Solving Real-World Vehicle Scheduling and Routing Problems

Jens Gottlieb

SAP AG
Walldorf, Germany
jens.gottlieb@sap.com
SAP offers two products covering transportation planning functionality:
- Since 2001: SAP Supply Chain Management, APO TP/VS
  (Advanced Planner and Optimizer, Transportation Planning / Vehicle Scheduling)
- Since 2007: SAP Transportation Management

SAP offers one product for service management and technician scheduling:
- SAP Multi Resource Scheduling

Since 2001, SAP has developed and continuously improved an optimization algorithm for the vehicle scheduling and routing problem, which is the planning engine in above products.
Agenda

1. The vehicle scheduling and routing problem
2. Solution approach
3. Selected scenarios
4. Conclusion
The vehicle scheduling and routing problem: Orders

- Order-based model
- Source and destination location per order

Order 1

Order 2

Order 3

Order 4

Order 5

- Priority (Non-delivery costs)
- Loading dimensions (weight, volume, ...)
- Characteristics (hazardous goods, frozen, ...)
- Loading/unloading durations (depending on vehicle)
Example 1:
Orders in classical CVRP scenario
Example 2:
Orders in selected customer scenario
The vehicle scheduling and routing problem:
Time restrictions per order

- Time windows per order (hard and soft) for loading and unloading

<table>
<thead>
<tr>
<th>Loading requires outbound handling resource at source location</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Business hours</td>
</tr>
<tr>
<td>- Capacities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unloading requires inbound handling resource at destination location</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Business hours</td>
</tr>
<tr>
<td>- Capacities</td>
</tr>
</tbody>
</table>
The vehicle scheduling and routing problem: Vehicles

- Travel capabilities (duration, distance, distance cost per lane)
- Characteristics (cooled, available for hazardous goods, …)
- Break calendar

Constraints:
- Start location, end location
- Duration
- Distance
- Number of stops
- Load capacity (weight, volume, …), may depend on number of stops

Costs:
- Fixed costs
- Duration
- Distance
- Number of stops
- Quantity costs (distance x load)
Example: Schedule for a selected customer scenario
The vehicle scheduling and routing problem: Trailers and compartments (1)
The vehicle scheduling and routing problem: Trailers and compartments (2)

- Trailers cannot move without vehicle

- Coupling/uncoupling activities

- Constraints for trailers like for vehicles
  - Start location, end location
  - Duration, distance, number of stops, load (weight, volume, …)

- Costs for trailers like for vehicles
  - Fixed costs, duration, distance, number of stops
  - Quantity costs (distance x load)

- Constraint for vehicle combinations: load (weight, volume, …)

- Compartments
  - Each vehicle/trailer has fixed number of compartments
  - Load capacity per compartment (weight, volume, …)
  - Fixed versus flexible load capacity
The Vehicle Scheduling and Routing Problem: Hubs

- Hub locations (= transshipment locations):
  - Indirect shipment via hub(s) versus direct shipment

- Minimum and maximum waiting time at hub
Example:
Selected customer scenario involving 5 hubs
The vehicle scheduling and routing problem: Incompatibilities and schedule vehicles

- Incompatibility constraints:
  - Between order characteristics
  - Between vehicle characteristics and order characteristics
  - Between trailer characteristics and order characteristics
  - Between compartment characteristics and order characteristics
  - Between vehicle characteristics and trailer characteristics
  - Between vehicle characteristics and trailer characteristics
  - Between order characteristics and hubs
  - Between vehicle characteristics and hubs
  - Between trailer characteristics and hubs

- Schedule vehicles:
  - Route is fixed a priori
  - Schedule is fixed a priori
The vehicle scheduling and routing problem: Summary

- **Goal:** Determine transportation plan that minimizes total costs and satisfies all constraints.

- A transportation plan is characterized by the following decisions:
  - per order: deliver or not?
  - per delivered order: select legs (= path through hub network)
  - per selected leg: select vehicle/trailer and compartment
  - per vehicle/trailer:
    - select relative ordering of activities (= routing)
    - assign start time to each activity (= scheduling)

- Total costs = weighted sum of costs for
  - orders (non-delivery, earliness, lateness), and
  - vehicles and trailers (fixed, duration, distance, stops, quantity)
Agenda

1. The vehicle scheduling and routing problem
2. Solution approach
3. Selected scenarios
4. Conclusion
Solution approach: Evolutionary local search

- Initialization
- Selection
- Population
- Variation

Selection
Solution approach:
Ingredients of evolutionary local search

Initialization
- Greedy insertion heuristics + local search

Variation
- Uses > 20 different atomic variation operators, grouped into:
  - Assignment moves (e.g. insert an order, delete an order, delete a vehicle)
  - Routing moves (e.g. 2-opt, variants of Or-opt, 3-opt, 4-opt)
  - Scheduling moves
- Moves are applied subsequently and with certain probabilities, using the following concepts:
  - Local search
  - Randomness
  - Iterated local search
  - Variable neighbourhood search
  - Tabu search
Solution approach: Key features

- Direct solution representation
- Only feasible solutions
- Local search
- Small population
- Many specialized atomic move operators
- Orchestration of atomic moves in the variation step
Agenda

1. The vehicle scheduling and routing problem
2. Solution approach
3. Selected scenarios
4. Conclusion
Using the optimizer

Input data specified by selection profile

Different operating modes

- Batch versus interactive start
- Long runs at night versus short runs during the day
- From scratch versus incrementally
- Planning horizon ranges from a few hours to several weeks

Run-time limits vary from a few minutes to several hours

Human transportation planner processes the optimizer‘s result:

- reviewing it,
- manipulating it interactively if needed, and
- releasing it to transportation execution

Side-effect of optimizer: Check input data

- Unexpected results typically indicate that input data are not clean.
## Characteristics of selected customer scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orders</td>
<td>75</td>
<td>255</td>
<td>662</td>
<td>778</td>
<td>804</td>
<td>1177</td>
<td>2029</td>
<td>7040</td>
<td>13569</td>
</tr>
<tr>
<td>Loading dimensions</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Locations</td>
<td>30</td>
<td>199</td>
<td>55</td>
<td>8</td>
<td>32</td>
<td>565</td>
<td>128</td>
<td>1873</td>
<td>14</td>
</tr>
<tr>
<td>Hubs</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sources</td>
<td>9</td>
<td>5</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Destinations</td>
<td>14</td>
<td>194</td>
<td>46</td>
<td>7</td>
<td>31</td>
<td>559</td>
<td>127</td>
<td>1872</td>
<td>13</td>
</tr>
<tr>
<td>Vehicle types</td>
<td>4</td>
<td>38</td>
<td>9</td>
<td>7</td>
<td>3</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Vehicles</td>
<td>58</td>
<td>93</td>
<td>301</td>
<td>281</td>
<td>680</td>
<td>2701</td>
<td>2011</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Schedule vehicle types</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schedule vehicles</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business hours</td>
<td>2</td>
<td>196</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>29</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Capacitive resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>54</td>
<td>32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1. The vehicle scheduling and routing problem
2. Solution approach
3. Selected scenarios
4. Conclusion
Conclusion

Summary
- Real-world problems are complex
- Heterogeneous instances of the same abstract problem
- One algorithm for the abstract problem, applicable to arbitrary special instances of our customers
- Metaheuristics work well in practice

Outlook
- Continuous extension of functionality
- Hub networks with several „parallel“ hubs and more than 2 „sequential“ hubs
- Different variants of trailer scenarios, depending on frequency of coupling and uncoupling
Thank you!