Cost-Oriented Vehicle Routing and Cargo Allocation with Minimum CO_2 Emissions Based on Harmony Search Algorithm

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Background

- Cargo carriers are obligated to reduce the CO_2 emissions from cargo transportation activities
- Most of cargo carriers in Japan entrust all of the deliveries to some subcontractors
- Both cargo carriers and subcontractors hope to reduce their cargo transportation costs rather than CO_2 emissions

CO_2 Emissions

- 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

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↓

Cost for subcontractor

- Transportation cost
  - Fuel cost
  - Labour cost

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Delivery route

  - Finding the route with the minimum CO_2 emissions

    Fuel cost↓

    Eco-friendly physical distribution
  - The route with the minimum CO_2 emissions is not so long

    Labour cost↓

VRCAP-MCMCE

Vehicle Routing and Cargo Allocation Problem with Minimum Cost and Minimum CO_2 Emissions

- Solution

  Cargo allocation and delivery routes for both the cargo carrier and the subcontractors
- Goal

high ↑ priority ↓ low

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

Proposed method in previous work

1. Generate a tentative cargo allocation with a low outsourcing fee
2. Adjust the cargo allocation to reduce CO_2 emissions while the outsourcing fee is kept at or below the original tentative allocation
   - Select one cargo from a truck, and allocate to the other truck
   - Select one cargo from two trucks respectively, and exchange them
3. Repeat 2

Gradual method

Purpose of this study

Gradual method is ...

- able to find valid solutions
- NOT a global search but a hill-climbing method

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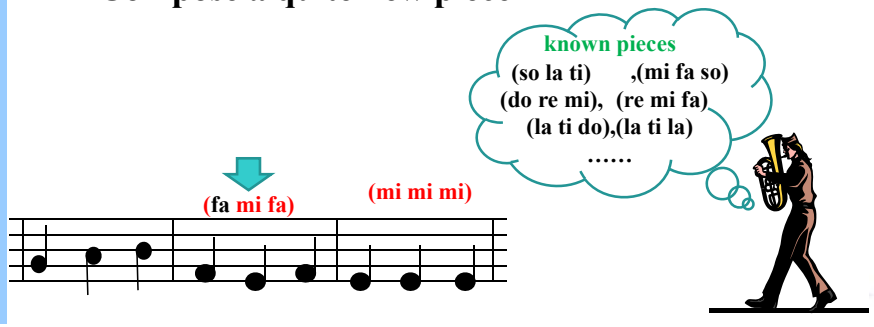
Apply an evolutionary computation algorithm to search a solution space globally and efficiently

Propose a method based on a harmony search algorithm

Harmony Search

- Metaheuristic optimization algorithm that imitates the musical improvisational process
  - Select any famous piece from his memory
  - Adjust the pitch of a known piece slightly
  - Compose a quite new piece



Harmony search

- harmony = a candidate solution
- harmony memory (HM) = a set of harmonies

1. Initialize HM
2. Generate a new harmony
   - Copy a variable in a harmony from HM
   - Adjust a variable in a harmony from HM
   - Generate a new variable randomly
3. Replace the worst harmony with the new one, if the new one is better than the worst one
4. Repeat 2 - 3

Initialization of HM

1. Generate a tentative cargo allocation in the same way as the gradual method
2. Adjust the tentative cargo allocation by applying one of the adjustment operators of the gradual method
3. Repeat 2, and make them harmonies of the initial HM

Generation of a new harmony

1. Adjust one harmony selected from HM as in a gradual method

Smaller change

2. The probability to use the first operator

$$P(k) = 0.5 \times \frac{k}{K} + 0.5$$

k : the repetition count

K : maximum number of repetitions

The larger the repetition count is, the more frequently the first operator is used

- Generate a new truck randomly

Evaluation value of a harmony

- Weighted sum of the total outsourcing fee and the total CO_2 emissions

$$h(s) = \beta \cdot g(U_1, \cdots, U_M) + f(\vec{r_1}, \cdots, \vec{r_M}) \cdot 10^3$$

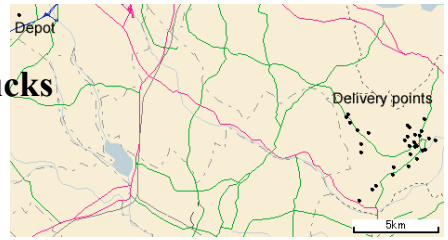
$f(\vec{r_1}, \cdots, \vec{r_M})$: total outsourcing fee

$g(U_1, \cdots, U_M)$: total CO_2 emissions

This should be set so that the outsourcing fee takes priority over CO_2 emissions

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
case1	$w_i = 750$ kg ($i = 6, 25$) $w_i = 150$ kg ($i \neq 6, 25$)
case2	$w_i = 750$ kg ($i = 1, 13$) $w_i = 150$ kg ($i \neq 1, 13$)
case3	$w_i = 750$ kg ($i = 9, 18$) $w_i = 150$ kg ($i \neq 9, 18$)

Solve 10 times respectively

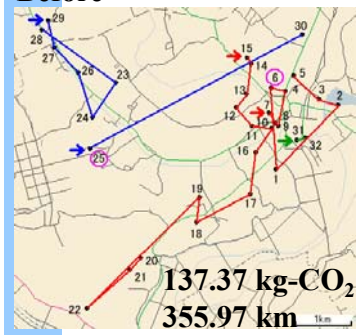
Effects of adjustment with the actual data

Labor cost ↓ Fuel cost ↓

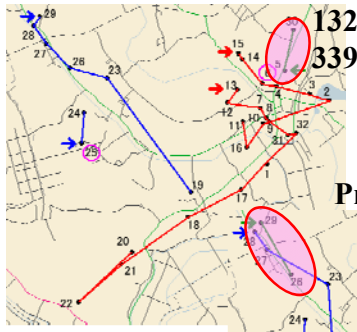
Scenario	Adjust	Transport distance [km]		CO_2 emission		No. of trucks		
		Ave.	SD	Ave.	SD	2 t	1 t	light
case1	before	355.61	0.46	137.14	0.21	2	2	1
	gradual	340.40	0.51	133.02	0.24	2	2	1
	proposed	340.27	0.90	132.95	0.32	2	2	1
case2	before	360.02	0.22	138.03	0.07	2	2	1
	gradual	342.78	1.74	133.61	0.64	2	2	1
	proposed	340.82	0.87	132.76	0.11	2	2	1
case3	before	360.05	0.26	138.29	0.09	2	2	1
	gradual	342.79	1.25	133.67	0.58	2	2	1
	proposed	342.02	1.06	133.23	0.22	2	2	1

Routes for *case1*

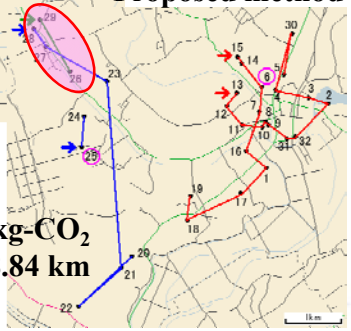
Before



Gradual method



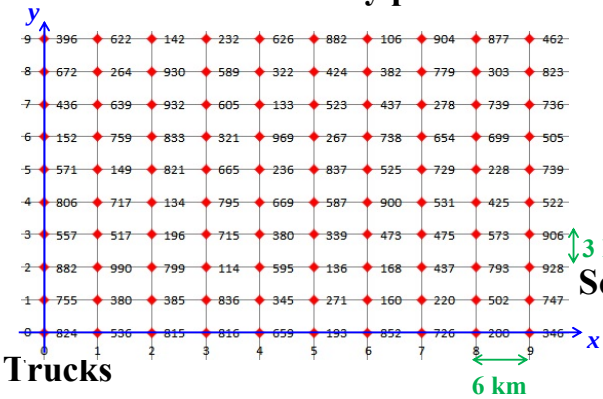
Proposed method



heavier cargo
by 2 t truck
by 1 t truck
by lightweight truck

Evaluation with synthetic data

- Locations of the delivery points and cargo weights



Solve 10 times

- Trucks
  - five 2 t trucks (30,000 JPY), five 4 t trucks (40,000 JPY), five 10 t trucks (50,000 JPY)

Effects of adjustment with the synthetic data

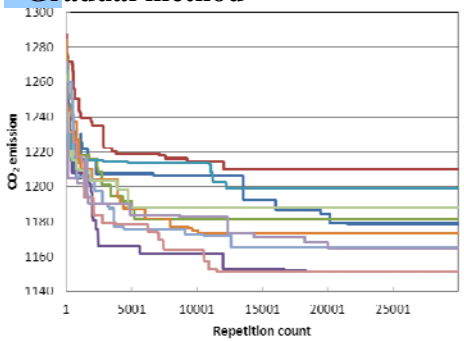
Adjust	Transport distance [km]		CO_2 emission [kg-CO_2]		Outsourcing fee [JPY]	No. of trucks		
	Ave.	*SD*	Ave.	*SD*		10t	4t	2t
before	1685	21.4	1279	16.5	330,000	5	2	0
gradual	1565	24.7	1176	18.2	320,000	5	1	1
proposed	1547	13.1	1161	8.3	320,000	5	1	1

Labor cost ↓ Fuel cost ↓ Outsourcing fee ↓

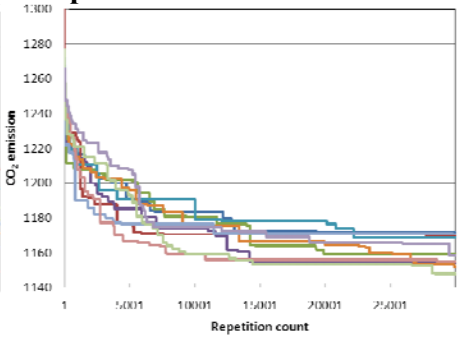
The proposed method could find better solutions stably than the gradual method

Evaluation value of the best harmony

Gradual method



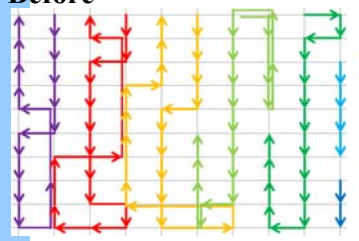
Proposed method



The proposed method could find better solutions certainly in earlier stage

Routes for the synthetic data

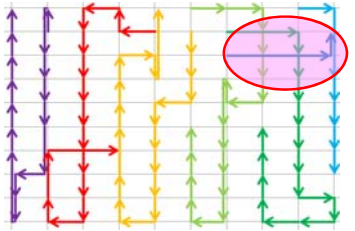
Before



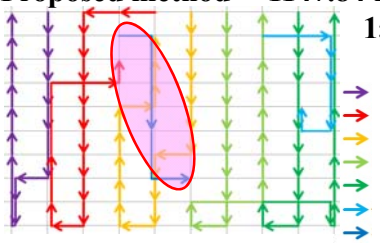
1295.95 kg-CO_2
1704 km

10 t truck 1
10 t truck 2
10 t truck 3
10 t truck 4
10 t truck 5
4 t truck 1
4 t truck 2

Gradual method 1151.51 kg-CO_2
1530 km



Proposed method 1147.84 kg-CO_2
1530 km



10 t truck 1
10 t truck 2
10 t truck 3
10 t truck 4
10 t truck 5
4 t truck
2 t truck

Conclusion

- **Propose the method for VRCAP-MCMCE based on a harmony search algorithm**

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  Cargo allocation and delivery routes with lower CO_2 emissions and costs were obtained

- **Future works**
  - **Develop new adjustment operators**
  - **Examine the applicability of other evolutionary computation algorithms**