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

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Chapters

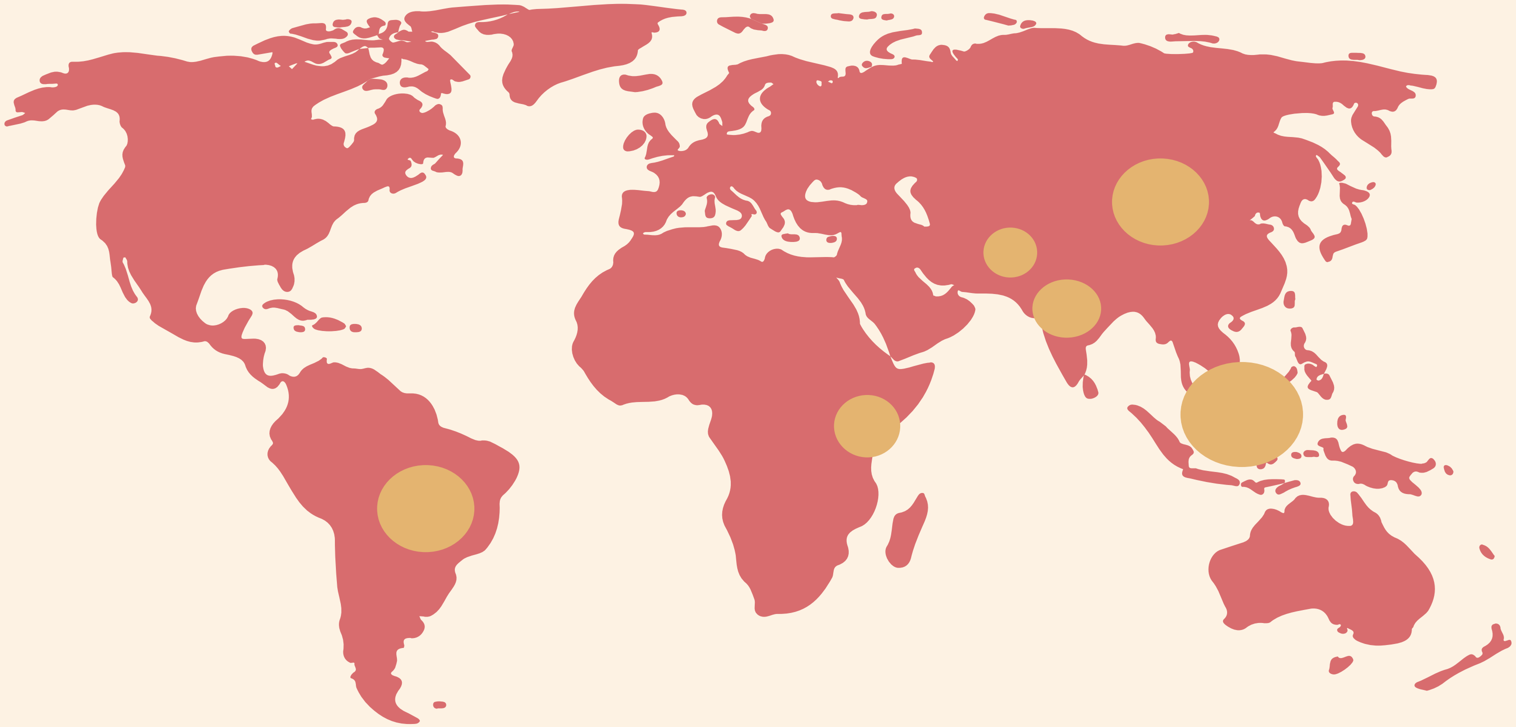
01

Problem Introduction

Agricultural waste management

- In developing countries, agricultural sectors have rapidly developednto become major contributions in the economy.
- Agricultural waste management has posed a challange 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

Vietnam
2019

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

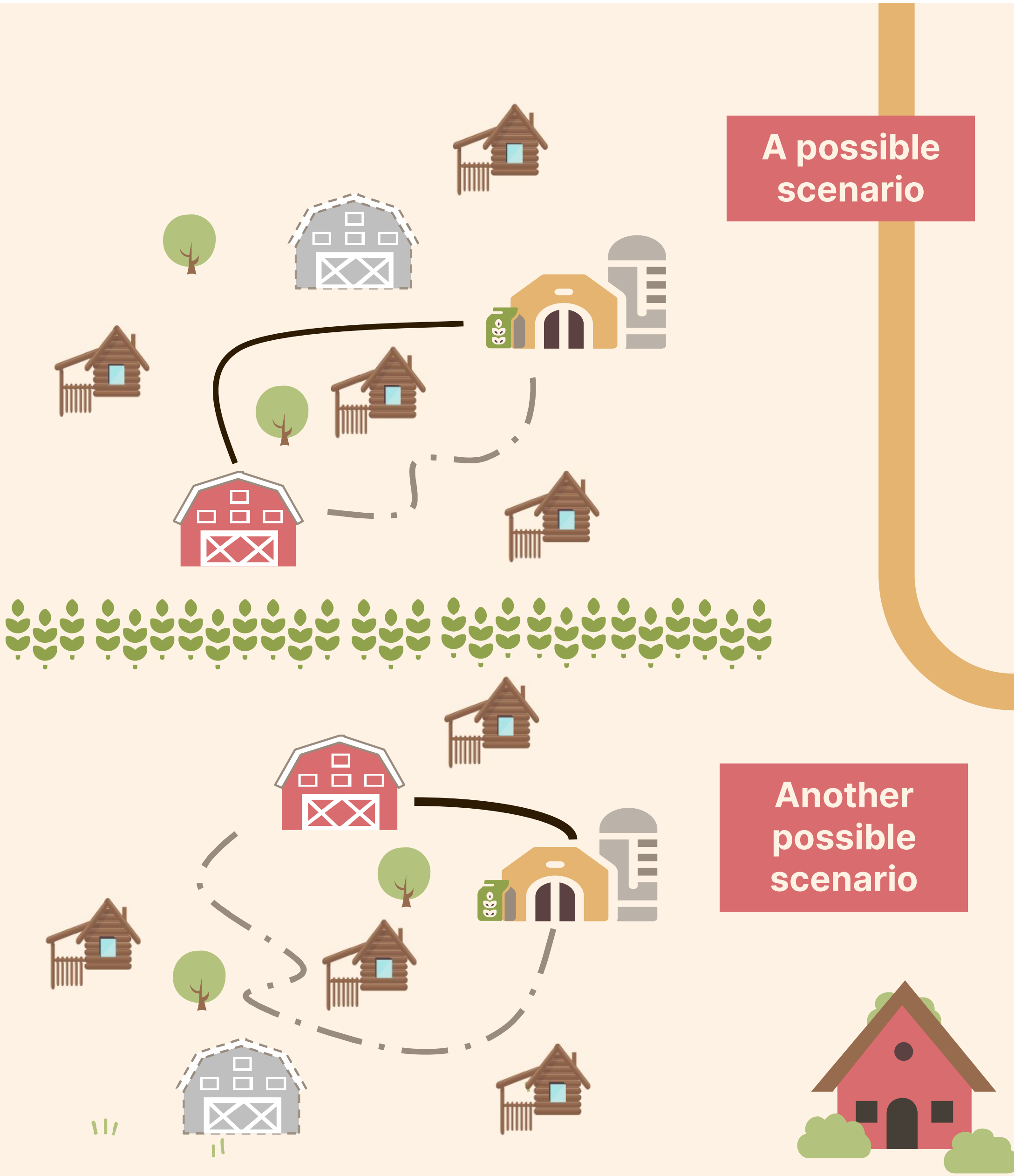
Logistic problem

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



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

Paramenters

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n Number of agricultural waste fields
m Number of storages
f_jFixed cost to open a storage j
$c_{i,j} c_{u,v}$ Distance between nodes i, j or u, v
d_i Ammount 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

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

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

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

T_u, T_v Auxiliary variables

Model Formulation

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

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

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

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

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

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

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

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

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

$$(C9) X_j \in 0, 1 \quad \text{for each } u, vinJ0 : u \neq v$$

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

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

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

Legenda

Capacitated facility location cstrs.

TSP adjusted for CVRP cstrs.

Assignment cstrs.

Model Formulation

Product of decision variables

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

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

Non-linear constrains

Linearization of non-linear constrains

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

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

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

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

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

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

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

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

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

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

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

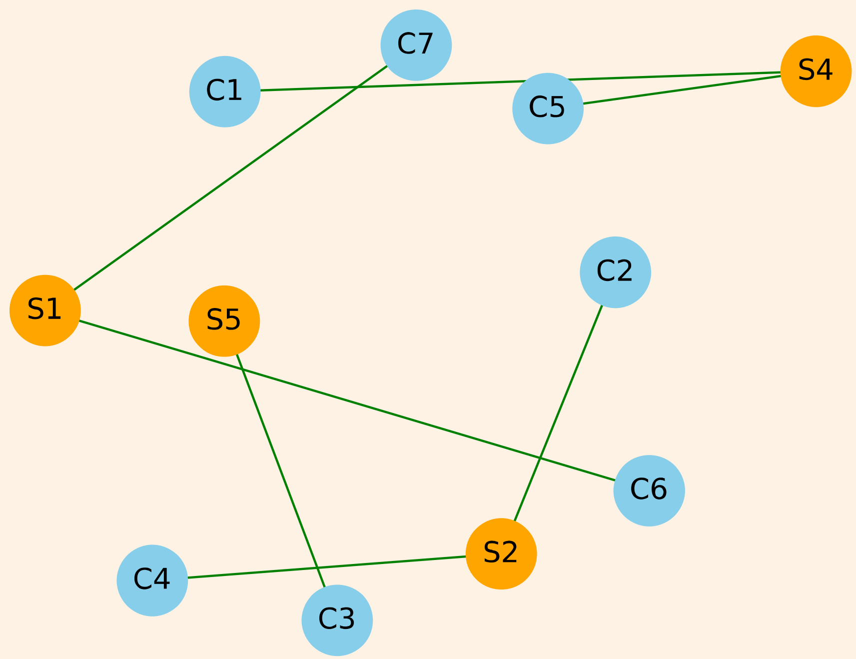
X 3 Truks with a certain capacity and capable to move agricultural wastes from storages to the main facility

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

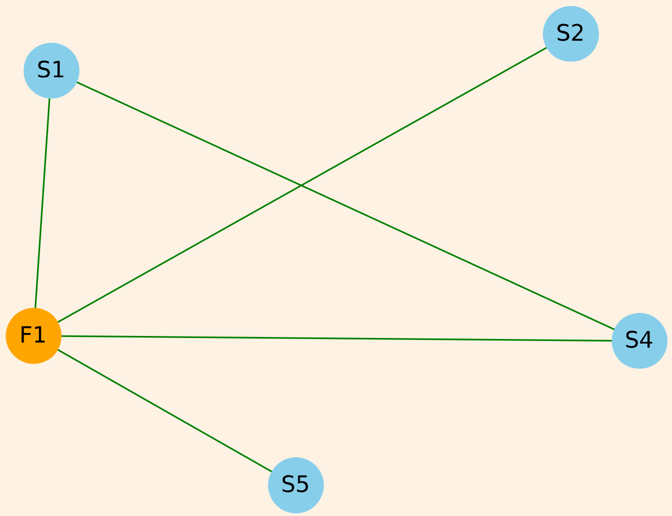
Location cost = 400
Assignment cost = 80,2



Graphical representations

scenario 1

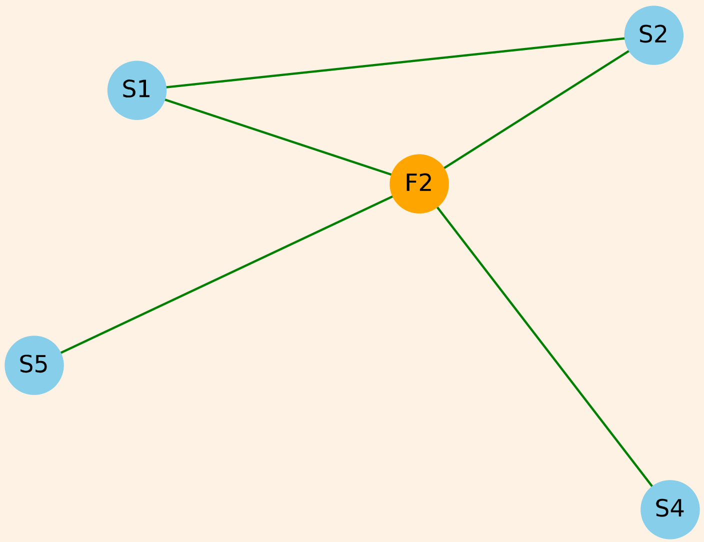
Transportation cost = 57,0
Total cost = 537,2



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

scenario 2

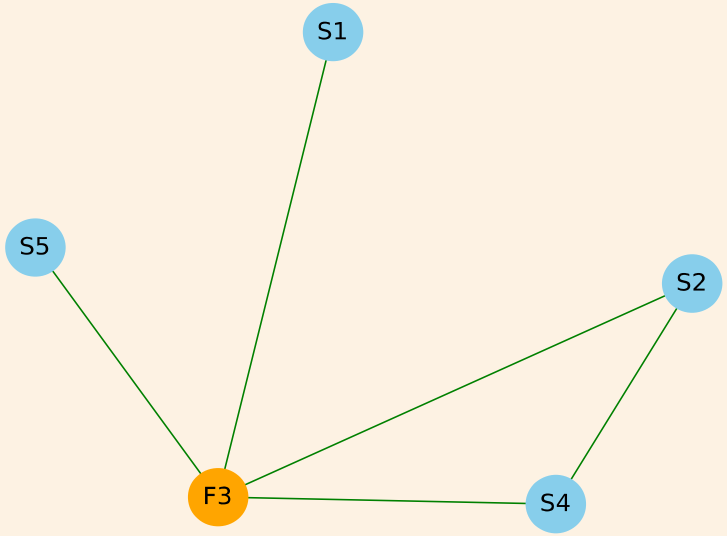
Transportation cost = 119,2
Total cost = 599,4



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 (1)

Parameters used for the experiment:

Facility = 'F'

Num iterations = 10

Num fields = [100]

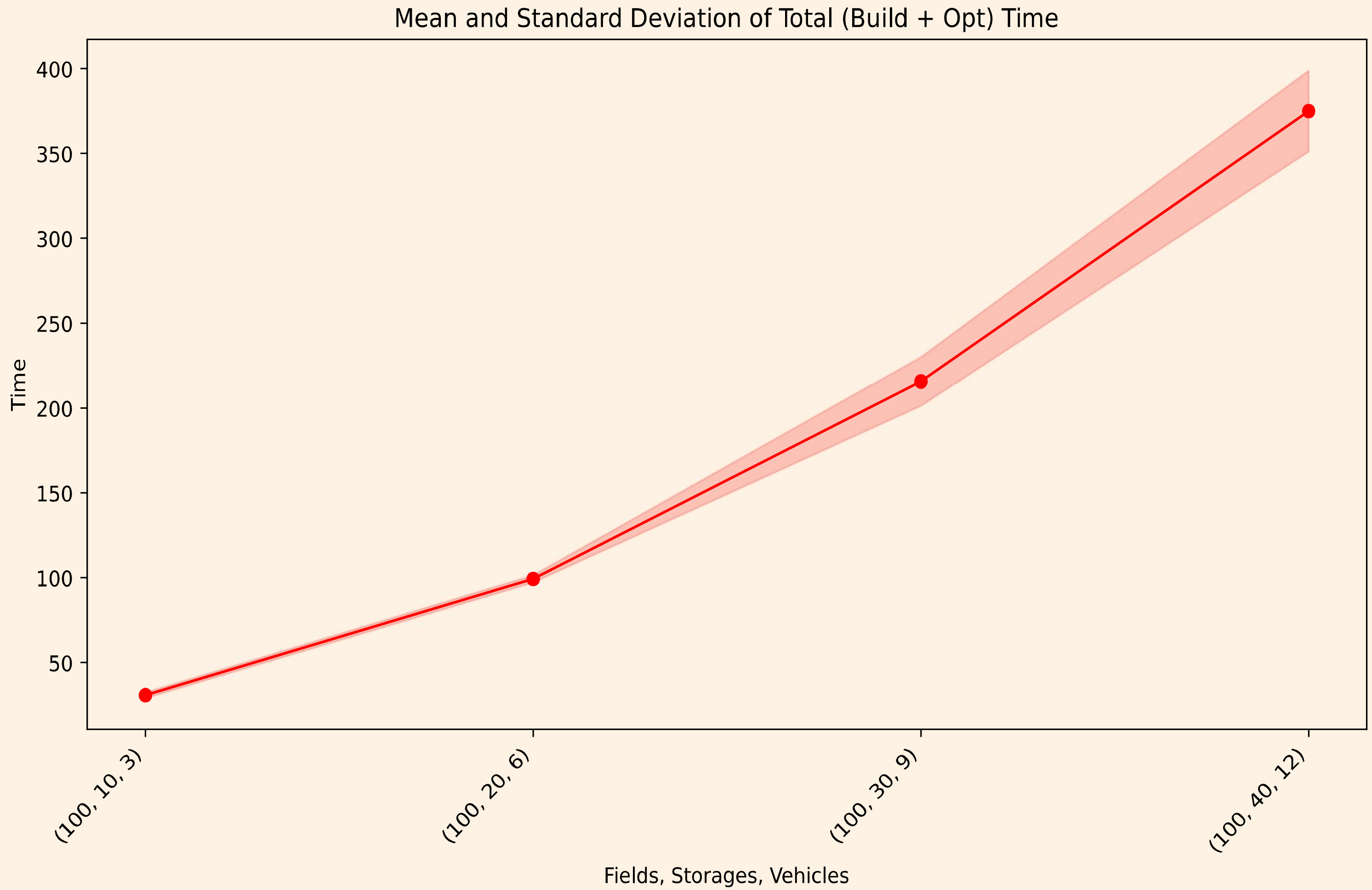
Num storages = [10, 20, 530, 40]

Num vehicles = [3, 6, 9, 12]

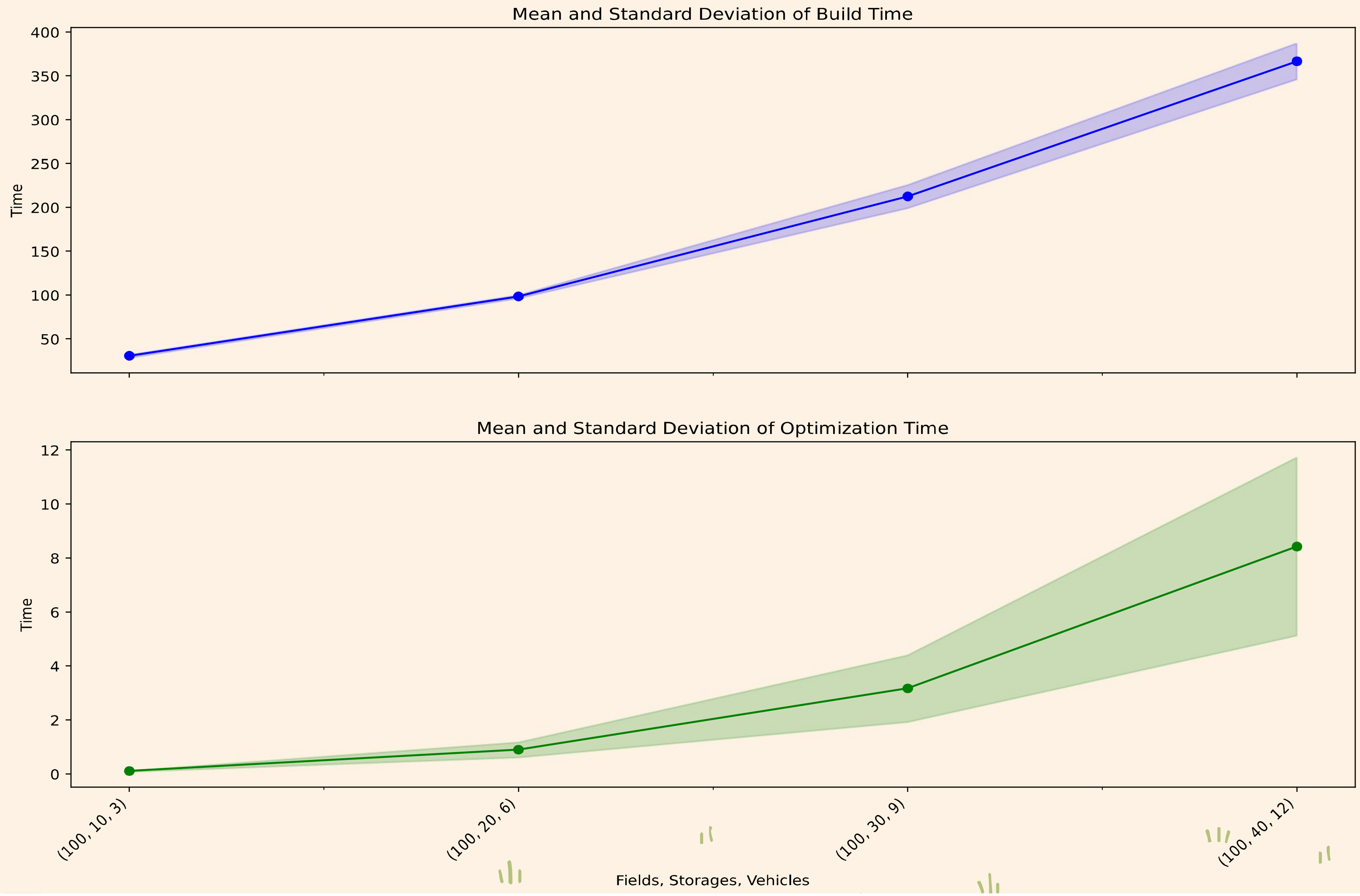
Vehicle capacity = 2000 (tons)

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.



Scalability analysis (2)



04

Water Flow Algorithm

A meta-heuristic improvement

References

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- A Waterflow Algorithm for Optimization Problems (2011), Tran Trung Hieu