Reduction of Both Cost and CO_2 Emissions in the Vehicle Routing and Cargo Allocation Problem

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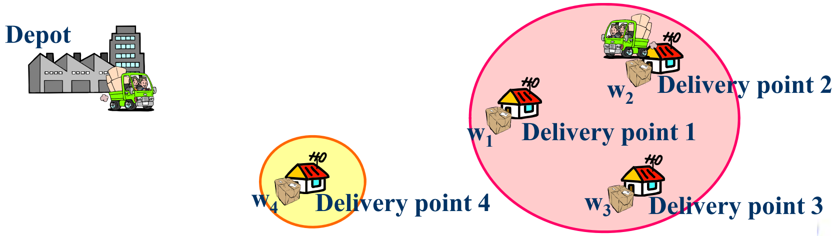
CO_2 Emissions

- Cargo carriers are obligated to reduce the CO_2 emissions from cargo transportation activities
- Revised Energy Conservation Law in Japan
  - CO_2 emissions from a truck with cargos e (t-CO_2)
    - $e = 2.62dwy / 1000$
      - d (km) : transport distance
      - w (t) : cargo weight
  - Amount of fuel consumed per ton-km y (L/t·km)
    - $\ln y = 2.71 - 0.812\ln(x/100) - 0.654\ln z$
      - x (%) : loading ratio
      - z (kg) : the maximum load of the truck

Delivery of cargos with different weights

- Delivery route
  - shortest ≠ with minimum CO_2 emissions
- CO_2 emissions
  - one operation > two or more operations



Previous work [Otani12]

- Vehicle Routing and Cargo Allocation Problem with Minimum CO_2 Emissions
  - Attach great importance to CO_2 emissions
  - Propose a method for solving VRCAP-MCE

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- ○ Effective for cargo carriers that deliver cargos by themselves
- × Not appliable for cargo carriers that entrust all of the deliveries to some subcontractors

Major in Japan

Purpose

- Develop the method to determine cargo allocation and delivery routes for both the cargo carrier and the subcontractors
  - Define VRCAP-MCMCE
    - Vehicle Routing and Cargo Allocation Problem with Minimum Cost and Minimum CO_2 Emissions
  - Propose a method for solving VRCAP-MCMCE

Cargo carriers and subcontractors hope to reduce their costs than CO_2 emissions

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Cost for cargo carrier

- Outsourcing fee = Charter fee of trucks
- Charter fee of a truck per day
  - Dependence on the maximum load of a truck
  - The larger truck is used, the higher fee is paid
  - Two small trucks cost more than a single large truck

⇩ Cargo allocation

Minimization of the number of trucks

Outsourcing fee↓

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Cost of subcontractor

- Transportation cost
  - Labour cost
  - Fuel cost

⇩ Cargo allocation

- Minimization of the number of trucks

  Labour cost↓

- Finding the route with the minimum CO_2 emissions (Delivery route)

  Fuel cost↓

  Eco-friendly physical distribution

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Definition of VRCAP-MCMCE

- Goal

priority (high → low)

1. Cargo allocation that minimizes the number of trucks <the outsourcing fee for the cargo carrier and the labor cost for the subcontractors>
2. Delivery route and cargo allocation that minimize the CO_2 emissions <the fuel cost for the subcontractors>

- Method for solving VRCAP-MCMCE
  1. Define a tentative cargo allocation
  2. Adjust the cargo allocation to reduce CO_2 emissions without increasing the number of trucks

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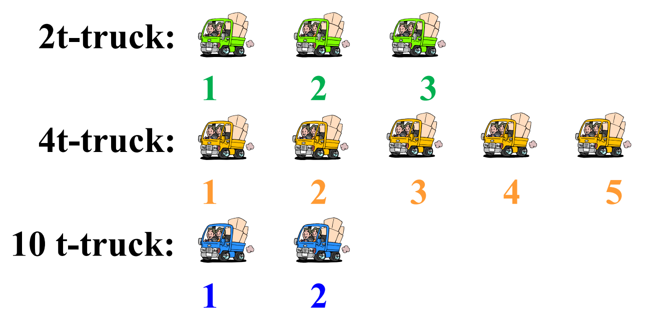
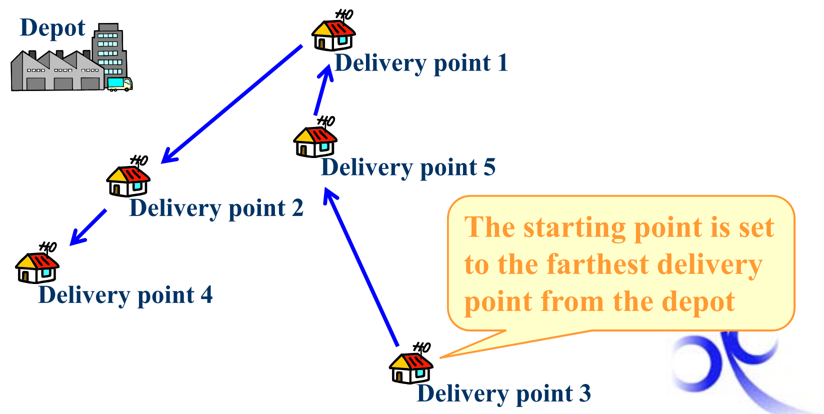
Defining a tentative cargo allocation (1)

1. Put the serial numbers to trucks by the maximum load



Defining a tentative cargo allocation (2)

2. Calculate a path that visits all delivery points using Dijkstra's Algorithm

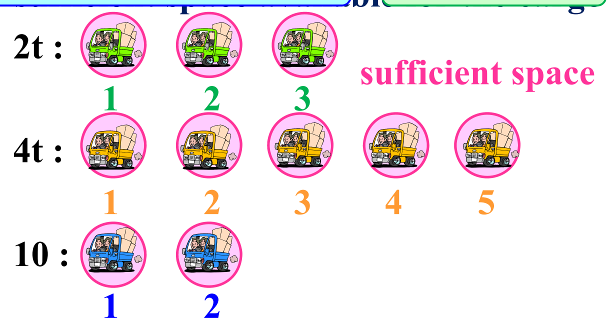


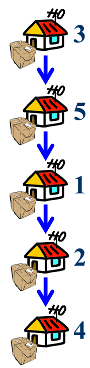
Defining a tentative cargo allocation (3)

3. cargos for neighbouring delivery points → the same truck
   - in the order of the path obtained in Step 2
   - Select the largest truck with the smallest serial number fr… trucks that … bl…

the unit fee for outsourcing ↓

No. of trucks ↓





Defining a tentative cargo allocation (4)

4. Calculate a delivery route for each truck and the corresponding CO_2 emissions

- Use the same method proposed in previous work
- Based on Symbiotic Evolution
  - A kind of evolutionary computation represented by the genetic algorithm

Adjustment of cargo allocation

Select a delivery point randomly

Move the cargo [...] any of the following three co[...]itions is satisfied

- The truck becomes empty
- The truck can be downsized to a smaller truck
- CO_2 emission ↓

Outsourcing fee ↓
Labor cost ↓

Outsourcing fee ↓

move

cannot mo[...]

Select one more deliver[...] randomly

cannot swap

Swap cargos, if the fo[...]

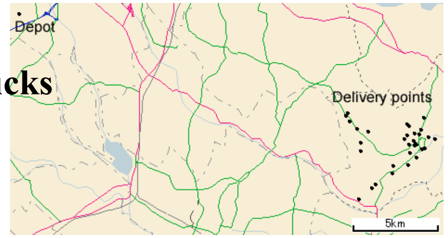
- Both of trucks don't ov[...]
- The total CO_2 emission ↓

swap

Fuel cost ↓ without increasing the outsourcing fee

Evaluation with actual data

- 32 delivery points and the depot
- Number of trucks
  - two lightweight trucks
  - two 1 t trucks
  - two 2 t trucks



Senario	Cargo Weight
flat	for all i $w_i = 186$ kg
heavy1	$w_i = 750$ kg (i = 6, 25) $w_i = 150$ kg ($i \neq 6, 25$)
heavy2	$w_i = 750$ kg (i = 1, 13) $w_i = 150$ kg ($i \neq 1, 13$)
heavy3	$w_i = 750$ kg (i = 9, 18) $w_i = 150$ kg ($i \neq 9, 18$)

Effects of adjustment with the actual data

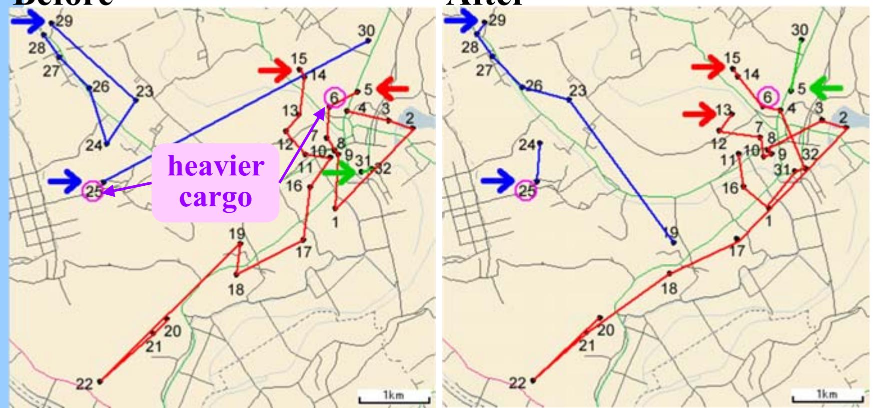
Scenario	Adjust	Transport distance [km]	CO_2 emission	No. of trucks		
				2 t	1 t	light
flat	before	436.21	154.57	2	2	2
	after	397.09	144.45	2	2	2
heavy1	before	355.47	137.01	2	2	1
	after	340.34	132.99	2	2	1
heavy2	before	360.02	137.99	2	2	1
	after	344.24	133.59	2	2	1
heavy3	before	359.79	138.15	2	2	1
	after	343.14	133.75	2	2	1

CO_2 emission ↓

Routes for *heavy1*

Before

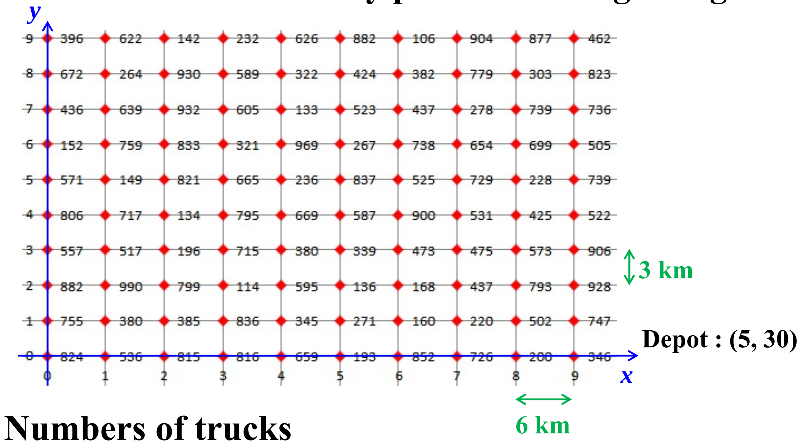
After



by 2 t truck | by 1 t truck | by lightweight truck

Evaluation with synthetic data

- Locations of the delivery points and cargo weights



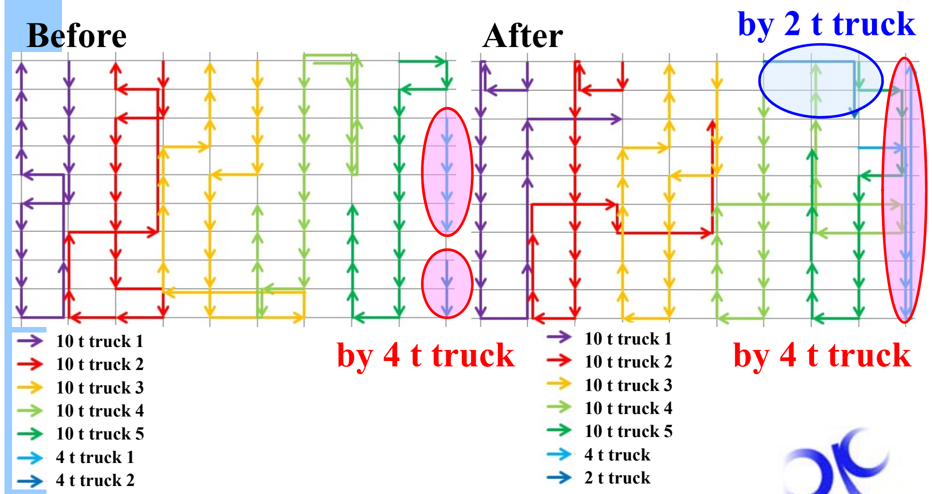
- Numbers of trucks
  - five 2 t trucks, five 4 t trucks, five 10 t trucks

Effects of adjustment with the synthetic data

Adjust	Transport distance [km]	CO_2 emission [kg-CO_2]	No. of trucks		
			10t	4t	2t
before	1626	1233.06	5	2	0
after	1566	1178.94	5	1	1

Fuel cost ↓ Outsourcing fee ↓
Labor cost ↓

Routes for the synthetic data



Conclusion

- Define VRCAP-MCMCE
- Propose the method for VRCAP-MCMCE

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Valid cargo allocation and delivery routes

- Future works
  - Dealing with the various situation
    - The maximum load is restricted
    - The delivery time is constrained