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

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Chapters

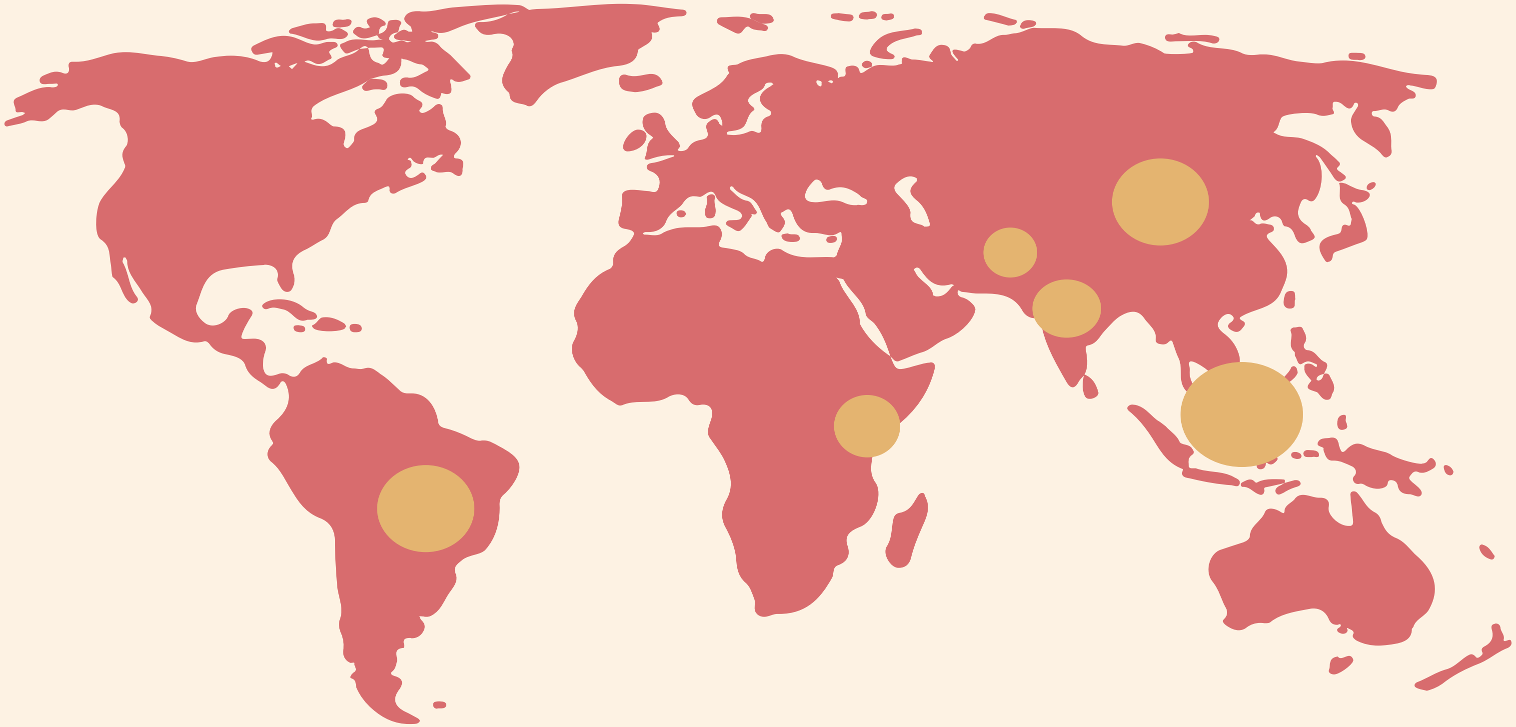
01

Problem Introduction

Agricultural waste management

- In developing countries, agricultural sectors have rapidly developed to become major contributors in the economy.
- Agricultural waste management has posed a challange for rural planners due to the lack of efficient planning tools.
- Burning the agricultural waste at fields after each harvesting season is the current solution but this causes 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 collect agricultural waste

02

Modelling

Location-Assignment-Routing-Problem

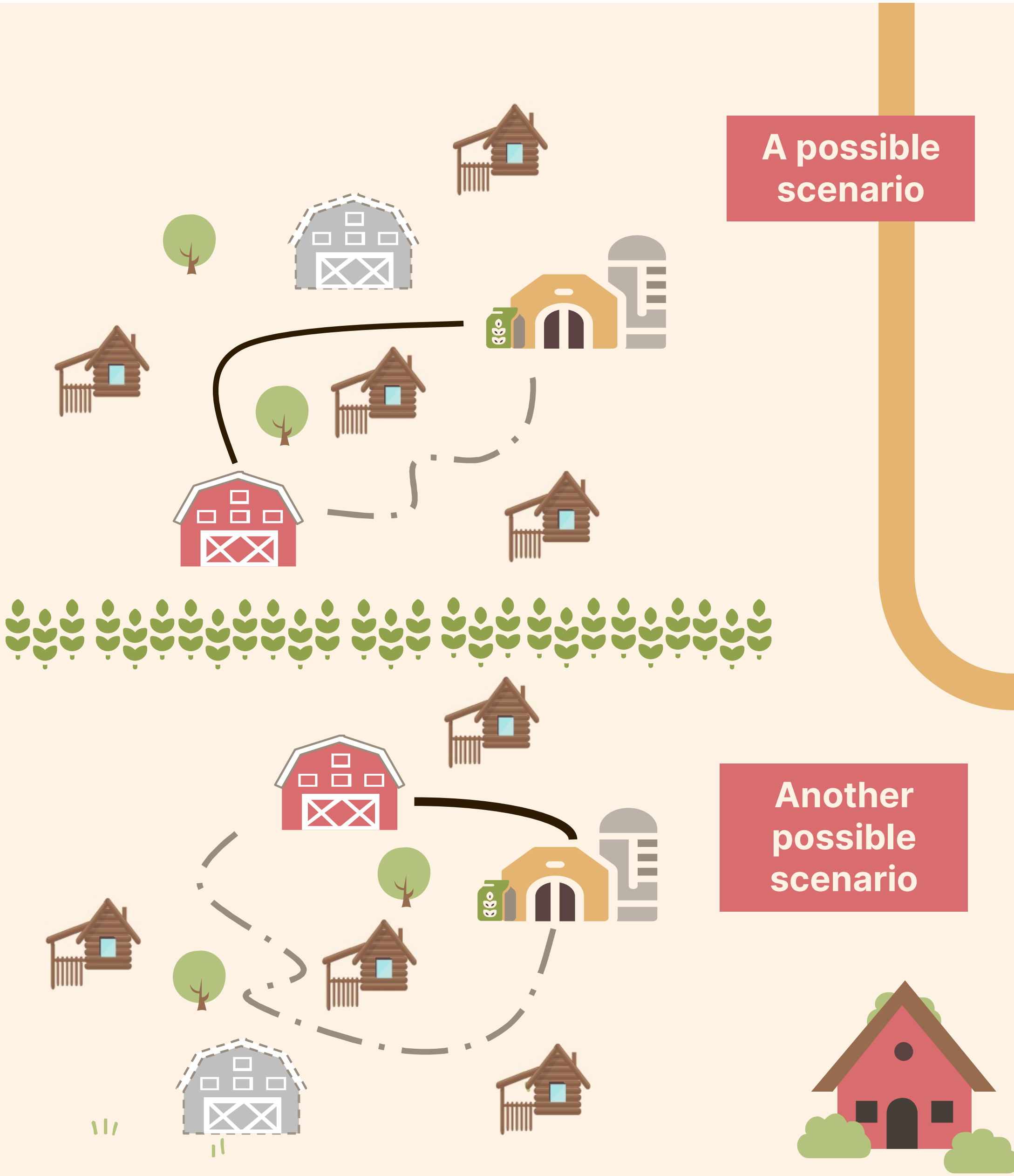
Logistic problem

Which and how many places should be chosen for building storages 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 (1/3)

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

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 (2/3)

location cost — assignment cost — transportation cost

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

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

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

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

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

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

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

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

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

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

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

$$(C11)\ Z_{uv} \in \{0,1\} \quad \text{for each } u, v \text{ in } J_0 : u \neq v$$

$$(C12)\ T_u \geq 0 \quad \text{for each } u \in J$$

Not required to empty the storages

Legenda

- Capacitated facility location
- TSP adjusted for CVRP
- Assignment

Model Formulation (3/3)

Product of decision vari

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

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

$$\boxed{\begin{array}{l} u \in J_0 : u! = v \\ v \in J_0 : v! = u \end{array}}$$

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

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

$$D_0 = 1 \quad \text{location of facility}$$

$$D_0 \cdot Z_{0v} = X_v \quad \text{for each} \quad v \in J$$

$$D_0 \cdot Z_{u0} = X_u \quad \text{for each} \quad u \in J$$

Linearization of non-linear constraints

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

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

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

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

$$(C15)\quad W_{uv} \leq Z_{uv} \quad \text{for each} \quad u, v \in J_0 : u \neq v$$

$$(C16)\quad W_{uv} \geq X_u + Z_{uv} - 1 \quad \text{for each} \quad u, v \in J_0 : u \neq v$$

$$(C17)\quad W_{uv} \in 0, 1 \quad \text{for each} \quad u, v \in J_0 : u \neq v$$

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

$$(C19)\quad W'_{uv} \leq X_v \quad \text{for each} \quad u, v \in J_0 : u \neq v$$

$$(C20)\quad W'_{uv} \leq Z_{uv} \quad \text{for each} \quad u, v \in J_0 : u \neq v$$

$$(C21)\quad W'_{uv} \geq X_v + Z_{uv} - 1 \quad \text{for each} \quad u, v \in J_0 : u \neq v$$

$$(C22)\quad W'_{uv} \in 0, 1 \quad \text{for each} \quad u, v \in J_0 : u \neq v$$

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

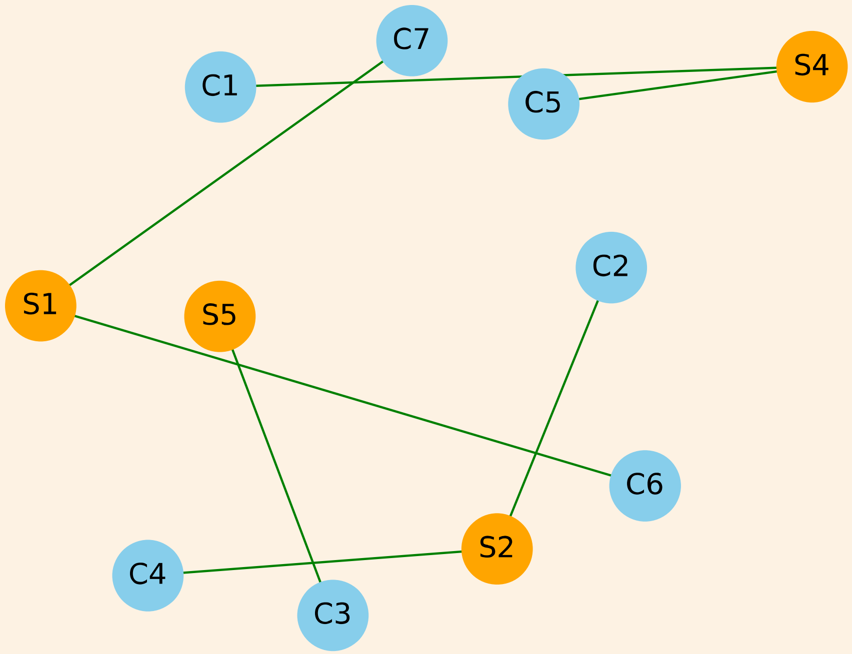
Graphical representations (1/2)

- 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 in these locations is not suggested

Same result as the **paper**!

Location cost = 400
Assignment cost = 80,2

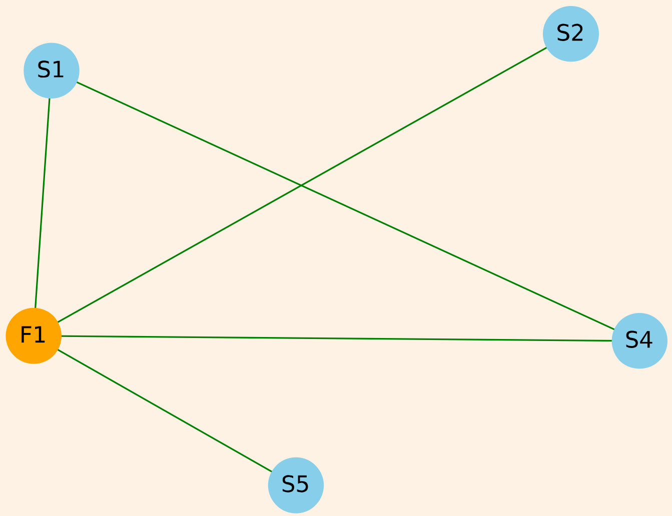


Graphical representations (2/2)

Same results as the **paper**!

scenario 1

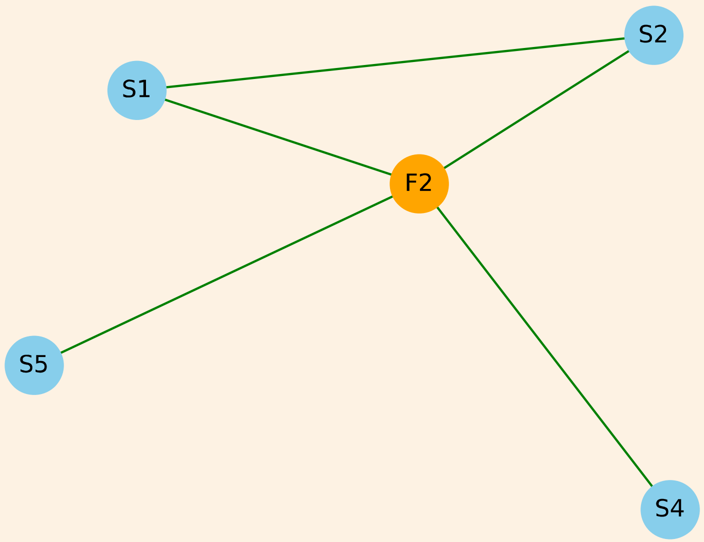
Transportation cost = 57,0
Total cost = 537,2



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

scenario 2

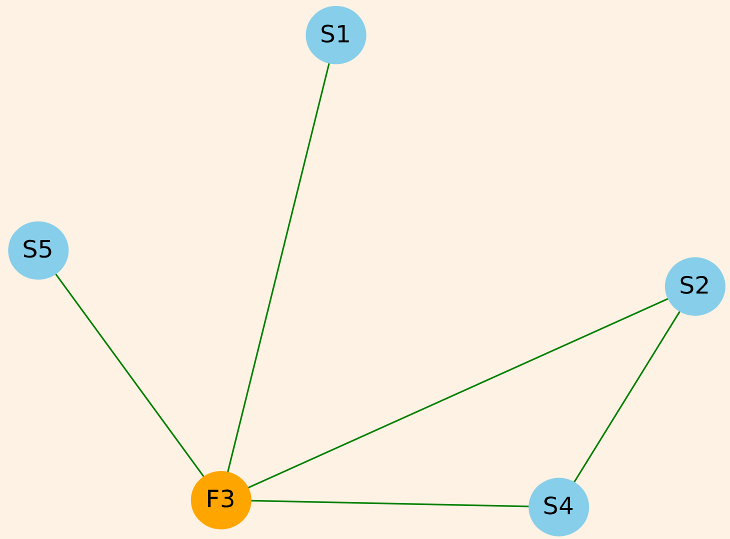
Transportation cost = 119,2
Total cost = 599,4



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:

Facility = ‘F’

Num iterations = 10

Num fields = 100

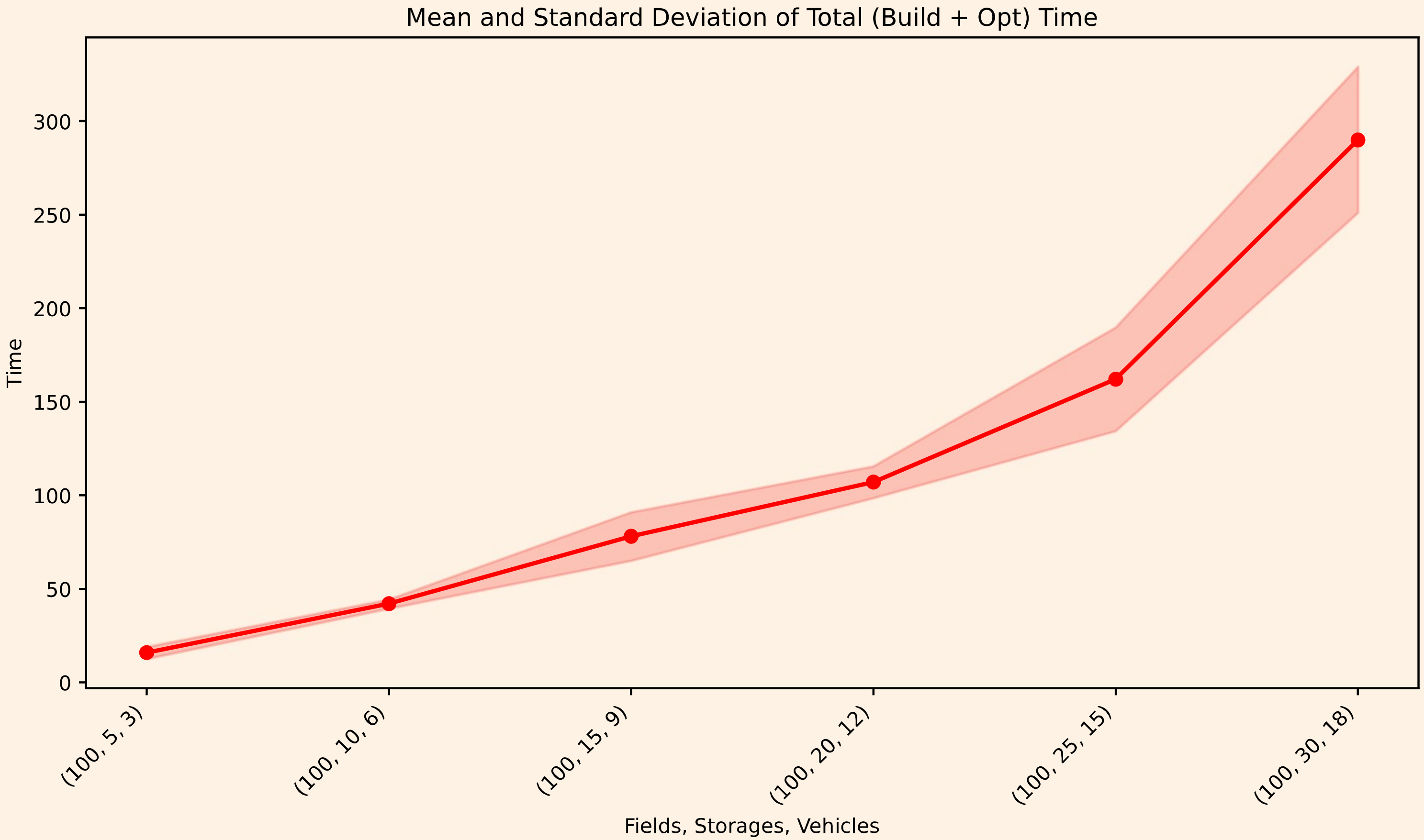
Num storages = [5, 10, 15, 20, 25, 30]

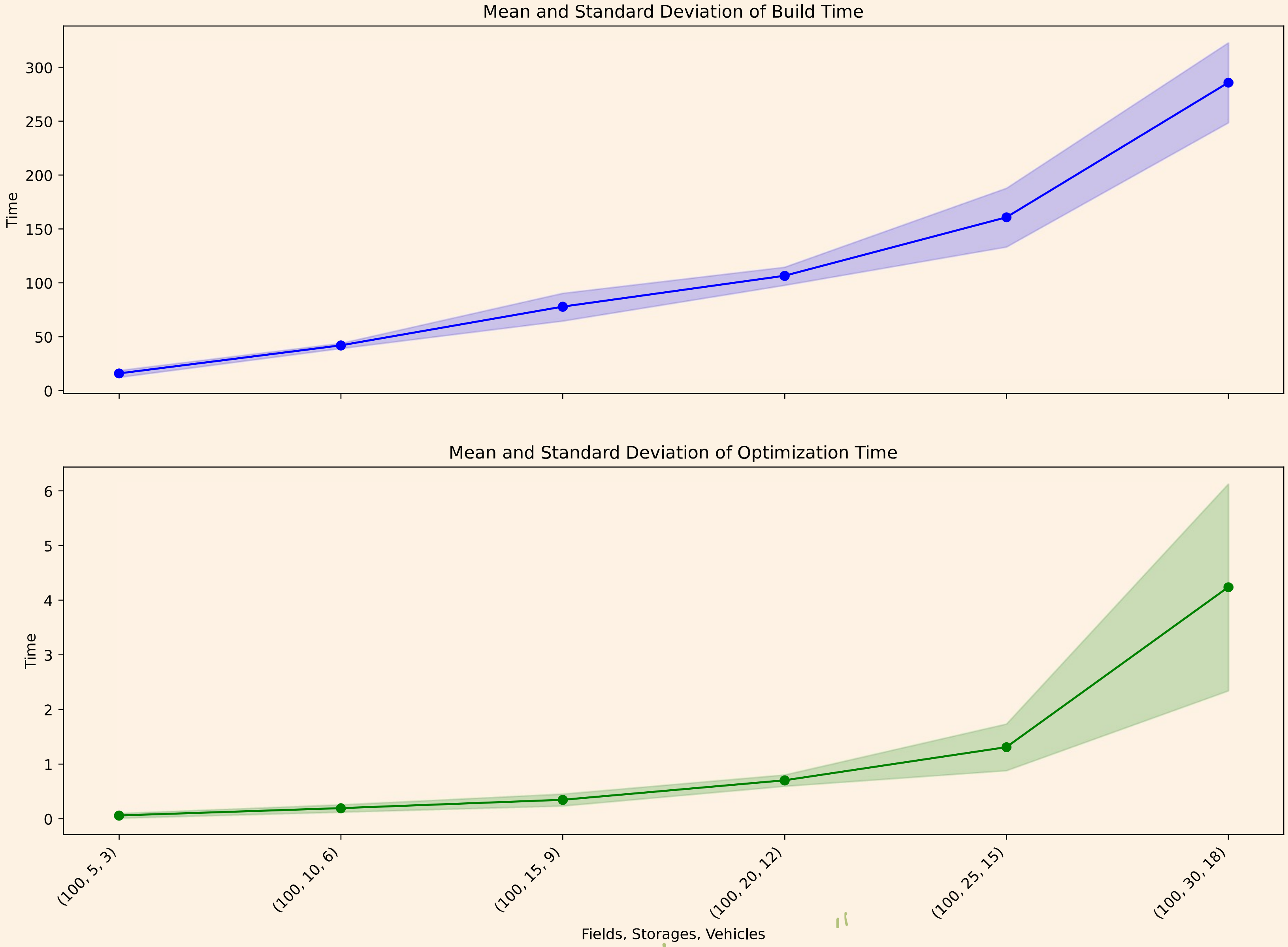
Num vehicles = [3, 6, 9, 12, 15, 18]

Vehicle capacity = 2000 (tons)

Proposed model formulation provides an optimal solution for different sizes of the problem, in different timeframe.

Scalability plot match the optimization model **complexity** of O(m2 + nm).





Major contribution to the Scalability Analysis comes from the **Build** phase

Optimization phase starts to relatively impact later

04

Water Flow Algorithm

A meta-heuristic improvement

Water Flow Algorithm

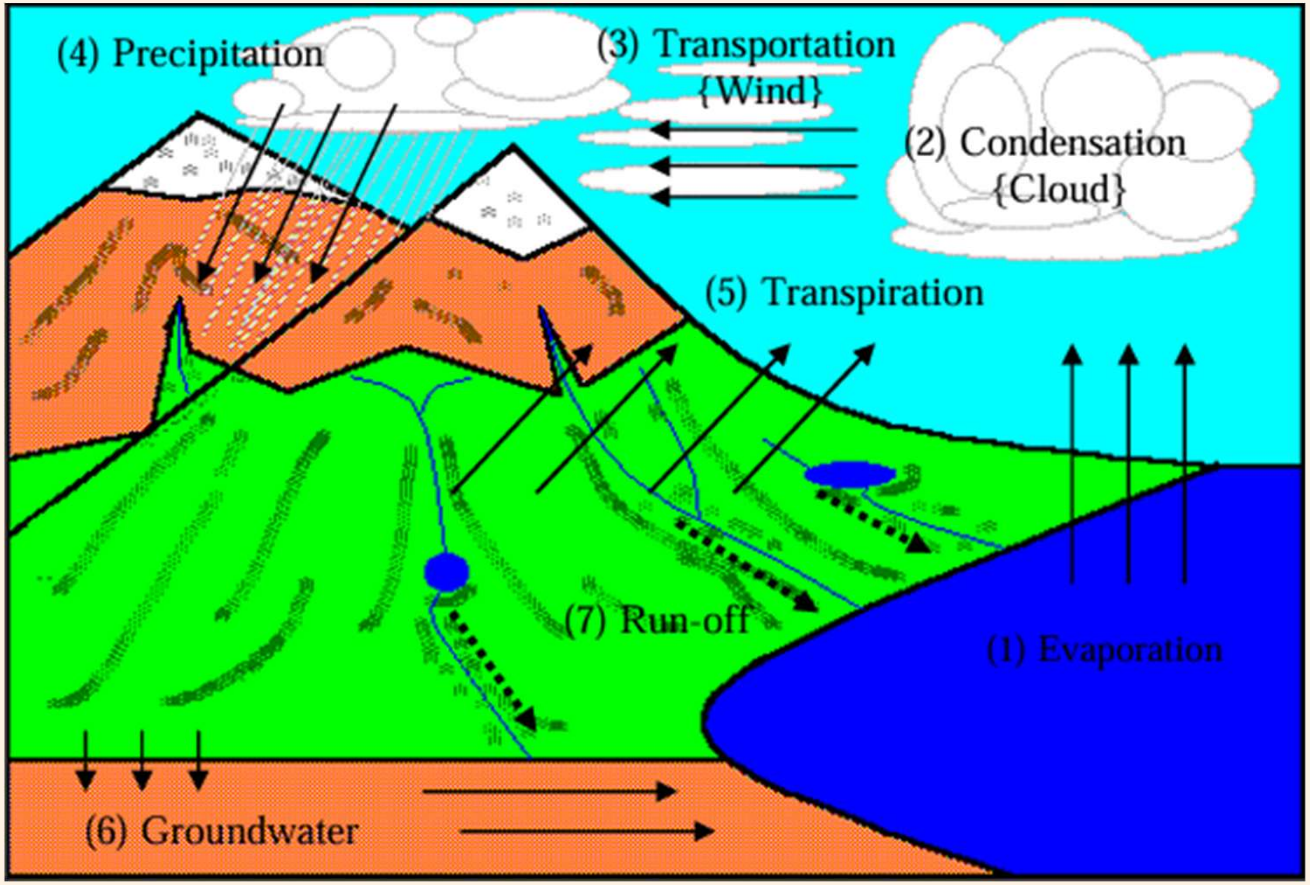
Disclaimer

Proposed description of the WFA is short, poor in detail and, at times, confusing

↓

A «personal» interpretation is implemented for this project

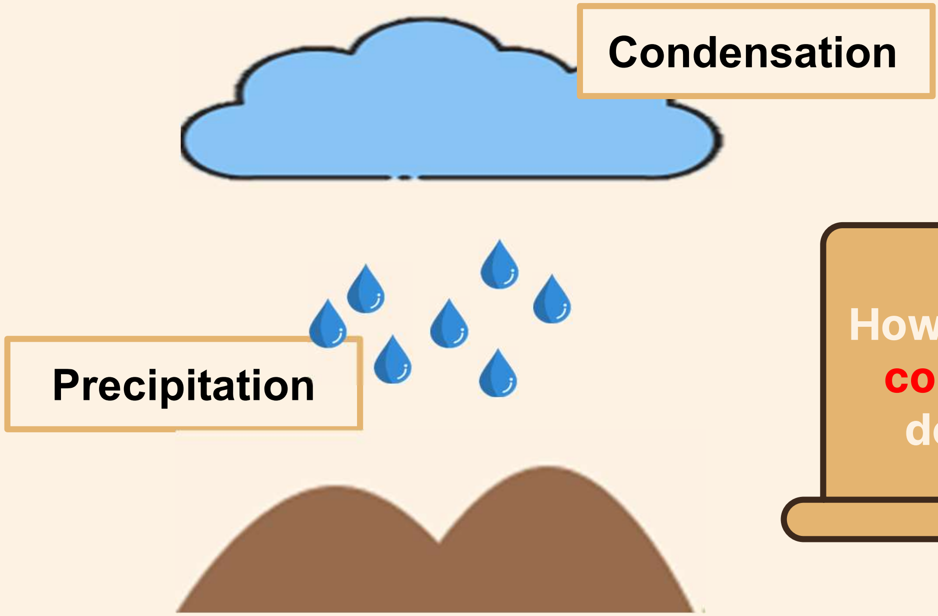
Basic Components of the Hydrological Cycle

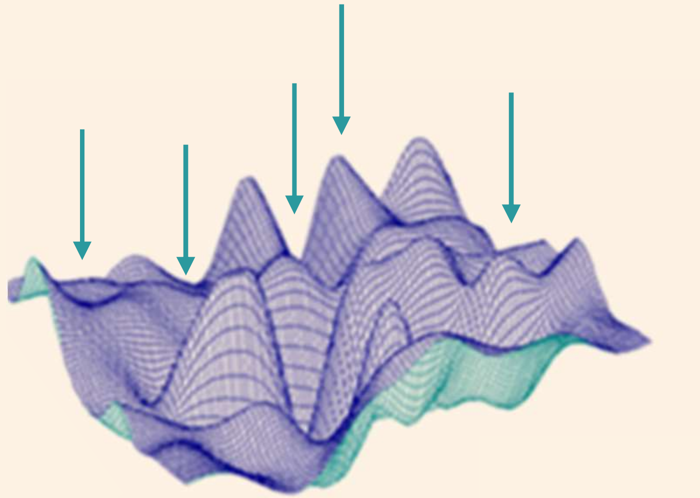


We focus just on the following stages:

- **(2) Condensation**
- **(4) Precipitation**
- **(6) Groundwater**

From Water Cycle to Water Flow Formulation (1/3)

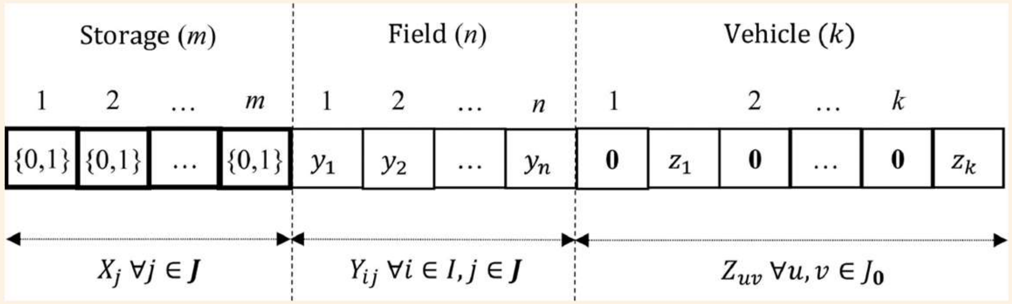




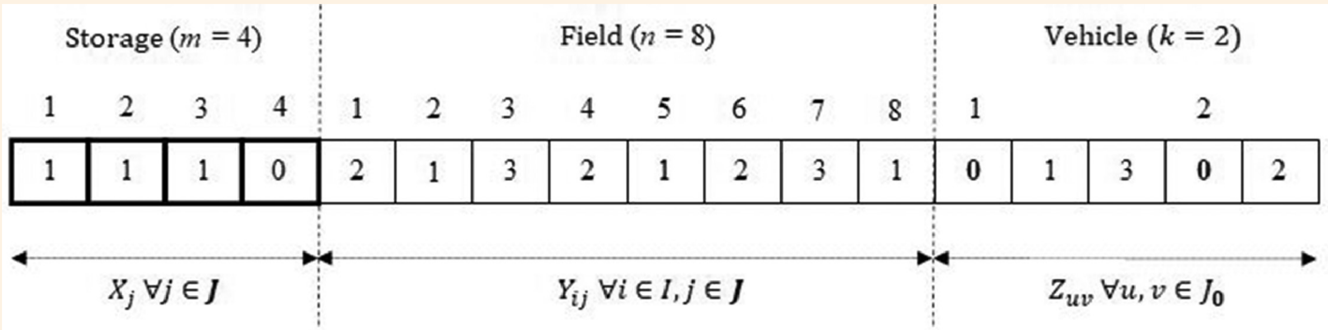
Drop-of-Waters (DOWs) are generated from a cloud and they fall on the earth

A «DOW» identifies a location (point) in the solution space for the LARP model, and a set of DOWs is randomly generated

From Water Cycle to Water Flow Formulation (2/3)



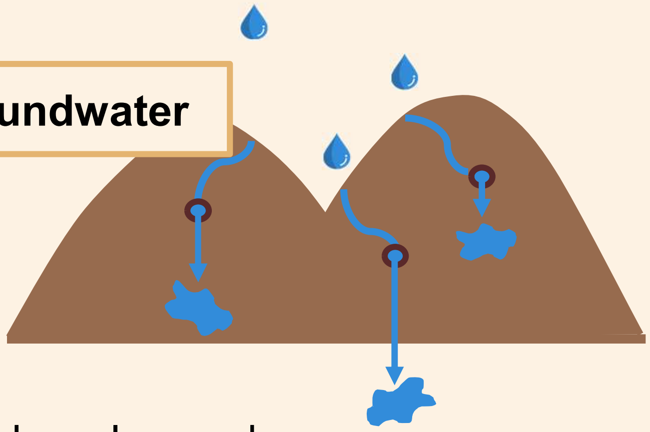
A «DOW» represents a solution for LARP model



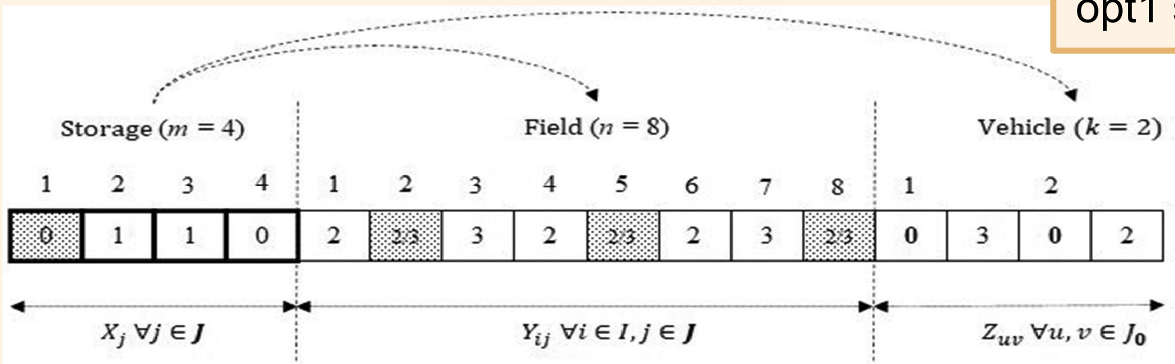
An example of DOW/Solution formulation

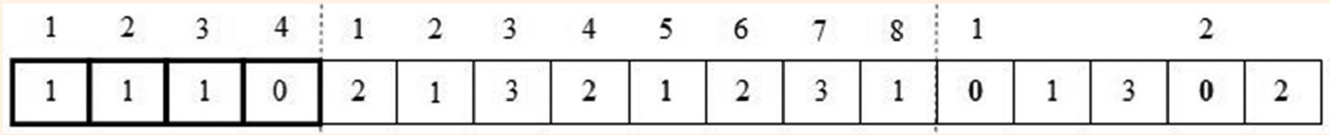
From Water Cycle to Water Flow Formulation (3/3)

Groundwater

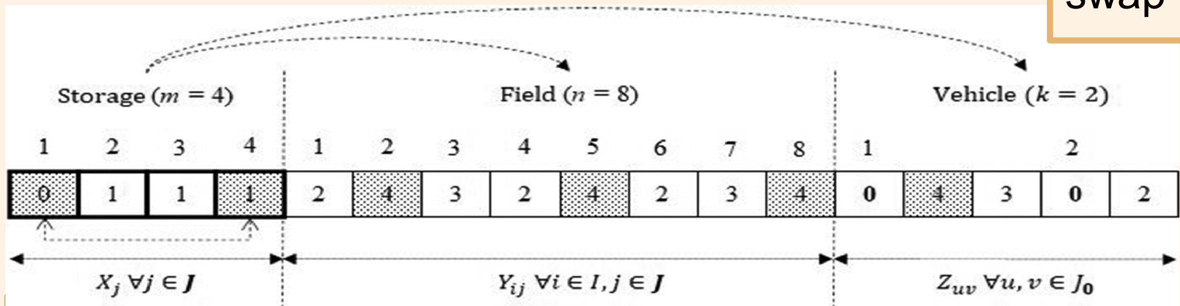


opt1 strategy





swap strategy



<u>Local search</u>

«DOWs» on the ground start to move down due to the Gravity force until they stop somewhere

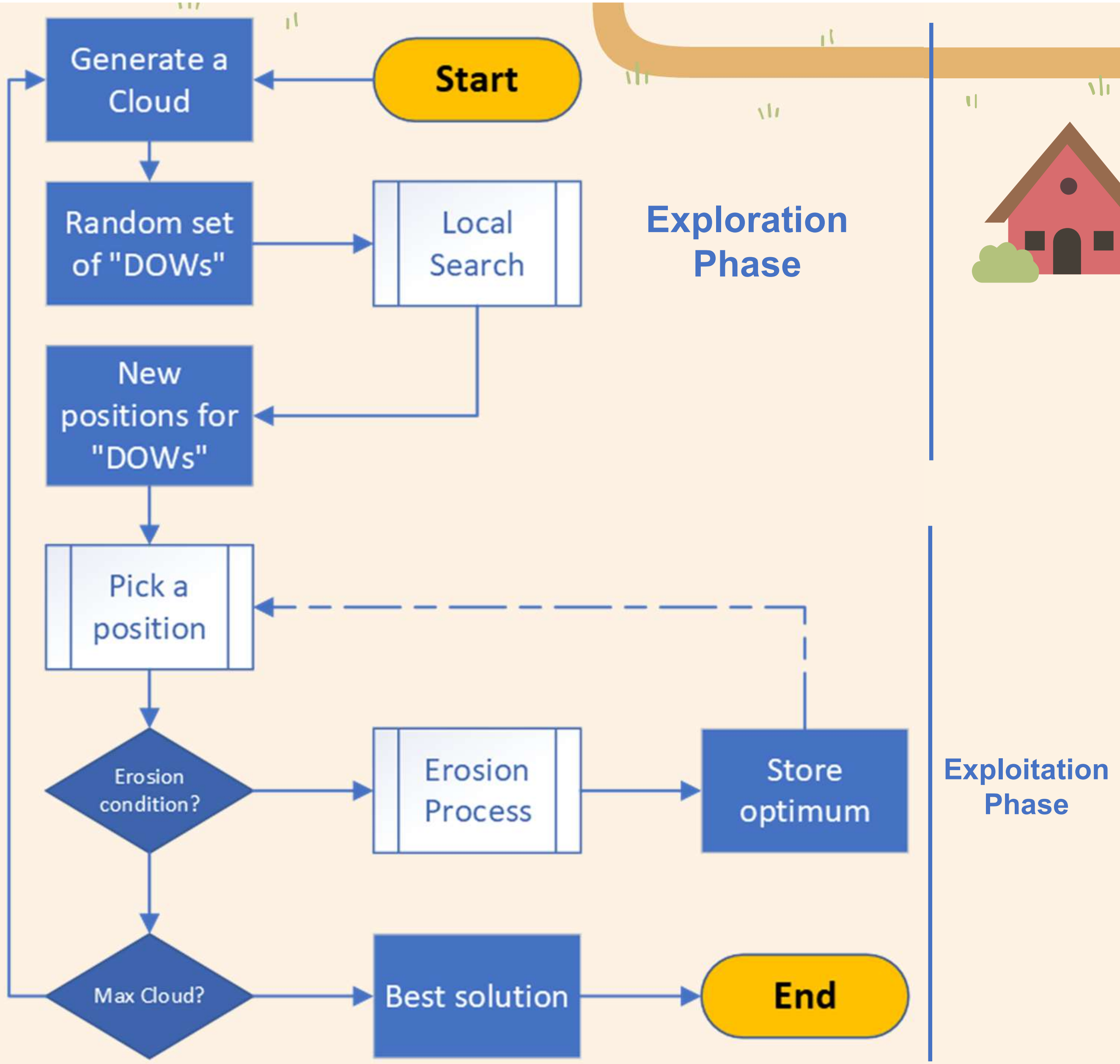
<u>Erosion process</u>

«DOWs», gathered in puddle, begin to seepage the ground

Simplified flow-chart for the Water Flow Algorithm

During the **Exploration phase** a Cloud is generated, the cloud rains a fixed number of water drops randomly which fall on the earth at some position and start to move somewhere down

During the **Exploitation phase** those water drops which are gathered in a single point start to erode the ground and infiltrate through the ground until they stop somewhere in a groundwater



Condensation

Precipitation

Gravity force

New positions

Erosion condition

Erosion process

New local optimum

```python
clouds = clouds_generator(max_cloud, larp, max_pop)

for cloud in clouds:
    print('start to rain...')
    rainfall, discarded_dows = cloud.make_rain(E_list, discarded_list)
    print('stopped to rain.')
    discarded_list.extend(discarded_dows)

    print('gravity force push down dows...')
    for dow in rainfall:
        local_optimum, neighbours, excluded_dows, discarded_dows = local_search(larp, dow)
        excluded_list.extend(excluded_dows)
        discarded_list.extend(discarded_dows)
        UE_list.append(local_optimum) # for erosion process

        if local_optimum not in optimal_dows.keys():
            optimal_dows[local_optimum] = neighbours
    print('dows sink in some local positions.')

    for dow, neighbours in optimal_dows.items():
        print('dow:\n', dow)
        print('n. neighbours:', len(neighbours))

    dow_occurances = Counter(UE_list)
    dow_occurances = [dow for dow, occurs in dow_occurances.items() if occurs >= min_ero]
    print(f'{len(dow_occurances)} optimal(s) satisfy the erosion condition.')
    for dow in dow_occurances:

        neighbours = optimal_dows[dow]
        print('following dow can start the erosion process:\n', dow)
        print(f'dow has {len(neighbours)} neighbours that might be considered...')

        tmp = erosion(larp, dow, neighbours, max_UIE,
            excluded_list, discarded_list, optimal_dows,
            P0_list, UE_list, E_list)

        dow_optimum, _, excluded_list, discarded_list, \
            optimal_dows, UE_list, E_list = tmp
        P0_list.append(dow_optimum)

        print('dow optimum:', dow_optimum)
```

Exploration

Exploitation

Scalability analysis (WFA)

Parameters used for the experiment:

Facility = ‘F’

Num iterations = 10

Num fields = 5

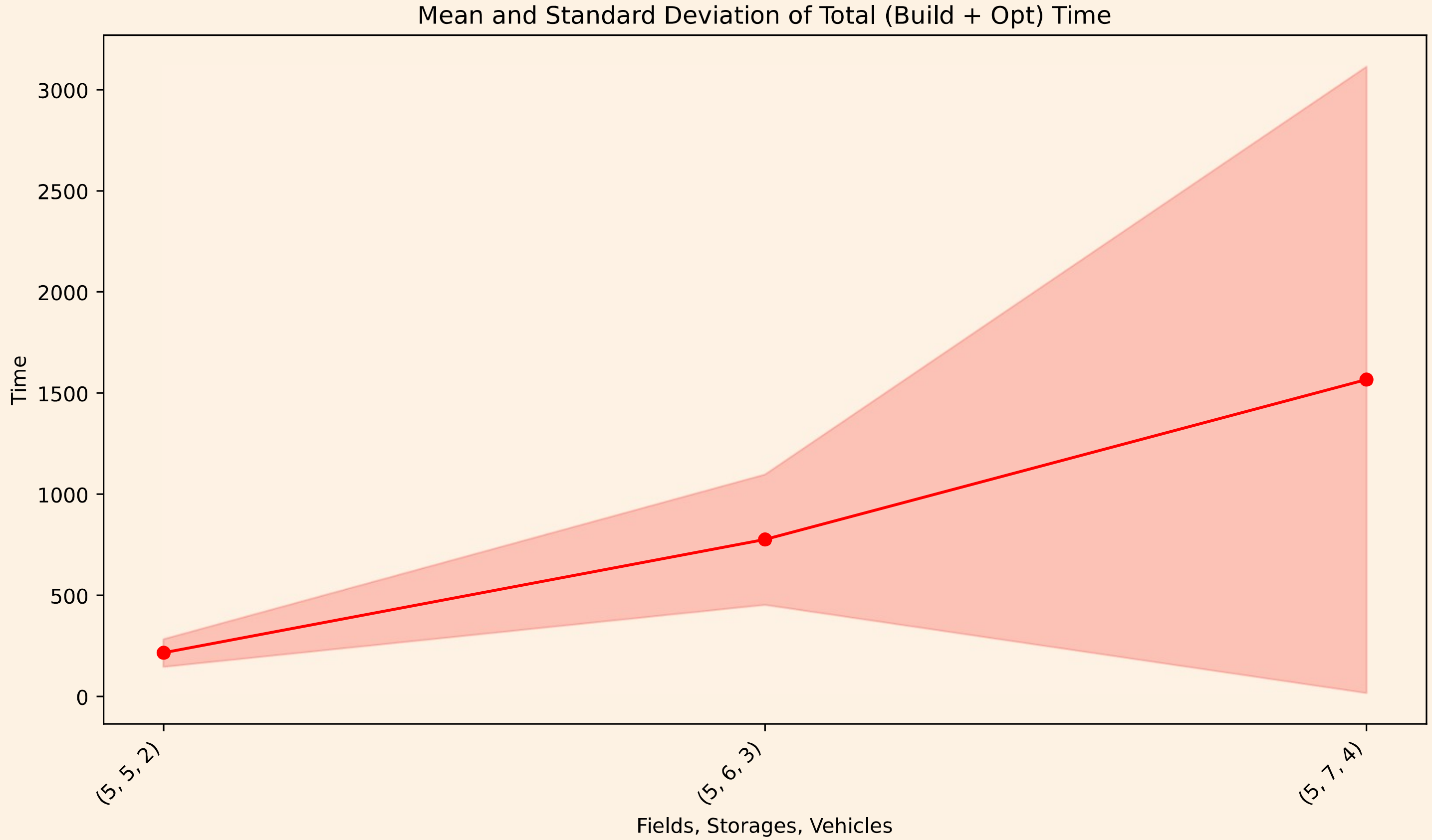
Num storages = [5, 6, 7]

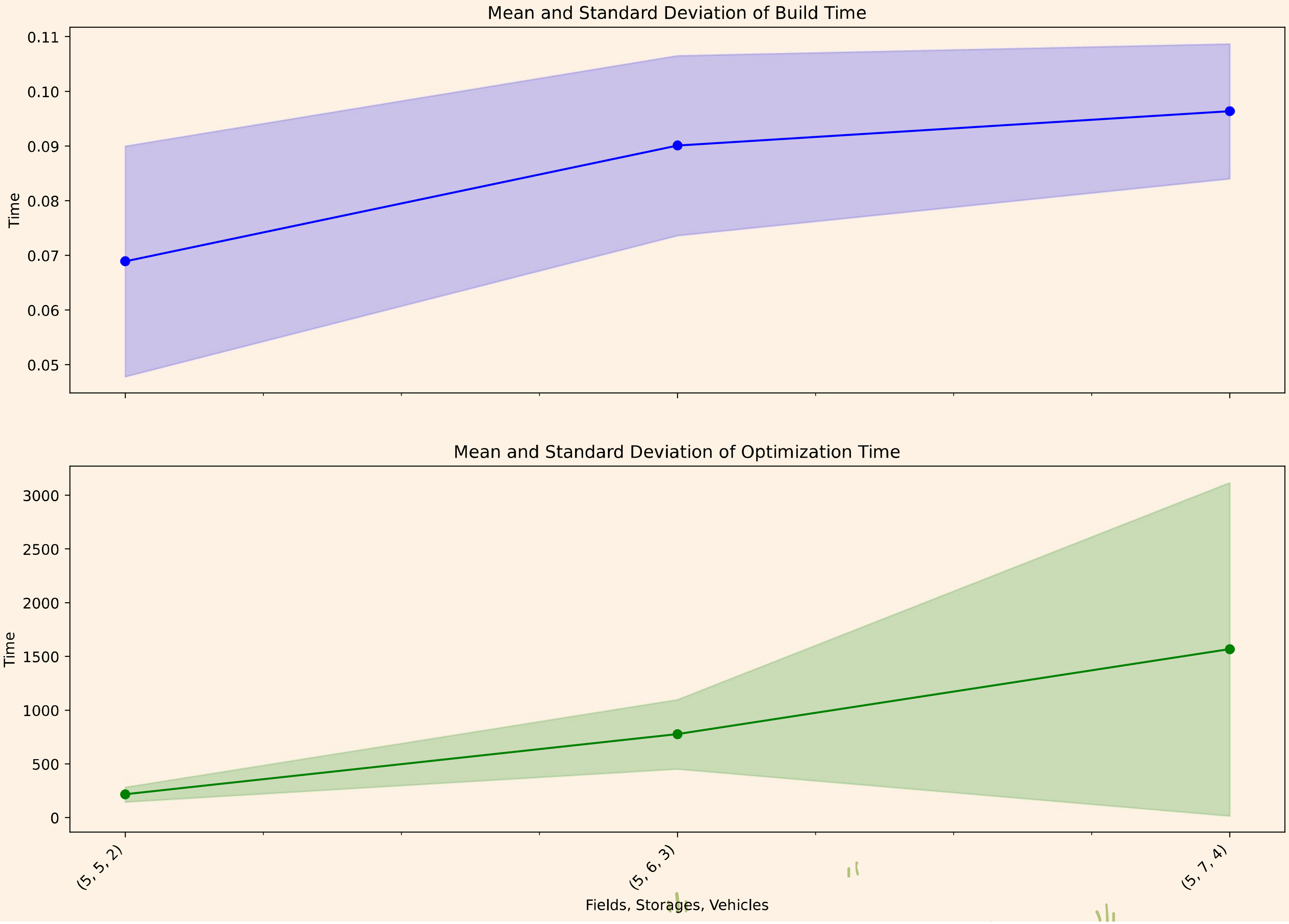
Num vehicles = [2, 3, 4]

Vehicle capacity = 2000 (tons)

The performance of the WFA (without parallelization) is not satisfactory in terms of execution time. The scale is much larger than the LARP one.

Positive aspect is the performance trend which is now **linear** and not quadratic, as for LARP





This time, the contribution of **Build** phase is irrelevant

This time, the contribution of **Optimization** phase is driving the Scalability Analysis

Scalability analysis (Parallelized-WFA)

Parameters used for the experiment:

Facility = ‘F’

Num iterations = 10

Num fields = 5

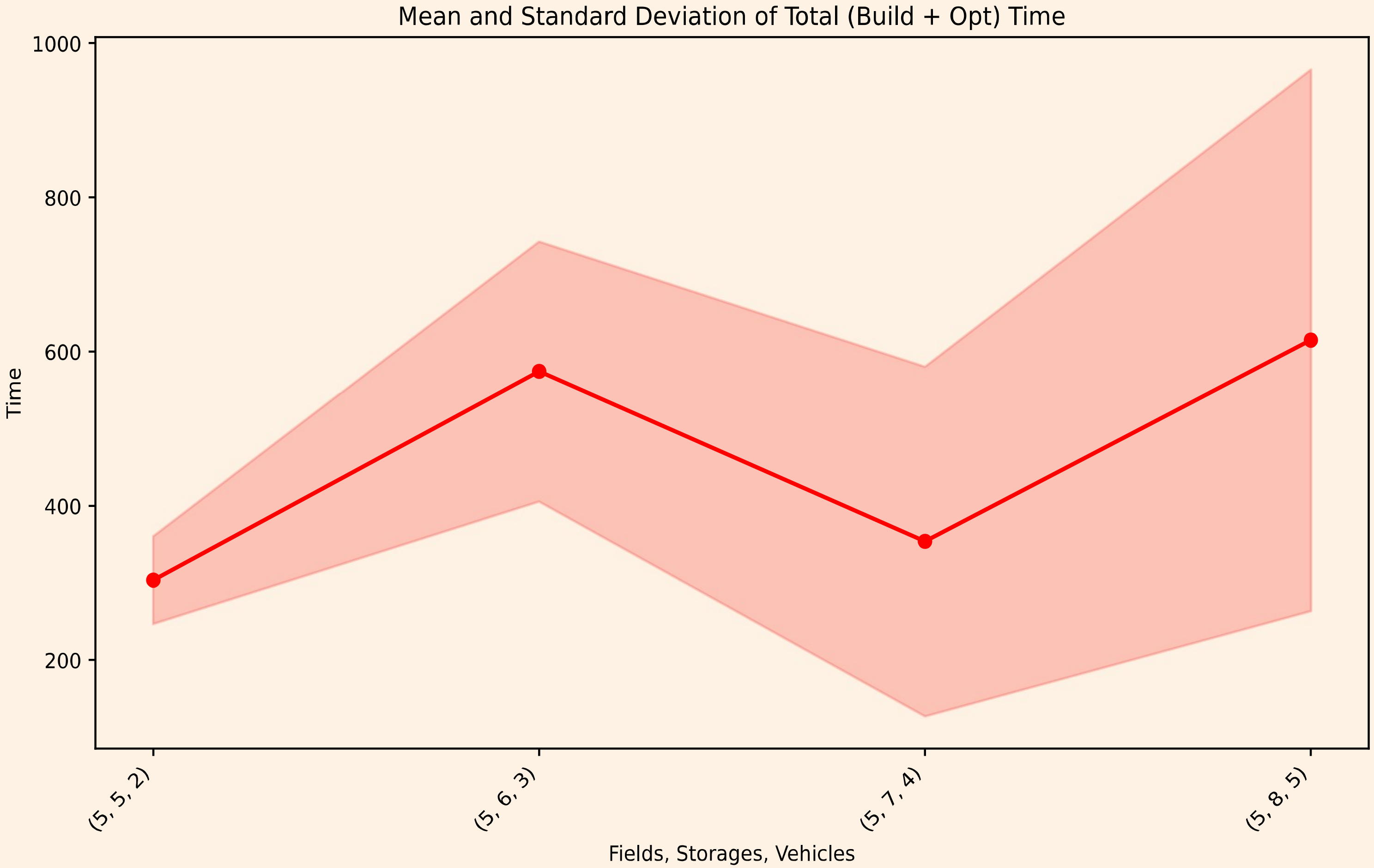
Num storages = [5, 6, 7]

Num vehicles = [2, 3, 4]

Vehicle capacity = 2000 (tons)

The parallelization does not improve the scalability of the WFA for small instances of the problem.

Positive aspect is the performance trend which is now **linear** and not quadratic, as for LARP



Contribution of **Build** phase is irrelevant, as the WFA trend

Contribution of **Optimization** phase is driving the Scalability Analysis, as the WFA trend

Final remarks

- During the execution of the Scalability Analysis for the LARP model, sometimes the algorithm needed a non-measurable amount of time to complete. This could be because of the data given to the model at the beginning, since the data are randomly generated.
- WFA on the other hand, is capable of reducing the complexity of the algorithm to linear. Moreover, it is always able to provide an «acceptable» solution, but this comes at the cost of execution speed.
- Parallelized-WFA mimics the results of the standard WFA, without much gain in execution speed, hence using the parallelization is not advisable for small instances of the problem.

Thank you for the attention!

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