Method for Solving the Vehicle Routing Problem with Minimum CO_2 Emissions

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Background

- Reduction of CO_2 emissions from freight transportation activities
- Delivery of cargos with different weights
  - Shortest route ≠ the route with minimum CO_2 emissions
  - Possibility of recalculation of the route because of the absence of the receiver

Necessity for solving VRP-MCE within permissible time Vehicle Routing Problem with Minimum CO_2 Emissions

VRP-MCE

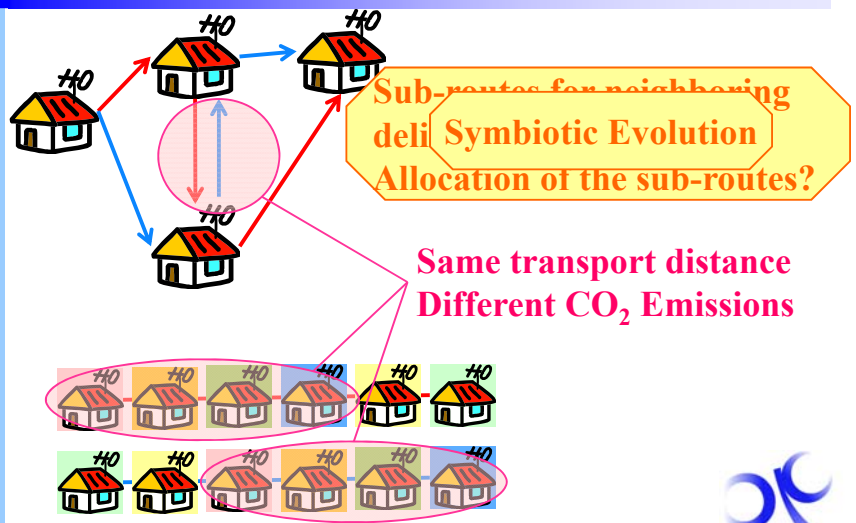
- Find the route with the minimum CO_2 emissions
- Starting point and terminal point are the depot
- Two of more delivery points with different weight cargos
- Total weight of cargos ≦ the maximum loading weight of the truck
- CO_2 emissions are calculated by the revised ton-kilometer method

Calculation method for CO_2 emissions

Revised ton-kilometer method

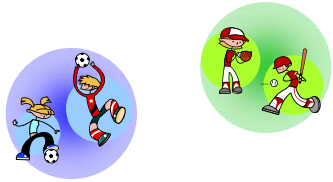
- Amount of fuel consumed per ton-km x (L/t·km)
  - $\ln x = 2.71 - 0.812\ln(1000w/z) - 0.654\ln z$
    - w (t) : cargo weight
    - z (kg) : the maximum load of the truck
- CO_2 emissions e (t-CO_2)
  - $e = 2.62xdw / 1000$
    - d (km) : transport distance

Characteristics of VRP-MCE



Symbiotic Evolution

- A kind of evolutionary computation represented by the genetic algorithm
- Teamwork
  - Whole solution = Combination of partial solutions
  - Parallel evolution of two populations
  - Avoid local minimum and find good solution

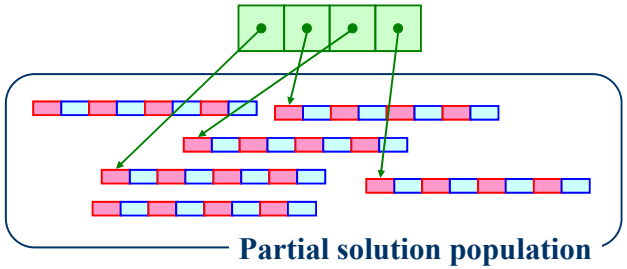


Chromosome

- Patial solution
  - Sub-route with L_p delivery points

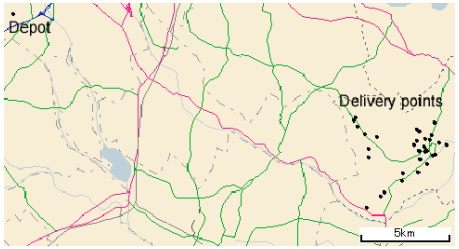
dpID1	dpID2	...	dpIDL_p

- Whole solution
  - Combination of pointers for partial solution



Experiments

- Truck
  - One 2000kg truck using light oil
- Delivery points
  - Customers of one freight carrier



Performance test with small datasets

- Number of delivery points : 9-13
  Possible to calculate the optimal solution by the very thorough search
- Cargo weights
  - random (0 - 62.5 kg)
- Comparison
  - Performances between the proposed method and the very thorough search

Performance test with small datasets

- Same route for all data
- Time for computation

Number of data	Proposed method	Very thorough search
9	6.62	0.11
10	6.74	1.23
11	7.50	14.29
12	7.61	180.22
13	7.56	2401.33

[second]

Very little change

Increase with *N* rapidly

Performance test with large datasets

- 32 delivery points
- Cargo weight data
  - *zero* ... 0kg
  - *random* … 0 - 2000/32 kg
  - *flat* … 62 kg
  - *heavy-1* ... w_6=w_{15}=250 kg, others=50 kg
  - *heavy-2* ... w_8=w_{21}=250 kg, others=50 kg
  - *heavy-3* ... w_{13}=w_{29}=250 kg, others=50 kg
  - *heavy-3** ... w_{13}=w_{29}=970 kg, others=2 kg
- Repeat computing for each data 10 times
- Compare with the saving method
  a conventional method for VRP

Results on large datasets

Data	Computation time [s]		CO_2 emission [kg-CO_2]		Transport distance [km]	
	Proposed	Saving	Proposed	Saving	Proposed	Saving
random	14.06	0.001	41.42	48.76	95.21	103.28
flat	15.34	0.001	47.21	54.26	94.58	103.28
heavy-1	15.46	0.001	46.26	54.00	93.83	103.28
heavy-2	14.86	0.001	46.60	54.46	93.99	103.28
heavy-3	14.90	0.001	46.85	54.29	94.11	103.28
*heavy-3**	8.51	0.001	37.85	53.26	107.12	103.28

Faster

Smaller

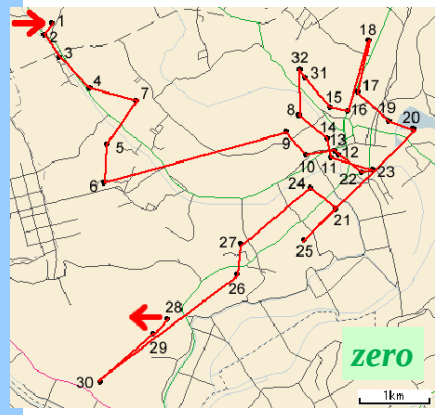
Shorter

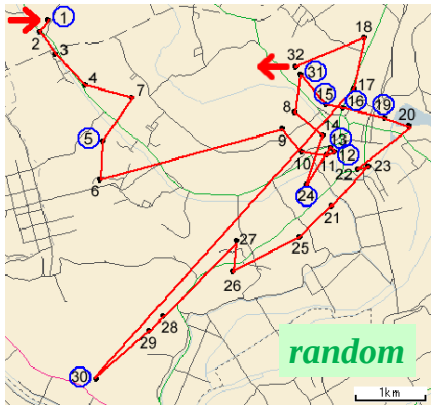
Comparison with the shortest route

Route / Data	For each data item		For *zero*	
	Transport distance [km]	CO_2 emission [kg-CO_2]	Transport distance [km]	CO_2 emission [kg-CO_2]
random	95.02	41.28	90.22	42.27
flat	93.57	46.51	90.22	47.03
heavy-1	93.57	46.08	90.22	46.61
heavy-2	93.67	46.30	90.22	46.87
heavy-3	93.57	46.43	90.22	46.98
*heavy-3**	103.57	37.57	90.22	46.39

Longer Smaller

Best route for *zero* and *random*



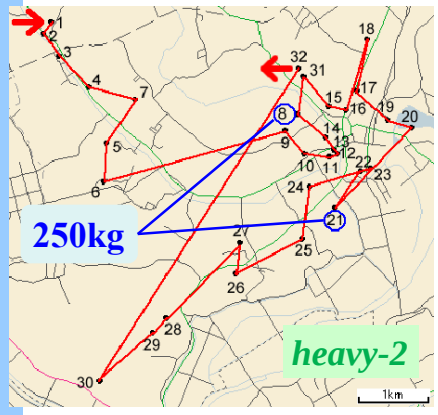


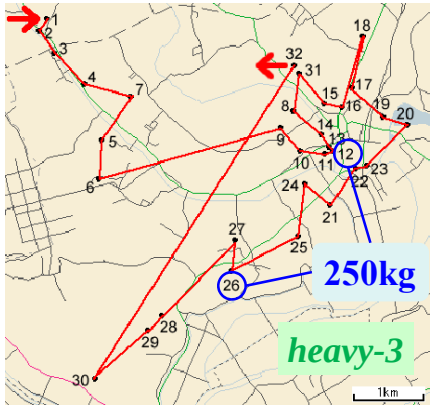
approximate shortest route

○… with heavier cargos

Visit delivery points with heavier cargos ahead

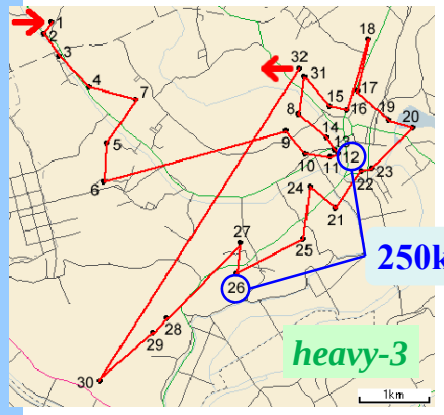
Best route for *heavy-2* and *heavy-3*

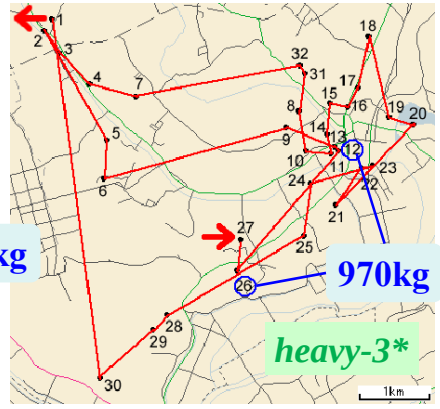




The order depends on the location of delivery points with heavier cargos

Best route for *heavy-3* and *heavy-3**





Extremely heavy cargos are deliverd first of all

Conclusion

- Define VRP-MCE
- Propose a method for solving VRP-MCE
  - Fast sufficiently
  - Optimal route in small datasets
  - Valid route in large datasets
- Future works
  - Extend VRP-MCE for use in various situations
  - Develop a method for solving the extended problem