



**Vilnius  
University**

# **Multi-Agent System for Facility Location**

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**Year of start & end of the PhD: 2023 - 2027**

# Courses of Study Plan

| Study Year                             | Examinations |           |
|----------------------------------------|--------------|-----------|
|                                        | Plan         | Completed |
| <b>1<sup>st</sup> Year – 2023/2024</b> | 1            | 1         |
| <b>2<sup>nd</sup> Year – 2024/2025</b> | 3            | 2         |
| <b>3<sup>rd</sup> Year – 2025/2026</b> | 0            | 1         |
| <b>4<sup>th</sup> Year – 2026/2027</b> | 0            | -         |
| <b>Total</b>                           | 4            | 4         |

# Publication Plan

| Year of Study              | Attending Conference |                   |          |                                     | Publications           |             |           |                       |                    |           |
|----------------------------|----------------------|-------------------|----------|-------------------------------------|------------------------|-------------|-----------|-----------------------|--------------------|-----------|
|                            | International        |                   | National |                                     | With impact factor     |             |           | Without Impact factor |                    |           |
|                            | Plan                 | Implemented       | Plan     | Implemented                         | Plan                   | Implemented | Condition | Plan                  | Implemented        | Condition |
| <b>1st<br/>(2023/2024)</b> |                      |                   |          | 1 (doctoral consortium – DBIS-2024) |                        |             |           |                       |                    |           |
| <b>2nd<br/>(2024/2025)</b> |                      |                   |          | 1 Presented DAMSS 2025              |                        |             |           |                       |                    |           |
| <b>3rd<br/>(2025/2026)</b> | 1                    | NUMTA - Presented |          |                                     | 1 (IEEE ACCESS)        |             | Submitted | 1                     | DAMSS Book Chapter | Submitted |
| <b>4th<br/>(2026/2027)</b> | 1                    |                   |          |                                     | 1 (MAS on HPC writing) |             |           |                       |                    |           |
| <b>Total</b>               | 2                    | 1                 | 1        | 2                                   | 2                      |             |           | 1                     |                    |           |

# Research Plan (Last 6 Months)

|        |                                                                                                                                                   |                     |                     |
|--------|---------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|---------------------|
| 2.3.   | <b>Empirical study:</b>                                                                                                                           |                     |                     |
| 2.3.1. | Data Collection for Agent Model Training and Analysis                                                                                             | 2025 y. III quarter | 2026 y. III quarter |
| 2.3.2. | Application of the developed methods to solve facility location problems.                                                                         | 2025 y. III quarter | 2026 y. III quarter |
| 2.3.3. | Experimental investigation of the developed methods and their evaluation (validation, Verification and calibration of the developed agent models) | 2025 y. III quarter | 2026 y. III quarter |
| 2.3.4. | Identification and tuning parameters for multi-agent systems                                                                                      | 2025 y. III quarter | 2026 y. III quarter |
| 2.4.   | <b>Analysis of got facts, summing-up, drawing conclusions:</b>                                                                                    |                     |                     |
| 2.4.1. | Summarising the theoretical study.                                                                                                                | 2025 y. IV quarter  | 2026 y. IV quarter  |
| 2.4.2. | Summarising the empirical study.                                                                                                                  | 2025 y. IV quarter  | 2026 y. IV quarter  |
| 2.4.3. | Analysis and description of the results and drawing conclusions.                                                                                  | 2025 y. IV quarter  | 2026 y. IV quarter  |

# Starting of Reporting Period

- Developed a P&R hub location MAS under customer-behavior uncertainty.
- Used binary and proportional behavior agents.
- Agents generated solutions using learned candidate location ranks.
- A base agent coordinated proposals, evaluations, duplicate control, and maintained the non-dominated solution set.
- Agent communication followed a simplified FIPA-ACL structure.
- Validated MAS results against complete enumeration and evaluated convergence using IGD.
- MMD was used at that stage to select a representative compromise solution.

# Main Improvement: Reporting Period

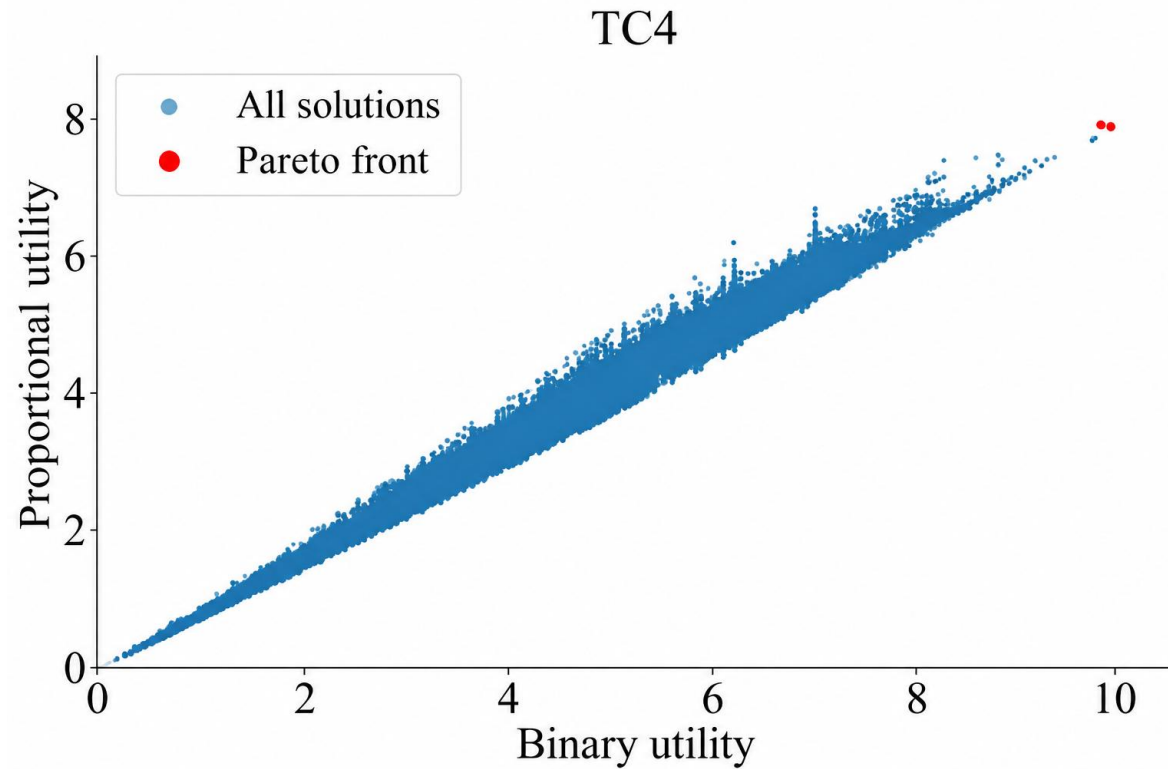
- Extended MAS to DCFLP with existing competitor facilities.
- Added a third behavior agent: Pareto-Huff, alongside Binary and Proportional.
- Expanded P&R experiments to  $k=2,3,4$  and larger candidate sets of 150,283,500.
- Compared MAS with GA, NSGA-II, MOEA/D, Uniform Random Search, and Forward Greedy.
- Investigated rank reuse, learning from other agents' proposals, and transfer ranks between test cases.
- Conducted parameter-sensitivity analysis and improved robust-solution selection using normalized MMD, NBI/CHIM, and min–max regret.

# P&R Hub MAS: Main Validation Results

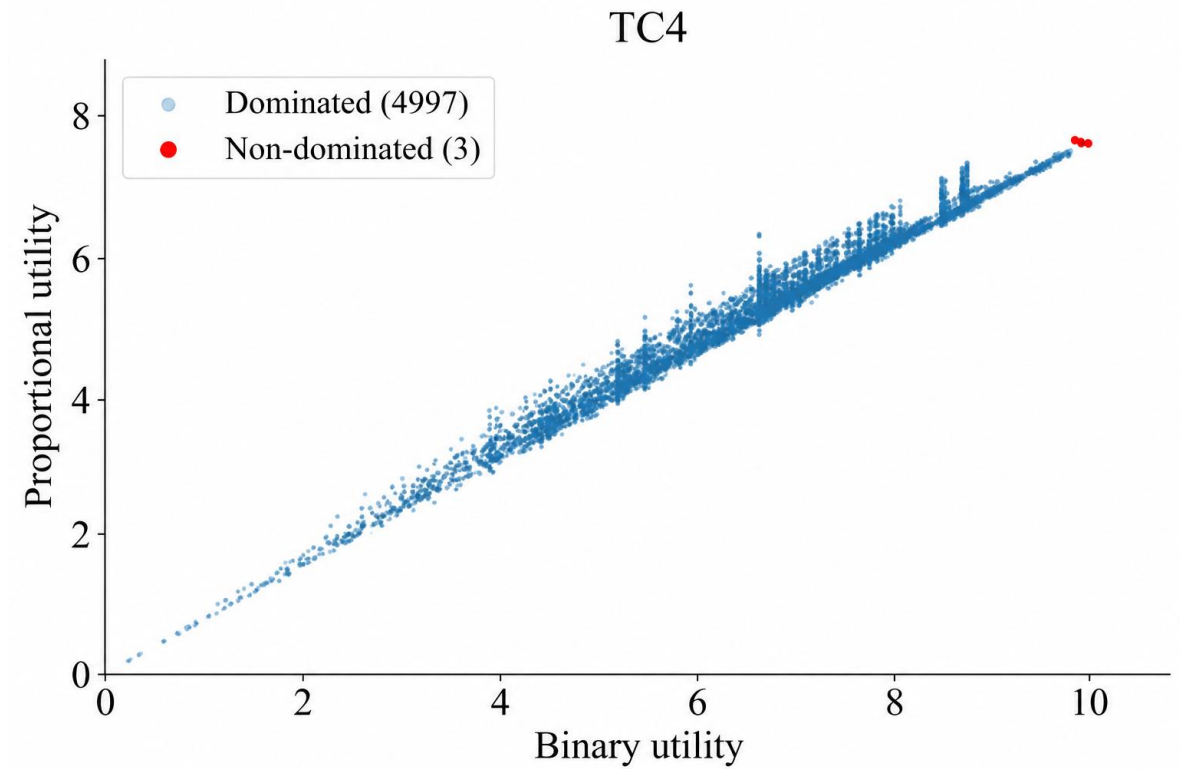
| Measure                           | Result           |
|-----------------------------------|------------------|
| Exact Pareto-front recovery       | 178/180 (98.89%) |
| Reference Pareto points recovered | 598/600 (99.67%) |
| MAS evaluations                   | 10,000           |
| CE evaluations                    | 7,475,162        |
| Evaluation reduction              | ≈99.87%          |

| Method         | Exact Recovery |
|----------------|----------------|
| MAS4FLP        | 98.89%         |
| NSGA-II        | 86.11%         |
| GA             | 63.89%         |
| MOEA/D         | 63.33%         |
| Uniform Random | 0.00%          |
| Forward Greedy | 0.00%          |

# CE vs MAS Scatter Plots (2BM, $k=3$ )



**Complete enumeration**



**MAS**

# P&R Hub MAS: Scalability, Sensitivity

| Candidate locations | Recovery |
|---------------------|----------|
| 150                 | 100.00%  |
| 283                 | 98.89%   |
| 500                 | 92.67%   |

- Parameter sensitivity & learning contribution
  - alpha, beta, epsilon sensitivity: 92.22%–100% recovery.
  - beta had the strongest effect on Pareto-front structure.
  - Rank ablation: learned ranks 178/180 exact fronts vs uniform selection 0/180.

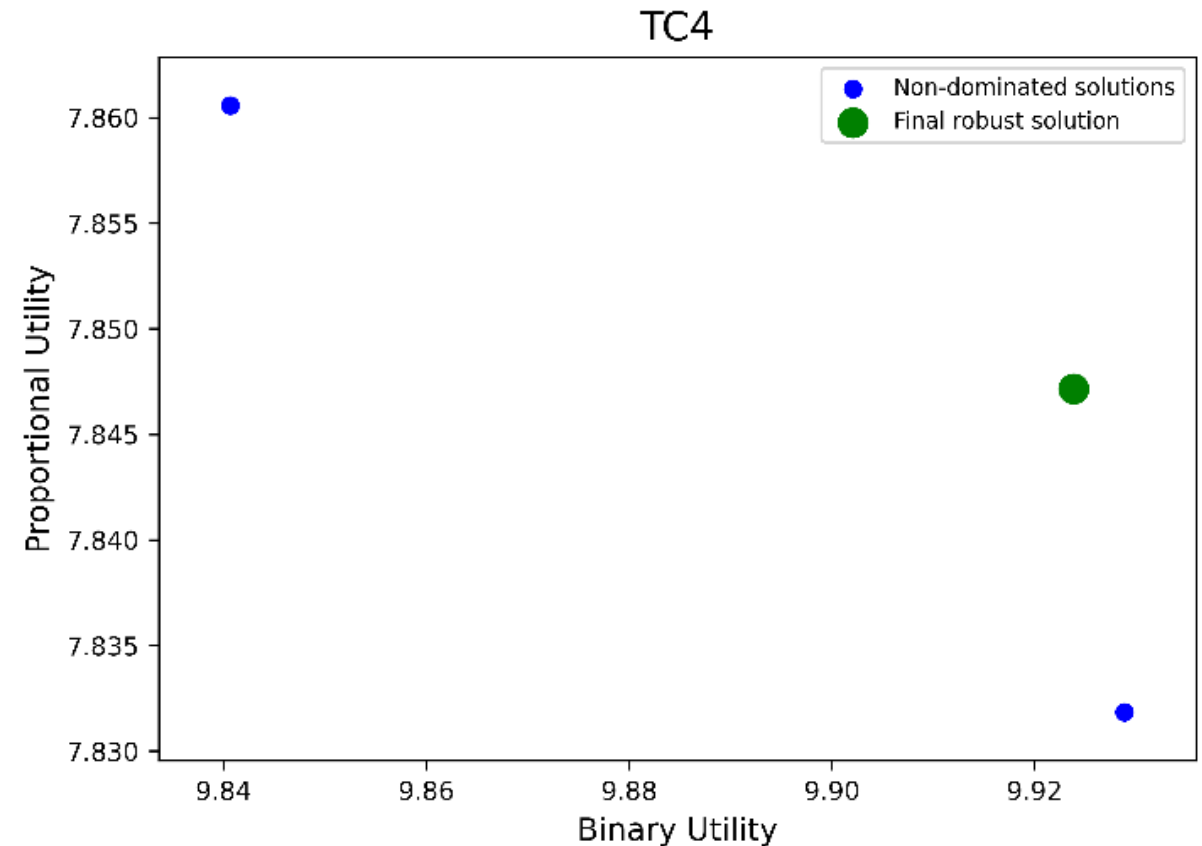
# Scalability behavior models

| Configuration                    | k=2     | k=3    | k=4    |
|----------------------------------|---------|--------|--------|
| 2BM:<br>Binary +<br>Proportional | 100.00% | 98.89% | 97.22% |
| 3BM: +<br>Pareto-<br>Huff        | 100.00% | 99.44% | 86.11% |

- MAS was extended from 2 to 3 behavior agents by adding Pareto-Huff.
- Recovery remained very high for k=2 and k=3.
- The most difficult configuration was 3BM, k=4 with 86.11% recovery.

# Robust solution selection

- Normalized MMD → compromise solution
- NBI/CHIM → geometric knee assessment
- Min-max regret (MMR) → final behaviorally robust solution



# DCFLP MAS: Competitive Facility Location

- Problem setup
  - 10,000 demand points, 90 candidate locations
  - 10 existing competitors
  - 10 test cases
  - $k=3$  facilities selected per solution
- Main difference from P&R
  - DCFLP: agents start with equal ranks and learn/update ranks during the MAS search

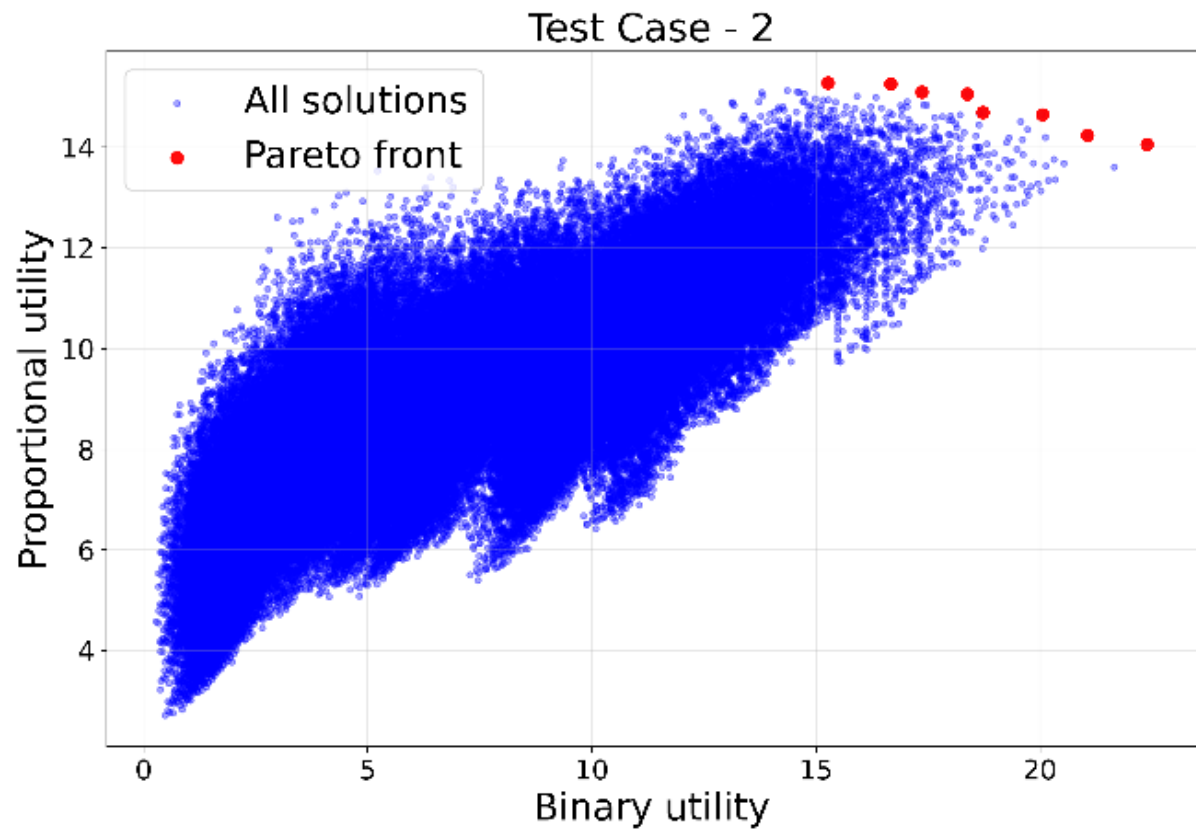
# DCFLP MAS: Rank Reuse, Other agent and Test Case transfer

| Configuration               | Mean zero-IGD iteration |
|-----------------------------|-------------------------|
| Run 1: equal initial ranks  | 3,450                   |
| Run 2: reused ranks         | 1,450                   |
| Own-proposal learning       | 2,765                   |
| Own + other agent proposals | 2,430                   |

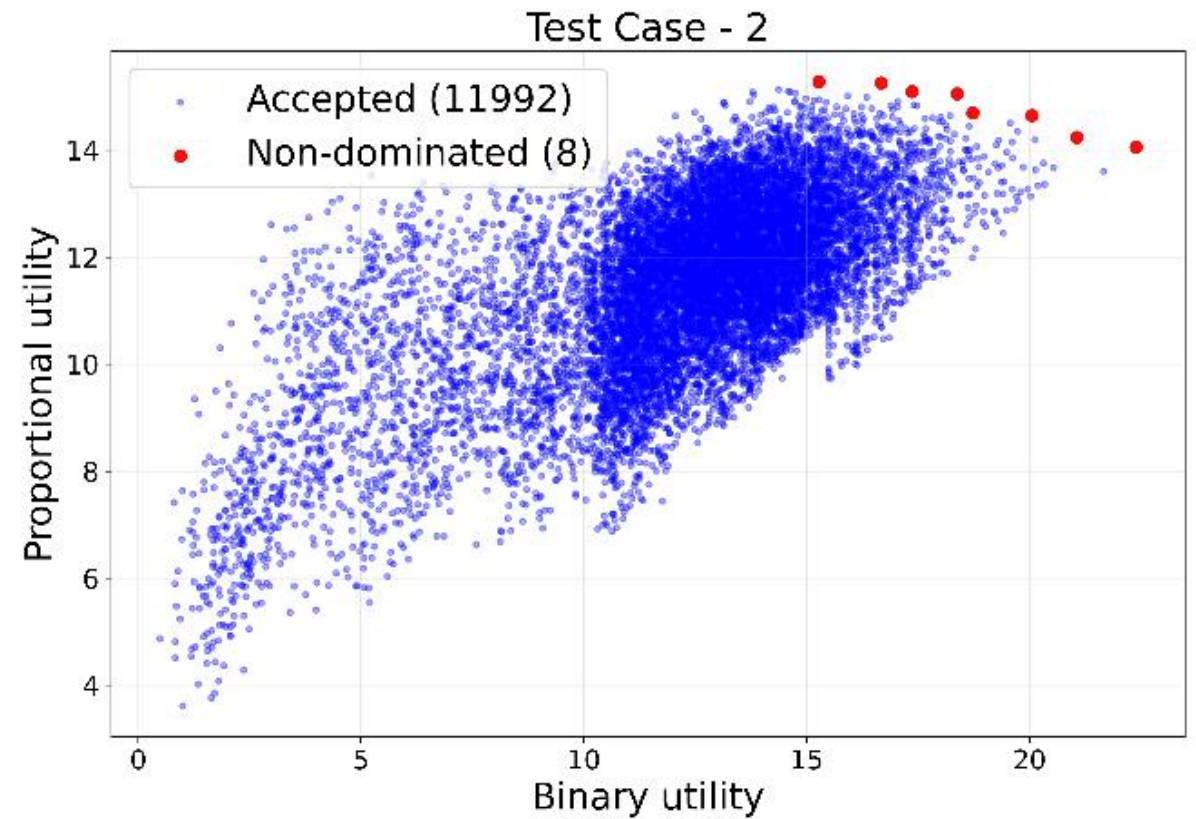
## Transfer between test cases

- Selected setting: transfer weight = 0.90, fallback = 125
- Mean IGD-AUC: 0.195484 → 0.133144
- Improvement: 31.89%
- Exact recovery maintained across 10/10 test cases
- Negative transfer observed in TC2, TC7, TC10
- Complete recovery was not always reached earlier.

# CE vs MAS DCFLP Scatter Plots



**Complete enumeration**



**MAS**

# Conclusion and Future Direction

- A common MAS framework was applied to both P&R hub location and DCFLP.
- MAS showed strong agreement with complete-enumeration Pareto fronts in both applications.
- For P&R, min–max regret was used for final behaviorally robust selection, while MMD and NBI/CHIM were used for compromise and knee assessment.
- Rank reuse and knowledge transfer can improve convergence, but other agent learning increases runtime and transfer can be negative in some cases.

## Next Research Steps

- Implement and evaluate the MAS in an HPC environment
- Improve agent learning and proposal generation
- Test larger and additional problem instances

**THANK YOU**