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A Multi-Agent System for Facility Location Problems

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Year of start & end of the PhD (2023 - 2027)

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- Study Progress
- Motivation, Objectives of the study
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Courses of Study Plan

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

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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
1st (2023/2024)				1 (doctoral consortium – DBIS-2024)						
2nd (2024/2025)			1 (progress writing an abstract for DAMSS conference)							
3rd (2025/2026)	1				1			1		
4th (2026/2027)	1				1					
Total	2		1	1	2			1		

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Research Plan (Last 6 Months)

2.2.	**Theoretical study:**		
2.2.1.	Analysis of scientific (and other) literature of Competitive Facility Location and Multi-Agent Base solutions.	2025 y. I quarter	2025 y. III quarter
2.2.2.	Selection and description of implementing multi-agent systems for facility location problem	2025 y. I quarter	2025 y. III quarter
2.2.3.	Creation of optimised algorithms for facility location using identified parameters over agent/s of the multi-agent system.	2025 y. I quarter	2025 y. III quarter
2.3.	**Empirical study:**		
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

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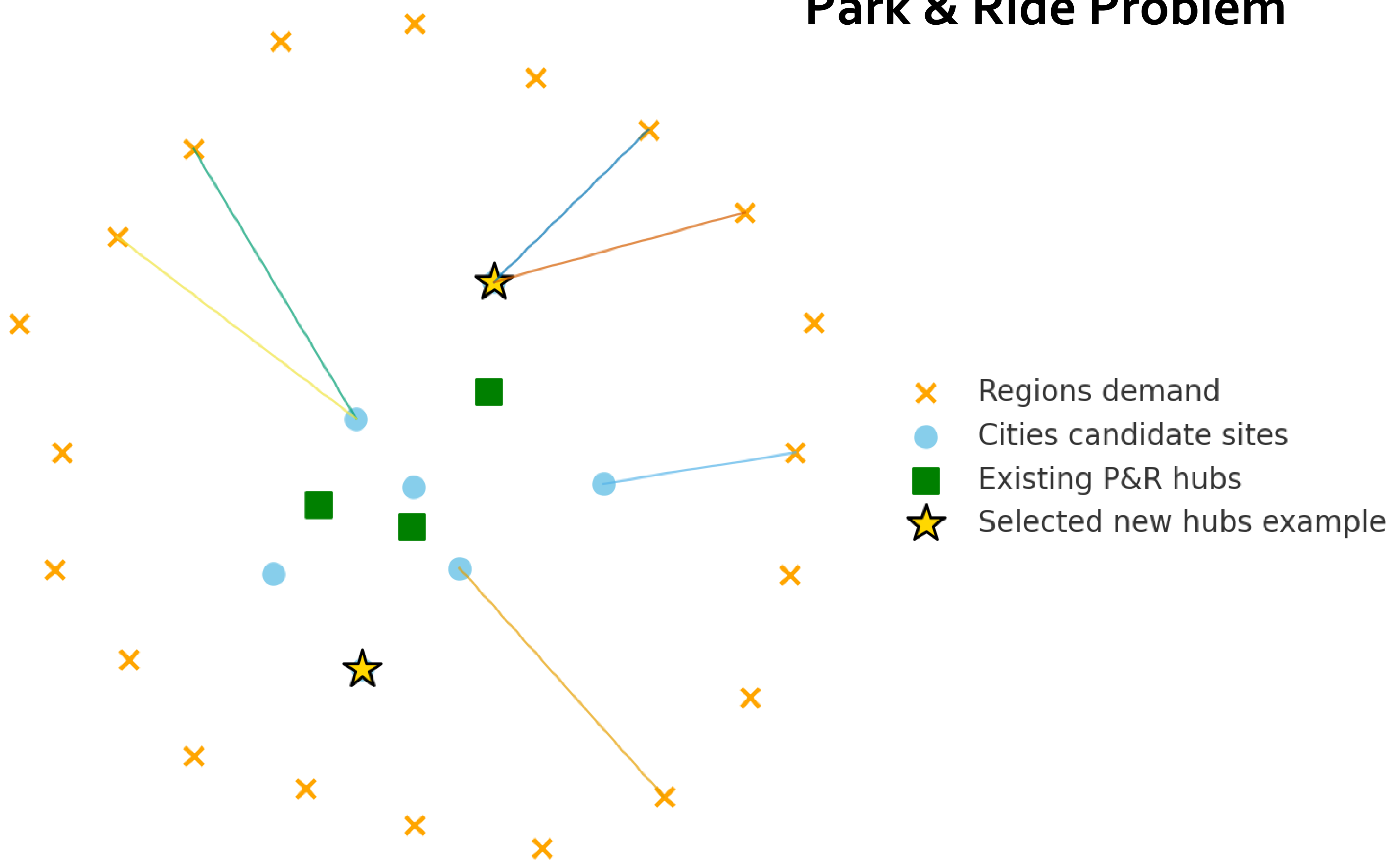
Motivation

- Facility Location Problem, specifically with the **park and ride model**, to solve the uncertainty behaviour of the customer, and find a Robust combination solution on binary and proportional customer behavioural models under both objectives in a maximisation manner.
- The multi-agent system used in this situation is studied further with a negotiating agent to find a non-dominated solution and finally to find a robust solution.

Park & Ride Problem



Objectives of the study

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Find the non-dominated set efficiently

- On this objective, it is necessary to prioritise the most suitable candidates to select for earlier evaluation of utility values through Binary and Proportional agents.

Utilise an agent communication model to find a non-dominated candidate combination set.

- This should be working on a standardised communication method and protocol. But needs to be suitable with existing requirements.

Find the robust solution based on the non-dominance frontier

- Find and evaluate available frontier methods to select a suitable solution for the current scenario. This should meet the solution for the uncertainty of the customer behaviour.

Verify the selected output is valid and correct

- The MAS system's given results should be verified with the standard practical method.

Utility models and Objective

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Binary (winner-takes-all):

- Each demand point picks the single most attractive site; we capture it if one of our k sites is best (ties split).

Proportional (share-by-attractiveness):

- Each demand point splits among all sites in proportion to attractiveness; we capture our share.

maximize both Ubin and Uprop

- Use the Pareto set to manage trade-offs before picking a robust single combo.

Use of Ranked Solutions with MAS Agents

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- Each agent (Binary / Proportional) keeps its own **rank table** over candidate sites, reflecting behaviour-specific attractiveness.
- Ranked candidates can be used by the agents by prioritising higher ranks to propose for negotiation.
  - Voting Base Negotiation
  - MAPN (Mediated Alternating-Proposal Negotiation; dominance-based)

Voting-based negotiation - Phase 1 (Ballot Building)

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- **Input:** Union of each agent's **Top-N** ranked sites.
- **Process:** For each k-combo, both agents compute utilities and apply **per-agent rules** (utility threshold, rank-match) → cast **YES/NO**.
- **Outcome:** Keep **Both_Accept** combos in a **ballot table**; later run Pareto filtering on these.

per-agent voting rules

- **Utility threshold,** eg 75% of the maximum utility Value
- Rank-match – e.g., at least two of the candidate locations should be within Top M of the agent ranked candidate list

Voting-Based Negotiation — Phase 2 (Mediation + Top-N Expansion)

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- Convert Both_Accept combinations (Phase-1) into a final ε-Pareto front and expand Top-N only if the frontier is too small, narrow, or stagnant.

Top N expansion factors

- The number of Pareto points
- Diversity of the Pareto front - measured in average pairwise L1 distance
- no improvement (best utilities or archive quality) over a last round.

Utility spread over Accepted vs Rejected from the Ballot table and Final Pareto Set

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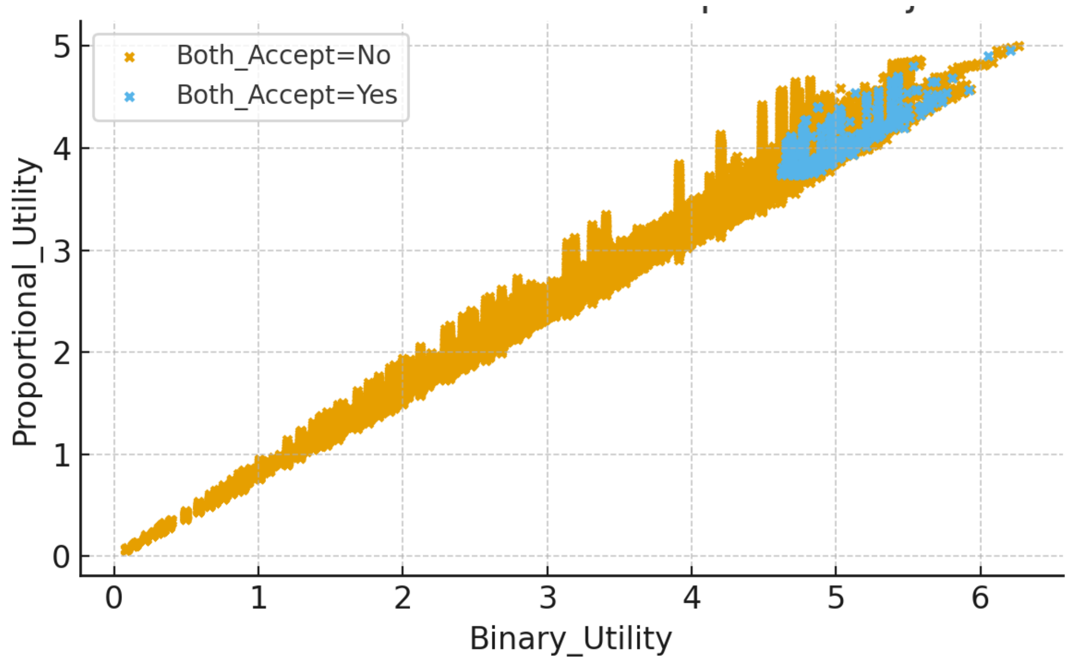
Combo_ID	Facilities	Binary_Utility	Bin_Util_OK	Bin_Rank_OK	Binary_Vote	Proportional_Utility	Prop_Util_OK	Prop_Rank_OK	Proportional_Vote	Both_Accept
7242	[137, 211, 213]	6.2618	Yes	No	No	5.0031	Yes	Yes	Yes	No
29747	[211, 213, 116]	6.205	Yes	Yes	Yes	4.9545	Yes	Yes	Yes	Yes
7250	[137, 211, 101]	6.2039	Yes	Yes	Yes	4.9817	Yes	No	No	No
7291	[137, 213, 245]	6.1751	Yes	No	No	4.9733	Yes	Yes	Yes	No
29847	[211, 101, 116]	6.1475	Yes	Yes	Yes	4.9323	Yes	No	No	No
30167	[213, 116, 245]	6.1164	Yes	No	No	4.9255	Yes	Yes	Yes	No
7391	[137, 101, 245]	6.1091	Yes	No	No	4.9555	Yes	Yes	Yes	No
29738	[211, 213, 96]	6.0855	Yes	No	No	4.8383	Yes	Yes	Yes	No
30763	[101, 116, 245]	6.0508	Yes	Yes	Yes	4.9069	Yes	Yes	Yes	Yes
29800	[211, 96, 101]	6.0367	Yes	Yes	Yes	4.8261	Yes	No	No	No
30095	[213, 96, 245]	6.024	Yes	No	No	4.8123	Yes	Yes	Yes	No
26173	[189, 211, 213]	5.9782	Yes	Yes	Yes	4.8312	Yes	No	No	No
30531	[96, 101, 245]	5.9591	Yes	No	No	4.8033	Yes	Yes	Yes	No
26181	[189, 211, 101]	5.9338	Yes	Yes	Yes	4.8103	Yes	No	No	No
7343	[137, 96, 101]	5.9331	Yes	No	No	4.5803	Yes	Yes	Yes	No
29744	[211, 213, 233]	5.9317	Yes	Yes	Yes	4.8064	Yes	No	No	No
30530	[96, 101, 116]	5.9173	Yes	Yes	Yes	4.5685	Yes	Yes	Yes	Yes
26222	[189, 213, 245]	5.9043	Yes	No	No	4.8095	Yes	Yes	Yes	No
7387	[137, 101, 233]	5.8964	Yes	Yes	Yes	4.6239	Yes	No	No	No
29844	[211, 101, 233]	5.8884	Yes	Yes	Yes	4.7861	Yes	No	No	No
7281	[137, 213, 96]	5.8862	Yes	No	No	4.5521	Yes	Yes	Yes	No
30094	[213, 96, 116]	5.8715	Yes	No	No	4.5426	Yes	Yes	Yes	No
7287	[137, 213, 233]	5.8672	Yes	No	No	4.6117	Yes	Yes	Yes	No
6956	[137, 189, 101]	5.8648	Yes	Yes	Yes	4.5992	Yes	No	No	No



Combo_ID	Facilities	Binary_Utility	Bin_Util_OK	Bin_Rank_OK	Binary_Vote	Proportional_Utility	Prop_Util_OK	Prop_Rank_OK	Proportional_Vote	Both_Accept
329919	[205, 239, 242]	7.8393	Yes	Yes	Yes	6.3796	Yes	Yes	Yes	Yes
539767	[176, 205, 239]	7.8356	Yes	Yes	Yes	6.3797	Yes	Yes	Yes	Yes

MAPN (Mediated Alternating Proposal Negotiation, dominance-based)

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- Binary agent (A1), Proportional agent (A2), Base agent (A0).
- Each agent utilizes its own behaviour Top-N lists of candidate locations.
- Agents **take turns** proposing a combo; the peer **evaluates**; the base agent **updates an ε-Pareto archive** (insert if non-dominated, prune dominated).
- **Outcome:** A **compact non-dominated set** is maintained **online**, ready for robust selection.

FIPA-ACL (Simplified) Envelope & Rationale

- Full FIPA has 13 fields; This MAS keep 6
- speed, clarity, and easy logging

{

"performative":"pr",

"sender":"agent1",

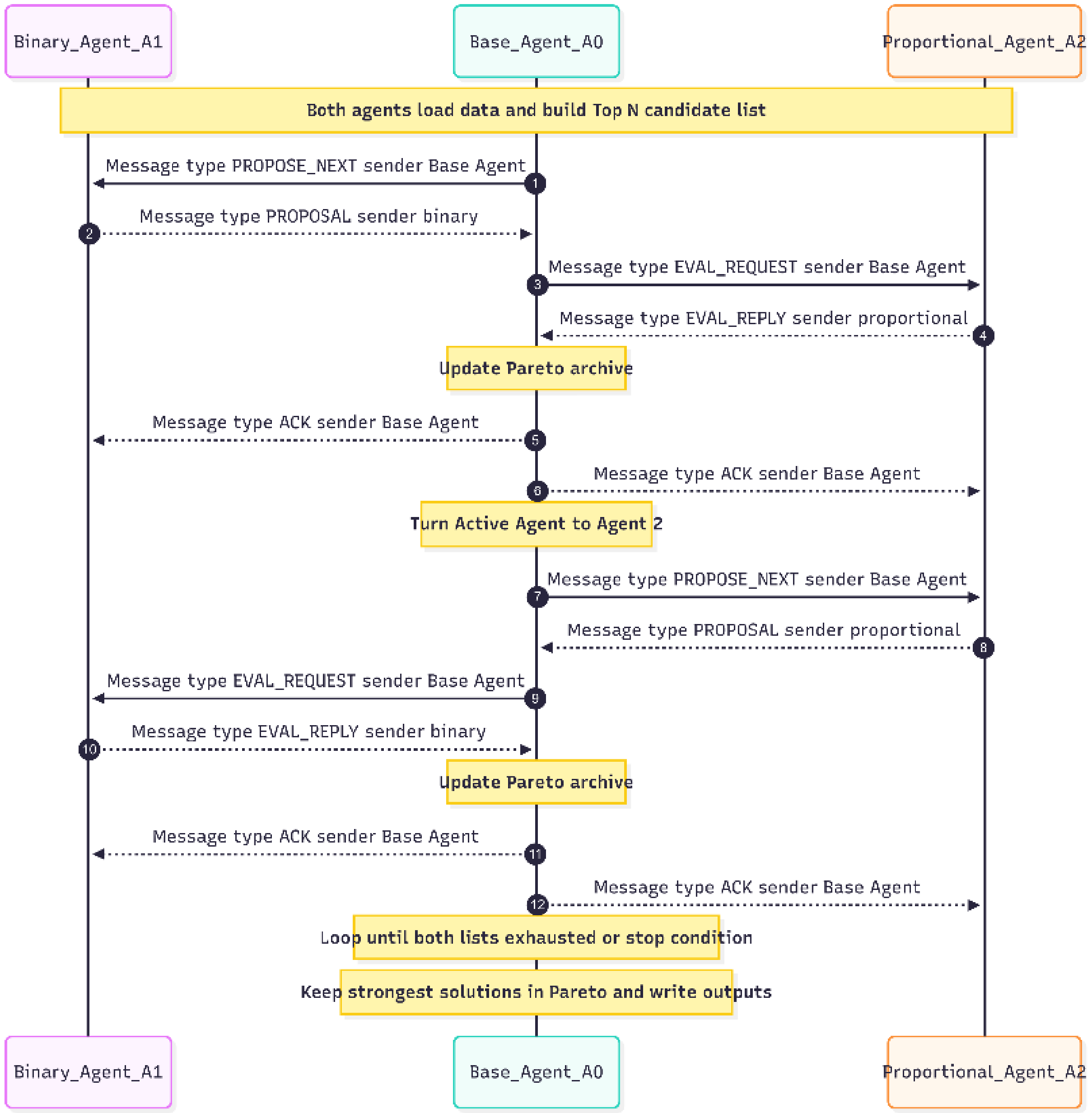
"receiver":"agento",

"conversation_id":"pp-20250914-42",

"reply_with":"B0001",

"content":{"combo":[146,255,274]," utility":9.6620}

}



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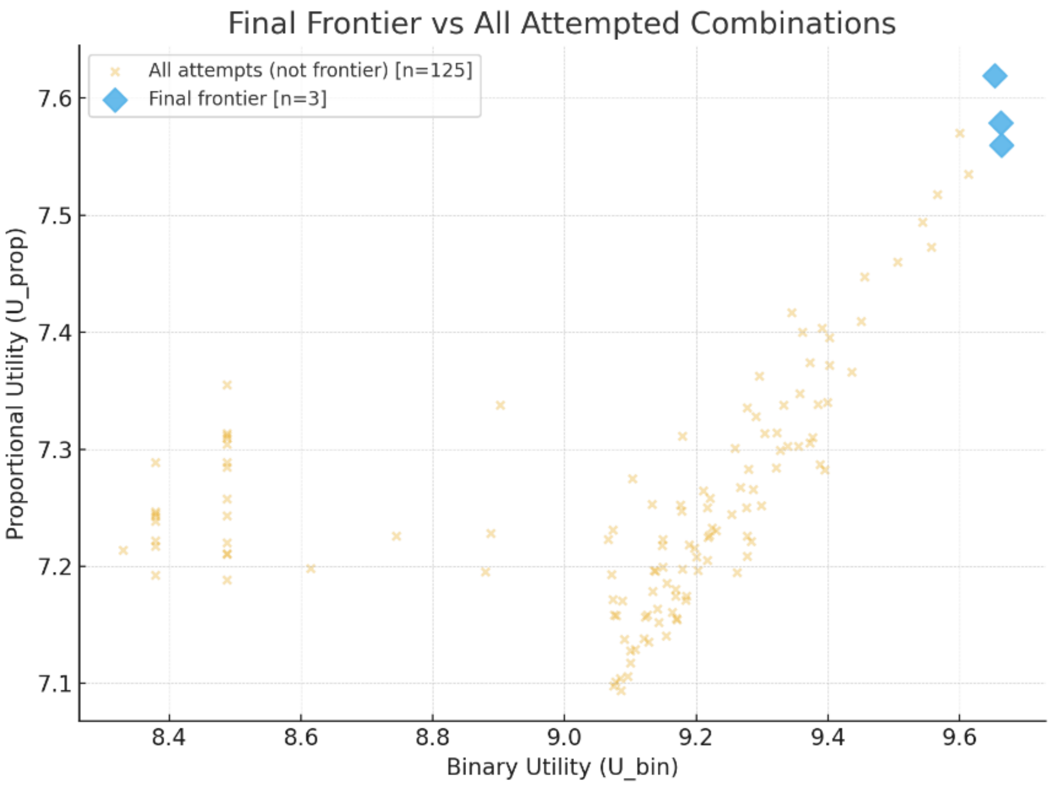
Final Non-Dominated set



rank	a	b	c	k	U_bin	U_prop	source
1	146	255	274	3	9.662967377958001	7.5600258306249835	binary
2	20	157	274	3	9.662086058255126	7.578686530169721	binary
3	20	255	274	3	9.652902375742302	7.6191380683403445	proportional

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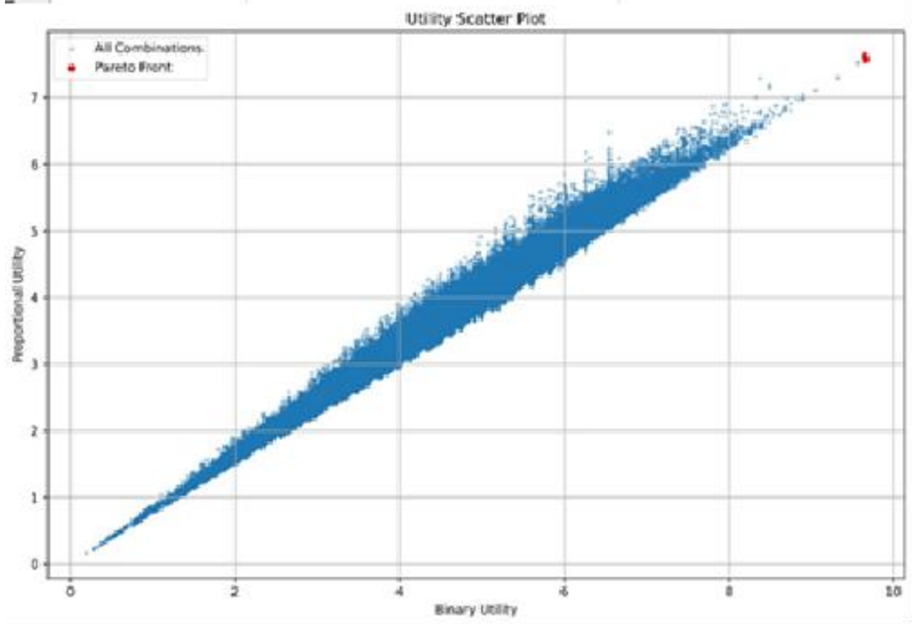
Complete Enumeration — Verification & Validation of MAS

- Establish a ground-truth Pareto set to verify MAPN/voting outputs.
- Evaluate all (Lk) combinations; compute Ubin,Uprop; extract the exact Pareto front

	A	B	C
1	Binary_Uti	Proportional_Utility	Facilities
2	9.663	7.56	[146, 255, 274]
3	9.6621	7.5787	[20, 157, 274]
4	9.6529	7.6191	[20, 255, 274]



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Comparison MAS MAPN with Complete Enumerated Pareto Results

Test Case	CityQualities	MAS Pareto Size	Enum Pareto Size	Overlap (%)
TC1	cityQualities_1.dat	3	3	~100%
TC2	cityQualities_2.dat	3	3	~100%
TC3	cityQualities_3.dat	6	6	~100%
TC4	cityQualities_4.dat	3	3	~100%
TC5	cityQualities_5.dat	3	3	~100%
TC6	cityQualities_6.dat	2	2	~100%

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Robust Solution Finding Methods

- **Distance-based**: Manhattan, Euclidean, Chebyshev
- **Rank-based**: TOPSIS, VIKOR
- **Curvature-based**: Knee point

- Most methods (Manhattan, Euclidean, Chebyshev, VIKOR, Knee) select (20,157,274) after normalization.
- TOPSIS depends on normalization type (vector $\longrightarrow$ (20,255,274); min–max $\longrightarrow$ (20,157,274)).

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Summary: Insight Future plan

- The voting frontier indicated that accepted combinations are located in the upper right corner of the scatter plot, suggesting that voting negotiation led to higher quality outcomes.
- MAPN-Dominance-based MAS for CFLP gave better results compared with the Pareto front generated with complete enumeration.

- Improving logic of the agents (reinforcement learning)
- Improving communication and negotiation strategies.
- Finding robust solutions (s) for facility location problems
- Extending experimental investigation to more test cases and data

THANK YOU