電腦科學系
Department of
Computer Science

香港城市大學
City University of Hong Kong

A Metaheuristic Approach for 3L-SDVRP

Fei Liu, Qingling Zhu

Department of Computer Science
City University of Hong Kong

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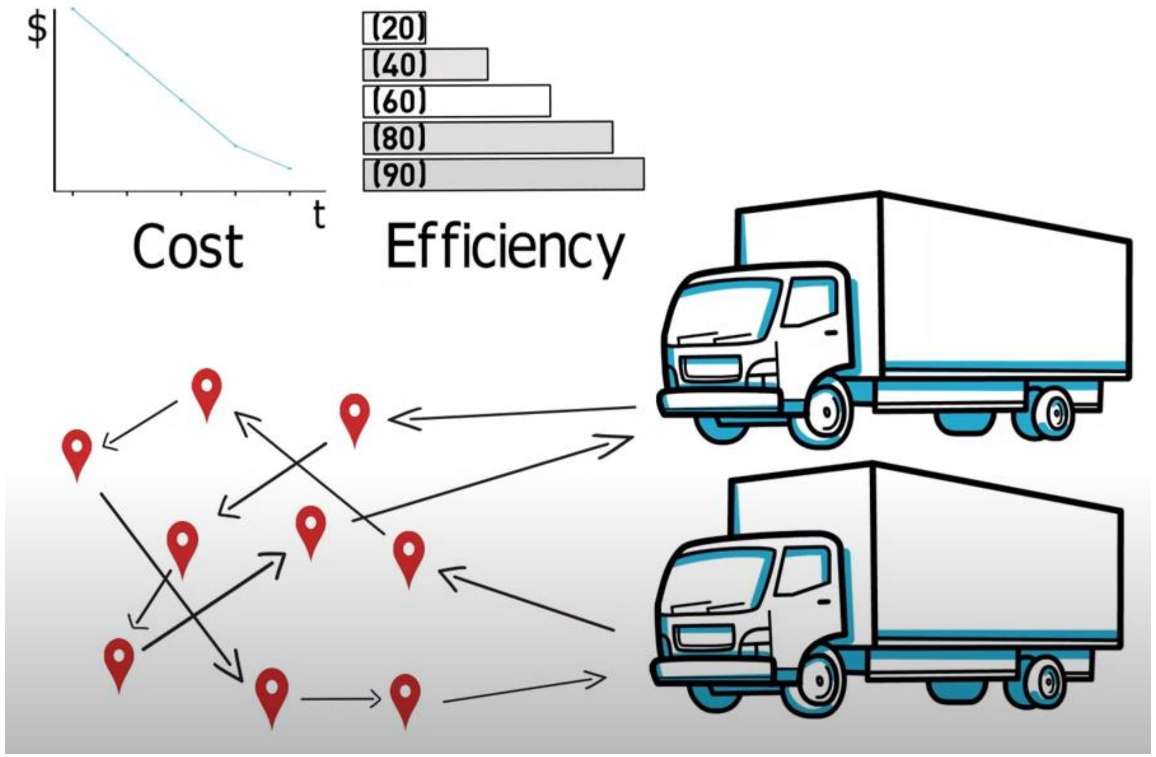
Outline

1. EMO2021 Competition – Huawei 3L-SDVRP
2. A Metaheuristic Approach for 3L-SDVRP
3. Conclusion

Outline

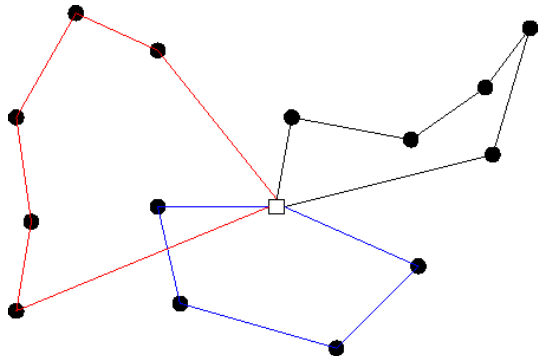
1. **EMO2021 Competition – Huawei 3L-SDVRP**
2. A Metaheuristic Approach for 3L-SDVRP
3. Conclusion

Vehicle Routing Problem (VRP)



- https://www.youtube.com/watch?v=OKMssWdC0I0

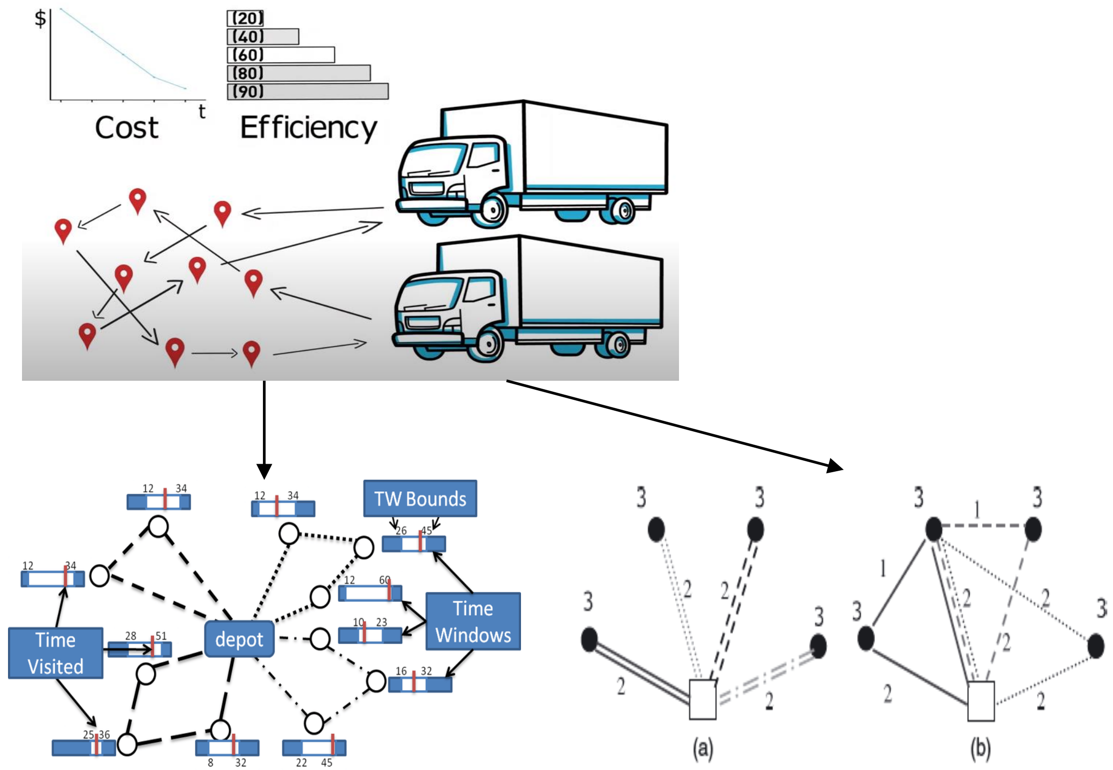
Vehicle Routing Problem (VRP)



Four components

- **Network**
- **Sites to be visited (customers to serve, tasks to process, etc.)**
- **Fleet of vehicles**
- **Depot(s)**

Variants of VRP



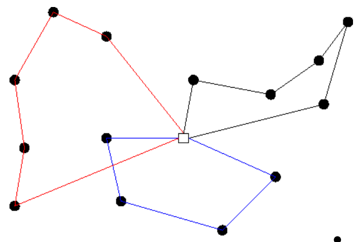
Objectives: Cost & Efficiency

Constraints:
- Limited capacities
- Many depots
- Customer demand
- Time windows
- Precedence and synchronization
- …

Typical VRPs:
- Capacitated Vehicle Routing Problem (CVRP)
- Vehicle Routing Problem with Backhauls (VRPB)
- Vehicle Routing Problem with Split Deliveries (VRPSD)
- Vehicle Routing Problem with Multiple Depot (VRPMD)
- Vehicle Routing Problem with Time Windows (VRPTW)
- …

- https://www.youtube.com/watch?v=OKMssWdC0I0

Methods for VRP



Dantzig and Ramser (**1959**) the first to introduce **"Truck Dispatching Problem"**

Clarke and Wright (**1964**) generalized this problem to a linear optimization problem **"Vehicle Routing Problem"**

Lenstra and Rinnooy Kan (**1981**) proved VRP is **an NP-hard problem**, exact algorithms are only efficient for small problems

time

1950 — 1960 — 1970 — 1980 — 2000 — 2021

1. Constructive Heuristics:

Savings heuristic

Sweep algorithm

2. Improvement Heuristics:

K-opt

λ-interchange

3. Exact algorithms:

Branch and Bound

Cutting Plane

Network-flows

Dynamic Programming

4. Metaheuristics:

Tabu search

Genetic Algorithm

Simulated Annealing

GRASP

Local search methods

Partical Swarm Optimization

Ant Colony Algorithm

5. Machine Learning:

Reinforcement Learning

Pointer network

Perhaps the most famous heuristic of this category is the Clarke and Wright (**1964**) savings heuristic

The development of exact algorithms for the VRP took off in **1981** with the publication of two papers by Christofides

The development of modern heuristics for the VRP really started in the **1990s** with the advent of metaheuristics.

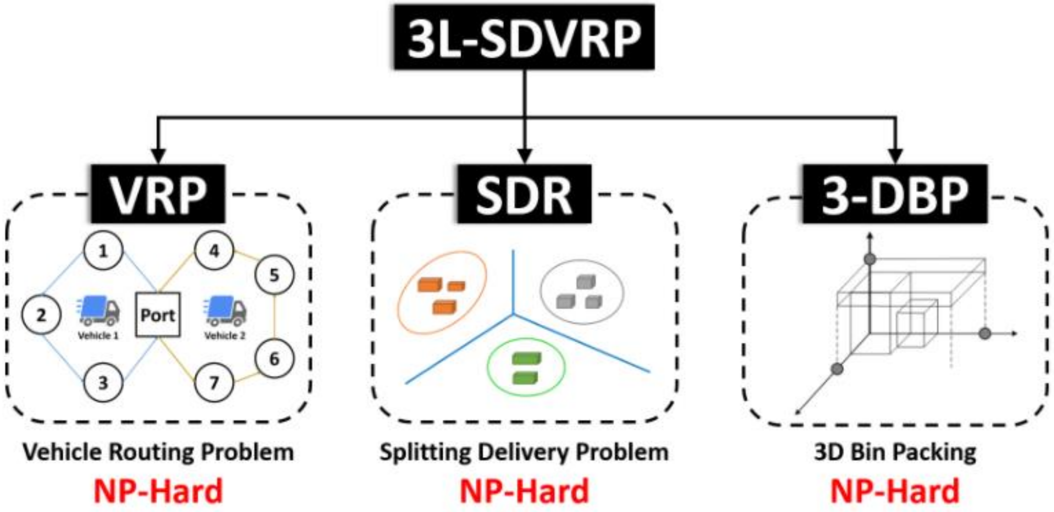
- Laporte, Gilbert, Paolo Toth, and Daniele Vigo. "**Vehicle routing: historical perspective and recent contributions.**" (2013): 1-4.

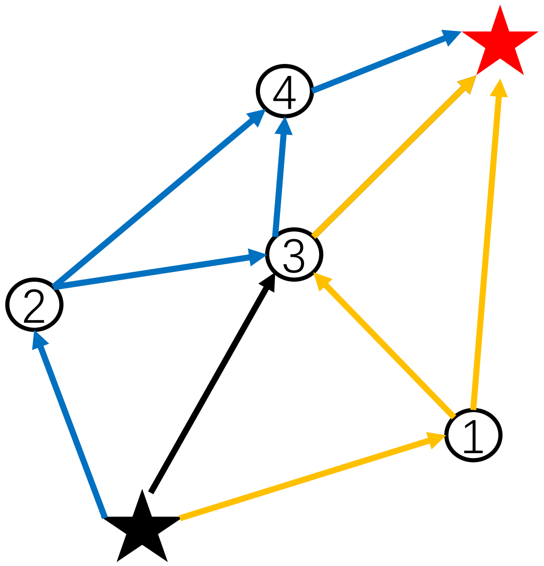
EMO2021 Competition – Huawei 3L-SDVRP

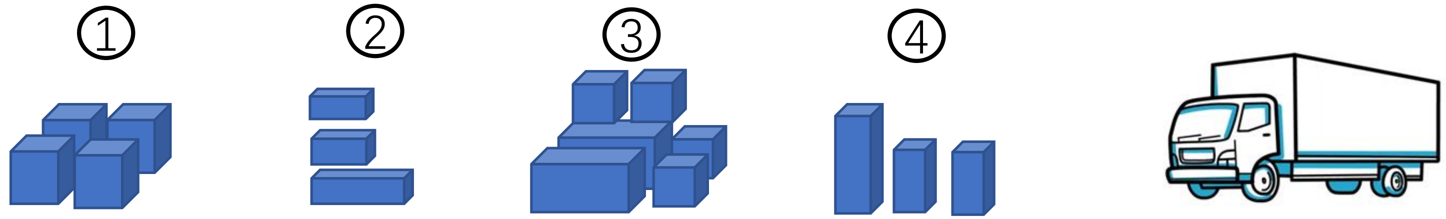
It involves **multiple-pickup-points**, **single-delivery-point**, **many types of cargoes**, **multiple kinds of trucks with containers**, and **various routes** to the port or airport.

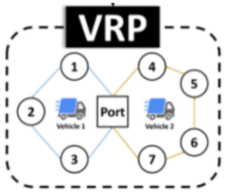
The two objectives of the MOCO problem are to **maximize the loading rate** as well as **to minimize the traveling distance** under specific constraints and requirements.

HUAWEI

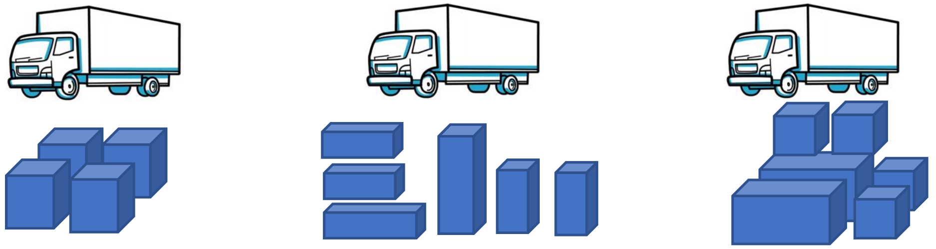




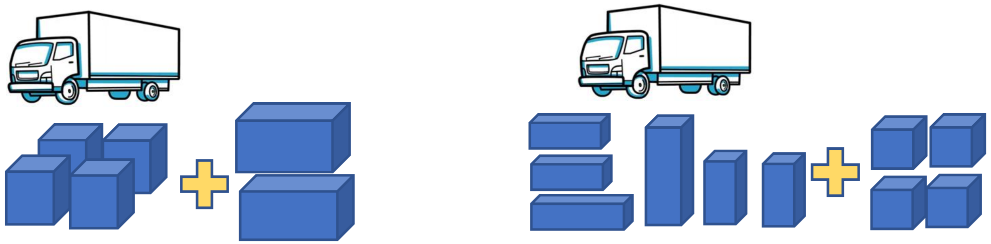


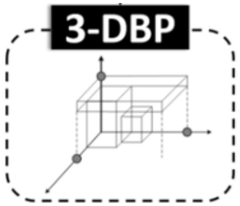


Vehicle Routing Problem
NP-Hard

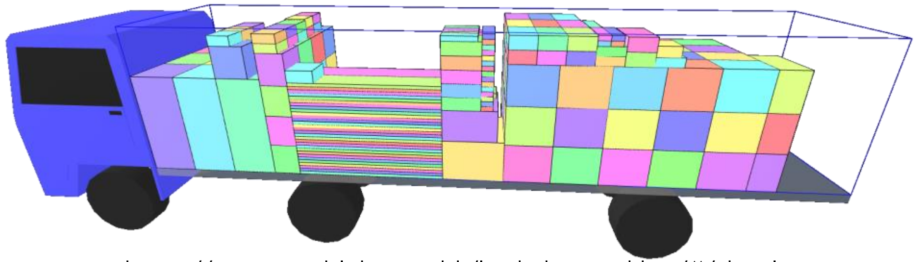


Splitting Delivery Problem
NP-Hard



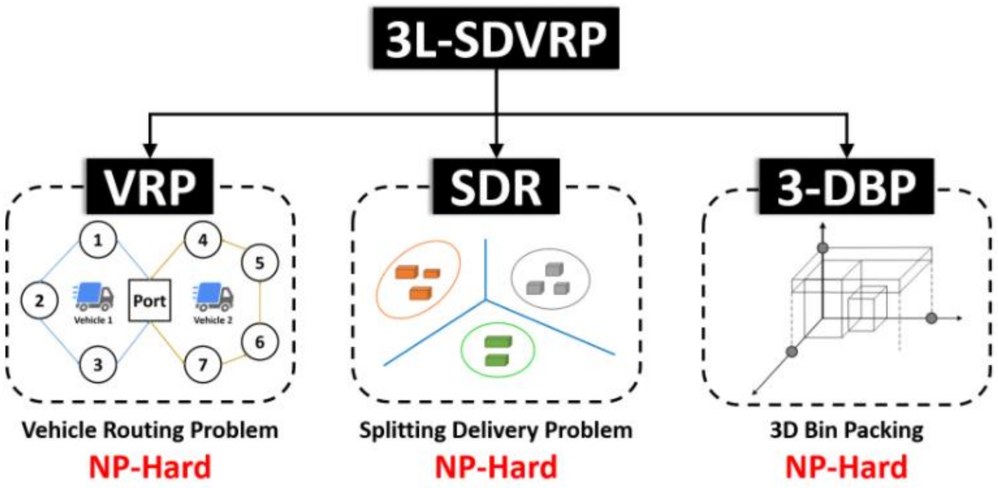


3D Bin Packing
NP-Hard



* https://www.noahlab.com.hk/logistics-ranking/#/simulator

EMO2021 Competition – Huawei 3L-SDVRP



Objective functions

- $f_1 = 1 - \sum_{i=1}^{n} loading\_rate_i / n$,
  where $loading\_rate_i = max(v\_rate_i, w\_rate_i)$,
  v_rate_i = the total volume of all the items in truck i / the size of the truck i ,
  w_rate_i = the total weight of all the items in truck i / the weight capacity of the truck i .
- $f_2 = \sum_{i=1}^{n} truck\_distance_i$
  where $truck\_distance_i$ is the distance traveled by the truck i .

Constraints

This problem includes two types of constraints: vehicle routing and 3-D loading,

- valid route constraints: each route must start from the starting point and end at the delivery point
- bonded warehouse constraints: the bonded warehouse is a special pickup point that can only be visited by empty trucks. Hence, if a pickup point is marked as a bonded warehouse, it must be the first of any route that contains it
- single visit constraints: each truck can only visit each pickup point once
- none-overlapping constraints: items cannot overlap in any dimension
- none-splitting constraints: one item can only be loaded in one truck
- supporting constraints: the item must have sufficient supporting surface, i.e., the supporting area should be greater than 80% of the bottom area of the item
- weight capacity constraints: the total weight of the cargoes loaded on one truck cannot exceed the weight capacity of the truck
- size constraints: all the items must be loaded inside the container
- one-time loading constraints: once a truck leaves a pickup point, the items loaded at the pickup point cannot be moved anymore

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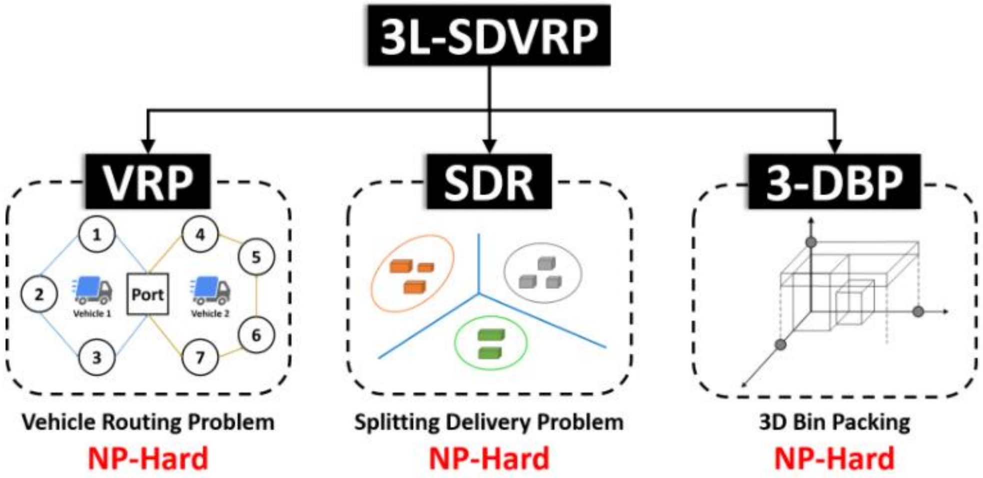
Approaches for 3L-SDVRP



The three approaches can hardly solve 3D-SDVRP directly

Exact algorithms

Heuristics

Machine Learning

Approaches for 3L-SDVRP

Applied Data Science Track Paper KDD 2018, August 19-23, 2018, London, United Kingdom

A Data-Driven Three-Layer Algorithm for Split Delivery Vehicle Routing Problem with 3D Container Loading Constraint

Xijun Li
Shanghai Jiao Tong University
Noah's Ark Lab of Huawei
lixijun@sjtu.edu.cn

Mingxuan Yuan
Noah's Ark Lab
Huawei Technologies
yuan.mingxuan@huawei.com

Di Chen
Noah's Ark Lab
Huawei Technologies
di.chen@huawei.com

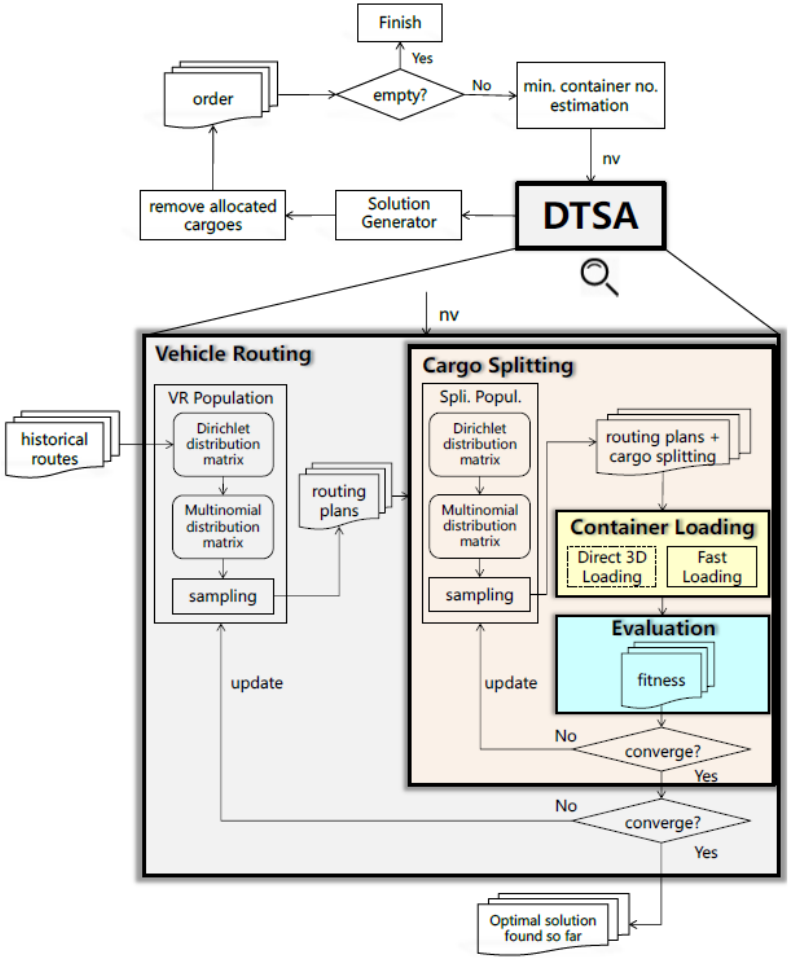
Jianguo Yao
Shanghai Jiao Tong University
jianguo.yao@sjtu.edu.cn

Jia Zeng
Noah's Ark Lab
Huawei Technologies
Zeng.Jia@huawei.com

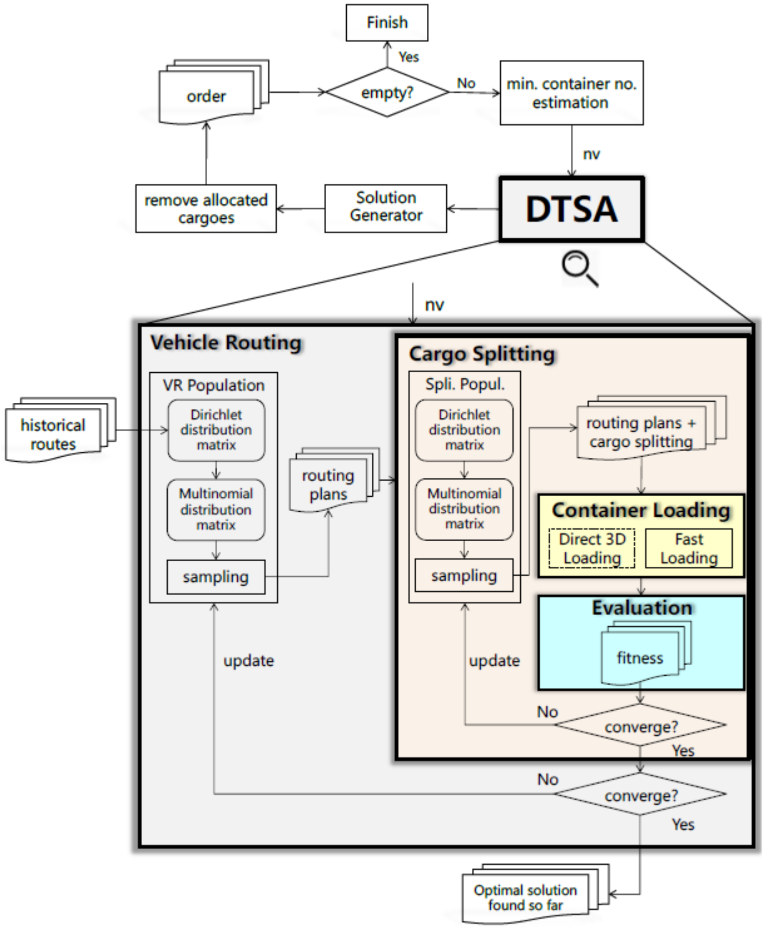
1. First propose 3L-SDVRP
(Split Delivery Vehicle Routing Problem with 3D Loading Constraints)

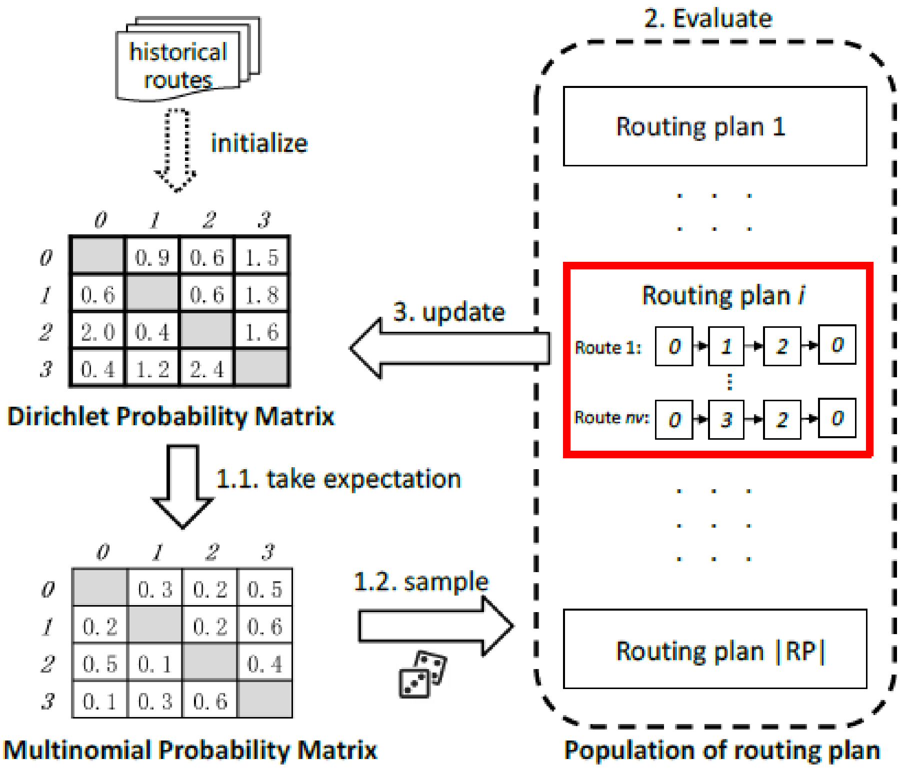
2. Three-Layer method

- Out-layer: vehicle routing
- Mid-layer: cargo splitting
- Inner-layer: container loading



Approaches for 3L-SDVRP

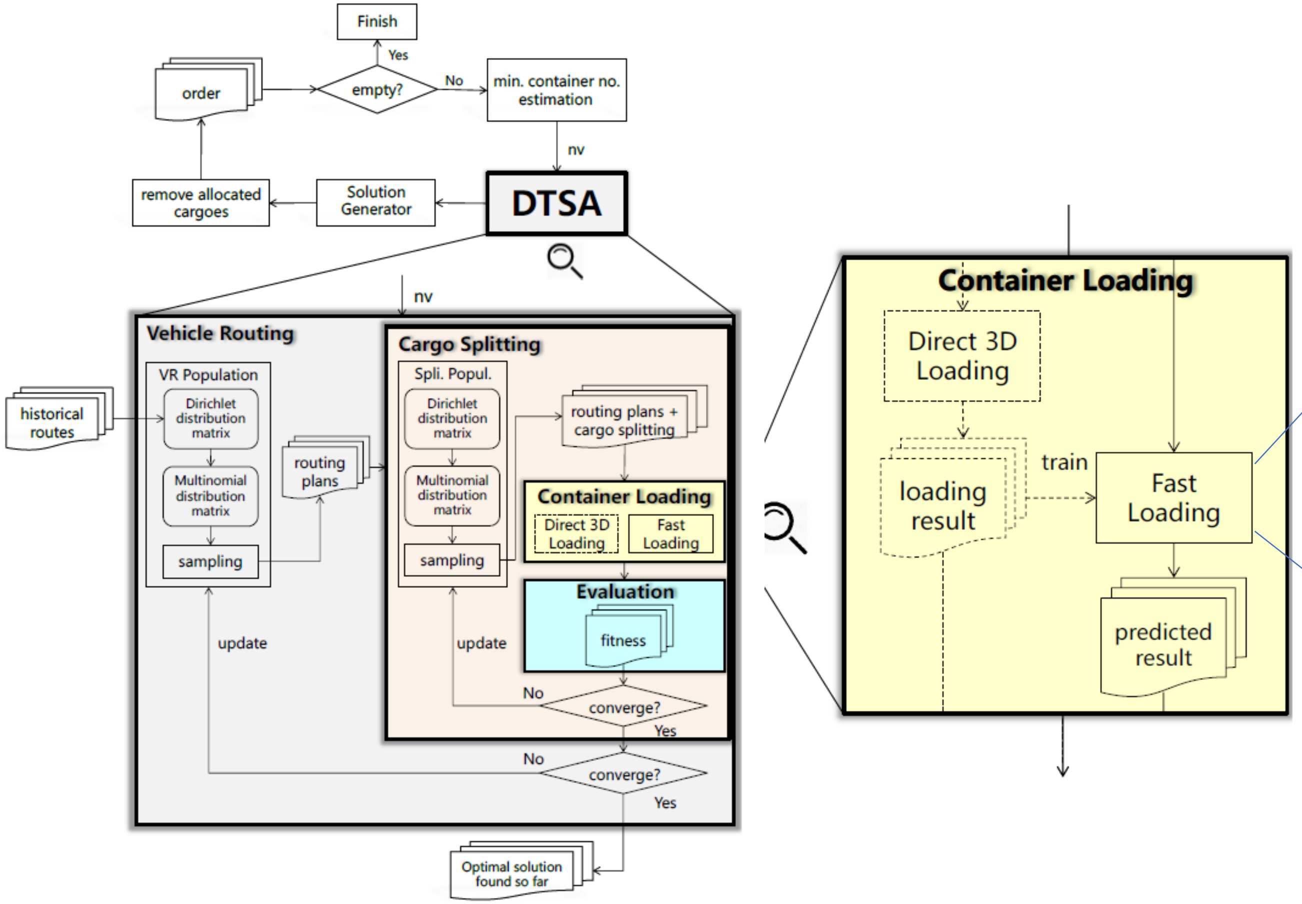


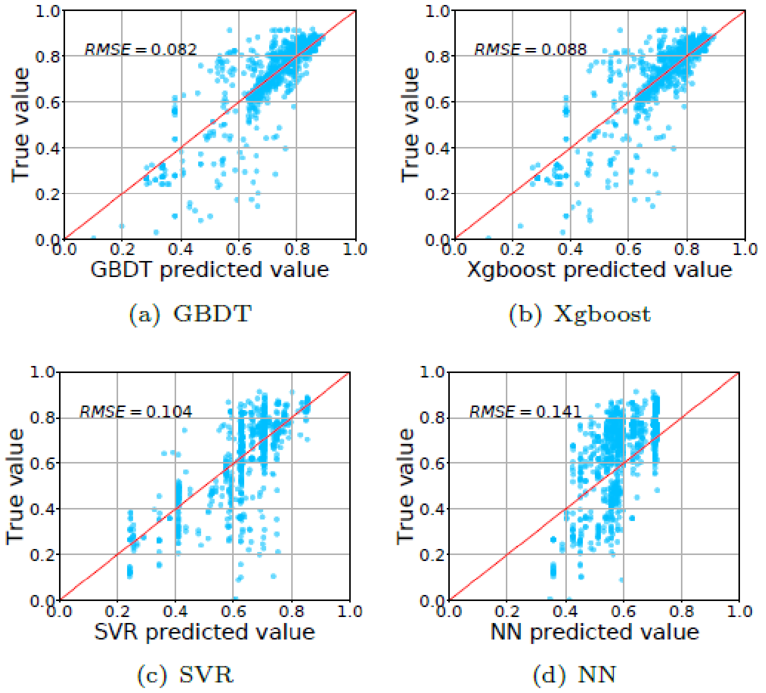


	0	1	2	3
0		0.9	0.6	1.5
1	0.6		0.6	1.8
2	2.0	0.4		1.6
3	0.4	1.2	2.4	

	0	1	2	3
0		0.3	0.2	0.5
1	0.2		0.2	0.6
2	0.5	0.1		0.4
3	0.1	0.3	0.6	

Approaches for 3L-SDVRP





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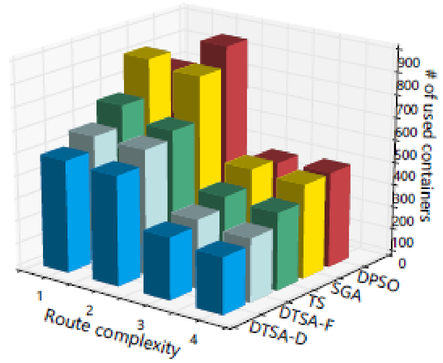
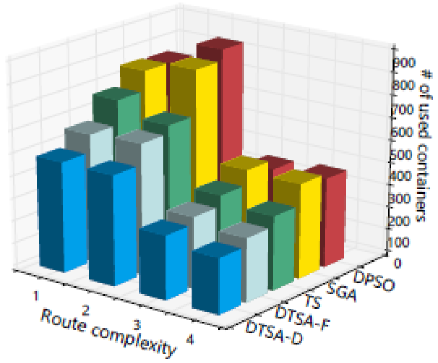
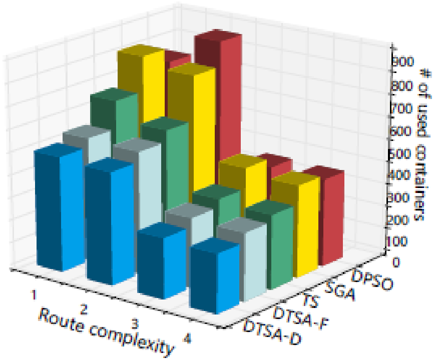
Approaches for 3L-SDVRP



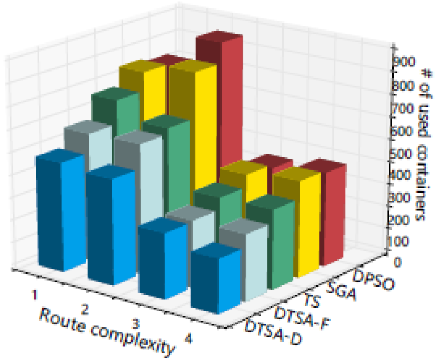
(a) NSGA



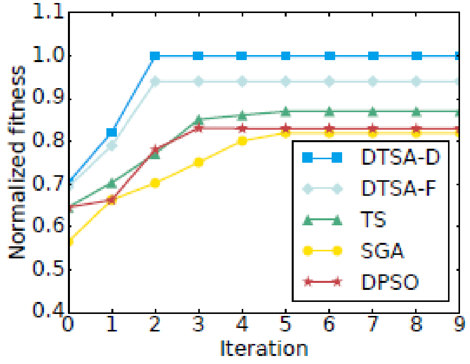
(b) SPEA



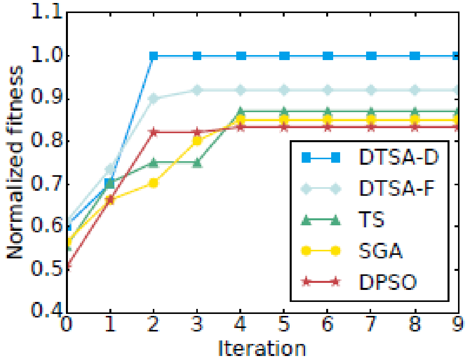
(c) $I_{\epsilon+}$



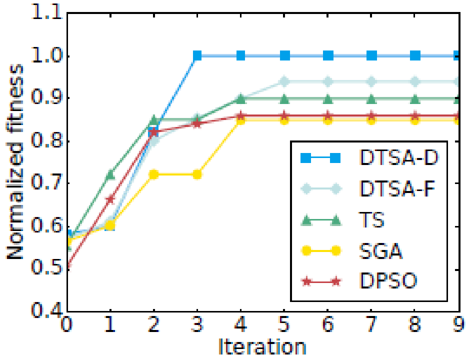
(d) MOEA/D



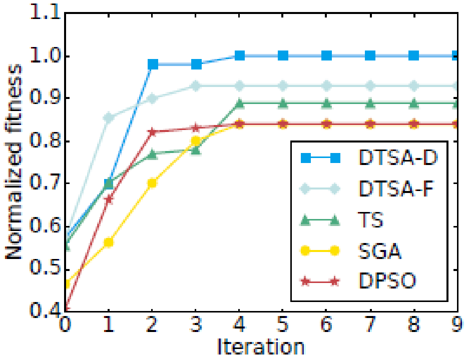
(a) NSGA



(b) SPEA



(c) $I_{\epsilon+}$



(d) MOEA/D

Approaches for 3L-SDVRP

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Production, Manufacturing, Transportation and Logistics

The Split Delivery Vehicle Routing Problem with three-dimensional loading constraints

Andreas Bortfeldt[a], Junmin Yi[b,*]

[a] Otto-von-Guericke-University Magdeburg, Germany
[b] Xiamen University of Technology, China

1. Introduce two variance of 3L-SDVRP

- 3L-SDVRP with *forced* splitting

  A delivery is only split if the demand of a customer cannot be transported by a single vehicle

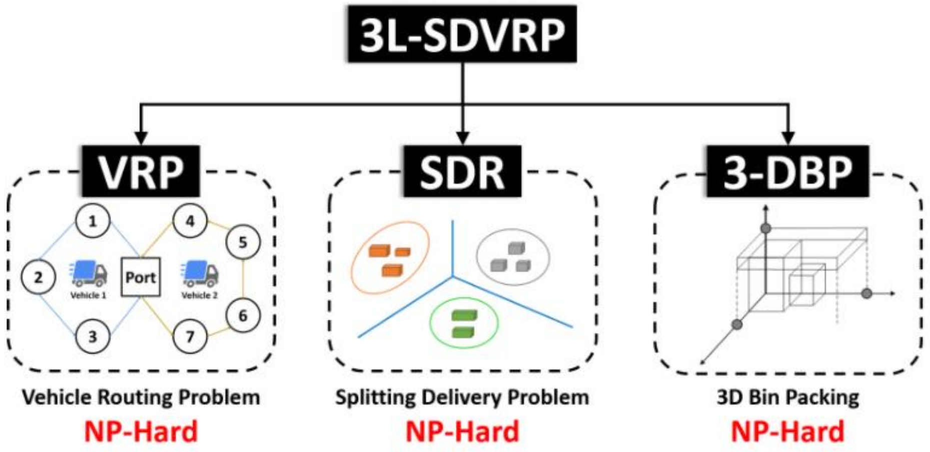
- 3L-SDVRP with *optional* splitting

2. Packing first hybrid algorithm

- a local search algorithm for routing
- a genetic algorithm and several construction heuristics for packing.

Algorithm 1 Overview of the hybrid algorithm.

```
SDVRLH2 (in: problem data, parameters, out: best solution s_best)
// Packing step
for each customer i do
    generate patterns for customer i (1C-FLPs where necessary, one 1C-SP)
    by container loading GA
endfor
for selected customer pairs (i,j) do
    generate 2C-SP pattern for customer pair (i, j) by construction
    heuristics
endfor
// Routing step
for each customer i
    generate as many direct trips 0→i→0 as 1C-FLPs for customer i do
    exist
endfor
if only forced splits allowed then
    solve remaining CVRP by local search
else // optional splits allowed
    solve remaining SDVRP by (modified) local search
endif
// Final step
prepare solution s_best consisting of best achieved routing plan and
    related 3D packing patterns
end.
```



1. Proposed in 2018
2. Complex and time-consuming
3. There are three approaches:
   - Routing first
   - Packing first
   - Mixed routing & packing

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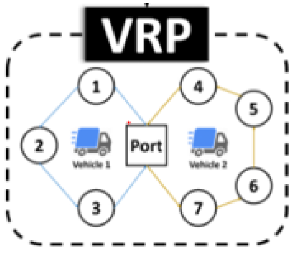
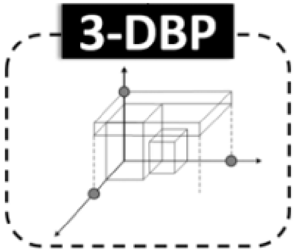
A Multiobjective Metaheuristic Approach for 3L-SDVRP

3L-SDVRP

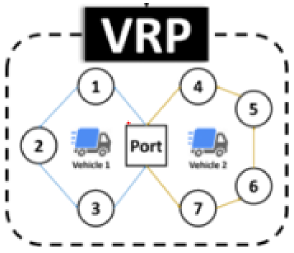


Vehicle Routing Problem



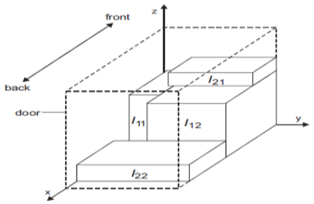
3D Bin Packing

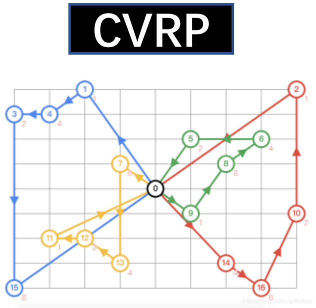
Splitting Delivery Problem



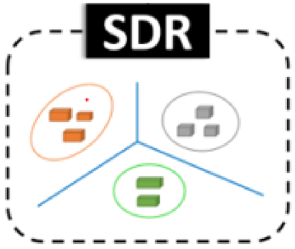
Vehicle Routing Problem

model



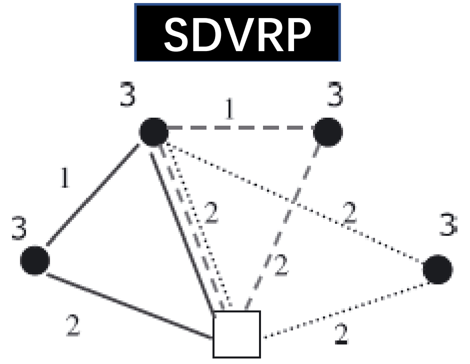


split on model



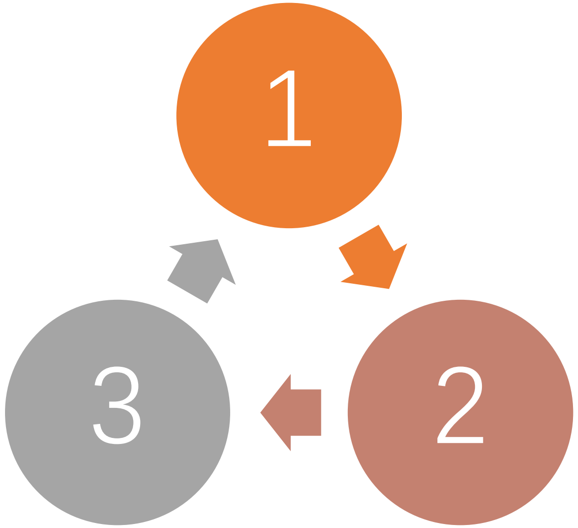
Splitting Delivery Problem

Split Delivery Vehicle Routing Problem



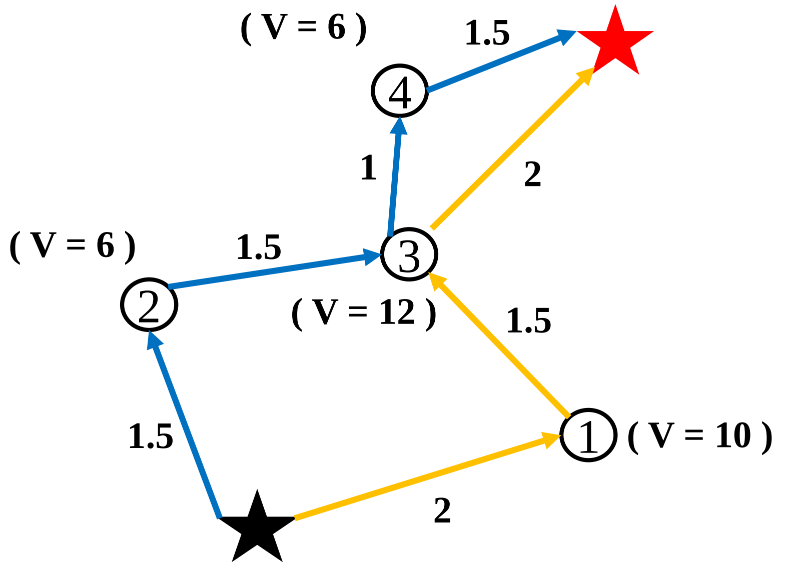
(b)

A Multiobjective Metaheuristic Approach for 3L-SDVRP



1. Objectives
2. Design space
3. Search method

A Multiobjective Metaheuristic Approach for 3L-SDVRP



(V capacity = 20)

Objectives:

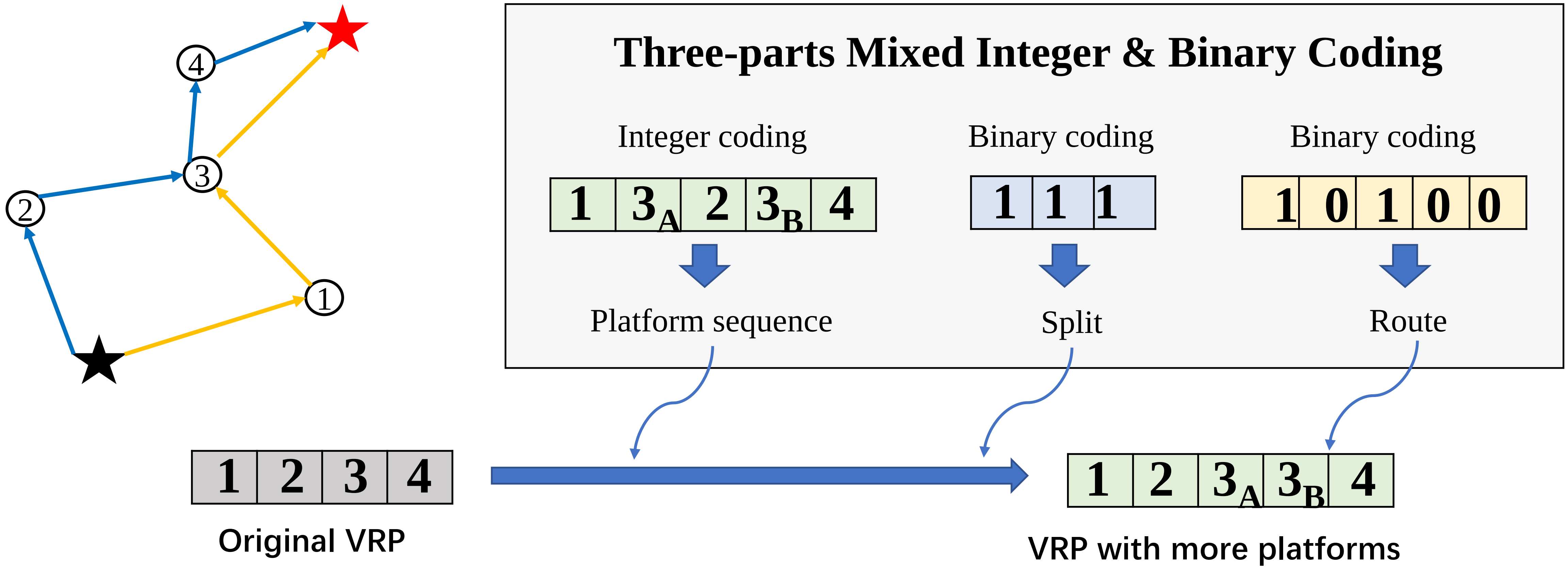
- $f_1 = 1 - \sum_{i=1}^{n} loading\_rate_i / n$,
  where $loading\_rate_i = max(v\_rate_i, w\_rate_i)$,
  v_rate_i = the total volume of all the items in truck i / the size of the truck i ,
  w_rate_i = the total weight of all the items in truck i / the weight capacity of the truck i .
- $f_2 = \sum_{i=1}^{n} truck\_distance_i$
  where $truck\_distance_i$ is the distance traveled by the truck i .

Example:

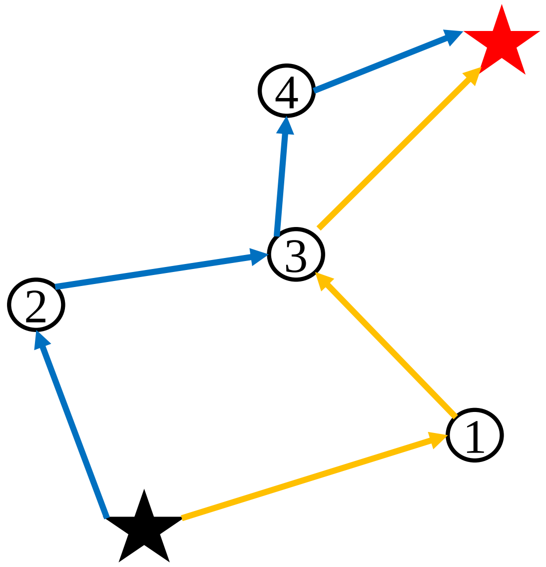
Objective 1 : 1 - ((10+6) /20 + (6+6+6)/20) / 2 = 0.15

Objective 2 : (2+1.5+2) + (1.5+1.5+1+1.5) = 11

A Multiobjective Metaheuristic Approach for 3L-SDVRP



A Multiobjective Metaheuristic Approach for 3L-SDVRP



Parents

Integer coding

1	3_A	2	3_B	4
3_A	4	2	3_B	1

Binary coding

1	0	1	0	0
1	0	0	0	1

Binary coding

1	1	1
0	0	1

Offspring

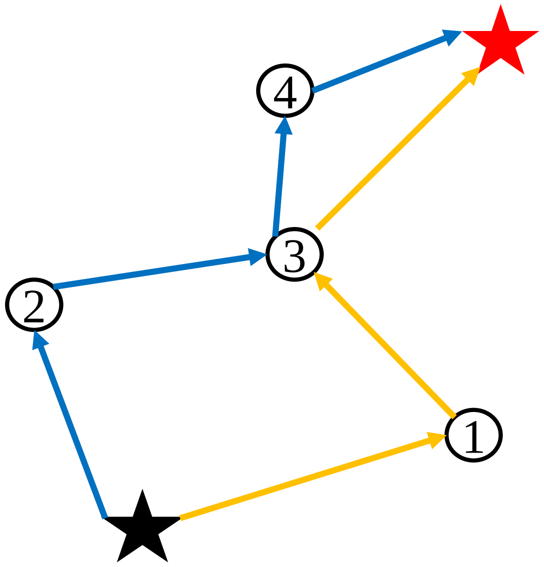
Integer coding

1	4	2	3_B	3_A
3_A	3_B	2	4	1

Binary coding

1	0	0	0	0
1	0	1	0	1

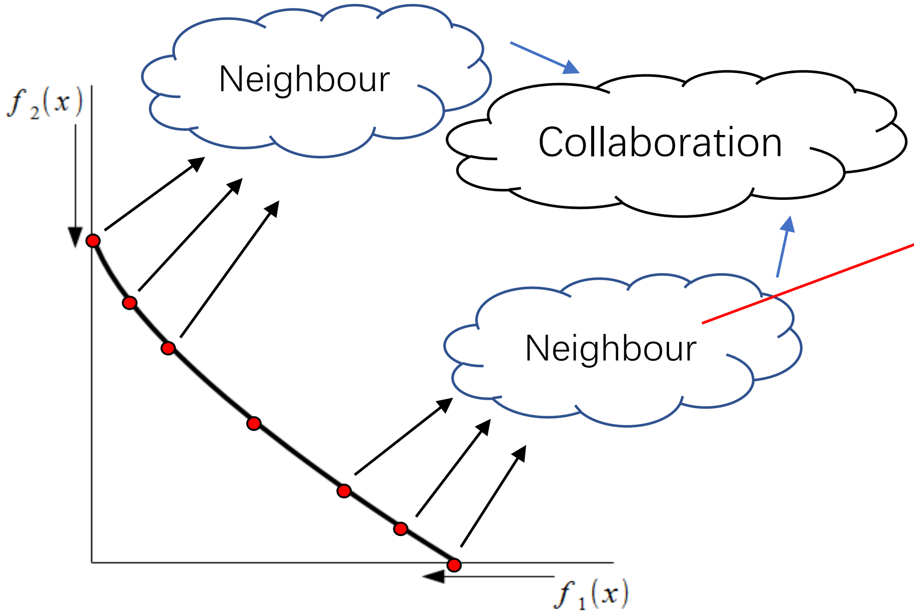
A Multiobjective Metaheuristic Approach for 3L-SDVRP

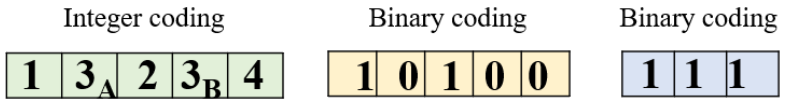


	Integer coding	Binary coding	Binary coding
Parents	1 3_A 2 3_B 4	1 0 1 0 0	1 1 1
	3_A 4 2 3_B 1	1 0 0 0 1	0 0 1
Offspring	1 3_B 2 3_A 4	1 0 0 0 0	
	3_A 4 1 3_B 2	0 0 0 0 1	

A Multiobjective Metaheuristic Approach for 3L-SDVRP

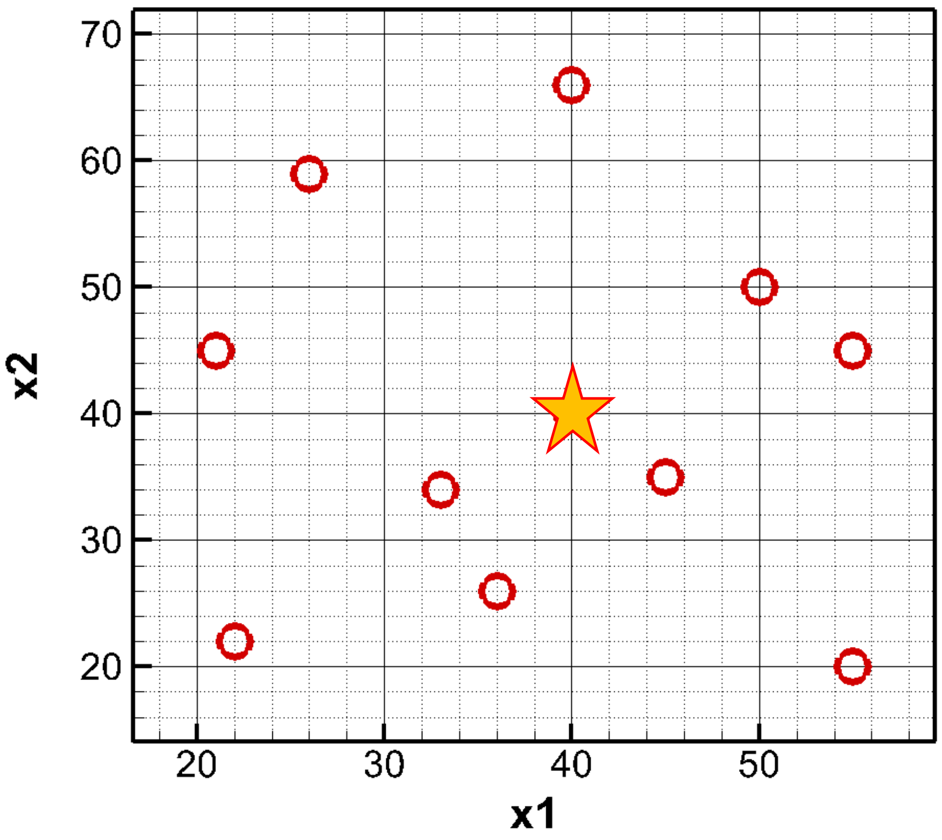
MOEA/D





- Mating — select from neighbour with *ps*
- Swap — mixed integer & binary
- Mutation — mixed integer & binary
- Replacement — replace neighbour with *pr*

A simple SDVRP test instance



(capacity = 50)

(capacity = 60)

```
{22, 22},  18
{36, 26},  26
{21, 45},  11
{45, 35},  30
{55, 20},  21
{33, 34},  19
{50, 50},  15
{55, 45},  16
{26, 59},  29
{40, 66},  26
{55, 65},  37
```

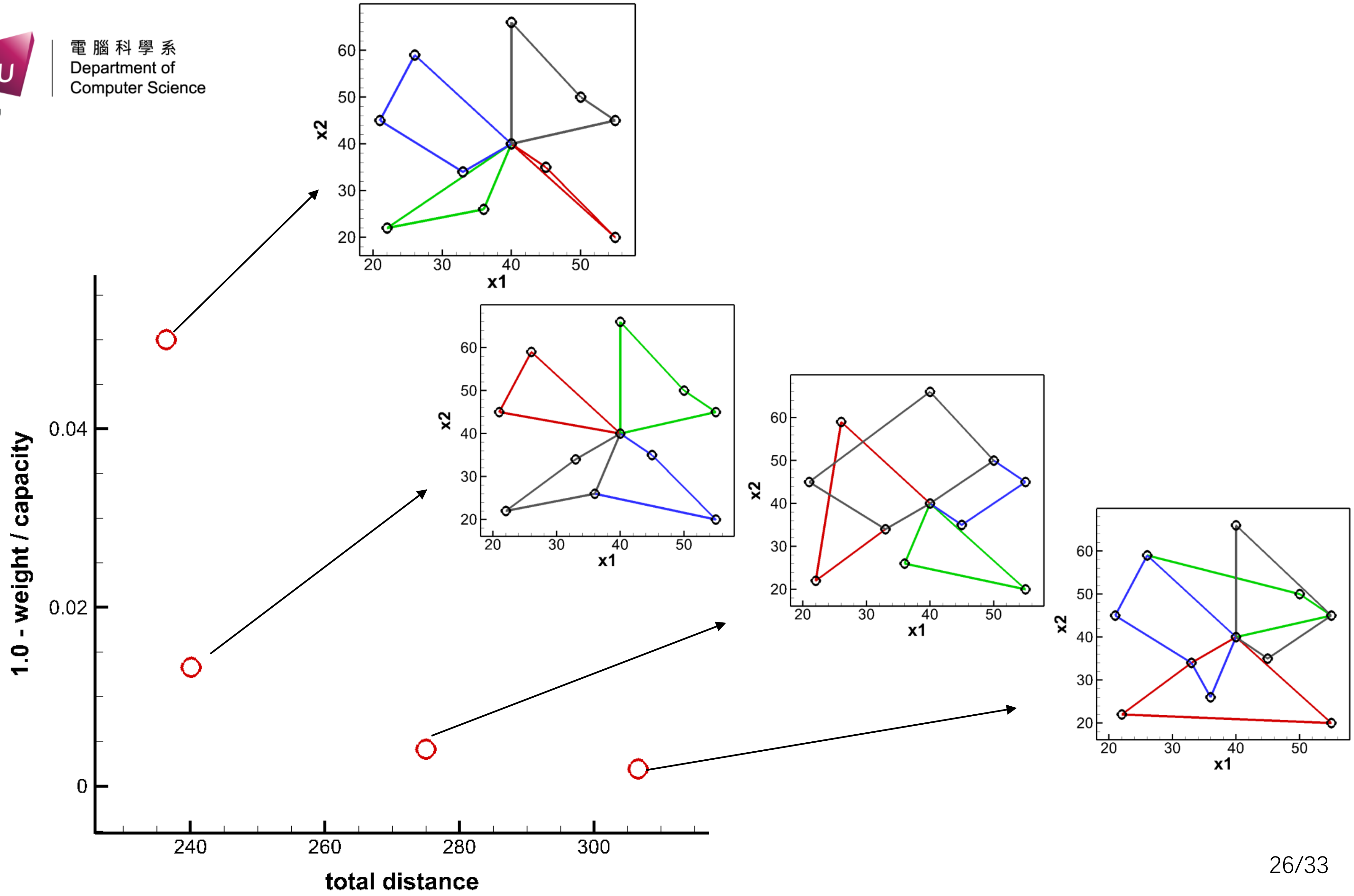
Two objectives:

$$f_1 = 1 - \sum_{i=1}^{n} loading\_rate_i / n$$

$$f_2 = \sum_{i=1}^{n} truck\_distance_i$$

Constraints:

- Start & end nodes
- Max capacity
- 2 Splits


1.0 - weight / capacity
0
0.02
0.04
total distance
240
260
280
300
x1
x2
20
30
40
50
60

A Multiobjective Metaheuristic Approach for 3L-SDVRP

Advantages:

1. Adaptive& Flexible
2. Extensible
3. Efficient
4. Constraints

Adaptive to different size of VRP problems, different split number and vehicle type …

Combine with 3D bin packing method or used in other framework.

In general, more efficient than exactly method.

Constraints can be integrated easily.

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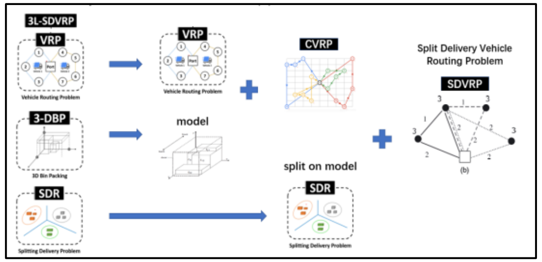
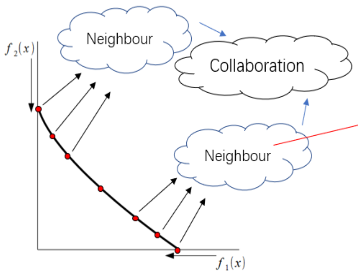
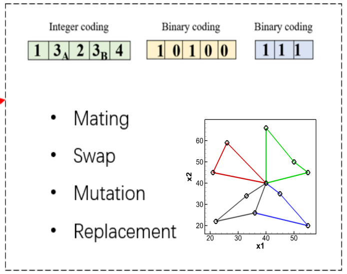


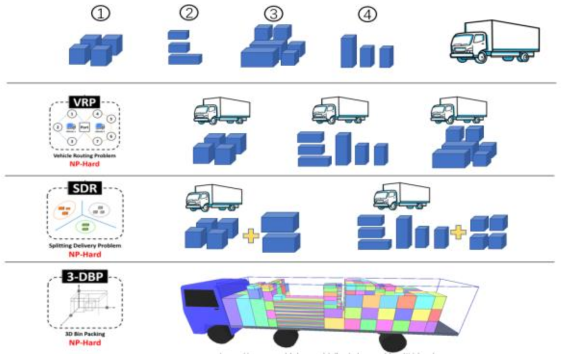
Proposed Multiobjective Metaheuristic



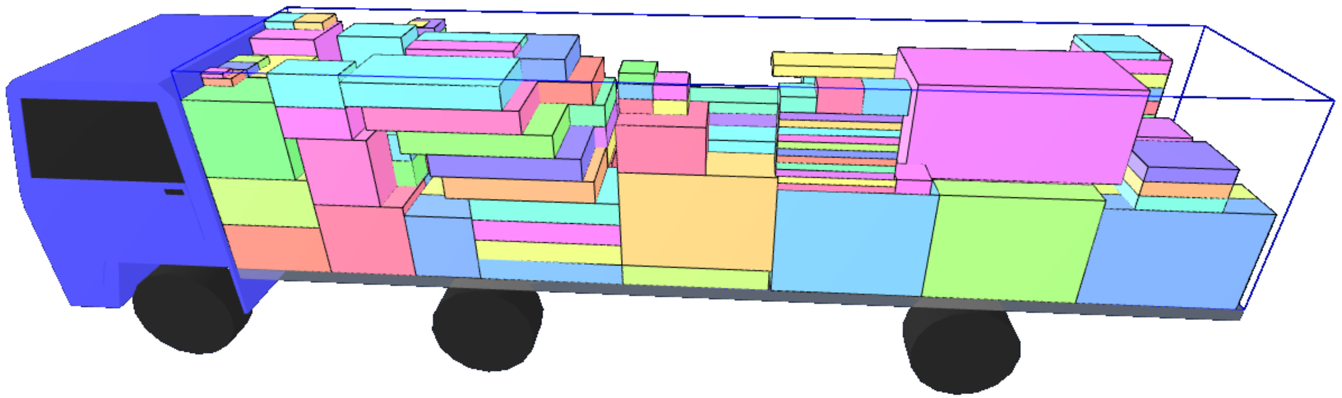


- **Model for packing**
- **Constraints**

HUAWEI



A Multiobjective Metaheuristic Approach for 3L-SDVRP (model for 3D bin packing)



• **V_boxs /V_truck**	Total volume of boxes / volume of truck
• **W_boxs/W_truck**	Total weight of boxes / capacity of truck
• **N_platform**	Number of platform
• **N_type_of_box**	Number of types of boxes
• **N_abnormal**	Number of abnormal boxes
• …	…

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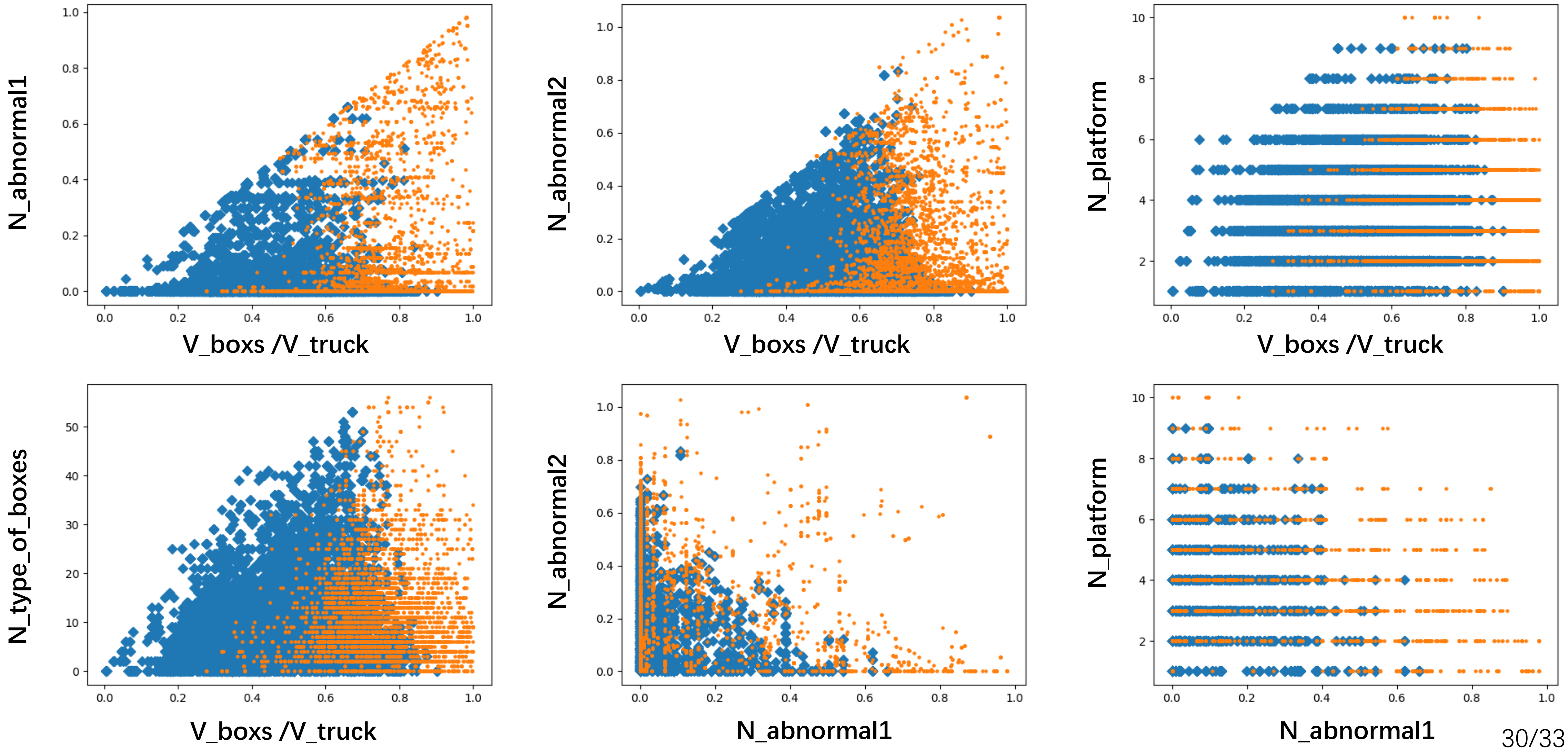
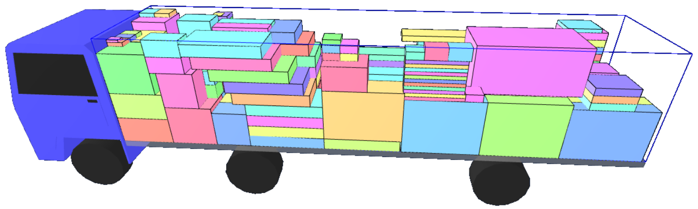
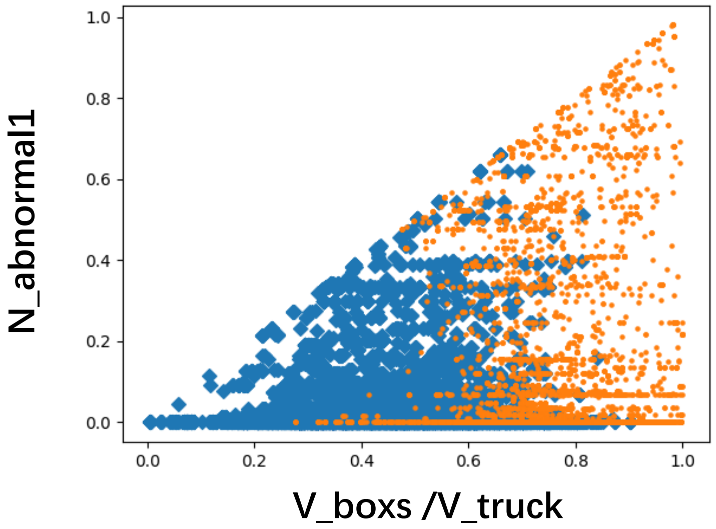
- 50000 data samples with label on if it is a successful packing
- 6 features
- V_box /V_truck is the most important feature



A Multiobjective Metaheuristic Approach for 3L-SDVRP (model for 3D bin packing)





80%-90%

- SVM, NN, linear or …
- Accuracy is not the most important thing ?
- Regression or Classification
- How to define features

- Volume ratio is much more significant than other features
- Multi-level volume ratio is used as the model

A Multiobjective Metaheuristic Approach for 3L-SDVRP (constraints)

Constraints

This problem includes two types of constraints: vehicle routing and 3-D loading,

- valid route constraints: each route must start from the starting point and end at the delivery point
- bonded warehouse constraints: the bonded warehouse is a special pickup point that can only be visited by empty trucks. Hence, if a pickup point is marked as a bonded warehouse, it must be the first of any route that contains it
- single visit constraints: each truck can only visit each pickup point once
- none-overlapping constraints: items cannot overlap in any dimension
- none-splitting constraints: one item can only be loaded in one truck
- supporting constraints: the item must have sufficient supporting surface, i.e., the supporting area should be greater than 80% of the bottom area of the item
- weight capacity constraints: the total weight of the cargoes loaded on one truck cannot exceed the weight capacity of the truck
- size constraints: all the items must be loaded inside the container
- one-time loading constraints: once a truck leaves a pickup point, the items loaded at the pickup point cannot be moved anymore

Routing constraints

implicit

- **Valid route constraints**
- **Single visit constraints**

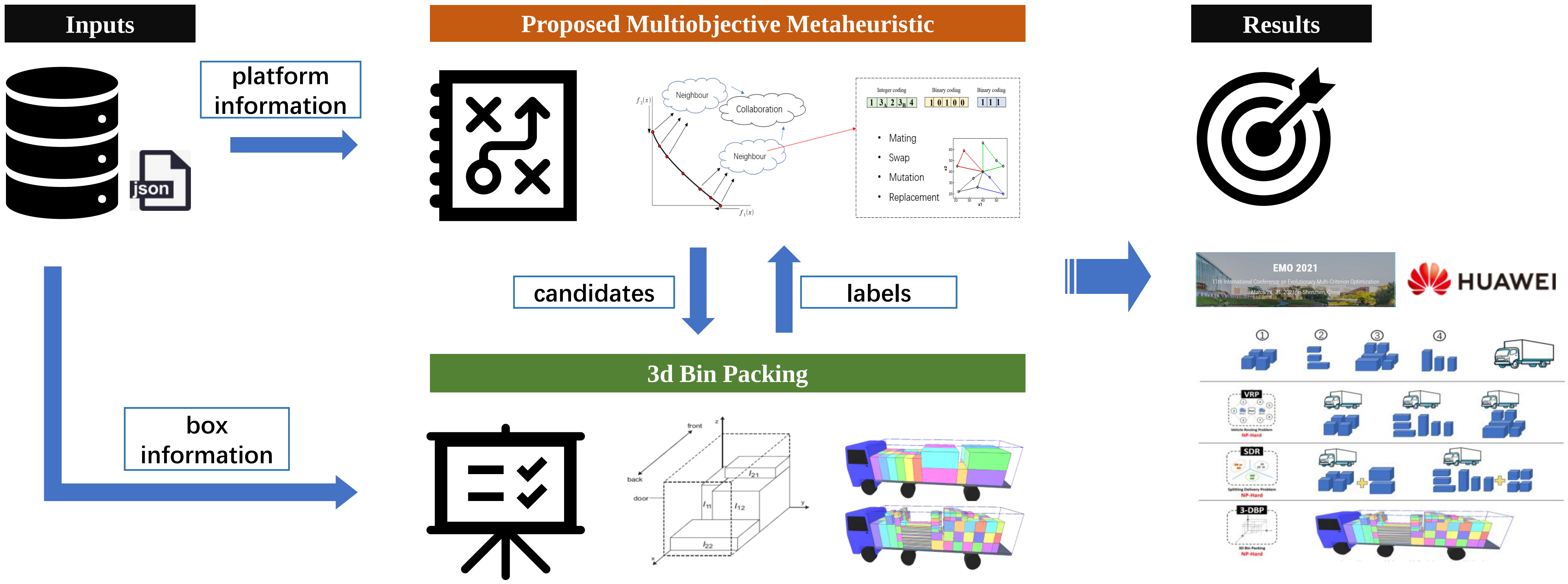
explicit

- **Weight capacity constraints**
- **Bonded warehouse constraints**

Packing constraints

- **none-overlapping constraints**
- **None-splitting constraints**
- **Size constraints**
- **One-time loading constraints**
- **Supporting constraints**

Solution for Huawei 3L-SDVRP



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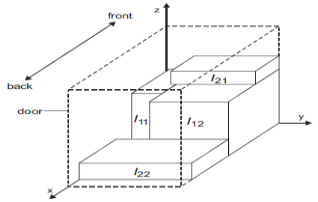
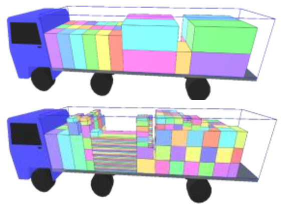
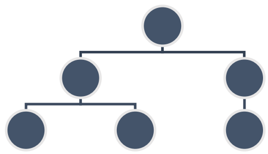
Final mixed version for Huawei 3L-SDVRP

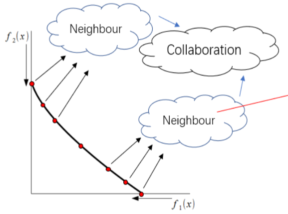


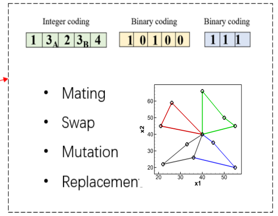
3d in packing

Packing first method → **Multiobjective metaheuristic** → **Improvement heuristic**









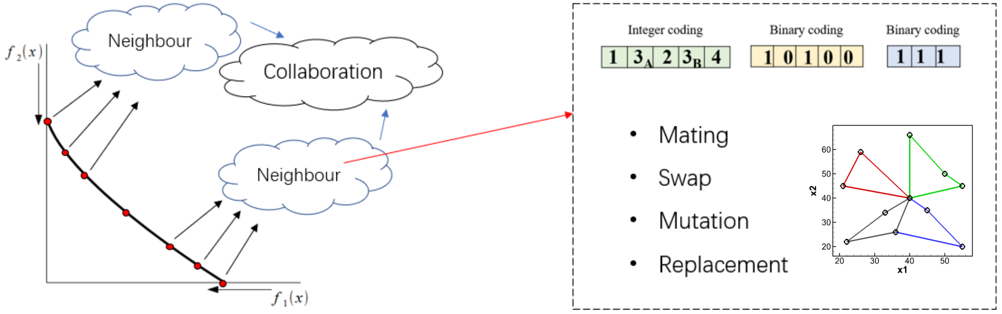
- https://www.noahlab.com.hk/logistics-ranking/#/ranking

Outline

1. EMO2021 Competition – Huawei 3L-SDVRP
2. A Metaheuristic Approach for 3L-SDVRP
3. **Conclusion**

Conclusion

- ➢ A metaheuristic approach is proposed for 3L-SDVRP
- ➢ The method is validated on a simple instance and the EMO competition
- ➢ Results show the flexibility of metaheuristic



Future works

- General encoding of design space & encoding of exploration and exploitation operators in metaheuristic
- Use offline & online knowledge in VRP and SDR
- Experiments on benchmark SDVRP instances, middle & large scale SDVRP, and compare with other methods
- …

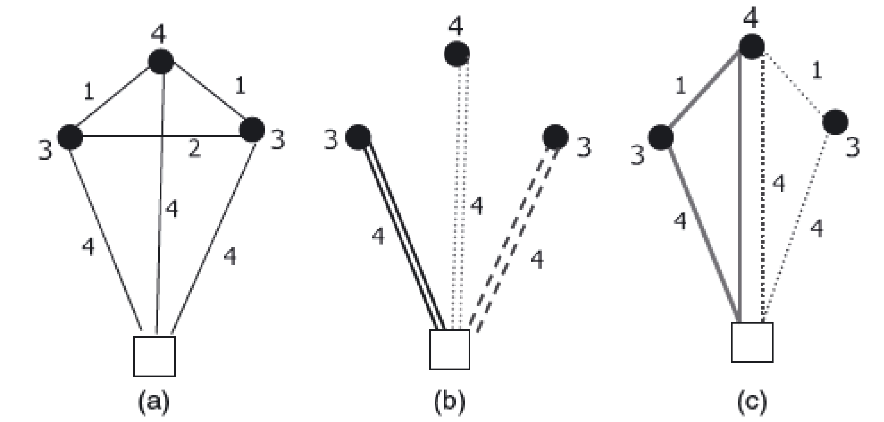
電腦科學系
Department of
Computer Science
香港城市大學
City University of Hong Kong

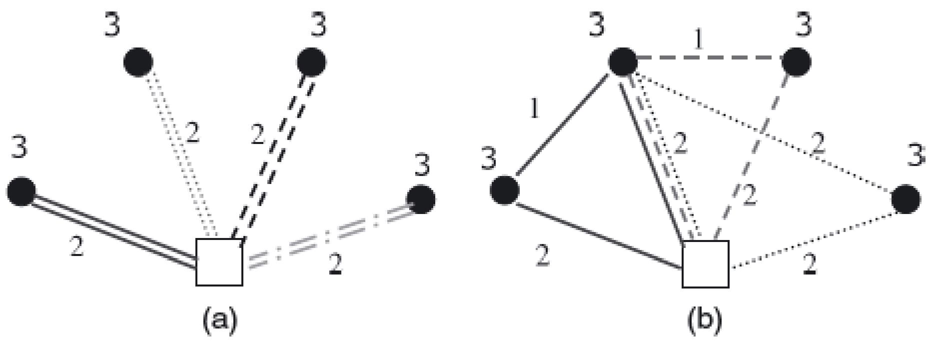
A Multiobjective Metaheuristic Approach for 3L-SDVRP

Thanks!

- **Fei Liu, Qingling Zhu**
- **March 1, 2021**
- **Email: fliu36-c@my.cityu.edu.hk**

Some conclusions on SDVRP





- The delivery cost reductions obtained when allowing split deliveries appear to be due primarily to the ability to **reduce the number of delivery routes**.
- The largest benefits are obtained when **the mean demand is greater than half but less than three quarters of the vehicle capacity.**
- The benefits from allowing split deliveries mainly depends on the relation between mean demand and vehicle capacity and on demand variance; there **does not appear to be a dependence on customer locations.**

- Archetti, Claudia, Martin WP Savelsbergh, and M. Grazia Speranza. "To split or not to split: That is the question." Transportation Research Part E: Logistics and Transportation Review 44.1 (2008): 114-123.
- Archetti, Claudia, and Maria Grazia Speranza. "Vehicle routing problems with split deliveries." International transactions in operational research 19.1-2 (2012): 3-22.

Some conclusions on SDVRP

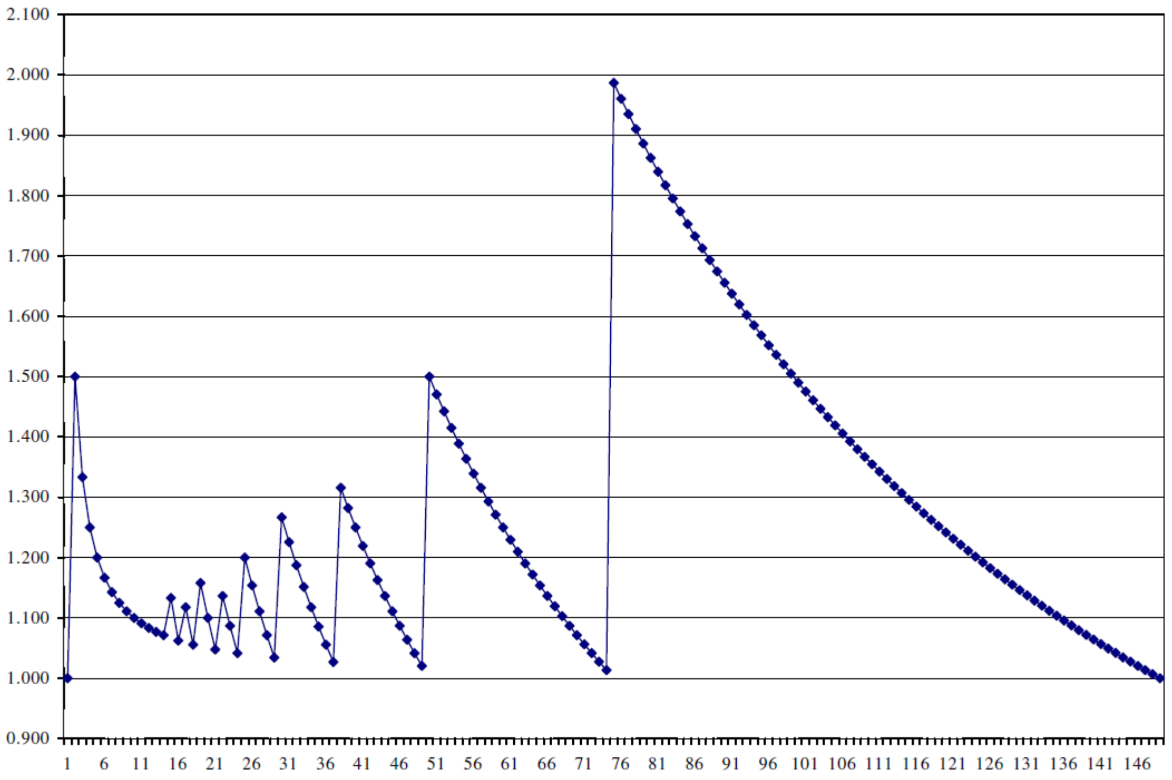
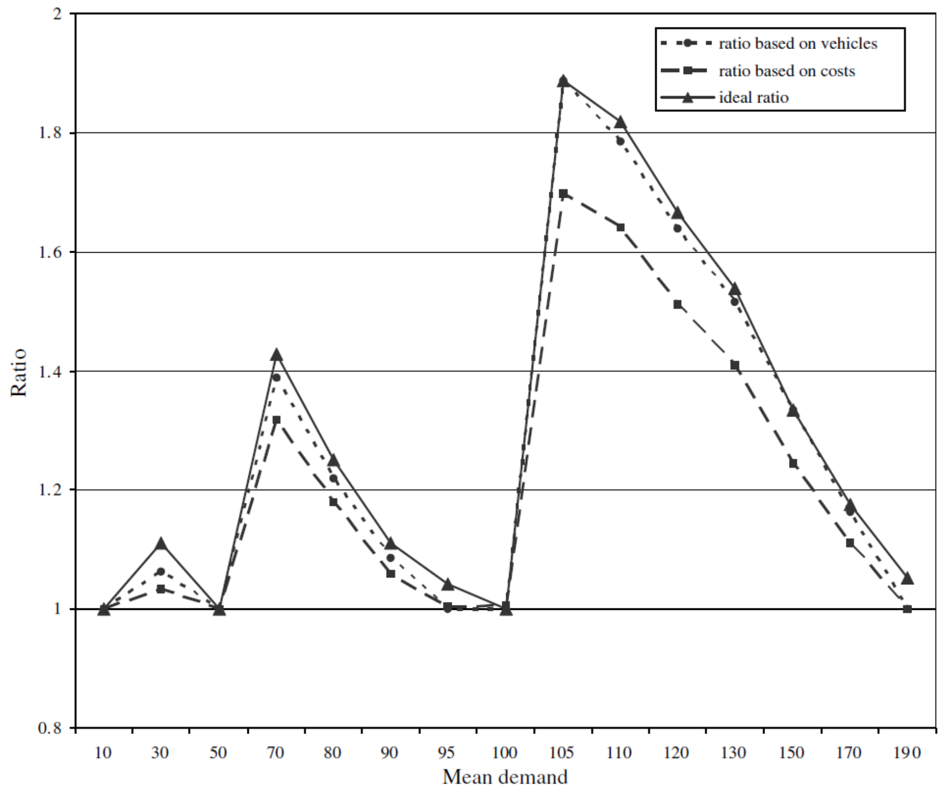


Fig. 1. Ratio $\frac{r(\mathrm{VRP})}{r(\mathrm{SDVRP})}$ as a function of d for an instance with 149 customers and vehicles with capacity 149.



Some examples on coding for VRP

coding

- Natural number coding

For example:
Chromosome:
(1 4 6 5 3 2 7)
Corresponding string:
(1 4 6 5 1 3 2 7 1)

crossover

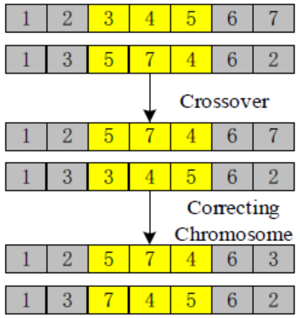


Figure 1. Chromosome Crossover

mutation

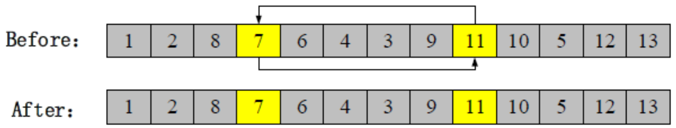


Figure 2. Chromosome Mutation

selection

- copying the best individuals, weeding out the worst individuals.

- Gao, Zhao, Guohua Sun, and Zhenglei Yuan. "Genetic Algorithm to the Split Delivery Vehicle Routing Problem." *2019 6th International Conference on Systems and Informatics (ICSAI)*. IEEE, 2019.