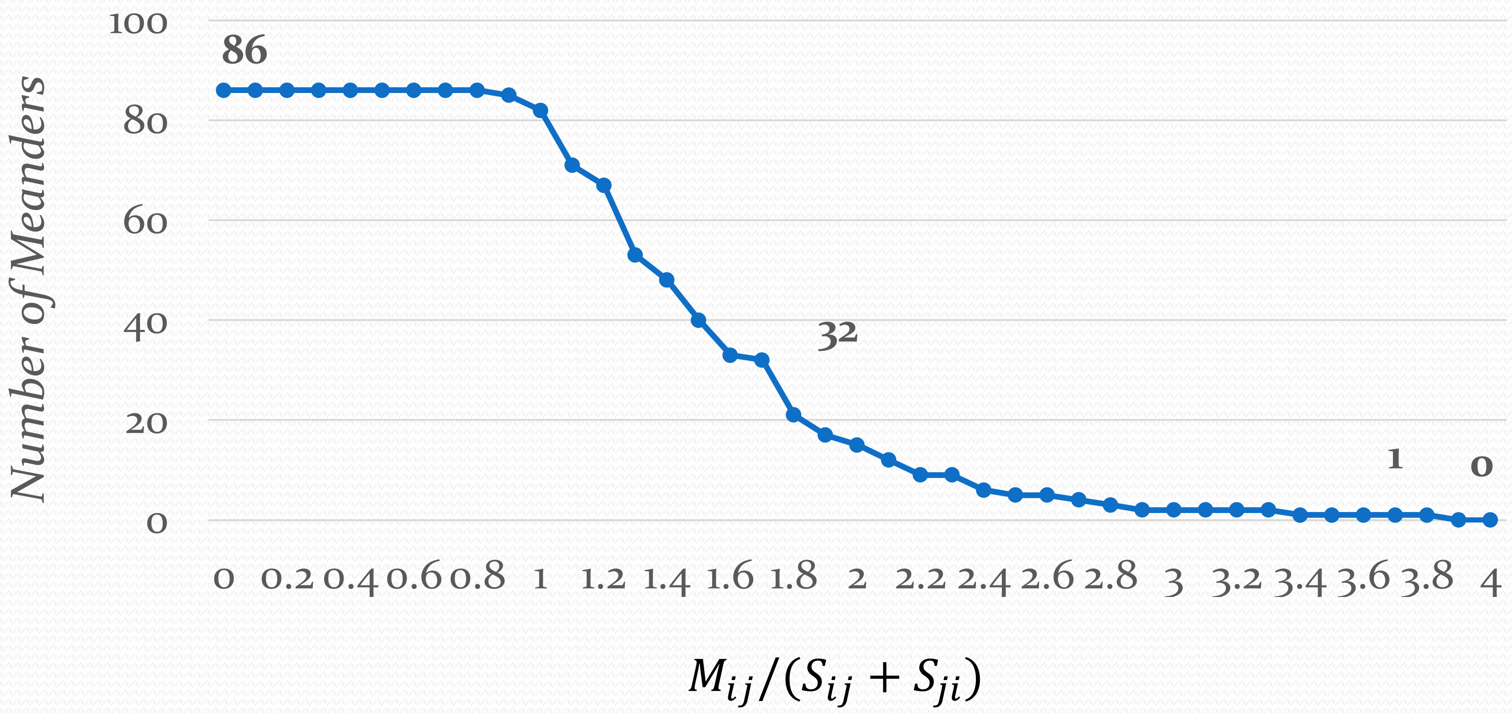
- Zhang & Ming (2013) formulated this problem as an IP
- It differs from Irnich's IP, but takes about the same amount of time to solve small instances
- Real-world instances were provided by RouteSmart
- Zhang & Ming solved an instance with 684 nodes, 4938 arcs, 20 components, and 240 meanderable streets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

The Impact of Meander Cost



The Importance of Meandering

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

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

- The meander at x = 3.8 has R = 1.2112
- The meander at x = 3.4 has 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

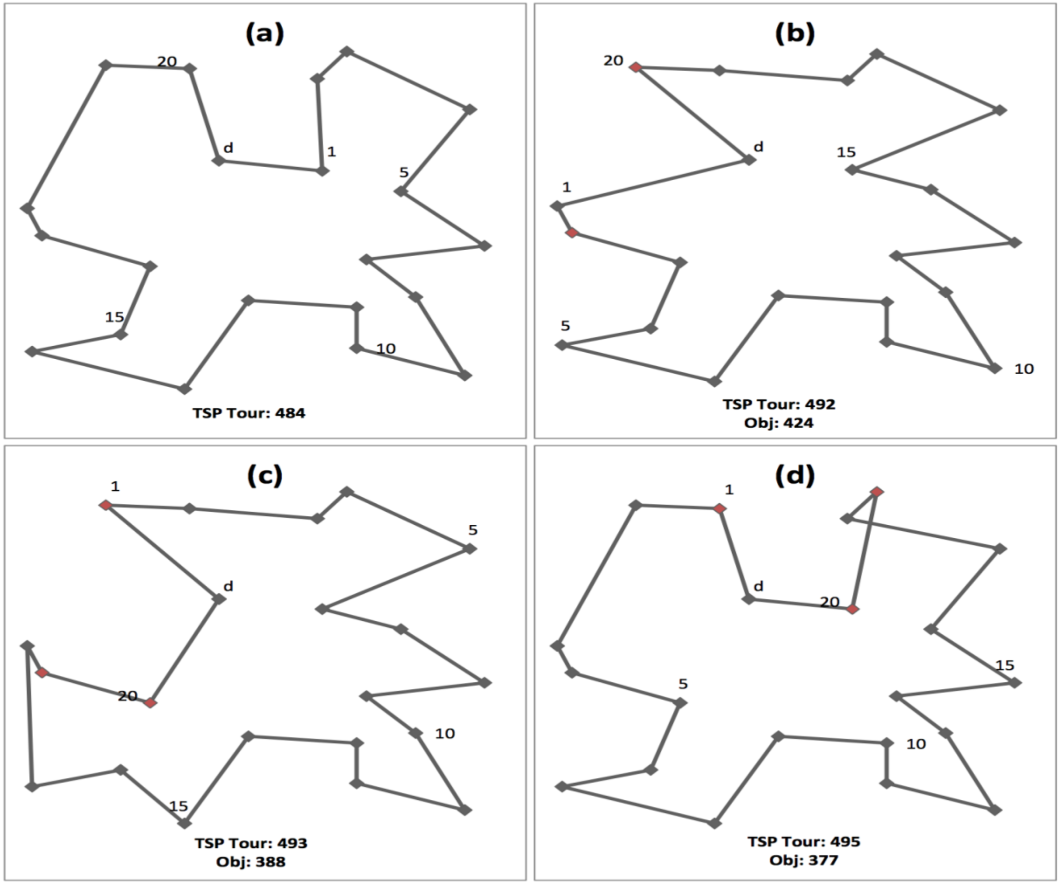
- 10 instances of 20 customers (n=20) each
- Coordinates generated randomly in a 100 x 100 square
- Distances are Euclidean
- 20%, 30%, or 40% of the customers place bids
- They bid for the first and last 3 or 5 positions
- Bids are generated using a Normal distribution
- The two formulations are solved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

The Impact of Bidding



(a) No bids

(b) 20% bids

(c) 30% bids

(d) 40% bids

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

A Simple Model for Humanitarian Relief Routing

- Suppose we have a single vehicle which has enough capacity to satisfy the needs at all demand locations from a single depot
- Each node (location) has a known demand (for a single product called an aid package) and a known priority
  - Priority indicates urgency
  - Typically, nodes with higher priorities need to be visited before lower priority nodes

Node Priorities

- Priority 1 nodes are in most urgent need of service
- To begin, we assume
  - Priority 1 nodes must be served before priority 2 nodes
  - Priority 2 nodes must be served before priority 3 nodes, and so on
  - Visits to nodes must strictly obey the node priorities

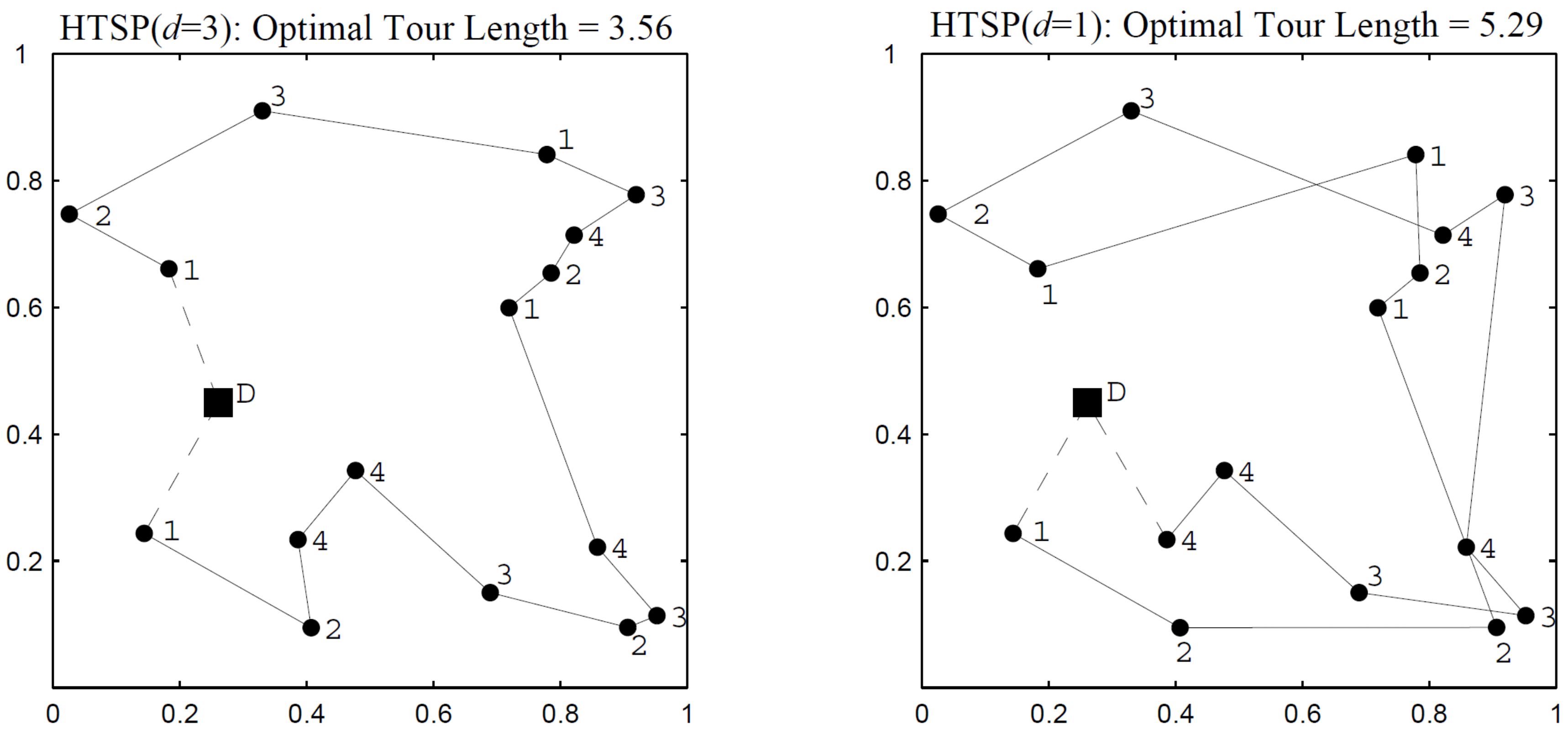
The Hierarchical Traveling Salesman Problem

- We call this model the Hierarchical Traveling Salesman Problem (HTSP)
- Despite the model's simplicity, it allows us to explore the fundamental tradeoff between efficiency (distance) and priority (or urgency) in humanitarian relief and related routing problems
- A key result emerges from comparing the HTSP and TSP in terms of worst-case behavior

A Relaxed Version of the HTSP

- Definition: The d-relaxed priority rule adds operational flexibility by allowing the vehicle to visit nodes of priority $\pi + 1, \ldots, \pi + d$ (if these priorities exist in the given instance) but not priority $\pi + d + \ell$ for $\ell \geq 1$ before visiting all nodes of priority π (for $\pi = 1, 2, \ldots, P$)
- When d=0, we have the strict HTSP
- When d= P-1, we have the TSP (i.e., we can ignore node priorities)

Efficiency vs. Priority



Main Results (*Optimization Letters*, forth.)

- Let P be the number of priority classes
- Assume the triangle inequality holds
- Let $Z^*_{d,P}$ and Z^*_{TSP} be the optimal tour length (distance) for the HTSP with the d-relaxed priority rule and for the TSP (without priorities), respectively
- We obtain the results below (and the bounds are tight)

$$(a) \quad Z^*_{0,P} \leq P Z^*_{TSP}$$

$$(b) \quad Z^*_{d,P} \leq \left\lceil \frac{P}{d+1} \right\rceil Z^*_{TSP}$$

What Next?

- We tried to generalize the previous worst-case bound
- What is the worst-case bound

$$\frac{Z^*_{d_1,P}}{Z^*_{d_2,P}} \quad \text{where } d_1 < d_2?$$

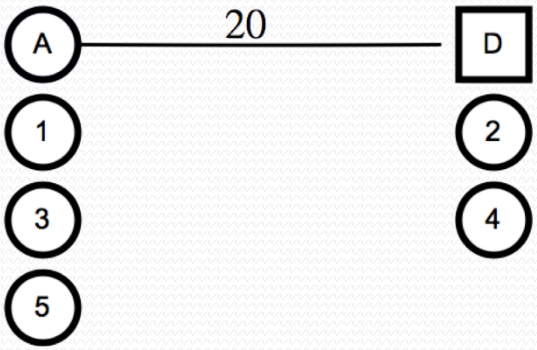
- We have only been able to derive a partial result
- New result (Xiong & Golden, 2013): For any HTSP problem where the triangle inequality holds,

$$\boxed{Z^*_{0,P} \leq 3Z^*_{1,P}}$$

and the bound is tight

New HTSP Result

- We developed a worst-case example, but a simpler one was found by two of my students (Kim & Park, 2013)
- Consider the example below with P=5



$$Z^*_{0,5} = 120$$

$$Z^*_{1,5} = 40$$

$$Ratio = 3$$

- I would be happy to see someone at this conference extend our work

Additional Topics of Interest

- Many real-world problems have elements of both node routing and arc routing
  - For streets with a high density of demand ⇒ service the arc
  - For streets with a low density of demand ⇒ service the nodes
  - For streets with a medium density of demand ⇒ let the algorithm decide
- For node routing and arc routing, our algorithms should be able to avoid U-turns

Additional Topics of Interest

- For node routing and arc routing, balance among routes is a key objective
- For many arc routing problems (e.g., residential sanitation), there is a need to service the opposite side of the street within an hour or so of servicing the first side of the street
- Amazon Fresh promises same day delivery of groceries
  - Orders arrive and they must be picked and assigned to trucks immediately (an incremental VRP)
  - The goal is to minimize the number of trucks
  - Now available in Seattle and L. A.
  - How would we solve this problem?

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