Urban logistics strategies for the efficient distribution of fresh produce

Freight in urban modeling and planning

M. Boile\textsuperscript{1}, S. Theofanis\textsuperscript{2}, E. Sdoukopoulos\textsuperscript{1}, A. Anagnostopoulou\textsuperscript{1}

\textsuperscript{1}Centre for Research and Technology Hellas (CERTH) / Hellenic Institute of Transport, Egialias 52, 15125, Marousi, Athens, Greece

\textsuperscript{2}Electronic Port Services SA, Kyvelis 38, 15238, Chalandri, Athens, Greece
Outline

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- Motivation
- Description of the problem

Literature Review
- VRPTW
- MDVRPTW

Solution Approach
- Initialization Phase
- Improvement Phase

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- Benchmark data sets
- Effect of distribution strategies

Conclusions
Introduction

**Importance:** The high frequency, the delivery time requirements and the large number of single shipments characterizing the delivery of fresh produce in an urban environment often result in increased congestion, energy consumption and other significant environmental impacts such as noise and air pollution.

**Challenge:** The implementation of actions and policies that improve urban fresh produce distribution.
Motivation

**Goal:** Distribution strategy that reduces environmental costs following an energy efficient routing plan.

**Distribution Strategies:**
- Single-depot strategy (Vehicle Routing Problem with Time Windows - VRPTW)
  
  All units to be delivered are initially located at a depot.

- Multi-depot strategy (Multi-depot Vehicle Routing Problem with Time Windows - MDVRPTW)
  
  Units to be delivered are located at multiple depots.
Operational Objectives:
1. Minimize the number of vehicles required to service all customers (primary)
2. Minimize the total distance traveled (secondary)

Environmental Objective:
1. Minimize the total fuel consumption required from all vehicles used to service all customers

Constraints:
• Each customer must be serviced within a hard time window
• Each customer must be visited only once by exactly one vehicle
• The load of a vehicle must not exceed a maximum capacity limit at any point along the route.
Literature Review

VRPTW:


Literature Review

**MDVRPTW:**


Solution Approach

**Aim:** a simple “cluster first – route second” algorithm to address both single-depot and multi-depot vehicle routing policies.

**Main effort:** is to improve the computational time of the search process in the solution space excluding particular regions and allowing the exploration only to certain promising regions of the entire solution space.

```plaintext
Input: v, ω, z // user-defined parameters
Output: Best feasible solution s*
        counter ← 0
        while counter ≤ ω do
            s ← Construction of initial solution // Initialization Phase
            s' ← Tabu Search (s, v, z) // Improvement Phase
        end while
```
Initialization Phase

Cluster-first:
• Parallel greedy construction heuristic
• Myopic approach
• Multiple clusters are constructed in parallel
• Assignment criteria: geographical closeness
• Termination Condition: all customers are assigned to depots

Route-second:
• Insertion-based construction scheme of Solomon (1987)
• Insertion criteria: geographical and temporal closeness
• Different weights for distance and waiting time
• One route is constructed at a time
• Find best unrouted customer and best insertion position at each iteration of the construction process
• Termination Condition: all customers are serviced
Improvement Phase

• Local search is important for the fast progression towards high quality regions

Tabu Search:
• Perform local search and improve initial solutions
• Neighborhood Structures: 2–Opt, Relocate, Exchange, Cross (equal selection probability)
• Tabu list: records the most recently visited solutions and helps the search to escape from local optimality and cycling
• Aspiration criteria: a new local optimum is gained
• Termination Condition: a maximum number of iterations without observing any further improvement
Computational Results

Benchmark data sets:
• Data sets based on Solomon (1987) R1 and R2 categories
  - 11 instances with 100-node problems for R1
  - 12 instances with 100-node problems for R2
  - R1 problems have short scheduling horizon
  - R2 problems have long scheduling horizon

• Data sets of Cordeau et al. (2001) (a) and (b) categories
  - 20 problem instances with customers up to 288 for both categories (a) and (b)
  - Category (a) includes customers with narrow time windows
  - Category (b) includes customers with loose time windows
## Computational Results

Integrated measure of **operational cost:**

100\( \text{Total Vehicles} + \text{Total Distance} \)

<table>
<thead>
<tr>
<th></th>
<th>Solomon (R1) Short-haul</th>
<th>Solomon (R2) Long-haul</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Additional number of vehicles for applying a multi-depot distribution strategy</strong></td>
<td>17.68%</td>
<td>25.00%</td>
</tr>
<tr>
<td><strong>Additional travelled distance for applying a multi-depot distribution strategy</strong></td>
<td>-9.01%</td>
<td>8.53%</td>
</tr>
<tr>
<td><strong>Additional operational cost for applying a multi-depot distribution strategy</strong></td>
<td>6.53%</td>
<td>13.87%</td>
</tr>
</tbody>
</table>
Computational Results

Environmental cost: fuel consumption
• The single-depot distribution strategy is highly competitive

<table>
<thead>
<tr>
<th>Solomon (R1) Short-haul</th>
<th>Single-depot Strategy</th>
<th>Solomon (R2) Long-haul</th>
<th>Single-depot Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>R101</td>
<td>-55.60%</td>
<td>R201</td>
<td>-16.40%</td>
</tr>
<tr>
<td>R102</td>
<td>-32.91%</td>
<td>R202</td>
<td>-17.85%</td>
</tr>
<tr>
<td>R103</td>
<td>-15.07%</td>
<td>R203</td>
<td>-27.26%</td>
</tr>
<tr>
<td>R104</td>
<td>-12.10%</td>
<td>R204</td>
<td>-32.89%</td>
</tr>
<tr>
<td>R105</td>
<td>-54.82%</td>
<td>R205</td>
<td>-18.92%</td>
</tr>
<tr>
<td>R106</td>
<td>-61.16%</td>
<td>R206</td>
<td>-26.03%</td>
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<tr>
<td>R107</td>
<td>-28.31%</td>
<td>R207</td>
<td>-50.65%</td>
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<tr>
<td>R108</td>
<td>-3.94%</td>
<td>R208</td>
<td>-21.24%</td>
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<tr>
<td>R109</td>
<td>-46.58%</td>
<td>R209</td>
<td>-23.78%</td>
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<tr>
<td>R110</td>
<td>-51.54%</td>
<td>R210</td>
<td>-26.43%</td>
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<tr>
<td>R111</td>
<td>-22.96%</td>
<td>R211</td>
<td>-32.55%</td>
</tr>
<tr>
<td>R112</td>
<td>-20.85%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Computational Results

Environmental cost: fuel consumption
• The single-depot distribution strategy is proved energy efficient for all problem instances

<table>
<thead>
<tr>
<th>Cordeau et al. (a) Short-haul</th>
<th>Single-depot Strategy</th>
<th>Cordeau et al. (b) Long-haul</th>
<th>Single-depot Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR01</td>
<td>-18.52%</td>
<td>PR01</td>
<td>-9.42%</td>
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<tr>
<td>RR02</td>
<td>-17.37%</td>
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<td>-12.60%</td>
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<td>PR03</td>
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<td>-11.41%</td>
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<td>PR04</td>
<td>-19.79%</td>
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<td>PR05</td>
<td>-13.84%</td>
<td>PR05</td>
<td>-10.93%</td>
</tr>
<tr>
<td>PR06</td>
<td>-16.54%</td>
<td>PR06</td>
<td>-10.86%</td>
</tr>
<tr>
<td>PR07</td>
<td>-41.20%</td>
<td>PR07</td>
<td>-27.38%</td>
</tr>
<tr>
<td>PR08</td>
<td>-15.15%</td>
<td>PR08</td>
<td>-16.46%</td>
</tr>
<tr>
<td>PR09</td>
<td>-20.32%</td>
<td>PR09</td>
<td>-13.68%</td>
</tr>
<tr>
<td>PR10</td>
<td>-25.18%</td>
<td>PR10</td>
<td>-13.02%</td>
</tr>
</tbody>
</table>
Computational Results

Extra fuel consumption rate for Solomon (1987) data sets (environmental cost)

• The rate for extra fuel consumption increases for both short- and long-haul instances when a multi-depot distribution strategy is applied, as compared to a single depot.
Computational Results

Extra fuel consumption rate for Cordeau et al. (2001) data sets (environmental cost)

• The rate for extra fuel consumption increases for both short- and long-haul instances when a multi-depot distribution strategy is applied, as compared to a single depot.
Conclusions

• A single-depot approach for the distribution of fresh produce can render considerable improvements to the quality of the entire service provided in urban freight transportation.
• Central fresh produce markets in urban areas may play this role, with direct distribution of fresh produce.
• In general, positive outcomes in terms of number of vehicles required, total travel distance and resulting operational costs result from the single-depot case.
• Centralized urban distribution plans result in significant energy efficient routes especially for fresh produce that have tight time windows and short scheduling horizons.
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