

Formulation and solution technique for agricultural waste collection and transport network design

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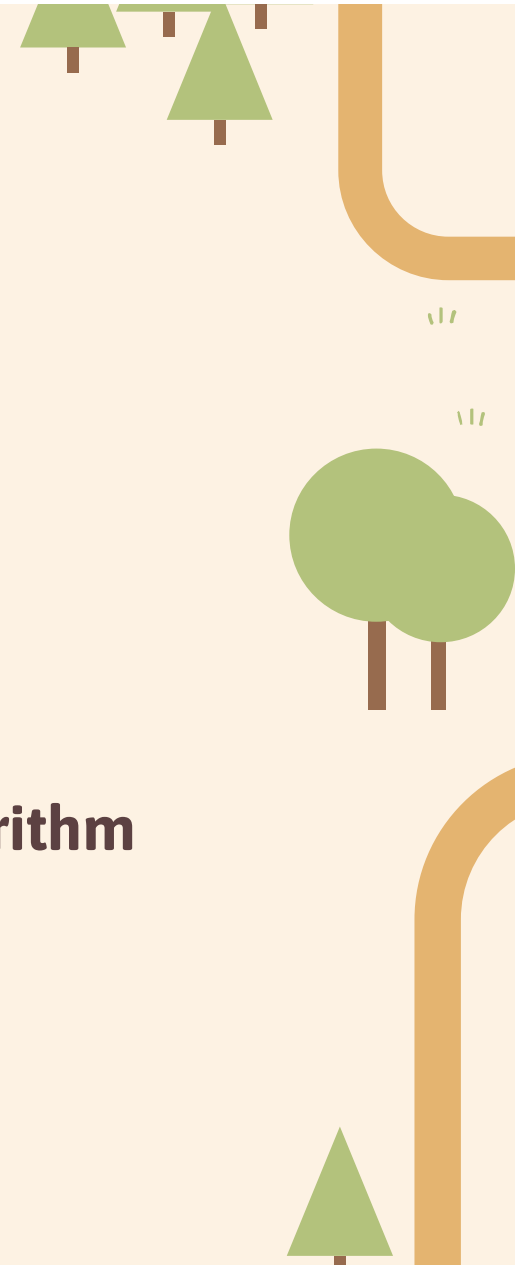
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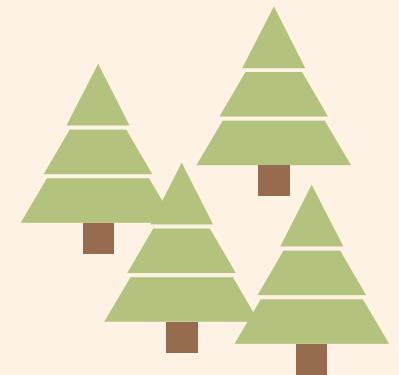
01

Problem Introduction

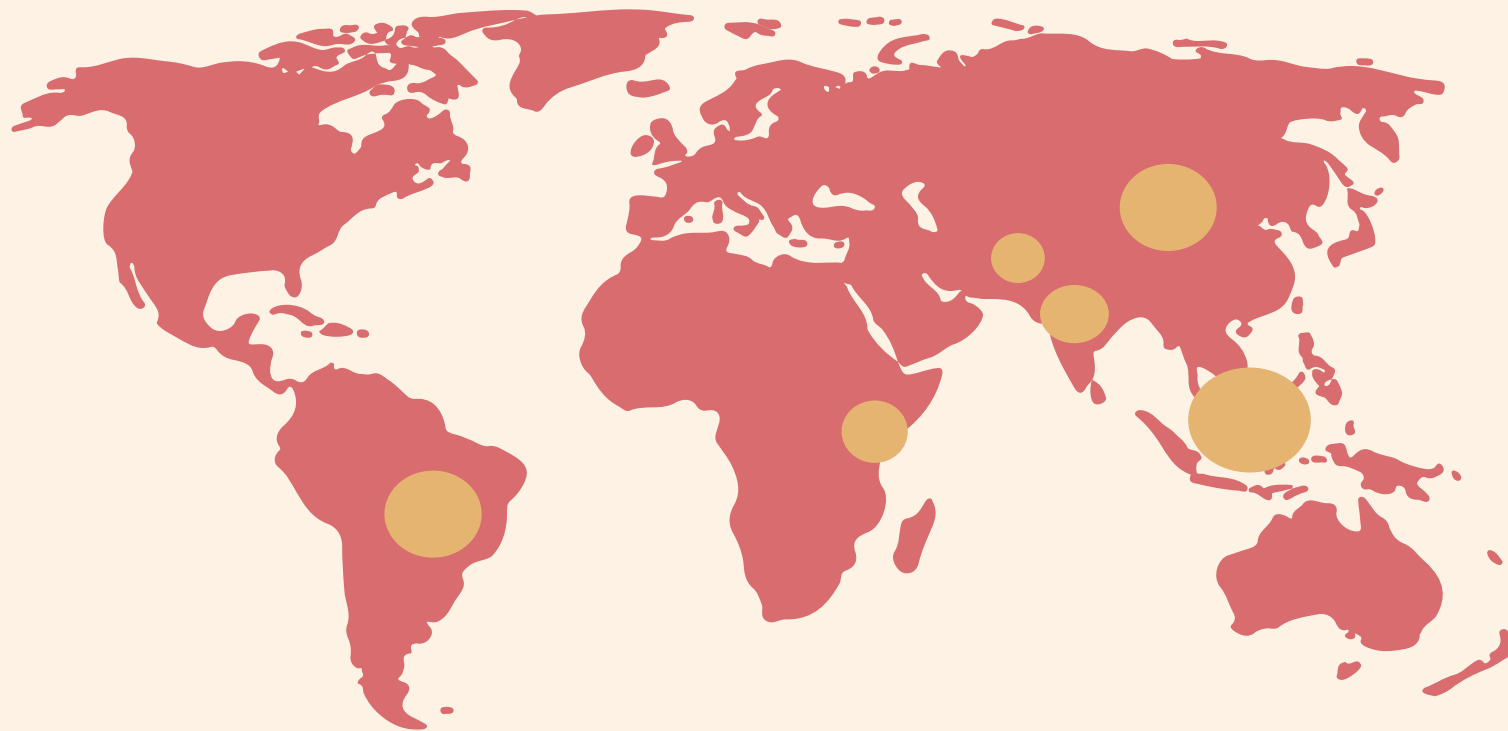
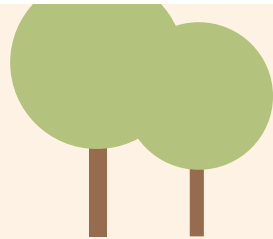
Agricultural waste management



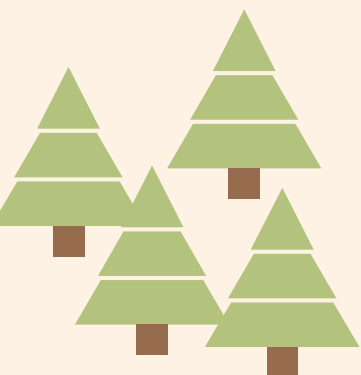
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- In developing countries, agricultural sectors have rapidly developed into become major contributions in the economy.
 - Agricultural waste management has posed a challenge for rural planner due to lack of efficient planning tool.
 - Burning the agricultural waste at fields after each harvesting season is the present solution, this caused air and water pollution in rural areas.
- 



Agricultural waste around the world for developing countries



source: International Journal of Environmental Research and Public Health



45,22 million tons

Rice straw

10 millions tons

Vegetable by-products

6,33 millions tons

Maize by-products



source: Ministry of Agriculture and Rural Development of Vietnam

An efficient way to recover agricultural waste



02

Modelling

Location-Assignment-Routing-Problem





Logistic problem

Which and how many places should be chosen where storages should be built to ensure coverage over all cultivation fields?

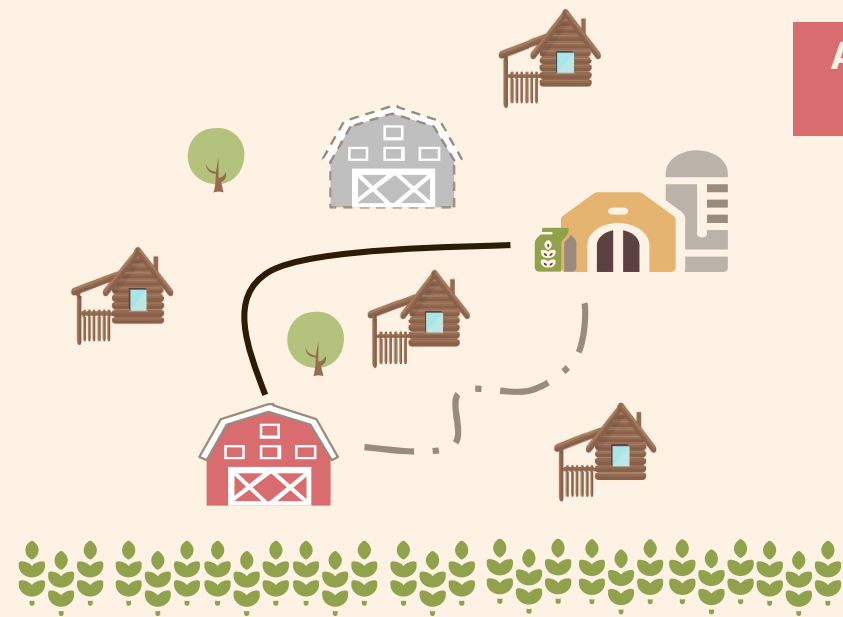


Location Assignment Problem

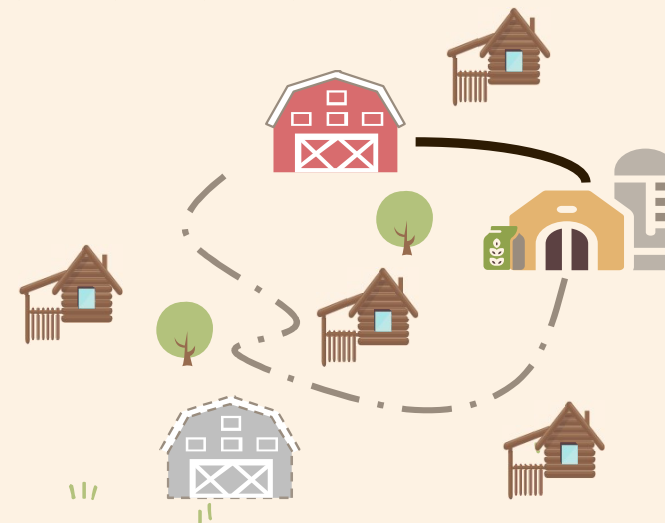
Which roads should trucks take to visit all the storages and bring agricultural waste to the fertiliser factory?



Routing Problem



A possible scenario



Another possible scenario



Model Formulation



Sets and indexes

I Set of agricultural waste fields (indexed by) i

J Set of storages (indexed by) j

J_0 Set of storages and the facility, i.e., $J_0 = J \cup 0$ indexed by u, v

Parameters

n Number of agricultural waste fields

m Number of storages

f_j Fixed cost to open a storage j

$c_{i,j}, c_{u,v}$ Distance between nodes i, j or u, v

d_i Amount of agricultural waste to be collected at field i

q_j Capacity of storage j

k Number of vehicles

Q Capacity of vehicle

Decision variables

$X_j = \begin{cases} 1 & \text{if storage is located at site } j \\ 0 & \text{otherwise} \end{cases}$

$Y_{ij} = \begin{cases} 1 & \text{if field } i \text{ is served by storage } j \\ 0 & \text{otherwise} \end{cases}$

$Z_{uv} = \begin{cases} 1 & \text{if a vehicle travels from node } u \text{ to node } v \\ 0 & \text{otherwise} \end{cases}$

T_u, T_v Auxiliary variables

Model Formulation

$$\min \sum_{j \in J} f_j \cdot X_j + \sum_{i \in I} \sum_{j \in J} c_{ij} \cdot d_i \cdot Y_{ij} + \sum_{u \in J_0} \sum_{v \in J_0: u \neq v} c_{uv} \cdot Z_{uv}$$

$$(C1) \sum_{j \in J} Y_{ij} = 1 \quad \text{for each } i \in I$$

$$(C2) \sum_{i \in I} d_i \cdot Y_{ij} \leq q_j \cdot X_j \quad \text{for each } j \in J$$

$$(C3) \sum_{u \in J} Z_{u0} = k$$

$$(C4) \sum_{v \in J} Z_{0v} = k$$

$$(C5) \sum_{u \in J_0: u \neq v} X_u \cdot Z_{uv} = X_v \quad \text{for each } v \in J$$

$$(C6) \sum_{v \in J_0: v \neq u} X_v \cdot Z_{uv} = X_u \quad \text{for each } u \in J$$

$$(C7) T_u - T_v + Q \cdot Z_{uv} \leq Q - \frac{1}{k} \cdot \sum_{i \in I} d_i \cdot Y_{iv} \quad \text{for each } u, v \in J : u \neq v$$

$$(C8) \frac{1}{k} \cdot \sum_{i \in I} d_i \cdot Y_{iv} \leq T_u \leq Q \quad \text{for each } u \in J$$

$$(C9) X_j \in \{0, 1\} \quad \text{for each } j \in J$$

$$(C10) Y_{ij} \geq 0 \quad \text{for each } i \in I, \text{ for each } j \in J$$

$$(C11) Z_{uv} \geq 0 \quad \text{for each } u \in J$$

$$T_u \geq 0 \quad \text{for each } u \in J$$

Legenda

Capacitated facility location cstrs.

TSP adjusted for CVRP cstrs.

Assignment cstrs.



Model Formulation



Product of decision variables

$$(C5) \quad \sum_{u \in J_0: u \neq v} \boxed{X_u \cdot Z_{uv}} = X_v \quad \text{for each } v \in J$$

$$(C6) \quad \sum_{v \in J_0: v \neq u} X_v \cdot Z_{uv} = X_u \quad \text{for each } u \in J$$



Non-linear constraints

Linearization of non-linear constraints

$$W_{uv} = X_u \cdot Z_{uv} \quad \text{for each } u, v \in J_0 : u \neq v$$

$$W'_{uv} = X_v \cdot Z_{uv} \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C12) \quad \sum_{v \in J_0: u \neq v} W_{uv} = X_u \quad \text{for each } u \in J$$

$$(C16) \quad \sum_{v \in J_0: u \neq v} W'_{uv} = X_v \quad \text{for each } u \in J$$

$$(C13) \quad W_{uv} \leq X_u \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C17) \quad W'_{uv} \leq X_v \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C14) \quad W_{uv} \leq Z_{uv} \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C18) \quad W'_{uv} \leq Z_{uv} \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C15) \quad W_{uv} \geq X_u + Z_{uv} - 1 \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C19) \quad W'_{uv} \geq X_v + Z_{uv} - 1 \quad \text{for each } u, v \in J_0 : u \neq v$$

03

Case studies & Scalability analysis

LARP optimal solution



Three scenarios for a proof-of-concept



X 3

Main facilities where bio-fertilizer is produced from the agricultural wastes (only one per scenario)



X 6

Storages with a certain capacity and fix opening cost



X 7

Cluster of agricultural fields with a certain amount of agricultural waste



X 3

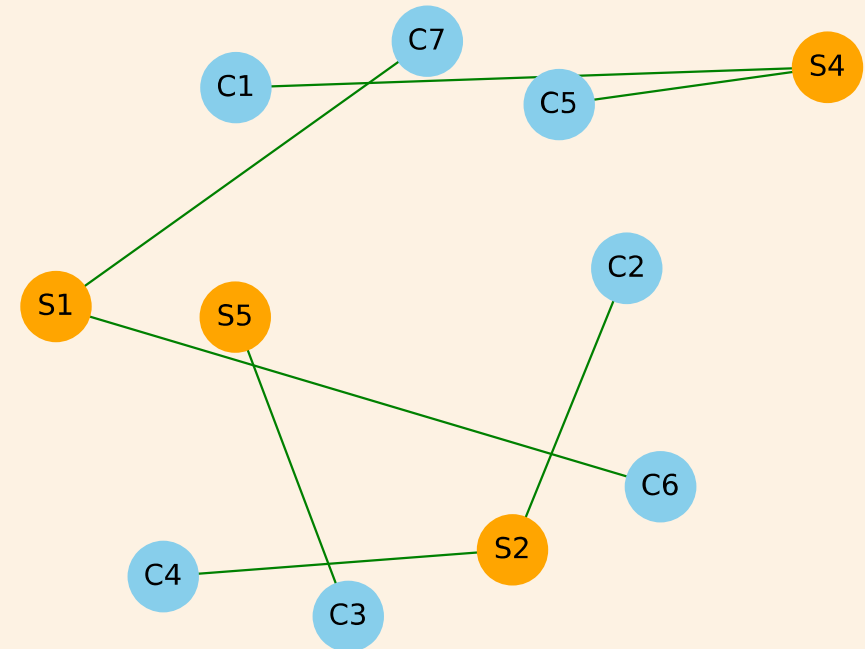
Truks with a certain capacity and capable to move agricultural wastes from storages to the main facility



Graphical representations

- All the scenarios share the same assignments among storages and agricultural fields
- Storages «S3» and «S6» are not considered in the result, it means that opening a storage to these locations is not suggested

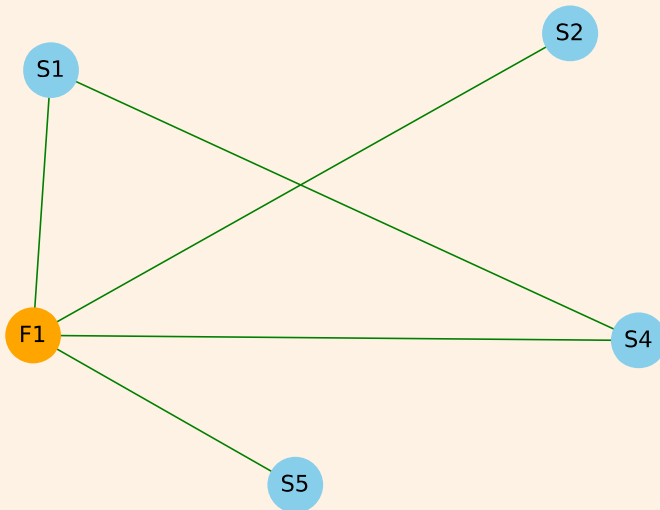
Location cost = 400
Assignment cost = 80,2



Graphical representations

scenario 1

Transportation cost = 57,0
Total cost = 537,2



R1 composed by: F1, S1, S4, F1
R2 composed by: F1, S2, F1
R3 composed by: F1, S5, F1

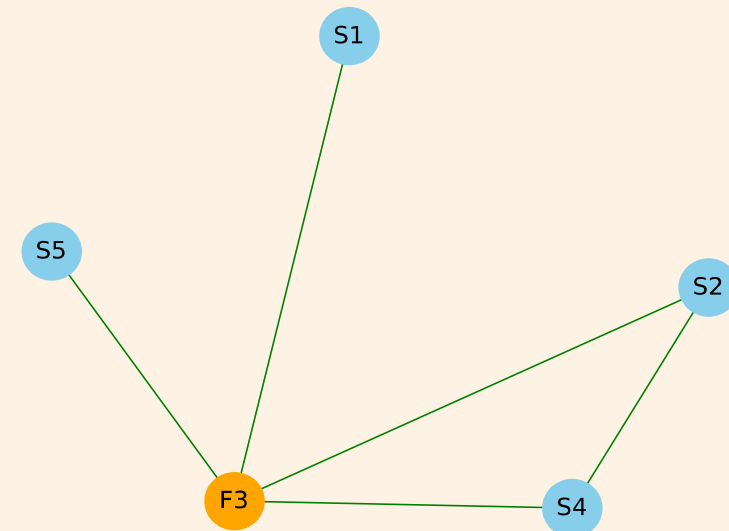
scenario 2

Transportation cost = 119,2
Total cost = 599,4

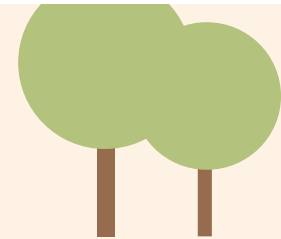
R1 composed by: F2, S1, S2, F2
R2 composed by: F2, S4, F2
R3 composed by: F2, S5, F2

scenario 3

Transportation cost = 55,0
Total cost = 535,2



R1 composed by: F3, S1, F3
R2 composed by: F3, S4, S2, F3
R3 composed by: F3, S5, F3



Scalability analysis

Parameters used for the experiment:

Num vehicles = 5

Vehicle capacity = 2000 (tons)

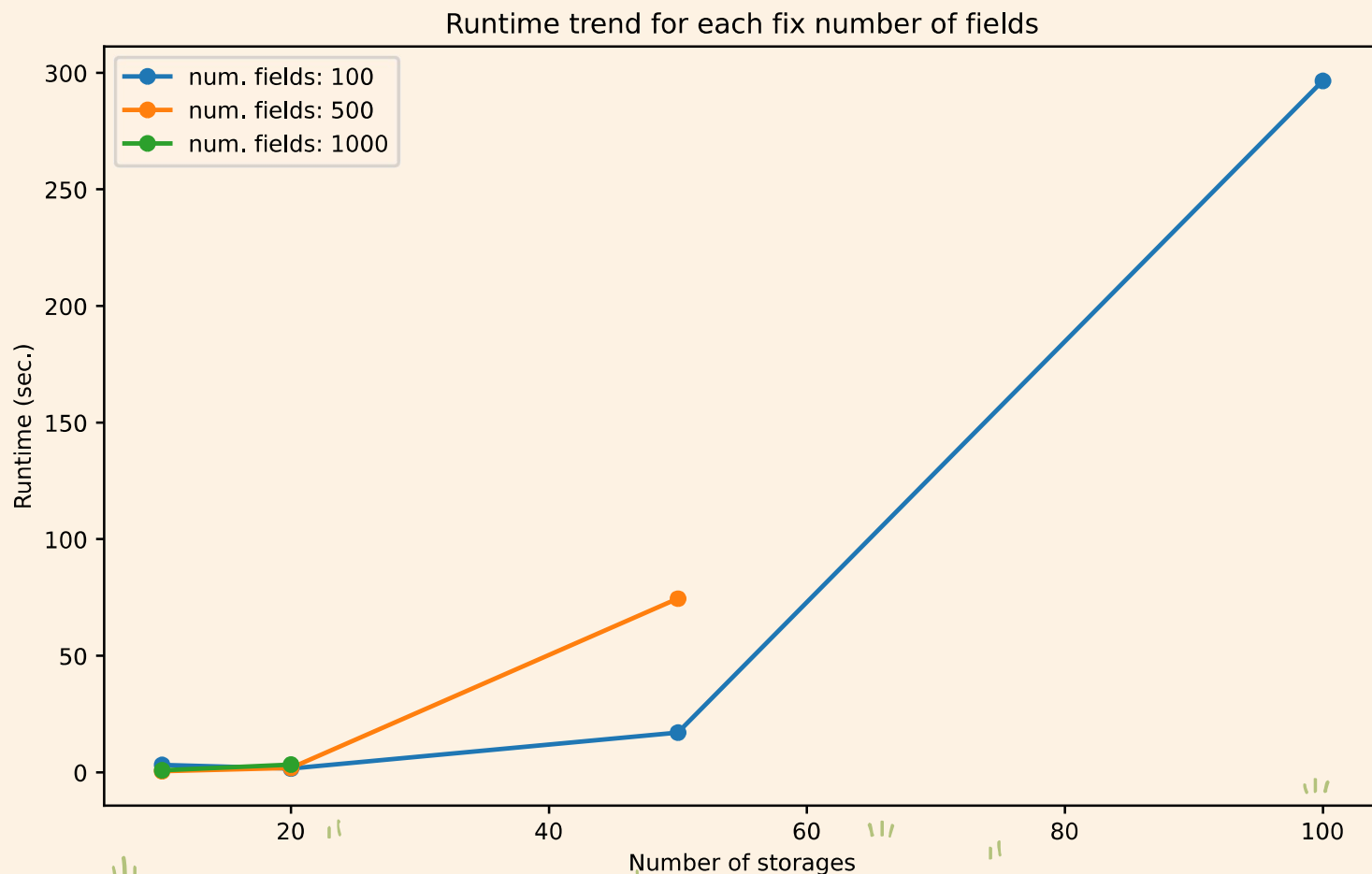
Facility = 'F'

Num fields = [100, 500, 1000]

Num storages = [10, 20, 50, 100, 200]

Proposed model formulation is clearly not able to provide an optimal solution for different sizes of the problem, in «acceptable» timeframe.

Scalability plot confirms the **NP-hard** nature of the problem.



04

Water Flow Algorithm

A meta-heuristic improvement



References

- Formulation and solution technique for agricultural waste collection and transport network design, European Journal of Operational Research
- Waste Mismanagement in Developing Countries: A Review of Global Issues, International Journal of Environmental Research and Public Health
- Statistics Report (2019), Ministry of Agriculture and Rural Development of Vietnam
- A Waterflow Algorithm for Optimization Problems (2011), Tran Trung Hieu

