Workforce Management in Periodic Routing: Practice, Modeling and Solution Approaches

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Presentation outline

**Background**
An overview of related work in periodic routing

**Practice**
Workforce management in practice

**Modeling**
Periodic routing models with workforce management objectives

**Solution approaches**
Exploit relationships among models

**Conclusions and future steps**
Workforce management in periodic routing

**Periodic distribution problems**
Route vehicles to visit nodes over a time period (possibly with schedule choice)

**Key idea:** Performance improves as drivers perform the same tasks multiple times (consistency)

**Customer Familiarity**
Reduce the cost per visit to a customer as the frequency of visits to that customer increases

*If the customer set varies significantly by day, it may be advantageous to consider a more aggregate level*

**Region Familiarity**
Reduce the cost per visit to a region as the frequency of visits to that region increases
## Workforce Management in Periodic Routing

### Modeling workforce management in periodic routing

*Christofides (1971), Beasley (1984), and Wong, Beasley (1984)*  
- Fixed territory strategies

*Zhong, Hall, Dessouky (2004)*  
- Learning/forgetting behavior for drivers

*Francis, Smilowitz, Tzur (2008)*  
- A posteriori calculation of workforce metrics

*Groer, Golden, Wasil (2009)*  
- Constraints to enforce consistency

*Smilowitz, Nowak, Jiang (2010)*  
- Incentives to achieve consistency

### Solution approaches for periodic routing

- Various heuristic approaches

*Francis, Smilowitz, Tzur (2008)*  
- Exact solution approach to assignment-routing formulation

*Baldacci, Bartolini, Mingozzi, Valletta (2011)*  
- Exact solution approach to set partitioning-like formulation based on earlier exact approach for CVRP
Workforce management

Assign 2 drivers to visit three nodes over a period of 2 days*, with 2 vehicles, each of capacity 2.

*Visitation dates for nodes are given, unlike traditional PVRP
Example

Assign 2 drivers to visit three nodes over a period of 2 days, with 2 vehicles, each of capacity 2

Min cost solution:
Use 1 driver on day 2, given low demand

Max region familiarity solution:
Partition drivers by region
Does workforce management matter and what does it cost?

“Many UPS drivers work the same route for 20 or 25 years. ...**UPS drivers form a real bond with customers**...A formal program that gathers sales leads from drivers generates volume of more than 60 million packages a year, largely because **drivers take tremendous ownership of their customers and routes**.

In contrast, a major competitor reserves the right to reconfigure some drivers' routes with five days' notice, meaning their customers, service area and earnings power can change quickly.”

- *UPS Corp. (2006)*

“While desirable to route the same drivers to the same customers each and every day, **that level of consistency can be inefficient**. As Hugh Gigante of *Appian* notes, `If we tell a customer that it costs them $100 a day to keep the same drivers servicing the same customers, **most fleets will decide it isn't worth the cost.**’’

- *Partyka and Hall (2010)*
PVRP model variations

- **Travel Distance: PVRP(TD)**
  - Minimize total travel distance across all routes
  - Problem decomposes by day (given no choice in schedule)

- **Region Familiarity: PVRP(RF)**
  - Maximize the number of visits by a driver to a region
  - Links driver-node assignments across days through region visit variables

- **Fixed Territory: PVRP(FT)**
  - Minimize total travel distance across all routes
  - Links driver-node assignments across days through fixed territory constraints

**Phase I**: Design vehicle routes (customer assignment & sequence) to minimize cost

**Phase II**: Assign drivers to routes to achieve workforce goals

**Single Phase**: Design vehicle routes (customer assignment & sequence) and assign drivers to routes to minimize cost and achieve workforce goals
PVRP (TD) Phase I

- **Travel Distance: PVRP(TD)**
  \[
  f_{TD} = \sum_{i,j,k,t} c_{ij} x_{ijk}^t
  \]

Allocation variables **by day**

\[
y_{ik}^t = \begin{cases} 
1 & \text{if node } i \text{ is visited by vehicle route } k \text{ on day } t \\
0 & \text{otherwise}
\end{cases}
\]

Routing variables **by day**

\[
x_{ijk}^t = \begin{cases} 
1 & \text{if vehicle route } k \text{ traverses arc } (i, j) \text{ on day } t \\
0 & \text{otherwise}
\end{cases}
\]
PVRP (TD) Phase I model

Minimize Travel distance

Subject to:

- Allocate nodes to schedules and vehicle routes \( \{y\} \)
  - service frequency requirement
  - capacity constraint

- Route vehicles \( \{x\} \)
  - balance flows
  - eliminate sub-tours

- Link allocation to routing \( \{x, y\} \)
  - vehicle routes must visit scheduled nodes

Solve independently for each day
PVRP (TD) Phase II

In Phase I, vehicle index, $k$, is arbitrary.

Assign drivers to vehicle routes, based on Francis, Smilowitz, and Tzur (2008).

$$y_{ik}^t = \begin{cases} 1 & \text{if node } i \text{ is visited by vehicle route } k \text{ on day } t \\ 0 & \text{otherwise} \end{cases}$$

$$\pi_{lk}^t = \begin{cases} 1 & \text{if driver } l \text{ is assigned to vehicle route } k \text{ on day } t \\ 0 & \text{otherwise} \end{cases}$$
PVRP (RF)

- Link driver and vehicle routes in a single model in which routes are designed and drivers are assigned to routes

Region/driver frequency variables

\[ u_{rl(k)}^n = \begin{cases} 
1 & \text{if region } r \text{ is visited by the driver of vehicle route } k, \text{ denoted } l(k), \text{ a total of } n \text{ times in the period} \\
0 & \text{otherwise} 
\end{cases} \]

- Region Familiarity: PVRP(RF)

\[ f_{RF} = f_{TD} + \phi_{RF} \sum_{r,k,n} n \beta^n u_{rl(k)}^n \]

- Reduce the per-visit cost to a region, \( \beta^n \), as the frequency of visits increases
- Include a weighting factor, \( \phi_{RF} \)

\[ \beta^n > \beta^{n+1} \]

The per-visit cost decreases as driver visits the region more frequently

\[ n \beta^n < (n+1) \beta^{n+1} \]

The total visit cost cannot decrease with more visits
PVRP (RF) model

Minimize  Travel distance + Workforce costs

Subject to:

- Allocate nodes to schedules and vehicle routes \{y\}
  - service frequency requirement
  - capacity constraint

- Calculate region visit frequency \{y, u\}

- Route vehicles \{x\}
  - balance flows
  - eliminate sub-tours

- Link allocation to routing \{x, y\}
  - vehicle routes must visit scheduled nodes
Quantifying trade-offs

- Test cases
  - Multi-day instances used by Groer, Golden, and Wasil (2009), adaptation of VRP benchmarks of Christofides and Eilon (1969)
  - Probability of service request: {0.6, 0.7, 0.8}
  - Multi-objective models: vary the importance of workforce metrics with a weight, $\phi$
  - Solutions obtained with Tabu Search

- Evaluate the effectiveness of one model in terms of achieving the goals of another model
  - $\Delta_I(PVRP(J_{\phi}))$: relative gap in the value of objective I between the PVRP solution in which J is the primary objective with weight $\phi$ and the minimum value of objective I

\[
\Delta_I(PVRP(J_{\phi})) = \frac{f_I(PVRP(J_{\phi})) - f_{I_{\MIN}}}{f_{I_{\MIN}}}
\]
Trade-off between customer familiarity and travel distance

Introducing workforce metrics into routing decisions with a small weight has a high reward with a low cost

\[ \phi_{CF} = 0 \]

\[ \phi_{CF} = 1000 \]
Observations and implementation challenges

• Introducing workforce metrics into routing decisions with a small weight has a high reward with a low cost

• Translating models to practice:
  – Similar results observed in tests with data from a major package carrier
  – Conducted interviews with carriers involved in periodic routing and software providers who develop routing software
Matching models with industry

<table>
<thead>
<tr>
<th>Importance of driver familiarity</th>
<th>No variation: All frequency of 5</th>
<th>Some variation: Mixed frequencies</th>
<th>Completely variation: All frequency of 1</th>
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<td>High</td>
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<td>Model options:</td>
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Assume 5-day period

Daily variation in customer set
Matching models with industry

Daily variation in customer set

- No variation: All frequency of 5
  - VRP (repeat daily)
  - PVRP(FT)
  - PVRP(RF) with small workforce weight
- Some variation: Mixed frequencies
  - PVRP(FT)
  - PVRP(RF)
- Completely variation: All frequency of 1
  - PVRP(RF) with small workforce weight or PVRP(TD)/VRP for each day

Importance of driver familiarity

High

Medium

Low

Daily variation in customer set
Matching models with industry: practitioner findings

**Importance of driver familiarity**

- **High**
  - UPS residential delivery
    - Benefits of driver familiarity: Efficiency; doorman access; revenue generation
    - Customer characteristics: Low volume; 1 stop per segment daily
    - Challenges of driver consistency:
      - Variation in demands; balance loads
    - Innovative ideas: Core area of 3/4 drivers; subdivide into trace
  - PVRP (repeat daily)

- **Medium**
  - PVRP(RF) with small workforce weight

- **Low**
  - PVRP(RF) with small workforce weight or PVRP(TD)/VRP for each day

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**Daily variation in customer set**

- **No variation:**
  - All frequency of 5

- **Some variation:**
  - Mixed frequencies

- **Completely variation:**
  - All frequency of 1
Modeling periodic routing: new opportunities

Daily variation in customer set

- No variation: All frequency of 5
- Some variation: Mixed frequencies
- Completely variation: All frequency of 1

Importance of driver familiarity

High

Medium

Low

What happens in the gray area?

Options:
1. Easy-to-solve VRP, decomposed by day
2. Easy-to-implement Fixed territory PVRP
3. PVRP with travel and workforce costs
4. Fixed territory models with limited (and intelligently placed) flexibility
PVRP model variations: sequential solution approaches to exploit bounds

\( f_I(PVRP(J)) \): value of objective I for solution to model variation PVRP(J)

\( f_{I}^{\text{MIN}} \): the minimum value of objective I

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1. **PVRP(TD)**
   - Decompose into independent VRP’s
   - To obtain \( f_{TD}(PVRP(TD)) \)
     - Solve with VRP heuristic:
     \[ f_{TD}(PVRP(TD)) \geq f_{TD}^{\text{MIN}} \]
     - Solve with VRP exact method:
     \[ f_{TD}(PVRP(TD)) = f_{TD}^{\text{MIN}} \]
   - To obtain \( f_{RF}(PVRP(TD)) \)
     - Use matching from FST (08):
     \[ f_{RF}(PVRP(TD)) \geq f_{RF}^{\text{MIN}} \]

2. **PVRP(FT)**
   - Solve multi-day PVRP with fixed territories
   - \( f_{TD}(PVRP(TD)) \leq f_{TD}(PVRP(FT)) \)
   - \( f_{RF}(PVRP(FT)) = f_{RF}^{\text{MIN}} \leq f_{RF}(PVRP(TD)) \)

3. **PVRP(RF)**
   - Solve multi-day PVRP with fixed territories
   - \( f_{TD}(PVRP(TD)) \leq f_{TD}(PVRP(RF)) \leq f_{TD}(PVRP(FT)) \)
   - \( f_{RF}(PVRP(FT)) \leq f_{RF}(PVRP(RF)) \leq f_{RF}(PVRP(TD)) \)
Exact solution approach, Francis, Smilowitz, Tzur (2008)

**Lagrangian Relaxation Phase**
- Relax constraints linking assignment and routing

**Assignment Sub-problem** \( y_{ik}^t \)
- Capacitated assignment problem
- Easy to solve in practice

**Routing Sub-problem** \( x_{ijk}^t \)
- Prize-collecting traveling salesman problem
- Use bounds when problem can’t be solved

**Updating Upper Bounds**
- \( y \to x \): time consuming but useful
- \( x \to y \): easy, but often infeasible

**Branch and Bound Phase**
- Close the gap using information from Lagrangian relaxation
- Given \( y \)'s, associated \( x \) sub-problem may have been solved

**Observations for current work:**
- Workforce variables contained within assignment sub-problem
- The LR phase does not take significant advantage of bounds from related models
- B&B phase can use bounds, but this is a small part of the solution effort
- Can we develop an approach that uses these bounds earlier?
Exact solution approach, Baldacci, Bartolini, Mingozi, Valletta (2011)

1. Create a set partitioning-like formulation of the PVRP

2. Apply exact approach from CVRP work *(can be used for PVRP(TD))*
   (i) Compute dual solution of LP-relaxation (with added valid inequalities)
   (ii) Use dual solution to generate reduced IP
   (iii) Solve reduced IP

3. Develop relaxations of the PVRP, required for Step (i) *(applications for PVRP(RF) and PVRP(FT))*?

4. Derive bounding principles
   (i) One relaxation involves a conversion to the CVRP

BBMV approach considers schedule choice; address the changes (simplifications) due to the lack of schedule choice
Conclusions and future steps

Practice
• Workforce management principles can be applied with a minimal impact on travel costs through multi-objective PVRP models.
• However, resulting solutions can be difficult to communicate/implement in the field.

Modeling
• We are now analyzing limited flexibility models to find solutions that come close to workforce management models with less complexity.

Solution approaches
• Exploit the relationships among models in a sequential solution approach

Extensions
• Choice in visitation dates
• Dynamic models: as drivers become more familiar with a region, more visits may be possible
Questions?