Transportation Management

Vehicle Routing

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Local Routing

Large Number of Network Problems – we will look at four

- Shortest Path Problem
  - Given: One origin, one destination
  - Find: Shortest path from single origin to single destination

- Transportation Problem
  - Given: Many origins, many destinations, constrained supply
  - Find: Flow from origins to destinations

- Traveling Salesman Problem
  - Given: One origin, many destinations, sequential stops, one vehicle
  - Find: Shortest path connecting each stop once and only once

- Vehicle routing Problem
  - Given: One origin, many destinations, many capacitated vehicles
  - Find: Lowest cost tours of vehicles to destinations
Shortest Path Problem

- Find the shortest path in a network between two nodes - or from one node to all others
- Result is used as base for other analysis
- Connects physical to operational network

Issues

- What route in practice is used? Shortest? Fastest? Unrestricted?
- Frequency of updating the network
- Using time versus distance (triangle inequality)
- Impact of real-time changes in congestion
- Speed of calculating versus look-up
Shortest Path

Network
- Arc/Link & Nodes
- Cost is on nodes, $c_{ij}$

Think of a string model

Basic SP Algorithm (s to t)
1. Start at origin node, $s=i$
2. Label each adjacent nodes, $j$, $L'_j = L_i + c_{ij}$ iff $L'_j < L_j$
3. Pick node with lowest label, set it to $i$, go to step 2
4. Stop when you hit node $t$

Building Shortest Path Tree

Many, many variations on this algorithm,
- Label Setting
- Label Correcting

Shortest Path Matrix

<table>
<thead>
<tr>
<th>i \ j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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</table>
Transportation Problem

- Find minimum cost routes for between multiple origins and destinations
- Flow is fungible – same products
  - Cost on arcs, $c_{ij}$
  - Flow on arcs, $x_{ij}$
- Many solution approaches
  - Balanced problem – Supply=Demand
  - Unbalanced –
  - Transhipment Problem – neutral nodes

$\text{Min } \sum_{ij \in N} c_{ij} x_{ij}$

s.t.

$\sum_{j=1}^{n} x_{ij} = \text{Supply}_i \ \forall i$

$\sum_{i=1}^{n} x_{ij} = \text{Demand}_j \ \forall j$

$x_{ij} \geq 0 \ \forall ij$
Traveling Salesman Problem

- Starting from an origin, find the minimum distance required to visit each destination once and only once and return to origin.
- m-TSP: best tour for \( m \) salesmen
- Very old problem ~1832

For history, see: [http://www.tsp.gatech.edu/index.html](http://www.tsp.gatech.edu/index.html)
TSP Solution Approaches

Heuristics

- Construction
  - Nearest neighbor
  - Greedy (complete graph, pick shortest edge until Hamiltonian path)
  - Sweep (example of Cluster-First, Route-Second)
  - Space filling curve (example of Route-First, Cluster-Second)
  - Insertion (nearest, cheapest)
  - Savings (Clarke-Wright)

- Local Improvement
  - 2-opt
  - 3-opt

- Meta-heuristics
  - Tabu Search
  - Ant System
  - Simulated Annealing
  - Genetic Algorithms
  - Constraint Programming

Adapted from Goentzel 2004
Traveling Salesman Problem

- **Nearest Neighbor Heuristic**
  - Start at any node and connect tour to closest adjacent node
  - In practice 20% above optimal

- **Insertion Heuristic**
  - Form some sub tour (convex hull) and add in the nearest/furthest/cheapest/random node one at a time
  - In practice 19% / 9% / 16% / 11% above optimal

- **2-Opt Heuristic**
  - Method of improving a solution
  - Select two edges \((a,b)\) and \((c,d)\) where total tour distance decreases the most if reformed as \((a,c)\) and \((b,d)\).
Vehicle Routing Problem

- Find minimum cost tours from single origin to multiple destinations using multiple vehicles

- Who needs to solve the problem?
  - Shippers – retailers, distributors, manufacturers
  - Carriers – LTL, package
  - Service companies – repair, waste, utility, postal, snow removal

- Types of problems
  - Commercial delivery (retailers, distributors, manufacturers)
  - Commercial pickup (retailers, distributors, manufacturers)
  - Mixed pickup & delivery (LTL and package carriers)
  - Residential appointment (online grocery, medical gases, repair)
  - Residential sweep (postal, waste, utility, snow removal)
Initial Routes

10 Routes
2006 Miles

Figure by MIT OCW.
Adapted from Goentzel 2004
Optimized Routes

From 10 to 7 Routes
30% savings

From 2006 to 1345 Miles
32% improvement

Difficult to evaluate quality by inspection

Figure by MIT OCW.
Adapted from Goentzel 2004
VRP is NP-Hard

Combinatorial Growth

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<th>3 stops</th>
<th>5 stops</th>
<th>10 stops</th>
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<td>Ways to select customers for the route</td>
<td>Ways to select and sequence the route</td>
<td>Hours of work to evaluate one per second</td>
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<tbody>
<tr>
<td>total on the route</td>
<td>Ways to select customers for the route</td>
<td>Ways to select and sequence the route</td>
<td>Hours of work to evaluate one per second</td>
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Days of work to evaluate one per second

Years of work to evaluate one per second

Adapted from Goentzel 2004
Vehicle Routing Problems

General Approaches

- Heuristics
  - Route first Cluster second
    - Space filling curve
    - Any earlier heuristic can be used
  - Cluster first Route second
    - Sweep Algorithm
    - Savings (Clarke-Wright)

- Optimal
  - MILP – Column Generation
Heuristic Approach – Cluster & Sweep
Heuristic Approach – Cluster & Sweep
Heuristic Approach – Cluster & Sweep
Heuristic Approach – Cluster & Sweep
Heuristic Approach – Cluster & Sweep

1. Cluster stops by density
2. Start at boundary and sweep CW adding stops until $V_{MAX}$
Savings Algorithm

Clark-Wright Algorithm

- Serve each node directly
- Identify savings for combining two nodes on same tour
- Add nodes together if savings > 0
  - $2c_{0i} + 2c_{0j} > c_{0i} + c_{ij} + c_{j0}$
  - Savings = $c_{0i} + c_{j0} - c_{ij}$

<table>
<thead>
<tr>
<th>i \ j</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td>3</td>
<td></td>
<td></td>
<td>5</td>
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</table>

Shortest Path Matrix
Savings Algorithm

Suppose Max Capacity = 3

Savings = c_{0i} + c_{j0} - c_{ij}

- S(1,2) = 10 + 15 - 8 = 17
- S(1,3) = 10 + 19 - 23 = 6
- S(1,4) = 10 + 22 - 35 = -3
- S(2,3) = 15 + 19 - 12 = 22
- S(2,4) = 15 + 22 - 21 = 16
- S(3,4) = 19 + 22 - 5 = 36

Shortest Path Matrix

<table>
<thead>
<tr>
<th>i \ j</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Benefits of this approach?
Optimal Approach – MILP w/CG

Each Row is a stop
Each Column is a generated vehicle route and its cost
Each matrix coefficient, $a_{ij}$, is $\{0,1\}$, identifying the stops on the j’th route
Define $Y_j$, $\{0,1\}$, “1” if the route is used ; else “0”

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<thead>
<tr>
<th>Route 1</th>
<th>Route 2</th>
<th>Route 3</th>
<th>....</th>
<th>....</th>
<th>Route M</th>
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<td>C2</td>
<td>C3</td>
<td>....</td>
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Minimize: $\sum_j C_j Y_j$

Subject to:
$\sum_{j=1}^{J} a_{ij} Y_j \geq D_i$ ; for all I
$Y_j = \{0,1\}$ , for all J
**Same Example**

- Each tour is a column
  - How are tours generated?
  - Could each column be a solution?
  - How could this be enhanced?

### Shortest Path Matrix

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### Total Dist

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MIT Center for Transportation & Logistics – ESD.260

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Regardless of Approach

**Rules of Thumb**
- Good routes are "rounded", not "star shaped"
- Good routes don't cross themselves or others
- Good sectors are "pie shaped", not "checker board"
- Good solutions "look like a daisy"

**Good Practice Tips**
- Always use a Preview-Analyze-Review methodology
- Periodically visit the internal logic within the TMS
- Never discount the salty expert who has been doing this longer than you’ve been alive
- Identify all special conditions (customer A must be delivered to first) and then validate or reject them
Other Extensions to VRP

- **More dimensions/elements**
  - **Sourcing**
    - Multiple depot
    - Dynamic sourcing (depot varies)
  - **Order**
    - Multiple dimensions (e.g. cube, weight)
    - Mixed pickup and delivery
    - Time window
    - “Vendor Managed Inventory”
  - **Plan**
    - Fixed / Static / Master
    - Variable / Dynamic / Daily
    - Zone
    - Real-time dispatch
  - **Resource**
    - Backhaul
    - Continuous moves

- **Academic problems**
  - Multiple Depot VRP (MDVRP)
  - Multi-commodity VRP
  - Vehicle Routing Problem with Pick-up and Delivering (VRPPD)
  - VRP with time windows (VRPTW)
  - Inventory Routing Problem (IRP)
  - Stochastic VRP (SVRP) – minimize expected costs for satisfying realized demand/customers
  - Dynamic VRP – redirect trucks during the execution of their route to accommodate new orders
  - Vehicle Routing Problem with Backhauls (VRPB)

Adapted from Goentzel 2004
Fixed vs. Dynamic Route Plans

**Fixed/static routes**
- Routes repeat on a cycle
  - Daily, weekly, whenever there is sufficient demand
- Routes are changed when customer base changes
  - Quarterly, annually
- Routes are based on “forecast” demand
- Routes are designed for “heavy days” related to truck capacity and driver hours
- Primary advantages
  - Driver familiarity
  - Ease of execution
- Primary disadvantages
  - Inefficiency caused by variability
  - Difficulty of efficient customer day assignment

**Variable/dynamic routes**
- Routes change continually
  - Typically every day
- Routes based on “actual” shipment requirements
- Routes are designed for vehicle and driver constraints
- Primary advantages
  - Utilization of trucks and drivers
  - Flexibility in customer ordering
- Primary disadvantages
  - Difficulty of determining optimum routes
  - Difficulty of maintaining route planning process
  - Execution may not match plan

Adapted from Goentzel 2004
Real-World Issues

- The real world does not behave according to uniform assumptions
  - Dock configuration
  - Dock hours
  - Trailer types
  - Moveable bulkheads (bulk liquids, grocery reefers)
  - Truck types
  - Truck-trailer combos: doubles & triples (pups)
  - Compatibility: order-vehicle, order-order, vehicle-site
  - Preferred customers (big box)
  - Driver preferences (seniority, local knowledge)
  - Driver skills (service technician)
  - Rush hour traffic
  - Real-time dispatching (deployed vehicles)
  - Refueling
  - Maintenance

Adapted from Goentzel 2004
Element Interactions

- **Truck & Trailer**
  - Trailers the tractor can handle – length, pups, specialized (e.g. car hauler)

- **Vehicle & Customer**
  - Must be able to visit the customer (loading dock, cornering, parking)

- **Vehicle & Order**
  - Products may not be deliverable on certain resources -- HazMat, loading/handling equipment (tanks, racks), capabilities (refrigeration), physical dimensions, etc.

- **Vehicle & Driver**
  - Not licensed for the truck, not able to load/unload trailer

- **Order & Order**
  - Products may not mix (lumber & light bulbs, bottled water & dehydrated food, etc.)

Adapted from Goentzel 2004
Manual Planning

Plan using paper, pencil, and experience

Advantages
- Cheap and easy

Challenges
- Cannot generate multiple solutions
- Difficult to evaluate result
- Decentralized

Image of drawn-on map removed due to copyright restrictions.

Adapted from Goentzel 2004 Map-on-the-wall
Interactive GIS

- Plan using human intuition, guided by simple heuristics

Advantages
- Evaluation is easier (distance, time, cost calculations, and visual)

Challenges
- Time consuming (and typically there is limited time for planning)
- Requires “super-users”
  - Need technical aptitude
  - Requires regular training
- Typically decentralized

Adapted from Goentzel 2004
Automated Heuristics

Plan using construction, local improvement, & other heuristics

Advantages
- Provides solutions relatively quickly

Challenges
- Solution quality hard to predict
  - Heuristics that work well for one problem may work poorly for another
  - Solution quality from heuristics can change drastically when the data changes
  - Hard to know when to settle on a solution
- Complexity
  - Not as good if there are complex constraints or shipments vary in size
  - Need sophisticated expert to improve or tune
- Typically users stick with the same approach and manually edit plans

Adapted from Goentzel 2004
Optimization

- Column generation and set covering IP

Advantages
- Determines best solution among the options considered

Challenges
- Quality depends on quality of options created (column generation)
- Requires significant computing power (parallel computing is advantageous)
- Requires regular maintenance by domain and technology experts

Adapted from Goentzel 2004
Questions?