Vehicle routing optimization with pickups and deliveries for nonprofit applications

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September 9, 2019
Outline

1. Problem statement
2. Justification
3. Theoretical framework
4. State of the art
5. Objectives
6. Methodology
7. Contributions
Vehicle routing problems (VRPs)
Problem statement

Vehicle routing problems (VRPs)

Commercial and profitable sectors

Nonprofit operations
Problem statement

Vehicle routing problems (VRPs)

Commercial and profitable sectors

Nonprofit operations

Nonprofit operations

Disaster management

Public transportation

Health care logistics

Equity and fairness
Problem statement

Vehicle routing problems with pickups and deliveries

Disaster management
Public transportation
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Disaster management
Public transportation
Health care logistics
Equity and fairness
Problem statement

Vehicle routing problems with pickups and deliveries

DONATE  DELIVER  FEED

Food rescue and delivery  Handicapped people transportation

Equity and fairness

Taken from: https://www.montgomerycountymd.gov/HHS/FoodRescueMiniGrants.html
Vehicle routing problems with pickups and deliveries

Food rescue and delivery

Handicapped people transportation

Equity and fairness
Justification

Practical issues
- In commercial sectors: routing costs vary from 19% to 37% of the total logistic cost [Ghiani et al., 2004].
- In nonprofit contexts: people (e.g., users, citizens, patients) are directly considered.

Theoretical issues
VRP and PDVRP are $\mathcal{NP}$-Hard problems [Toth and Vigo, 2014].

Algorithmic issues
- Robust, efficient and low complexity algorithms
- Several features and conditions from the problem should be included
- Computational resources availability
- Large and complex problems
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Theoretical framework
Mixed-integer linear programming (MILP) model for the CVRP – [Toth and Vigo, 2014]

Sets:
- $\mathcal{N}$: set of nodes
- $\mathcal{K}$: set of vehicles
- $S$: subset of nodes ($S \subseteq \mathcal{N}$)

Parameters:
- $c_{ij}$: cost of traveling from node $i$ to node $j$
- $r(S)$: number of vehicles required to serve all the nodes in $S$

Decision variables:
- $x_{ij} = \begin{cases} 1 & \text{if arc } (i, j) \text{ is used in the solution} \\ 0 & \text{otherwise} \end{cases}$
Theoretical framework
MILP model for the CVRP - [Toth and Vigo, 2014]

\[
\begin{align*}
\text{min } f &= \sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{N}} c_{ij} \cdot x_{ij} \\
\text{subject to,} & \\
\sum_{j \in \mathcal{N}} x_{ij} &= 1 \quad \forall \ i \in \mathcal{N} \setminus \{0\} \quad (2) \\
\sum_{i \in \mathcal{N}} x_{ij} &= 1 \quad \forall \ j \in \mathcal{N} \setminus \{0\} \quad (3) \\
\sum_{i \in \mathcal{N}} x_{i0} &= |\mathcal{K}| \quad (4) \\
\sum_{j \in \mathcal{N}} x_{0j} &= |\mathcal{K}| \quad (5) \\
\sum_{i \notin S} \sum_{j \in S} x_{ij} &\geq r(S) \quad \forall \ S \subseteq \mathcal{N} \setminus \{0\}, S \neq \emptyset \quad (6) \\
x_{ij} &\in \{0, 1\} \quad \forall \ i \in \mathcal{N}, j \in \mathcal{N} \quad (7)
\end{align*}
\]
Most often addressed VRP attributes [Braekers et al., 2016]:
- Capacitated vehicles
- Heterogeneous vehicles
- Time windows
- Backhauls
- Multiple depots
- Multi-period time horizon
- Precedence and coupling constraints
- Split deliveries*
- Stochastic demands
- Time-dependent travel times
- Stochastic travel times
- Dynamic requests
Theoretical framework

MILP model for a PDVRP – [Toth and Vigo, 2014]

Sets:
- $\mathcal{N}$: set of nodes
- $\mathcal{K}$: set of vehicles
- $\mathcal{S}$: subset of nodes ($\mathcal{S} \subseteq \mathcal{N}$)

Parameters:
- $c_{ij}$: cost of traveling from node $i$ to node $j$
- $Q$: vehicle capacity
- $d_i$: demand (units to pickup or delivery) at node $i$

Decision variables:
- $x_{ijk} = \begin{cases} 
1 & \text{if vehicle } k \text{ goes from node } i \text{ to node } j \text{ in the solution} \\
0 & \text{otherwise} \end{cases}$
- $f_{ij}$: load of the vehicle when going from $i$ to $j$
Theoretical framework

MILP model for a PDVRP – [Toth and Vigo, 2014]

\[
\min f = \sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{N}} \sum_{k \in \mathcal{K}} c_{ij} \cdot x_{ijk}
\]

subject to,

\[
\sum_{j \in \mathcal{N}} \sum_{k \in \mathcal{K}} x_{ijk} = 1 \quad \forall \ i \in \mathcal{N} \setminus \{0\}
\]

\[
\sum_{j \in \mathcal{N}} x_{ijk} - \sum_{j \in \mathcal{N}} x_{jik} = 0 \quad \forall \ i \in \mathcal{N}, k \in \mathcal{K}
\]

\[
0 \leq f_{ij} \leq Q \cdot \sum_{k \in \mathcal{K}} x_{ijk} \quad \forall \ i, j \in \mathcal{N}
\]

\[
\sum_{j \in \mathcal{N}} f_{ji} - \sum_{j \in \mathcal{N}} f_{ij} = d_i \quad \forall \ i \in \mathcal{N} \setminus \{0\}
\]

\[
\sum_{i \in \mathcal{S}} \sum_{j \in \mathcal{S}} x_{ijk} \leq |\mathcal{S}| - 1 \quad \forall \ \mathcal{S} \subseteq \mathcal{N} \setminus \{0\}, \mathcal{S} \neq \emptyset, k \in \mathcal{K}
\]

\[
x_{ijk} \in \{0, 1\} \quad \forall \ i, j \in \mathcal{N}, k \in \mathcal{K}
\]
Theoretical framework

Vehicle routing problems

<table>
<thead>
<tr>
<th>Exact approaches</th>
<th>Heuristics</th>
<th>Metaheuristics</th>
<th>Matheuristics</th>
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Constructive heuristics

- Clarke and Wright algorithm
- Nearest neighbor algorithm
- Best insertion algorithm
- Sweep algorithm
- Split algorithm
- k-Opt heuristics
- $\lambda$-interchange heuristic

Improvement heuristics

- Palacio, J.D., Rivera J.C.
- Nonprofit PDVRPs
- September 9, 2019
Theoretical framework
Components of metaheuristic algorithms - [Gendreau and Potvin, 2005]

Vehicle routing problems

<table>
<thead>
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<th>Matheuristics</th>
</tr>
</thead>
</table>

- Recombination
- Construction
- Improvement
- Random modification
- Neighborhood update
- Memory update
A general scheme for metaheuristic algorithms [Zäpfel et al., 2010]

1: Create one or several start solutions (e.g., via specific heuristic)
2: while termination criterion not satisfied do
3:   if intensify then
4:     Create new solution by intensification step
5:   else
6:     Create new solution by diversification step
7:   end if
8: Update best found solution (if necessary)
9: end while
10: return Best found solution
1. Problem statement

2. Justification

3. Theoretical framework

4. State of the art

5. Objectives

6. Methodology

7. Contributions
<table>
<thead>
<tr>
<th>Problem</th>
<th>Author(s)</th>
<th>Exact</th>
<th>Metaheuristic</th>
<th>Matheuristic</th>
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<tr>
<td>1-PDVRP &amp; 1-PDTSP</td>
<td>[Hernández-Pérez and Salazar-González, 2004a] ✓</td>
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<td></td>
<td>[Hernández-Pérez and Salazar-González, 2004b] ✓</td>
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<td></td>
<td>[Hernández-Pérez et al., 2009]</td>
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<td></td>
<td>[Zhao et al., 2009]</td>
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<td></td>
<td>[Mladenović et al., 2012]</td>
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<td></td>
<td>[Hernández-Pérez et al., 2018]</td>
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<td>m-PDVRP &amp; m-PDTSP</td>
<td>[Rodríguez-Martín and Salazar-González, 2012] ✓</td>
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<td></td>
<td>[Hernández-Pérez and Salazar-González, 2014] ✓</td>
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<td>DARP</td>
<td>[Parragh et al., 2010]</td>
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<td>[Muelas et al., 2013]</td>
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<td>[Parragh and Schmid, 2013]</td>
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<td></td>
<td>[Liu et al., 2015]</td>
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<td>[Braekers and Kovacs, 2016]</td>
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<td>[Masmoudi et al., 2017]</td>
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</table>
### State of the art

- **Bicycle repositioning problems**

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Sol. strategy</th>
<th>Key features on problem and sol. strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Raviv et al., 2013]</td>
<td>MILPs</td>
<td>Min. Cost and user dissatisfaction</td>
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<tr>
<td>[Chemla et al., 2013]</td>
<td>B&amp;C and TS</td>
<td>Multiple visits</td>
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<tr>
<td>[Dell’Amico et al., 2014]</td>
<td>B&amp;C</td>
<td>Multiple vehicles</td>
</tr>
<tr>
<td>[Erdoğan et al., 2015]</td>
<td>Bender’s dec.</td>
<td>Multiple visits</td>
</tr>
<tr>
<td>[Alvarez-Valdes et al., 2016]</td>
<td>MILPs</td>
<td>Total dissatisfaction + balance route durations</td>
</tr>
<tr>
<td>[Ho and Szeto, 2014]</td>
<td>TS</td>
<td>Min. User dissatisfaction</td>
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<tr>
<td>[Forma et al., 2015]</td>
<td>Matheuristic</td>
<td>Clustering + Routing + Repositioning</td>
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<tr>
<td>[Kadri et al., 2016]</td>
<td>GA + LR</td>
<td>Min. Waiting times on stations</td>
</tr>
<tr>
<td>[Dell’Amico et al., 2016]</td>
<td>D&amp;R + VND</td>
<td>Balance route durations</td>
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<tr>
<td>[Cruz et al., 2017]</td>
<td>ILS + VND</td>
<td>Multiple visits</td>
</tr>
<tr>
<td>[Ho and Szeto, 2017]</td>
<td>HLNS</td>
<td>Min. Cost and user dissatisfaction</td>
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</tbody>
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B&C: branch-and-cut • TS: tabu search • GA: genetic algorithm
LR: lagrangian relaxation • D&R: destroy and repair
VND: variable neighborhood descent
ILS: iterative local search • HLNS: hybrid large neighborhood search
## State of the art

### Home and health care logistics

<table>
<thead>
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<th>Author(s)</th>
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<tbody>
<tr>
<td>[Melachrinoudis et al., 2007]</td>
<td>TS and MILPs</td>
<td>Min. Early/late pickups and deliveries</td>
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<td>[Liu et al., 2013]</td>
<td>GA and TS</td>
<td>Four commodities; time windows</td>
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<td>[Fikar and Hirsch, 2015]</td>
<td>Matheuristic</td>
<td>DRP + walking routes</td>
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<tr>
<td>[Zhang et al., 2015]</td>
<td>MA</td>
<td>Multi-trip</td>
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<tr>
<td>[Lim et al., 2016]</td>
<td>ILS + VND</td>
<td>Multi-trip and time windows</td>
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<tr>
<td>[Detti et al., 2017]</td>
<td>TS and VNS</td>
<td>Multi-depot and heterogeneous fleet</td>
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<td>[Shi et al., 2018]</td>
<td>GA, BA, FA and MILP</td>
<td>Stochastic travel times</td>
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<tr>
<td>[Osaba et al., 2019]</td>
<td>BA</td>
<td>Rich VRP</td>
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</table>

DRP: dial-a-ride problem  
BA: bat algorithm  
FA: firefly algorithm  
MA: memetic algorithm
State of the art

- Disaster relief

<table>
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<tbody>
<tr>
<td>[Yi and Kumar, 2007]</td>
<td>ACO and MILP</td>
<td>Split demand; min. Unsatisfied injured people and demand</td>
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<td>[Jotshi et al., 2009]</td>
<td>MILPs</td>
<td>Patient pickup and patient delivery problem</td>
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<td>[Wohlgemuth et al., 2012]</td>
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<td>Time-dependent; time windows</td>
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</table>

- Food rescue and delivery problem

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<td>MILPs and TS</td>
<td>Periodic; LS as post-optimization for TS</td>
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</table>

ACO: ant colony optimization
LS: local search
Objectives

Solution methods
- Mathematical programming models
- (Meta) Heuristics
- Hybrid algorithms

VRPs with pickups and deliveries
- Commercial and profit applications
- Nonprofit contexts

Palacio, J.D., Rivera J.C. Nonprofit PDVRPs September 9, 2019 29 / 50
Objectives

**Identify**
- Research opportunities and novel insights

**Design**
- Mathematical programming models for PDVRPs
- Heuristic-based solution strategies (metaheuristics and hybrid algorithms)
- Exact and heuristic-based solution strategies for PDVRPs with additional features

VRPs with pickups and deliveries for nonprofit contexts
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Methodology

Phase I
Literature review: variants, models, solution strategies and nonprofit applications

Phase II
Mathematical models and solution strategies: design, implementation and validation

Phase III
Doctoral thesis document and scientific publications: writing and oral presentations
## Methodology

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<td>PhD thesis - writing</td>
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</tbody>
</table>
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2. Justification
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6. Methodology
7. Contributions
Contributions

Mixed-Integer Linear Programming Models for One-Commodity Pickup and Delivery Traveling Salesman Problems

Juan D. Palacio and Juan Carlos Rivera
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Abstract. This article addresses two different pickup and delivery routing problems. In the first one, called the one-commodity pickup and delivery traveling salesman problem, a known amount of a single product is supplied or demanded by a set of two different types of locations (pickup or delivery nodes). Therefore, a capacitated vehicle must visit each location once at a minimum cost. We also deal with the relaxed case where locations can be visited several times. In the last problem, the pickup or delivery operation can be split into several smaller pickups or deliveries, and also locations can be used as temporal storage points with the aim of reducing the cost of the route. To solve these problems, we present two mixed-integer linear programming models and we solve them via commercial solver. We analyze how several visits to a single location may improve solution quality and we also show that our simple strategy has a good performance for instances with up to 60 locations.

Keywords: Pickup and delivery · Traveling salesman problem · Mixed-integer linear programming · Split delivery

Accepted for publication
The one-commodity pickup and delivery vehicle routing problem: A mixed-integer linear programming approach

Juan D. Palacio and Juan Carlos Rivera*

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Received DD MMMM YYYY; received in revised form DD MMMM YYYY; accepted DD MMMM YYYY

Abstract

In this paper we study the one-commodity pickup and delivery vehicle routing problem. It aims to design a set of routes able to pick up or deliver a known amount of a single product supplied or demanded by two different types of locations (pickup or delivery nodes). To do so, a capacitated fleet of homogeneous vehicles is available to meet the demand while the total traveling cost is minimized. However, when several vehicles are available, optimal routes for the problem are not typically cost-balanced. Therefore, we propose a mixed-integer linear program to model the one-commodity pickup and delivery vehicle routing problem with length route constraints and we compare the performance and balance for different length parameters. To solve this mathematical model, we use a commercial solver, we test instances with up to 40 nodes and different target values for balancing routes. Finally, we provide some insights about how the number of nodes, number of vehicles and vehicle capacity affect imbalance throughout the route costs.

Keywords: Pickup and Delivery; Mixed-integer linear programming; Vehicle routing problem
A multi-start evolutionary local search for the bicycle repositioning problem

Juan D. Palacio · Juan Carlos Rivera

Received: date / Accepted: date

Abstract  Bicycle sharing systems (BSS) are known around the world as an alternative and economical way for individual transportation when short distance trips are required. BSS arise from a lack of efficient and sustainable transportation systems in urban areas where mobility, environmental aspects and public health are main government concerns. When providing an efficient BSS operation, an adequate availability of bicycles and parking slots is required throughout the system. To do so, one vehicle must serve a set of stations and pick up or deliver bicycles according to a previous demand estimation and a fixed number of available bicycles. In this paper, we address the BBS vehicle operation as a bicycle repositioning problem and we propose a hybrid metaheuristic based on multi-start evolutionary local search and variable neighborhood descend to solve it. To test the performance of our algorithm, we solve instances with up to 500 stations available in the literature and we demonstrate that our approach is able to provide competitive results when comparing to other existing strategies. Finally, we also use our metaheuristic algorithm to solve a set of a real case instances based on Enciela, a public BSS within the Aburrá Valley, in Antioquia, Colombia.

Keywords  Bicycle repositioning problem · Sustainable transportation · Pickup and delivery traveling salesman problem · Evolutionary local search · Variable neighborhood descend

Manuscript submitted: july 1st, 2019
Mixed-Integer linear programming models for one-commodity pickup and delivery traveling salesman problems

The one-commodity pickup and delivery vehicle routing problem: A mixed-integer linear programming approach

Modelos de programación lineal entera mixta para el problema de reposicionamiento de bicicletas

Diseño de rutas para la distribución de bicicletas compartidas: estrategias exactas y heurísticas
Contributions

A Mixed-Integer Linear Programming Model for a Selective Vehicle Routing Problem

Authors
Andrea Posada, Juan Carlos Rivera, Juan D. Palacio

Conference paper
First Online: 13 September 2018

Part of the Communications in Computer and Information Science book series (CCIS, volume 916)
Contributions

Selective Vehicle Routing Problem: A Metaheuristic Approach*

Andrea Posada, Juan Carlos Rivera\textsuperscript{[0000–0002–2160–3180]}, and Juan D. Palacio

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Abstract. In this paper we deal with a selective vehicle routing problem (SVRP), which was proposed in [18]. In this problem each node belongs to one or several clusters. Contrary to classical vehicle routing problems, here it is not necessary to visit all nodes, but to visit appropriate nodes in such a way that all clusters are visited exactly once. A genetic algorithm (GA) based on random key representation is proposed to solve this SVRP variant. The proposed algorithm is a hybrid metaheuristic which integrates randomized constructive solutions, a variable neighborhood search procedure, an order-first cluster-second operator, and a mixed-integer linear model to repair unfeasible solutions. The metaheuristic is tested by using instances with up to 63 nodes adapted from the generalized vehicle routing problem (GVRP). The GVRP is a special case of this SVRP where each node belongs to exactly one cluster. The results allow to evaluate the impact of different clusters configuration on the instance complexity, the impact of each algorithm’s component on the metaheuristic performance, and the efficiency of the method by a comparison with a mixed-integer linear program.

Accepted for publication
Work in process

For the Ph.D. thesis project:

- Matheuristic algorithms for the 1–PDTSP
  - MILPs as neighborhood within a ELS+VND procedure: destroy and repair strategy
  - MILP as post-optimization procedure
- Latency on PDVRPs
  - MILPs with maximum latency constraints
  - Minimum latency 1–PDVRP
  - Number of vehicles and latency: lexicographic strategy
- Selective-based strategies for the 1–PDTSP
- 1–PDVRP with synchronization constraints

For undergraduate research projects:

- Optimization models to improve repositioning logistic operations in a bike sharing system
- Multi-objective optimization approaches for the repositioning logistic operation in bike sharing systems
Acknowledgments

So far, we would like to thank:

- Área Metropolitana del Valle de Aburrá (AMVA).
- Universidad EAFIT.
- Thesis proposal reviewers:
  - Maria Gulnara Baldoquín (Universidad EAFIT, Colombia)
  - José Manuel Belenguer (Universitat de València, Spain)
  - Pablo Andrés Maya (Universidad de Antioquia, Colombia)
Vehicle routing optimization with pickups and deliveries for nonprofit applications

Juan David Palacio Domínguez, Juan Carlos Rivera Agudelo
jpalc26@eafit.edu.co, jrivera6@eafit.edu.co


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The multi-commodity pickup-and-delivery traveling salesman problem. 

Heuristic algorithm for the split-demand one-commodity pickup-and-delivery travelling salesman problem. 

Solving a static repositioning problem in bike-sharing systems using iterated tabu search. 

A hybrid large neighborhood search for the static multi-vehicle bike-repositioning problem. 

Dispatching and routing of emergency vehicles in disaster mitigation using data fusion. 


A variable neighborhood search algorithm for the optimization of a dial-a-ride problem in a large city.

Scheduling and routing models for food rescue and delivery operations.
Socio-Economic Planning Sciences, 63:18–32.

A discrete and improved bat algorithm for solving a medical goods distribution problem with pharmacological waste collection.
Swarm and evolutionary computation, 44:273–286.

Variable neighborhood search for the dial-a-ride problem.

Hybrid column generation and large neighborhood search for the dial-a-ride problem.

Static repositioning in a bike-sharing system: models and solution approaches.

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