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Vehicle Routing in Glass Waste Collection

Tino Henke[1], M. Grazia Speranza[2], Gerhard Wäscher[1]

[1]University of Magdeburg, Germany
[2]University of Brescia, Italy

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A Glass Waste Collection Problem

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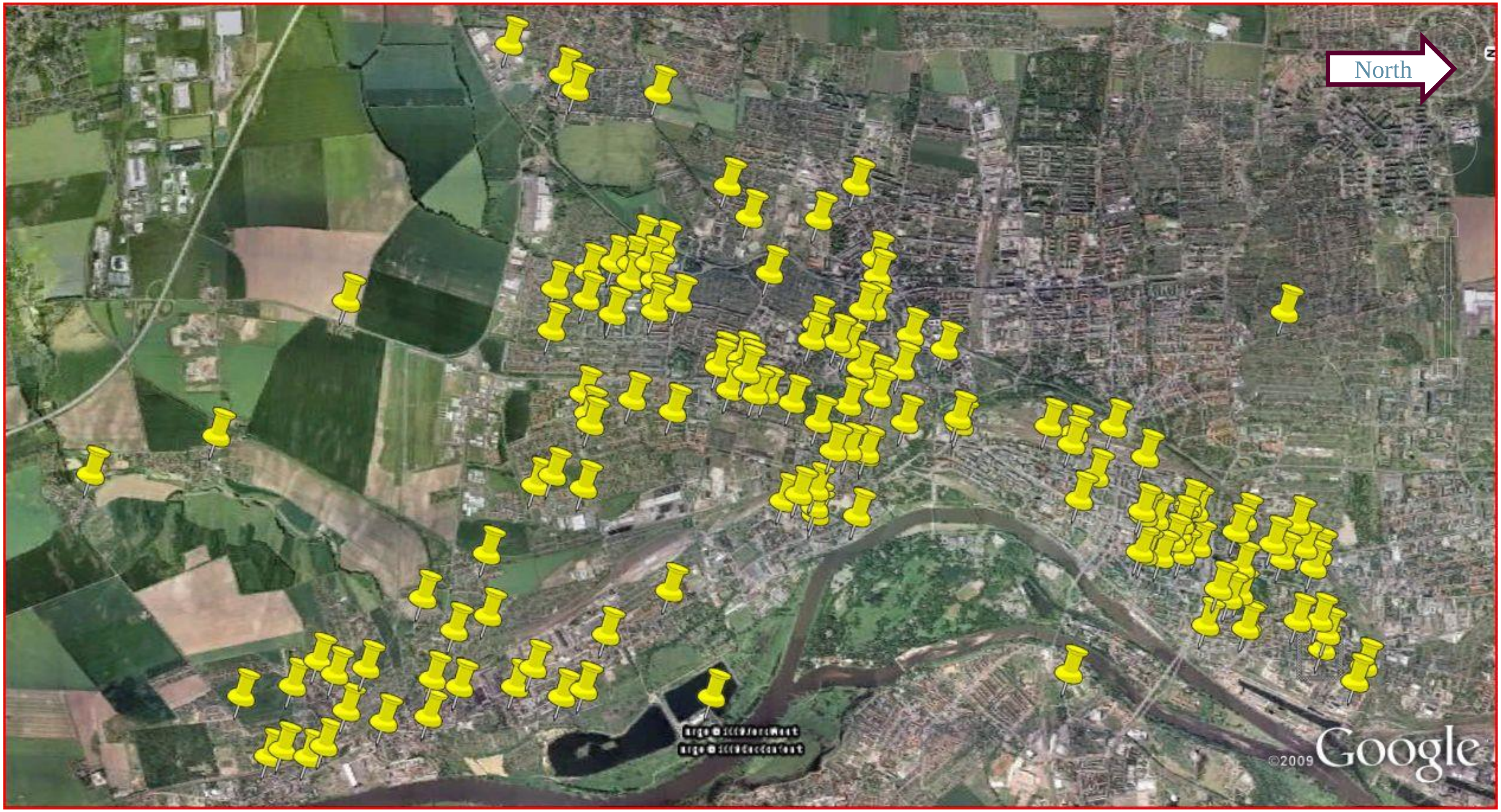
A Glass Waste Collection Problem



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A Glass Waste Collection Problem

Extension of the Capacitated Vehicle Routing Problem w.r.t. the following aspects:

- Several product types have to be collected from (distributed to) the customer locations
- The capacity of each vehicle can be divided individually into different compartments such that several product types can be collected (distributed) on each tour

→ **Multi-Compartment Vehicle Routing Problem (MCVRP)**

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Outline

1. Introduction and Motivation
2. Problem Definition
3. Literature Review
4. Variable Neighborhood Search
5. Numerical Experiments
6. Outlook

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The Multi-Compartment Vehicle Routing Problem

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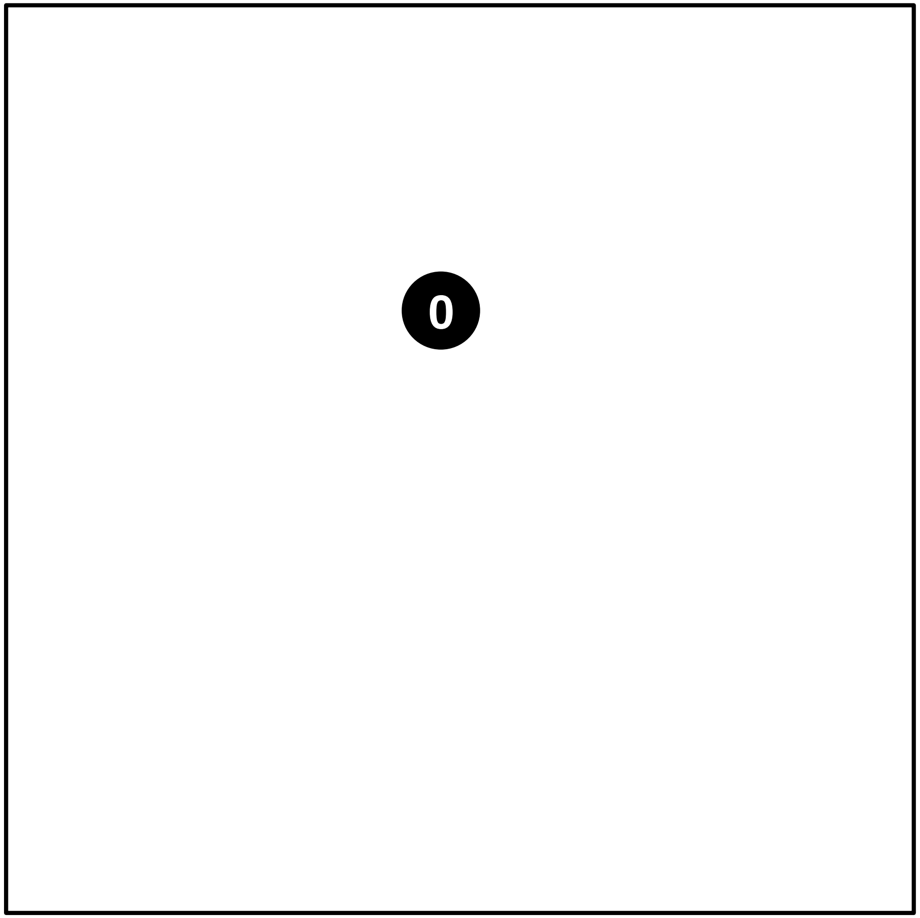
The Multi-Compartment Vehicle Routing Problem

- Depot



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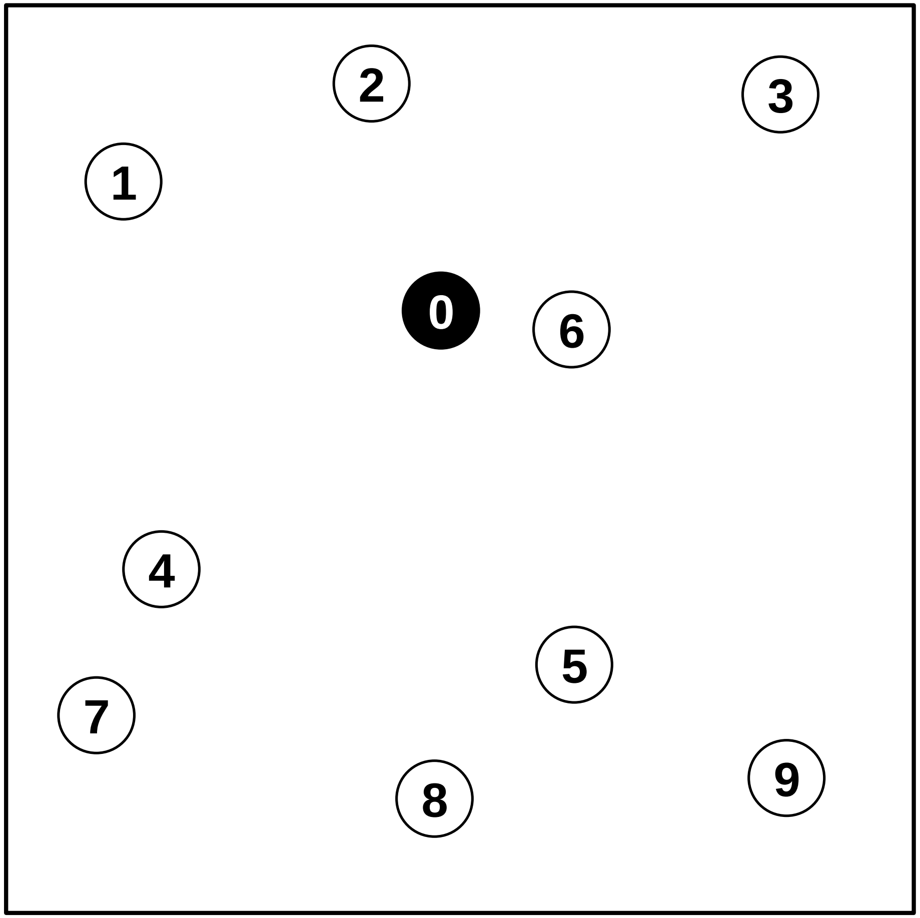
The Multi-Compartment Vehicle Routing Problem

- Depot
- Customer locations



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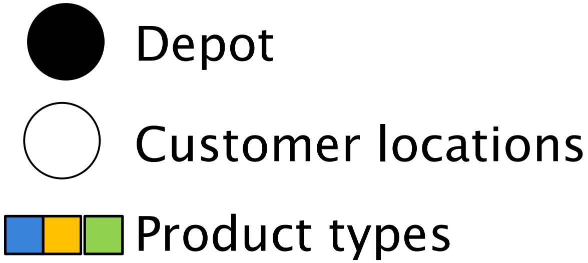
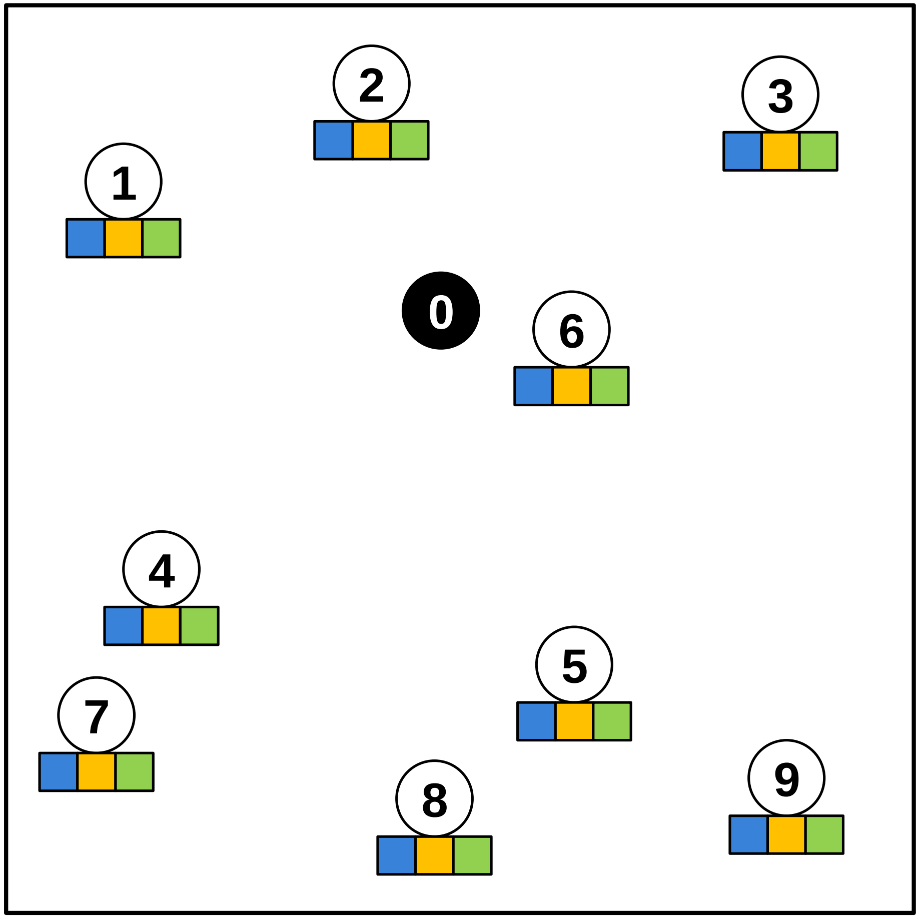
The Multi-Compartment Vehicle Routing Problem





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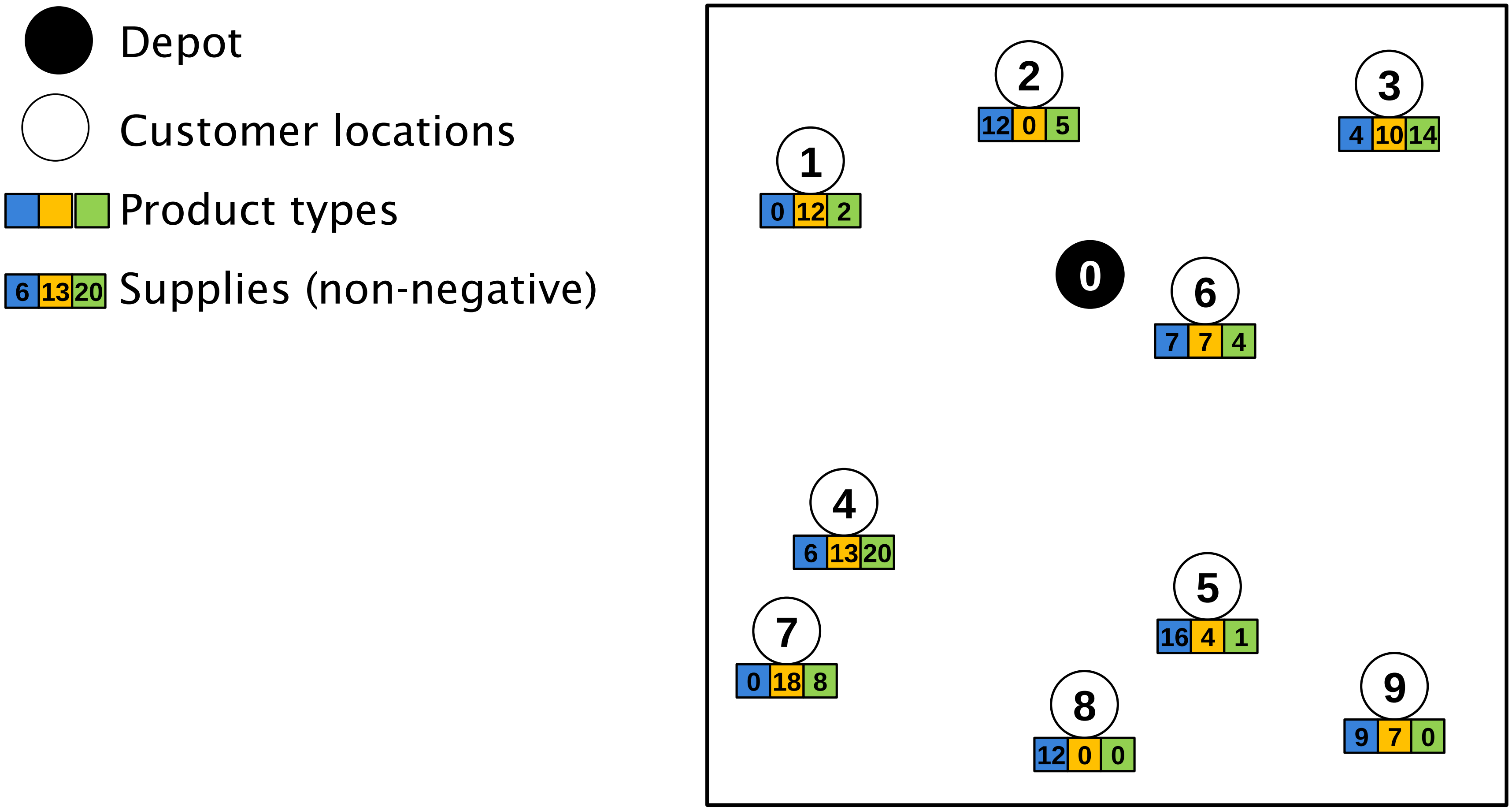
The Multi-Compartment Vehicle Routing Problem



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The Multi-Compartment Vehicle Routing Problem

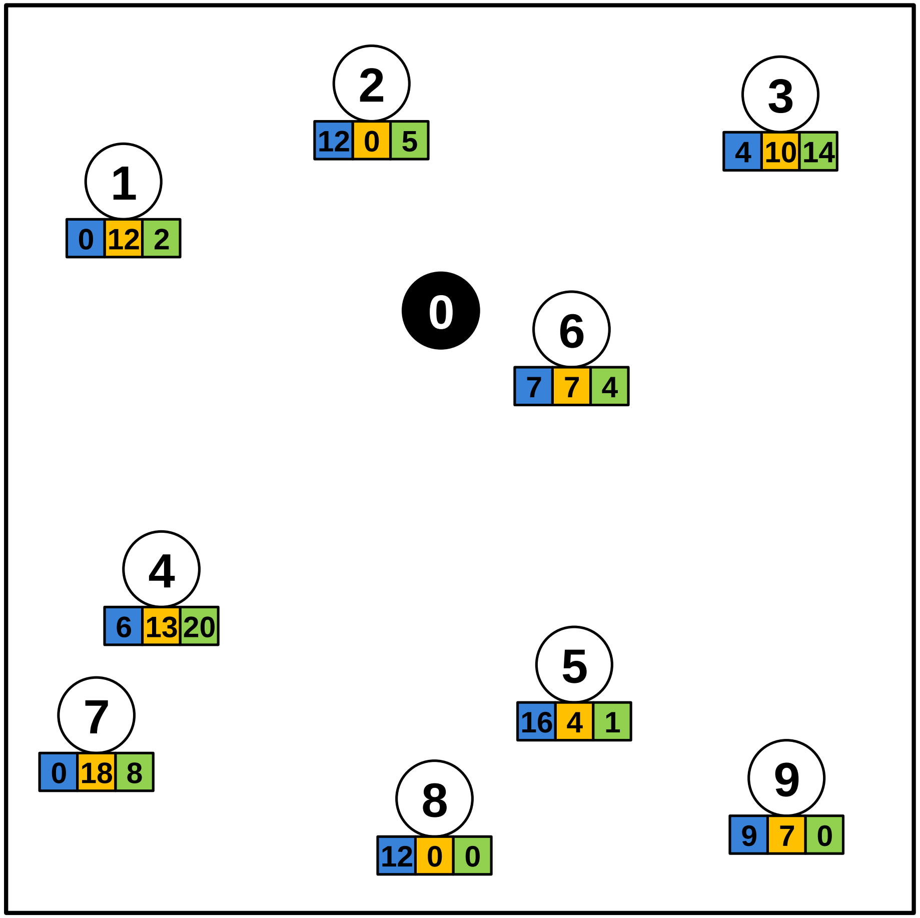
Depot

Customer locations

Product types

6 13 20 Supplies (non-negative)

- Each supply must be satisfied by a single delivery (no split deliveries)



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The Multi-Compartment Vehicle Routing Problem

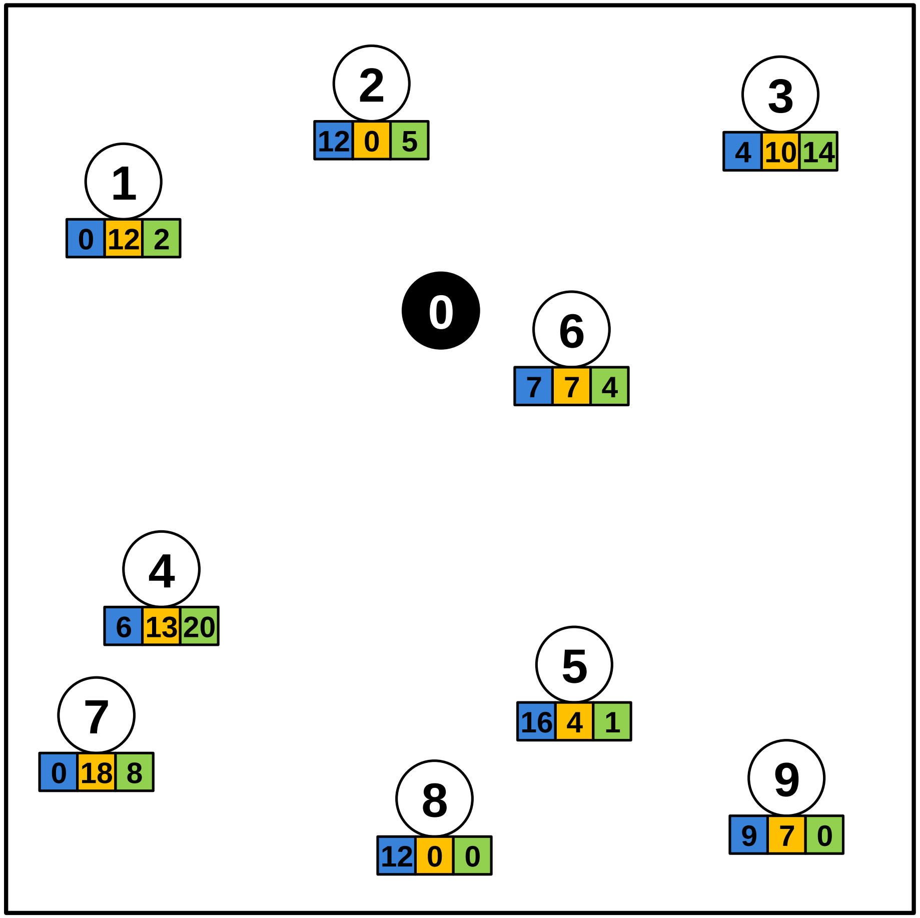
Depot

Customer locations

Product types

6 13 20 Supplies (non-negative)

- Each supply must be satisfied by a single delivery (no split deliveries)
- All distances are symmetric



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The Multi-Compartment Vehicle Routing Problem

Vehicles and Compartments

- A sufficiently large number of homogeneous vehicles is available, each of which providing an identical total capacity Q
- Each vehicle serves a single tour if being use
- The total capacity Q of each vehicle can be divided individually into a limited number of compartments
- The size of each compartment has to be selected from a set of potential compartment sizes,
  - e.g. it may make up for 10%, 20%, …, 100% of the total capacity Q
- To each compartment only a single product type can be assigned
- The capacity of each compartment must not be exceeded

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The Multi-Compartment Vehicle Routing Problem

Decisions

- Supply-Vehicle-Assignment: Which locations should be visited by each vehicle?
  - ➢ Location-Vehicle-Assignment
- Location-Sequencing: In which sequence should the locations be visited by each vehicle?
- Compartment-Vehicle-Assignment: How should the total capacity of each vehicle be divided into compartments?
- Product-Compartment-Assignment: Which products should be assigned to each compartment of each vehicle?
  - ➢ Product-Vehicle-Assignment

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The Multi-Compartment Vehicle Routing Problem

Decisions

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    - ➢ Location-Vehicle-Assignment
- Location-Sequencing: In which sequence should the locations be visited by each vehicle?
- Compartment-Vehicle-Assignment: How should the total capacity of each vehicle be divided into compartments?
- Product-Compartment-Assignment: Which products should be assigned to each compartment of each vehicle?
    - ➢ Product-Vehicle-Assignment

Objective Function

- Minimize the total length, i.e. the sum of all distances traveled

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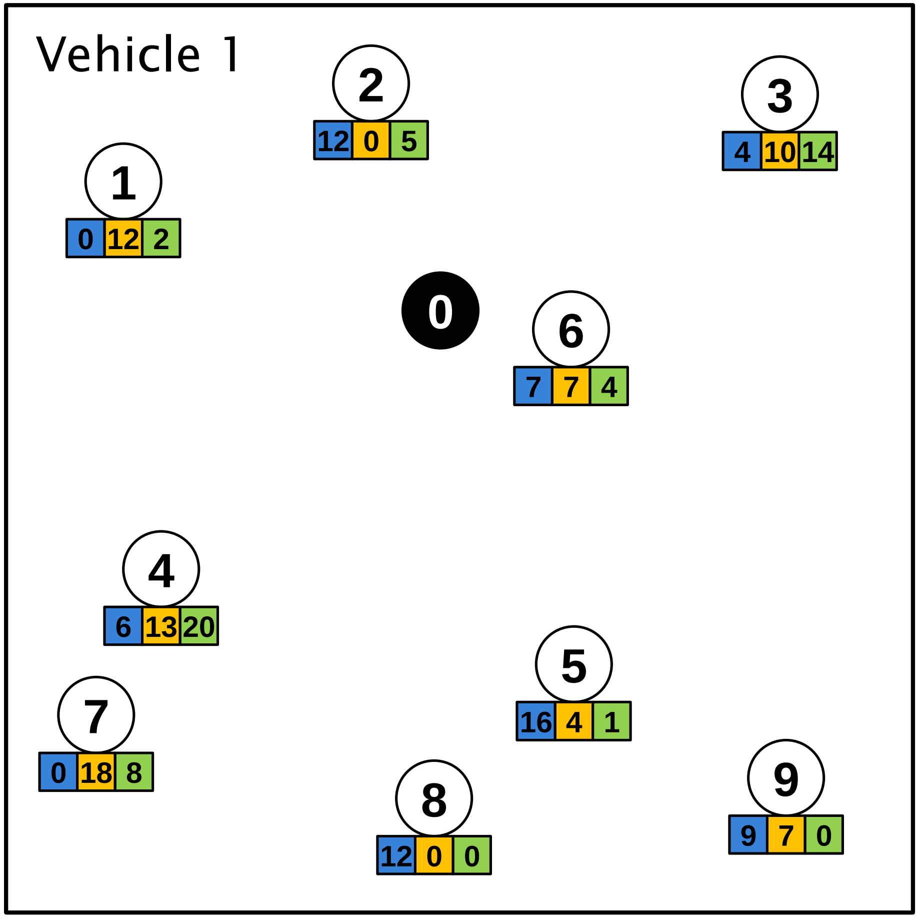
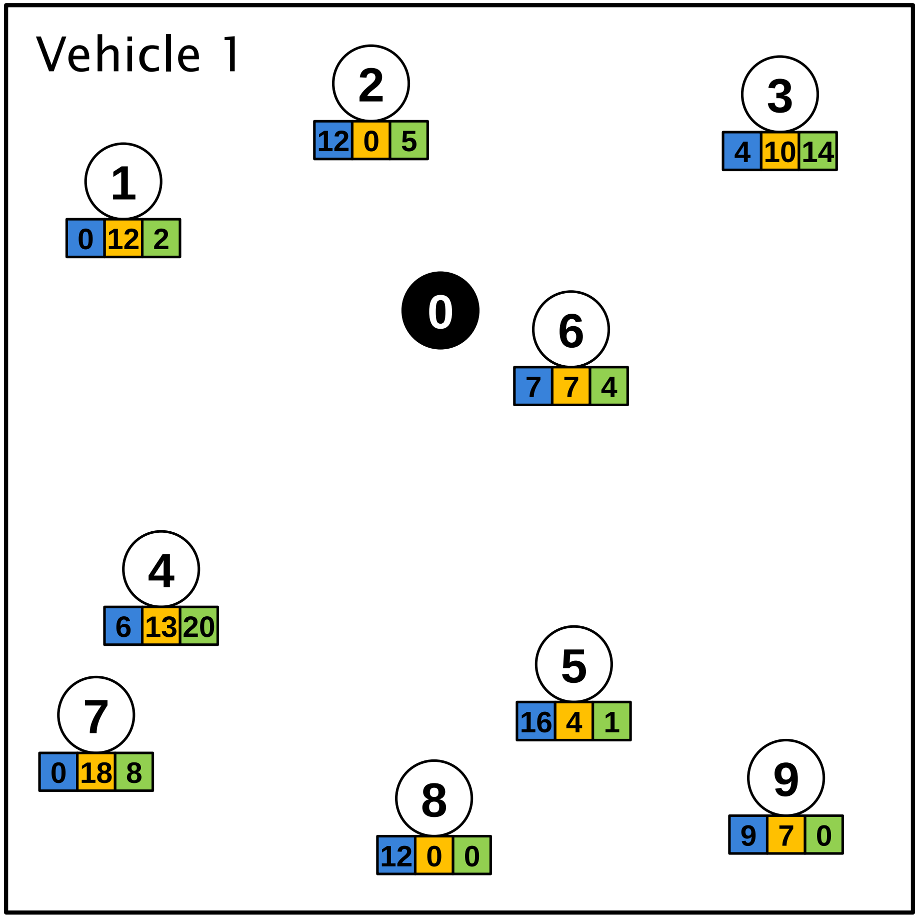
A Solution to the MCVRP



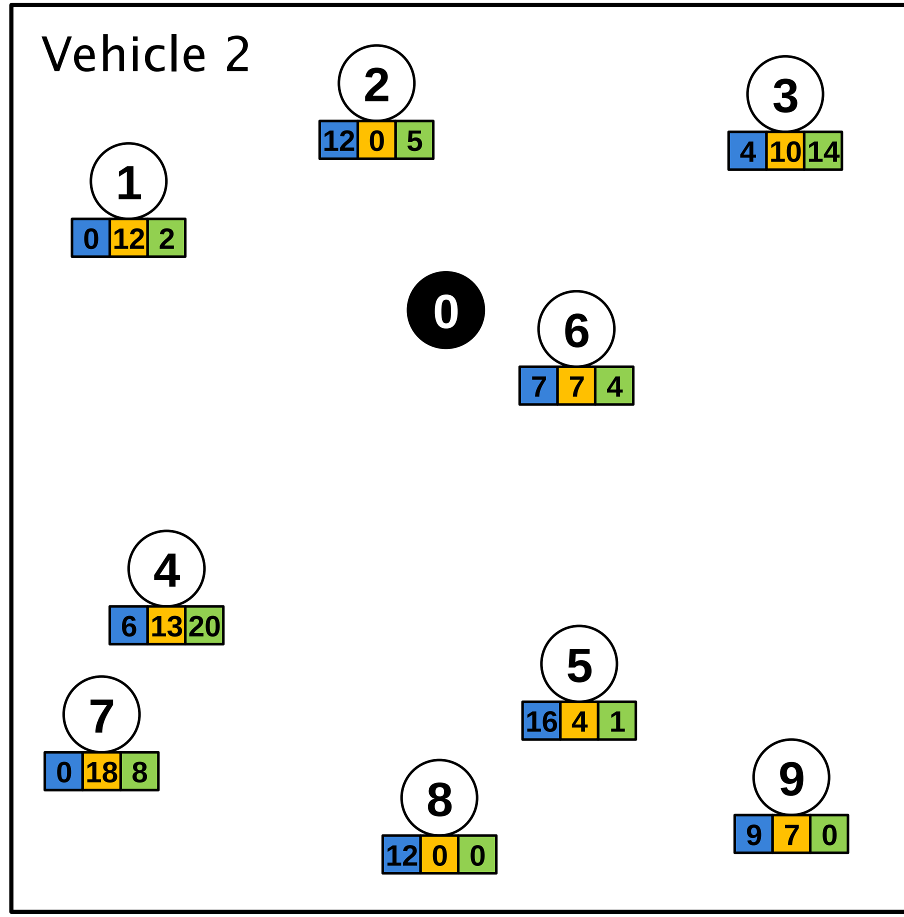
Assigned products: None

- # customer locations: 9
- # product types: 3
- Capacity: 100
- # compartments: 2

A Solution to the MCVRP

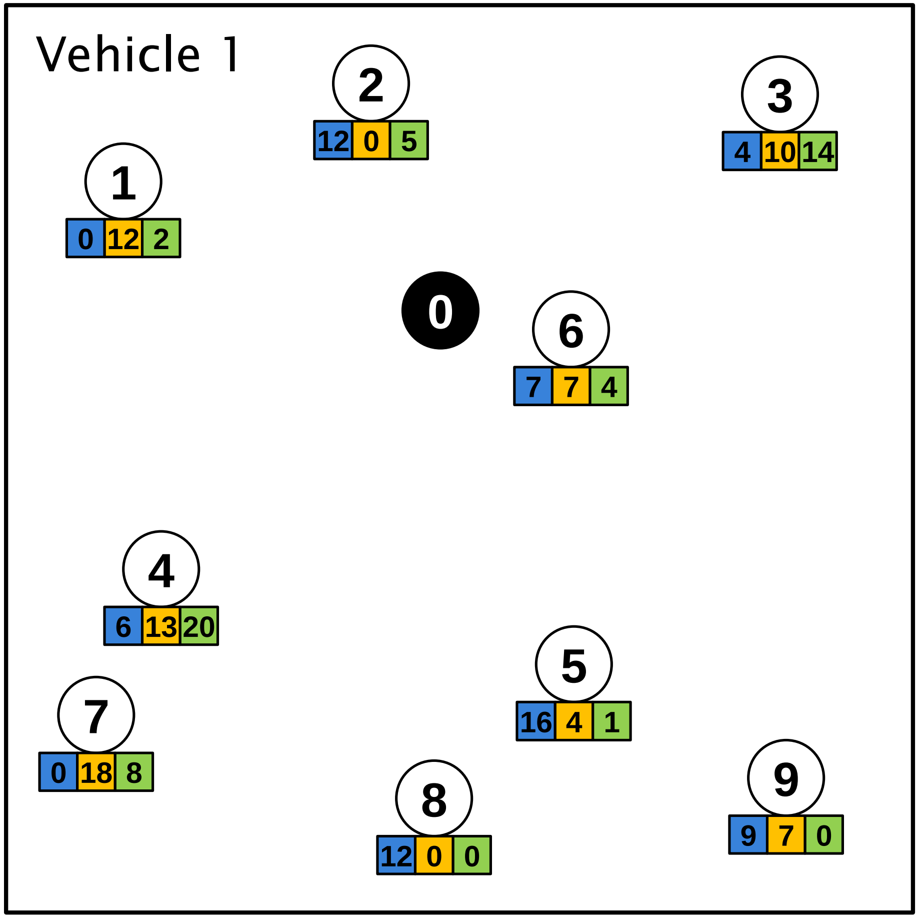


Assigned products: None

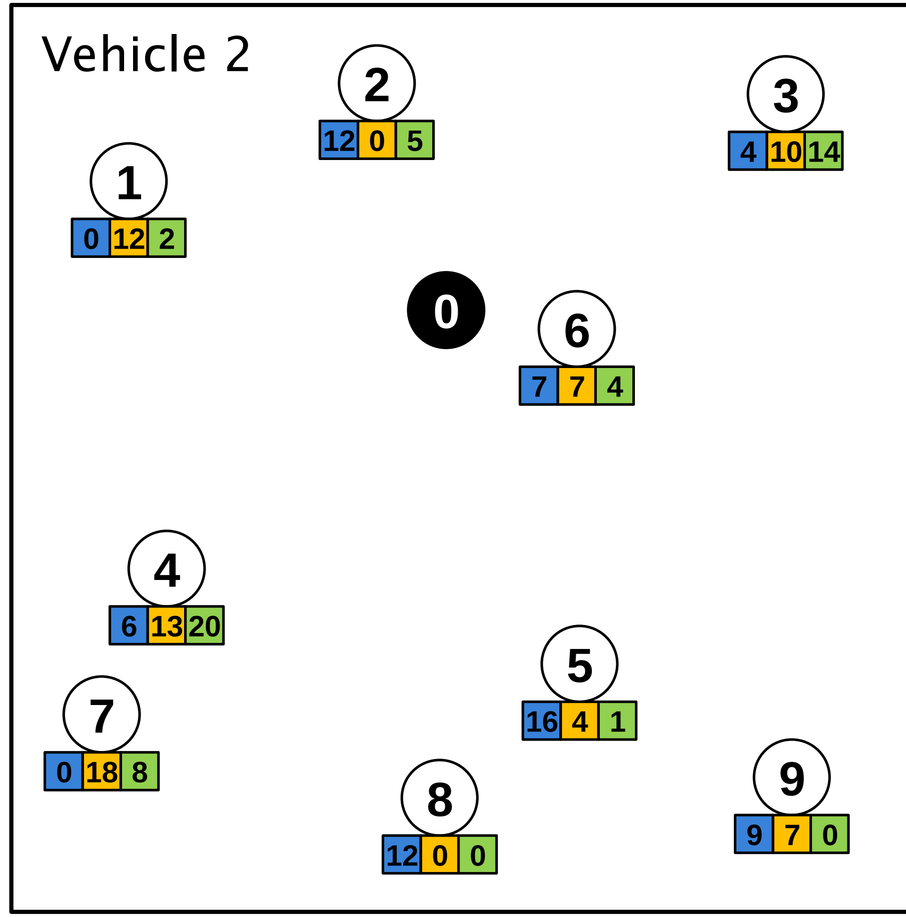


Assigned products: None

A Solution to the MCVRP

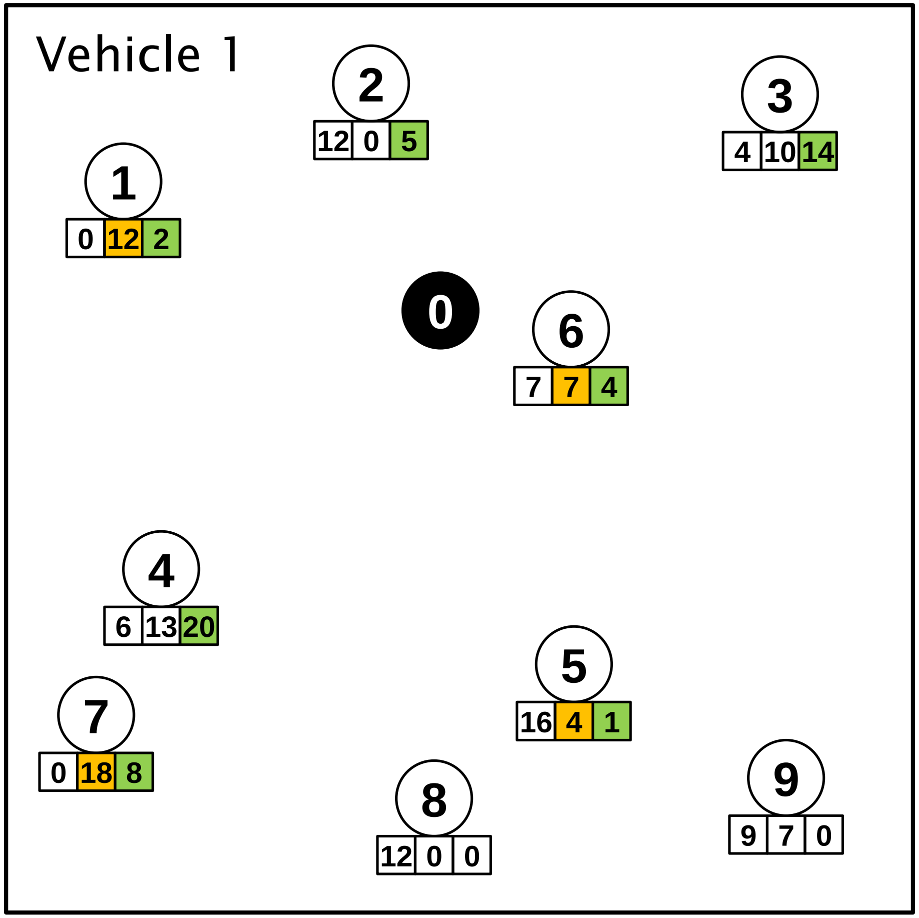


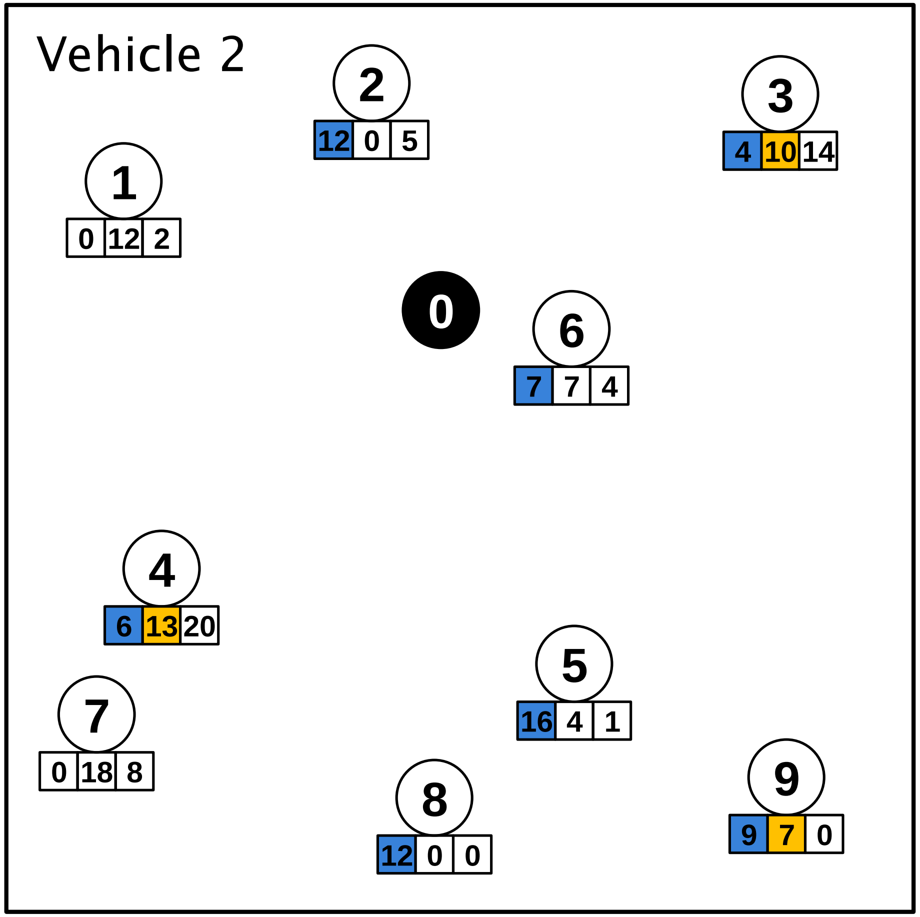
Assigned products:



Assigned products:

A Solution to the MCVRP





Assigned products:

Assigned products:

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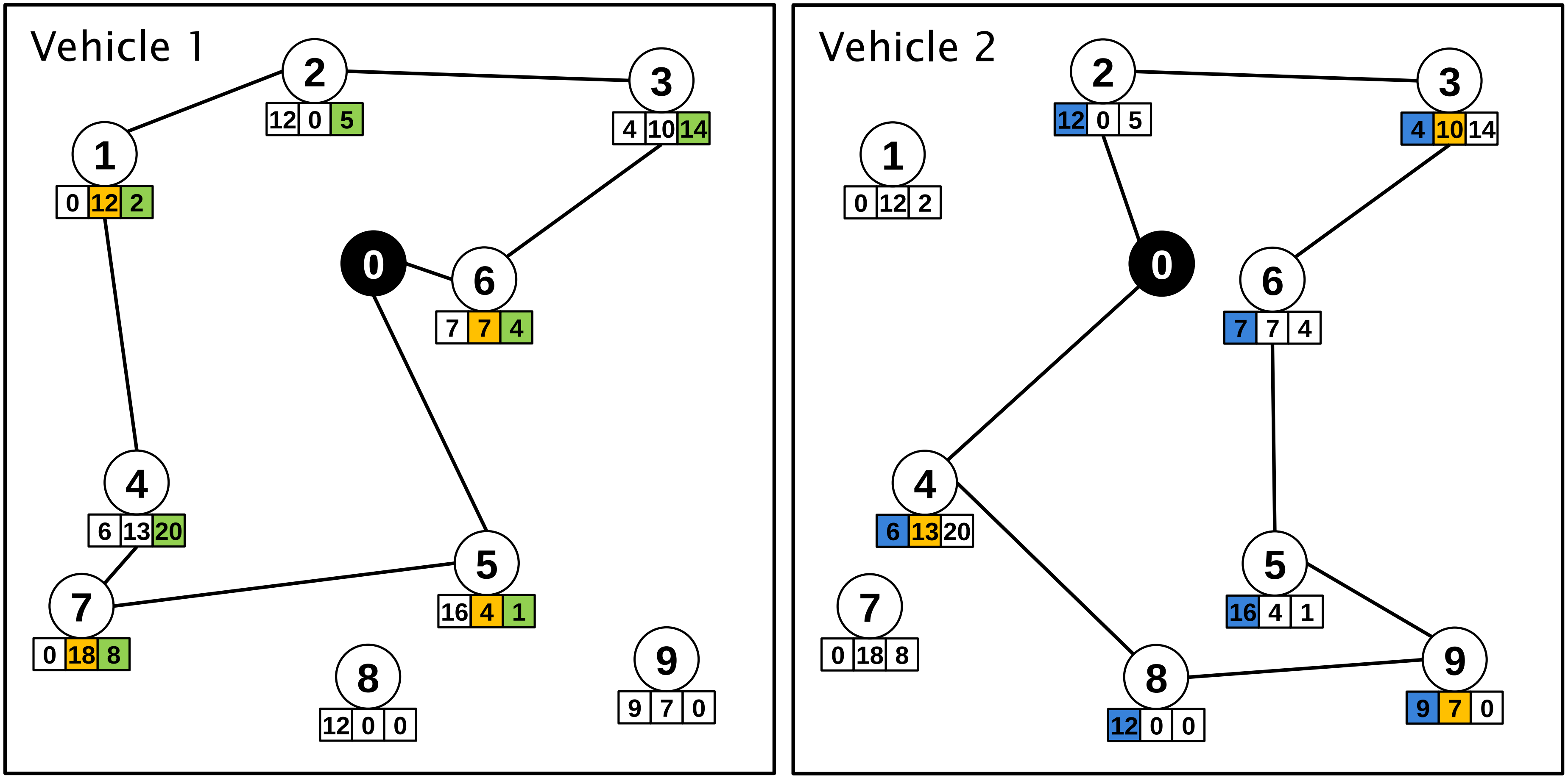
A Solution to the MCVRP



Assigned products:

Assigned products:

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Literature Review

- Derigs et al. (2011), OR Spectrum:
  - Fixed and flexible compartment sizes, compatibility constraints
  - Large neighborhood search
- El Fallahi et al. (2008), C&OR:
  - Fixed compartment sizes
  - Tabu search, memetic algorithm
- Mendoza et al. (2011), Transportation Science:
  - Stochastic demands
  - Memetic algorithm
- Muyldermans, Pang (2010), EJOR:
  - Fixed compartment sizes
  - Guided local search

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Applications

Fuel Delivery

- Avella et al. (2004), EJOR
- Brown, Graves (1981), Management Science
- Cornillier et al. (2002), EJOR

Applications in Agriculture

- Caramia, Guerriero (2010), Interfaces
  Collection of milk at farms
- El Fallahi et al. (2008), C&OR:
  Distribution of animal food to farms

Applications (cont.)

Distribution

- Chajakis, Guignard (2003), J Global Optimization
  Delivery of food and grocery products to convenience stores

Maritime Transportation

- Fagerholt, Christiansen (2000), JORS

Special Features of this particular MCVRP in Glass Waste Collection

- For each vehicle, the partition of the total capacity into compartments is not given in advance, but has to be fixed
- The total capacity of each vehicle can only be partitioned discretely (not: continuously) into different compartments
- For each vehicle, the number of compartments can be smaller than the number of product types (i.e. on each tour, only a limited number of product types may be collected / distributed)

Outline

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Variable Neighborhood Search with Multiple Starts

```
input: problem data, k^max;

x0(xbest) := ∞;
do
        generate an initial solution x with objective function value x0(x) randomly;
        k := 1;
        do
                select a neighbor x' from neighborhood k of x randomly (shaking);
                apply local search to x' and determine a local optimum x'';
                if x0(x'') satisfies the acceptance criterion then
                        x := x''; k := 1;
                        if x0(x) < x0(xbest) then xbest := x; endif

                else
                        k := k + 1;
                        if k = k^max + 1 then k := 1; endif
                endif
        until vns termination criterion is satisfied
until ms termination criterion is satisfied

output: xbest;
```


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Generation of an Initial Solution

- All supplies are sequenced randomly
- According to the sequence, the supplies are assigned one after another to a vehicle if:
  (1) The corresponding product type is already assigned or can still be assigned to this vehicle
  (2) The vehicle capacity will not be exceeded
- Otherwise another vehicle is checked

Neighborhood Structures: Selection Types

Supply-related

- The assignment of single supplies to vehicles is changed

Location-related

- The assignment of locations to vehicles is changed

Product-related

- The assignment of product types to vehicles is changed

Neighborhood Structures: Move Types

Shift

- All or a part of selected supplies are moved to the same vehicle

Swap

- Two selected sets of supplies which are assigned to two different vehicles are exchanged

Split

- All selected supplies are moved individually to vehicles

Neighborhood Structures: Overview

- The following combinations of operators are used:

	Shift	Swap	Split
Supply-related	x	x	
Location-related	x	x	x
Product-related	x	x	x

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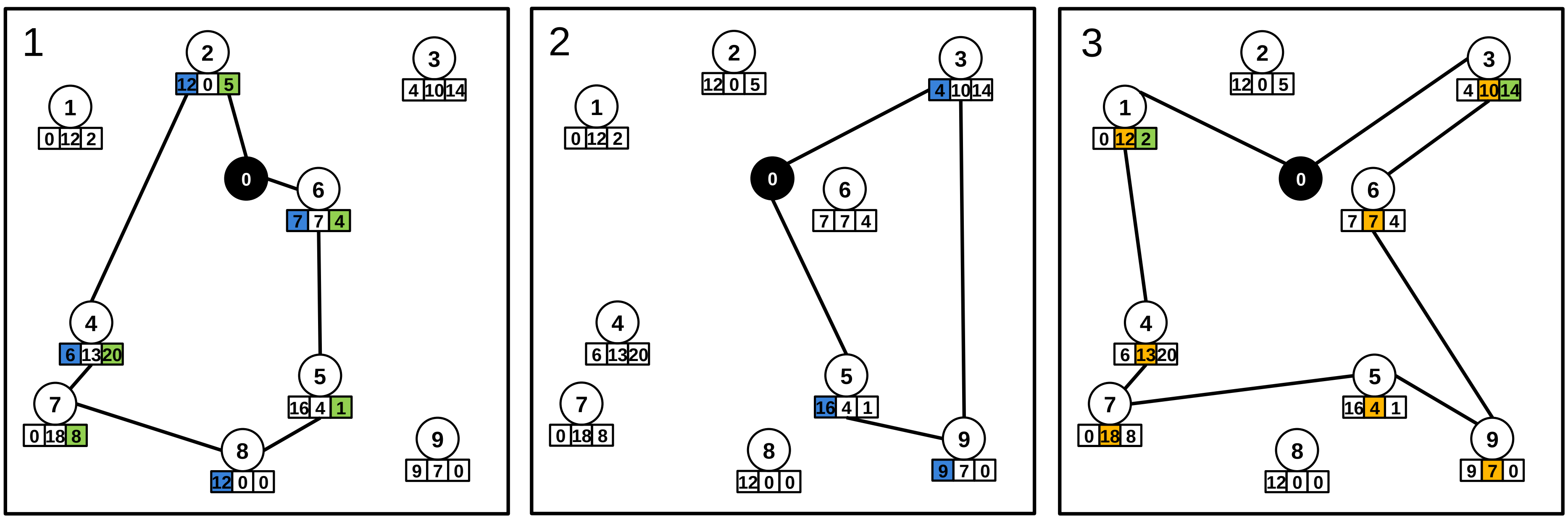
Location Split: Illustration

- One customer location is randomly selected from one vehicle and all respective supplies are inserted individually into another vehicle, into a new vehicle or into the original vehicle



Assigned products: | Assigned products: | Assigned products:

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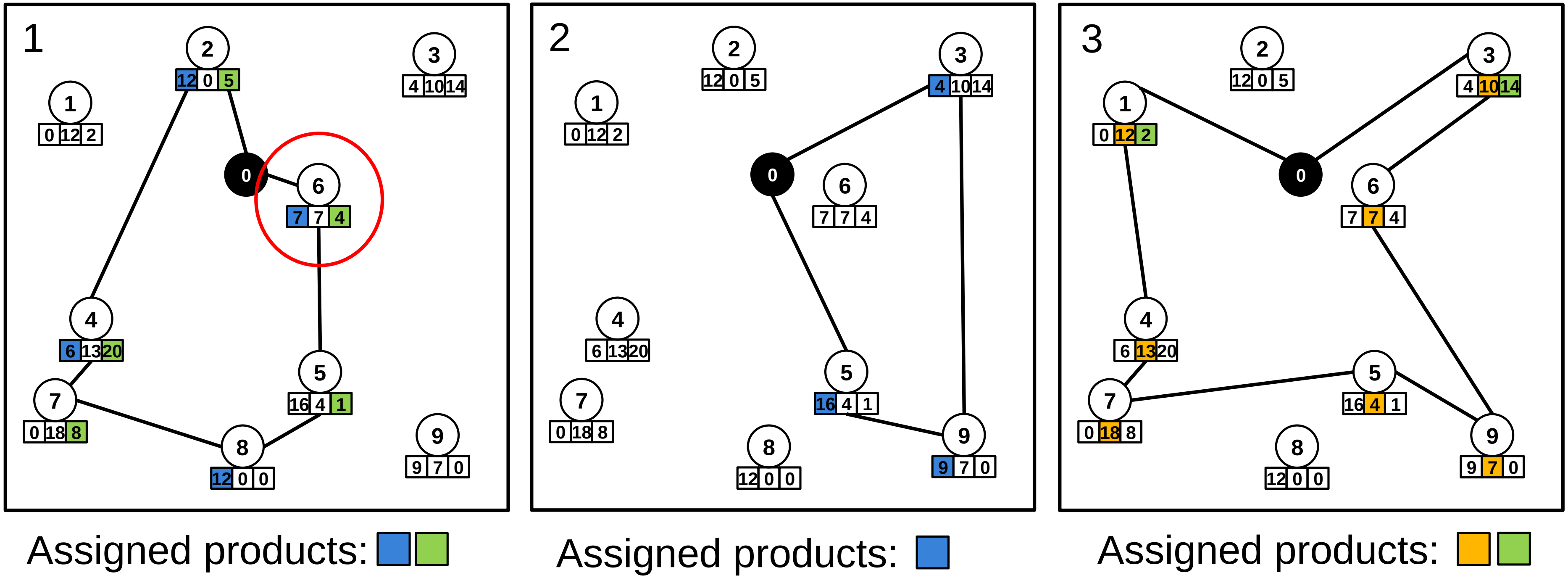

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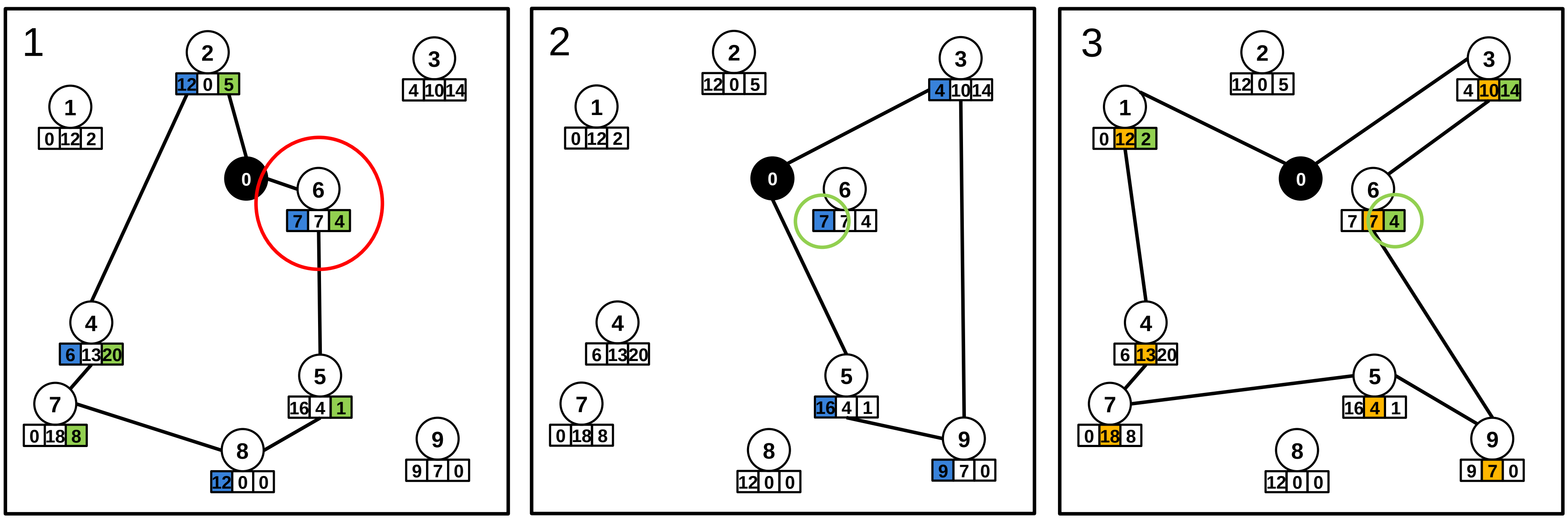

Assigned products: | Assigned products: | Assigned products:

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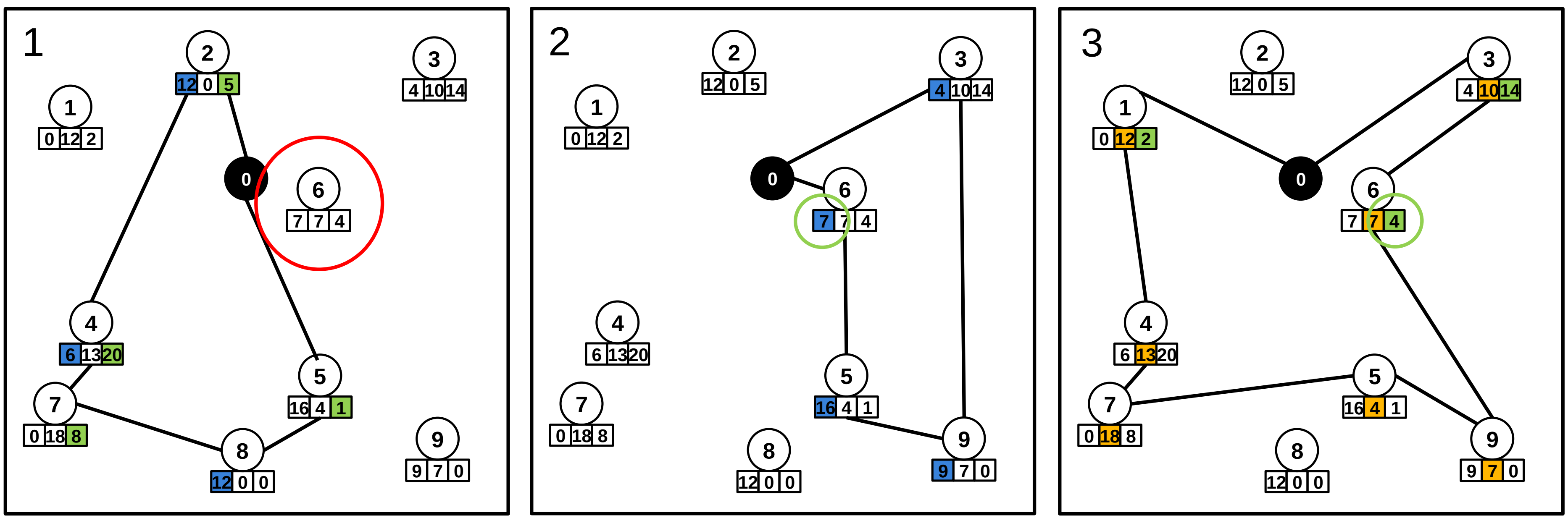

Assigned products: ■■ | Assigned products: ■ | Assigned products: ■■

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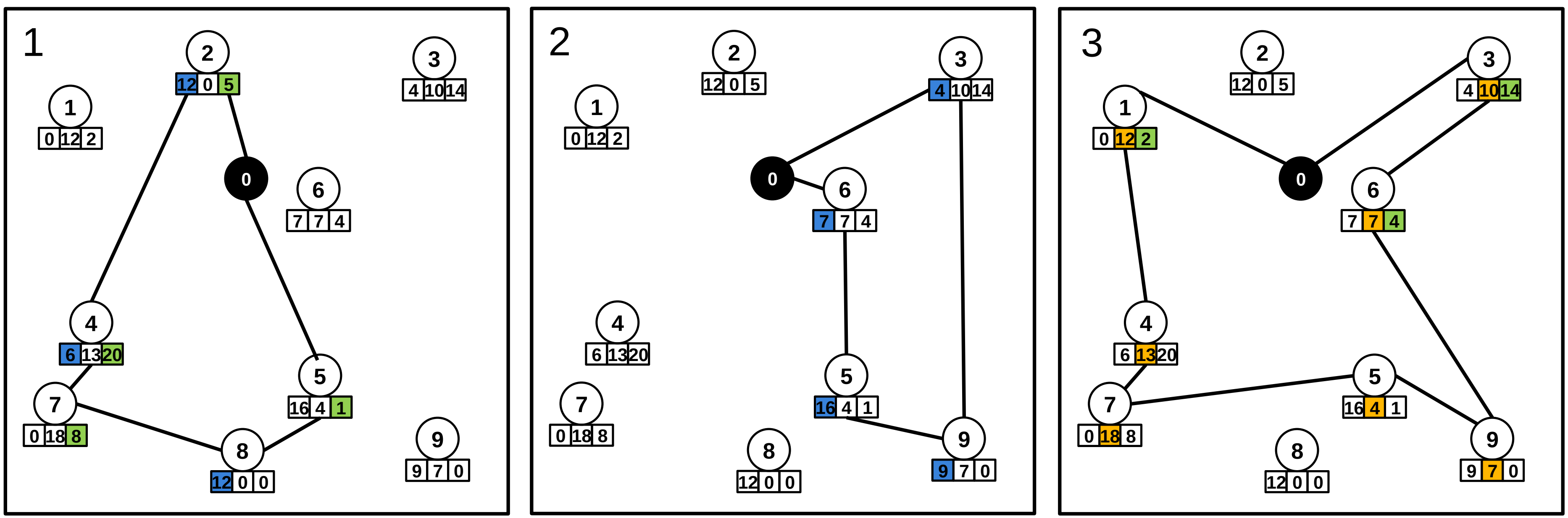
Product Shift: Illustration

- One product type is randomly selected from one vehicle and the respective supplies are inserted collectively into another vehicle or into a new vehicle



Assigned products: (1) blue, green; (2) blue; (3) orange, green

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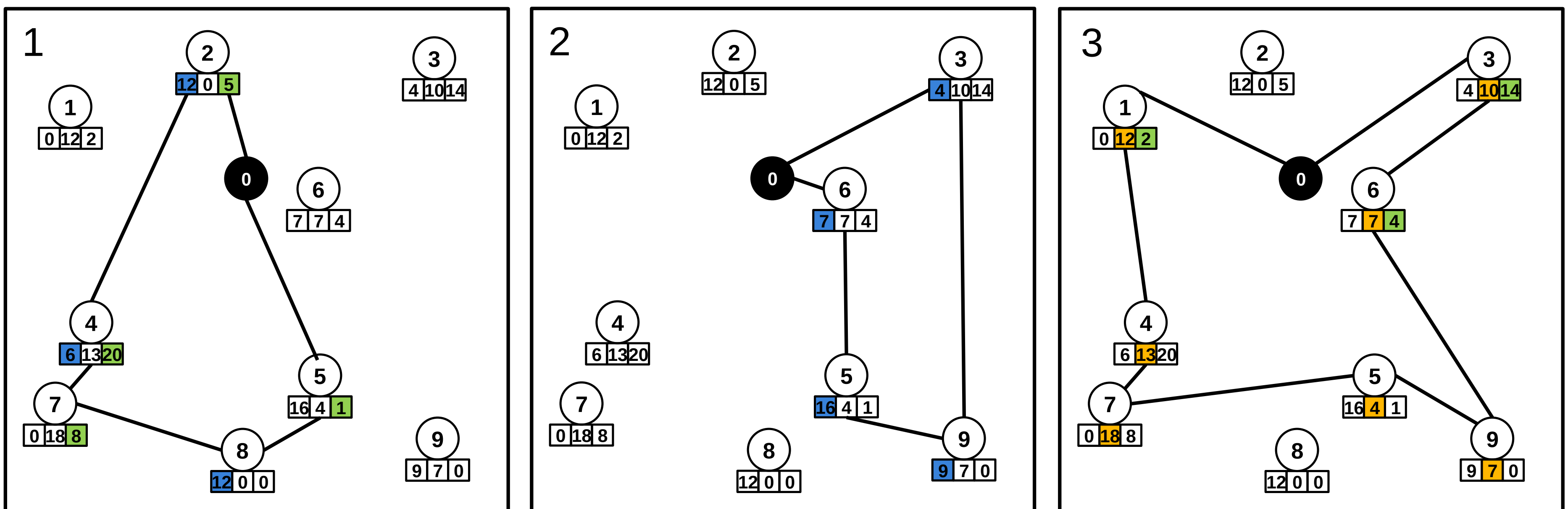
Product Shift: Illustration

- One product type is randomly selected from one vehicle and the respective supplies are inserted collectively into another vehicle or into a new vehicle



Assigned products: Assigned products: Assigned products:

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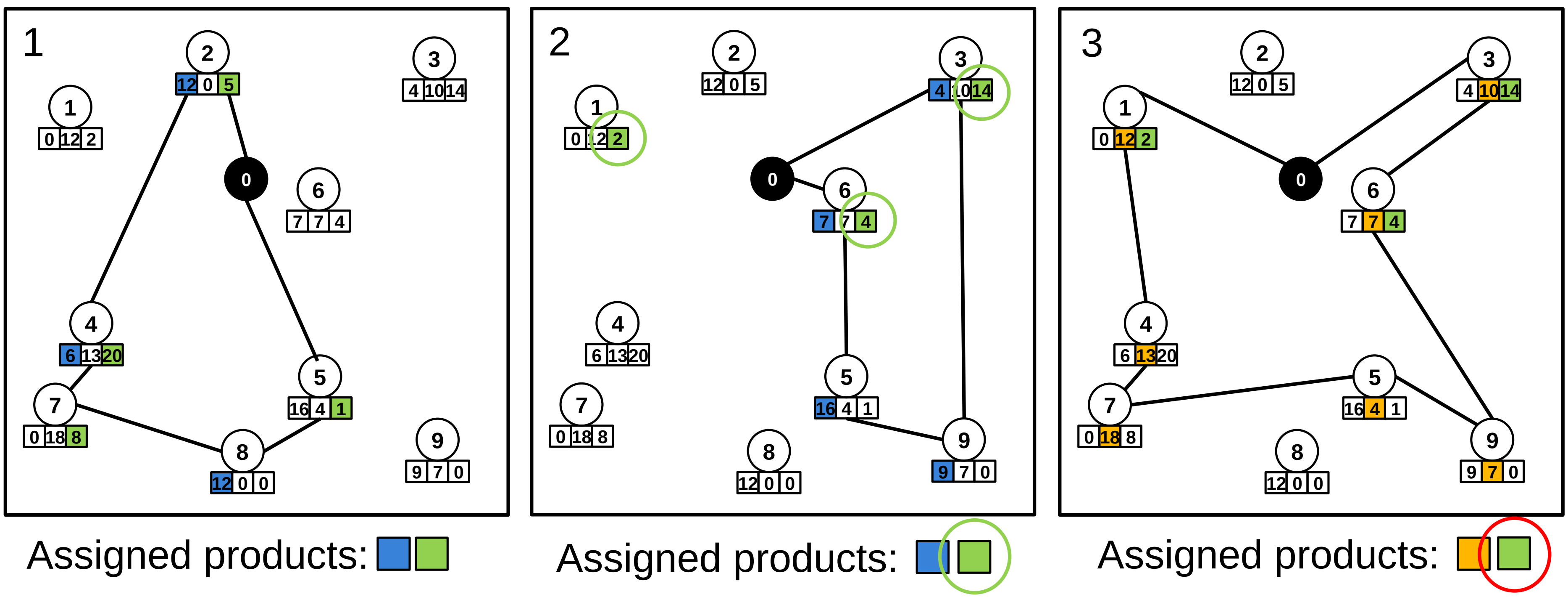

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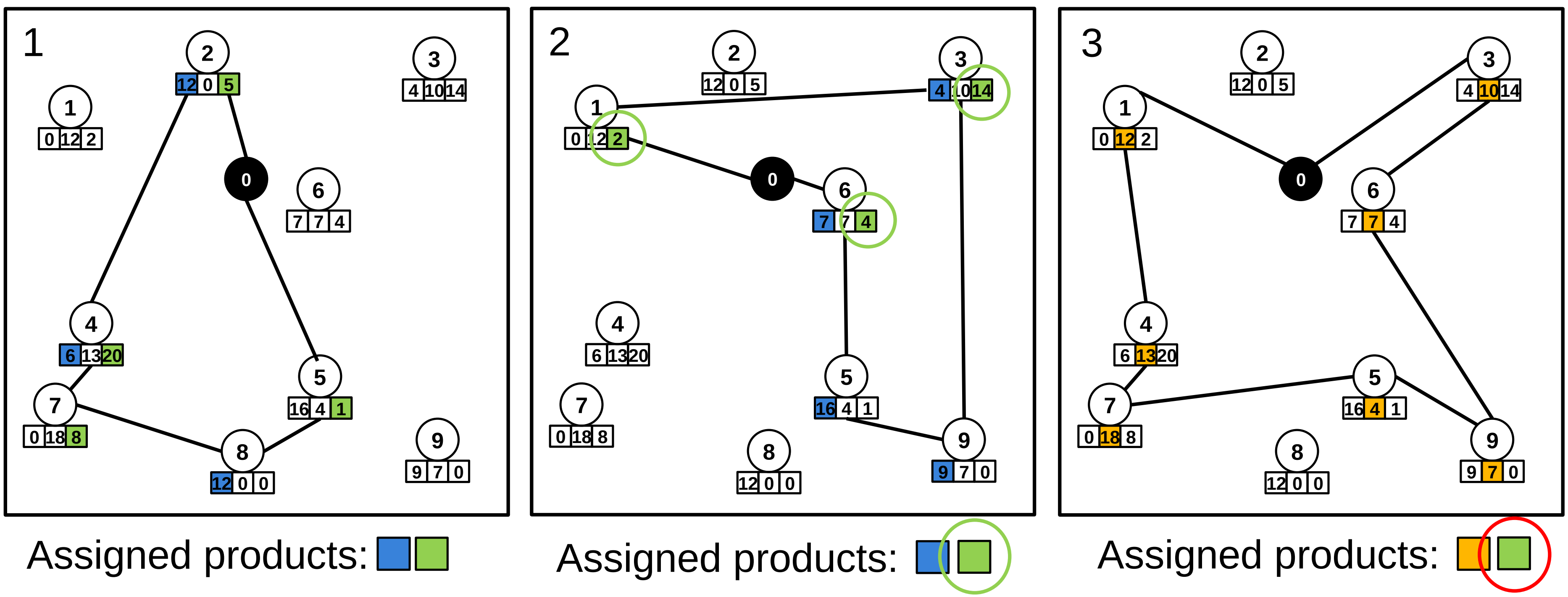

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Further Characteristics (1)

Solution Space

- Feasible and infeasible solutions with regard to the vehicle capacity

Objective Function

- Total length and penalty term

Acceptance Criterion

- Threshold accepting with a dynamically adjusting parameter

Local Search

- 3-opt neighborhood with strict descent and first find

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Further Characteristics (2)

Termination of a VNS Loop

- Number of iterations without finding a new best solution

Termination of the Algorithm

- Number of VNS loops without finding a new best solution

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    - **6.1 Small Randomly Generated Problem Instances**
    - 6.2 Large Randomly Generated Problem Instances
    - 6.3 Real-World Problem Instances
6. Outlook

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Problem Classes

Input Parameters

- Number of locations: 10
- Number of product types: 3, 6, 9
- Maximum number of compartments:
  - 3 product types: 2, 3
  - 6 product types: 2, 4, 6
  - 9 product types: 2, 4, 7, 9
- Number of product types supplied at each location:
  - Small (up to $1/3$ of the number of product types)
  - Medium (between $1/3$ and $2/3$ of the number of product types)
  - Large (between $2/3$ and $3/3$ of the number of product types)

➢ 50 instances per problem class

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Implementation

Exact Approach

- Mathematical model implemented in Visual C++ Express 2012 with the ILOG CPLEX 12.5 interface on a 3,2GHz PC with 8GB memory

Heuristic Approach

- Implemented in Visual C++ Express 2012 (on a 3,2GHz PC with 8GB memory)
- Algorithm parameters:
  - VNS loops without an improvement: #Locations·#Products/6
  - Iterations without an improvement: 500·#Locations·#Products

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Computing Times: Exact Approach

- Average computing time (seconds) per problem class, exact approach

#products		3		6			9			
#compartments		**2**	**3**	**2**	**4**	**6**	**2**	**4**	**7**	**9**
#supplies	**s**	5.4	2.6	5.9	5.0	4.0	502.4	12.9	5.3	3.9
	m	11.4	2.7	4.8	27.8	5.9	1,921.6	267.7	49.3	10.5
	l	2.0	5.0	1.8	310.7	9.0	5,400.9	1,324.6	496.0	32.9

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Solution Quality and Computing Times: Heuristic

- Average deviation (%) per instance of the total tour length obtained by the VNS algorithm in comparison to the optimal total tour length
- Average computing times per instance in seconds (in brackets)

#products		3		6			9			
#compartments		2	3	2	4	6	2	4	7	9
#supplies	s	**0.00%** (2.3s)	**0.00%** (2.5s)	**0.00%** (12.1s)	**0.00%** (12.5s)	**0.00%** (12.1s)	**0.00%** (46.1s)	**0.00%** (41.2s)	**0.00%** (37.8s)	**0.00%** (39.0s)
	m	**0.00%** (2.9s)	**0.00%** (3.4s)	**0.00%** (11.5s)	**0.00%** (15.0s)	**0.00%** (14.9s)	**0.00%** (50.5s)	**0.00%** (48.0s)	**0.26%** (47.3s)	**0.05%** (43.4s)
	l	**0.00%** (2.9s)	**0.00%** (3.7s)	**0.00%** (13.0s)	**0.15%** (15.1s)	**0.00%** (15.6s)	**0.00%** (55.8s)	**0.00%** (51.1s)	**0.02%** (54.7s)	**0.10%** (47.0s)

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Problem Classes

Input Parameters

- Number of locations: 50
- Number of product types: 3, 6, 9
- Maximum number of compartments:
  - 3 product types: 2, 3
  - 6 product types: 2, 4, 6
  - 9 product types: 2, 4, 7, 9
- Number of product types supplied at each location:
  - Small (up to $1/3$ of the number of product types)
  - Medium (between $1/3$ and $2/3$ of the number of product types)
  - Large (between $2/3$ and $3/3$ of the number of product types)

➢ One instance per problem class

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Implementation

Heuristic Approach

- Implemented in Visual C++ Express 2012 (on a 3,2GHz PC with 8GB memory)
- Algorithm parameters:
  - VNS loops without an improvement: 6 hours
  - Iterations without an improvement: 500·#Locations·#Products

Solution Quality

- Average deviation (%) of the total tour lengths obtained by the VNS algorithm in comparison to the total tour lengths found after 6 hours

	deviation of the best solution found after					
	10min	**20min**	**30min**	**40min**	**50min**	**60min**
minimum	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
average	5.62%	3.98%	2.94%	2.75%	2.48%	2.03%
maximum	20.16%	10.89%	7.30%	7.10%	7.07%	6.35%

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Solution Quality

- Average deviation (%) of the total tour lengths obtained by the VNS algorithm in comparison to the total tour lengths found after 6 hours

	deviation of the best solution found after					
	60min	120min	180min	240min	300min	360min
minimum	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
average	2.03%	1.40%	0.79%	0.53%	0.24%	0.00%
maximum	6.35%	5.04%	4.06%	3.13%	2.97%	0.00%

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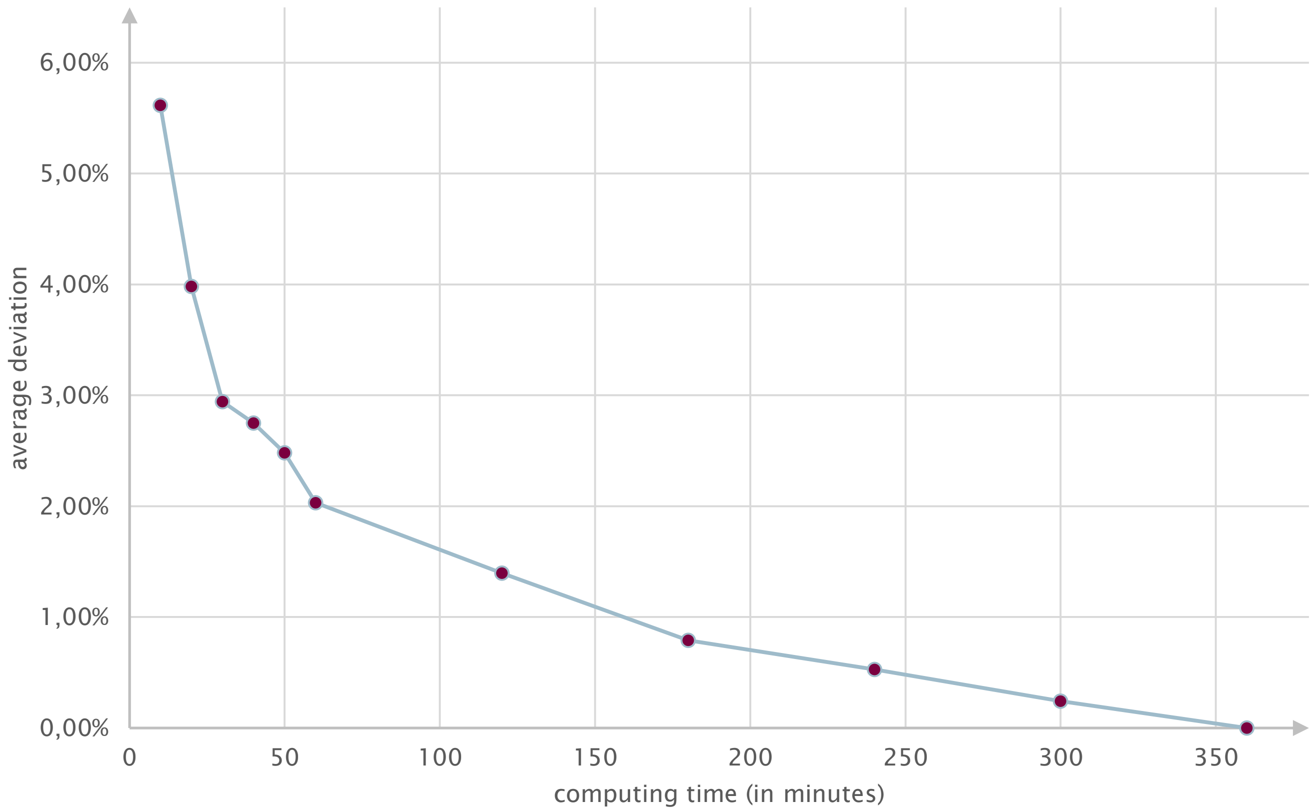
Solution Quality



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Outline

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Problem Classes

Input Parameters

- Number of product types: 3
- Number of locations: 26 – 34
- Number of supplies: 34 – 54
- Maximum number of compartments:
  - 2 (MCVRP)
  - 1 (VRP)

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Implementation

Heuristic (VNS) Approach

- Algorithm parameters:
  - Number of VNS loops: #Locations·#Products/6
  - Number of iterations per loop: 500·#Locations·#Products
- Computing times: 107 – 452 seconds per instance

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Solution Quality: CVRP vs. MC-VRP

instance	parameters		total length (in km)			#tours	
	#locations	#supplies	CVRP	MCVRP	deviation	CVRP	MCVRP
1	32	54	123.8	83.4	32.7%	3	2
2	26	38	117.6	78.1	33.6%	3	2
3	33	44	130.2	91.2	30.0%	3	2
4	33	46	136.2	95.5	29.9%	3	2
5	31	48	149.2	80.0	46.4%	4	2
6	29	34	115.1	77.2	32.9%	3	2
7	34	54	163.4	94.5	42.2%	4	2
8	28	40	132.7	92.7	30.1%	3	2
9	30	44	117.1	78.7	32.8%	3	2
10	31	44	122.7	82.3	32.9%	3	2
11	34	48	160.2	90.3	43.6%	4	2
12	30	36	125.6	85.7	31.8%	3	2
13	32	54	123.8	83.5	32.6%	3	2
14	26	38	117.6	78.1	33.6%	3	2
15	33	44	130.2	91.2	30.0%	3	2
16	33	46	136.2	95.5	29.9%	3	2
17	31	48	149.2	80.0	46.4%	4	2
18	29	34	115.1	77.2	32.9%	3	2
19	34	54	163.4	94.5	42.2%	4	2
20	28	40	132.7	92.7	30.1%	3	2
21	30	44	117.1	78.7	32.8%	3	2
22	31	44	122.7	82.3	32.9%	3	2
23	34	48	160.2	90.3	43.6%	4	2
24	30	36	125.6	85.7	31.8%	3	2
25	32	54	123.8	83.5	32.6%	3	2
avg	**31.0**	**44.6**	**132.5**	**85.7**	**34.8%**	**3.2**	**2.0**

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Outline

1. Introduction and Motivation
2. Problem Definition
3. Literature Review
4. Variable Neighborhood Search
5. Numerical Experiments
6. **Outlook**

Outlook

- Further research on the described problem
  - Improvement of the exact solution approach
- Further research on variants and extensions
  - Consideration of stochastic supplies
  - Extension to multiple periods

Thank your for your attention!

Any questions?

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