Some Exciting New Problems in Vehicle Routing

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Outline of Lecture

- Some opening remarks
- The CETSP over a street network (2006)
- The CETSP over a street network (2016)
- The vehicle routing problem with drones
- Connections
- Other new problems
- Conclusions
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 this 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
- 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
### IP Formulation

Minimize \[ \sum_j c_j x_j \]

subject to

\[ \sum_j a_{ij} x_j \geq 1 \quad \text{for all } i \]

\[ x_j \in \{0,1\} \]

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
How do we choose the street segments to feed into RS?

We tested several choices for the objective function

- **IP1**: Minimize the number of road segments chosen
  \[ c_j = 1 \text{ for all } j \]

- **IPD1**: Minimize the distance of the road segments chosen
  \[ c_j = \text{the distance of road segment } j \]
Shuttleworth et al. Results

- We presented several heuristics for solving this new class of problems
- The best heuristics seemed to work well
- A RS illustration is provided on the next few slides
- As the technology improves (i.e., the radius increases) the savings will continue to increase
A Neighborhood on a Route
A Traditional Route through a Neighborhood
An *RFID* Route through the same Neighborhood
The CETSP Over a Street Network (2016)

- In 2016, we acquired data from ITRON (which manufactures the RFID transmitters and receivers) via RS
- RFID tags are placed with customers
- RFID reading devices are placed in trucks
- A route segment and customer locations are shown on the next slide
- We quickly learn that the real problem is more complicated than the 2006 problem
- This work is part of Debdatta Sinha Roy’s Ph.D. research
A Route Segment and Customer Locations
Observations from the Data

- The vehicle location is tracked every second
- Data is not transmitted continuously
  - It pulses every 10 or so seconds
- Some customers within range \( r \) are not read
- One customer at distance \( 10 \times r \) from the truck is read
- An enormous amount of data is generated
- This creates opportunities to combine data analytics with route optimization
Interesting Observations from the Data
Customers 300 Feet from the Route
Customers 600 Feet from the Route
Customers 1,000 Feet from the Route
Solving the 2016 CETSP Over a Street Network

- Obtain sample data from route segments
- Estimate $p_{ij}$ using logistic regression
  - $p_{ij} = \text{the probability that the signal succeeds at some point on street } j \text{ for customer } i$
- Suppose we require a 95% success rate for each meter
- This leads to the following IP
- The selected streets become input to a RPP
IP for Selecting Streets to Cover

Minimize $\sum_{j} c_j x_j$

s.t. $\pi_j \left(1 - p_{ij}\right)^{x_j} \leq 0.05, \forall i$

$x_j \in \{0, 1\}$

or

Minimize $\sum_{j} c_j x_j$

s.t. $\sum_{j} x_j \log \left(1 - p_{ij}\right) \leq \log(0.05), \forall i$

$x_j \in \{0, 1\}$
The Vehicle Routing Problem with Drones

- Motivated by Amazon, FedEx, DHL, and others
- Limited research so far
  - Gambella, Lodi, Vigo: Presented in 2015
  - Agatz, Bouman, Schmidt: Presented in 2015
The VRP with Drones (VRPD): Initial Assumptions

- n customers are served by m trucks, each carrying k drones
- Each customer demands one parcel to be delivered either by a truck or a drone
- Each truck has a capacity of C parcels and a drone can carry at most one parcel while in the air
- Drones have at most U time units of battery life
The VRPD: Initial Assumptions

- The speed of a drone is $\alpha$ times the speed of a truck
- Both the drone and the truck follow the same distance metric
- A drone can be launched from a truck and picked up by the same truck, but only at the nodes (customer and depot locations)
- The truck can continue serving other customers after a drone is dispatched and pick up the drone at possibly a different node
The VRPD: Initial Assumptions

- A truck or drone may arrive at a node and have to wait for the other vehicle to arrive
- There is no service time for delivery
- The objective is to minimize the completion time
- We denote the new problem by \( \text{VRPD}_{m, \alpha} \)
A VRPD Example and Feasible Solution

- The truck route is represented by the solid black line and the drone routes are represented by the blue and red dashed lines.

- A VRPD$_{1,1}$ solution with $k = 2$.
Future Work on the VRPD

- Better heuristics and exact methods
- Let the truck and drone operate on different metric spaces
- Let the drone carry more than one package at a time
- Model battery behavior more realistically
- Allow for drones to launch and land on different trucks
Connections between the CEVRP and the VRPD

- First, consider the CETSP and the CEVRP in Euclidean space
- Next, define $VRPD_{ur}$ in the same way as the ordinary $VRPD$, except we do not restrict drone launches and retrievals to nodes
- Let the RFID range (r) in the CEVRP be analogous to the drone’s range of flight
- We obtain

\[
\lim_{\alpha \to \infty} Z(VRPD_{ur}, \alpha) = Z(CEVRP)
\]
Other Exciting, Emerging Problems

- Vehicle routing with roaming delivery locations
- The routing of electric & hybrid vehicles (battery issues)
- Strategic placement of telemetry in inventory routing
- Intermediate facilities and synchronization in vehicle routing
- Vehicle routing with subcontracting
- The information-collecting vehicle routing problem
Conclusions

- There are many exciting new topics for young (and not so young) researchers to explore
- Our field continues to thrive
- In particular, the intersection of machine learning and route optimization looks especially ripe