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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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Content

- Research Plan
- Competitive FLP
- Uncertainty of Customer Behavior
- Multi Agent System
- MAS Design with Customer Behavioral Models
- Results
- Insights and Future works

Research Plan

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2.	**Prosecution of scientific research:**			
2.1.	**Formation of study methodology:**			
2.1.1.	Formulation of the aim and objectives of the dissertation to identify quantitative and qualitative research methodologies of the problem	2024 y. IV quarter	2025 y. I quarter	
2.1.2.	Selection and description of methodologies	2024 y. IV quarter	2025 y. I quarter	Below are the intially identified research methods for this study. further need to investigatesuitable methods. 1. Literature Review: 2. Conceptual Framework: 3. Research Design: 4. Data Collection: 5. Agent-Based Modeling: 6. Data Analysis Techniques: 7. Validation and Verification: 8. Ethical Considerations:
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	In this stage need to fulfil 1. Literature Synthesis: 2. Theoretical Framework Development: 3. Conceptual Model Construction: 4. Hypothesis Formulation:
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	

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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							
3rd (2025/2026)	1				1			1		
4th (2026/2027)	1				1					
Total	2		1	1	2			1		

Competitive Facility Location Problems and Customer Behavior Models

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- Customer Behavior Models (CBM) play a crucial role in facility location problems as they help in
  - **understanding** how customers behave
  - **make decisions** regarding their **choice** of facilities.
- Main Classifications of CBM for FLP
  - **Binary Model**
  - Partially Binary Model
  - **Proportional Model**
  - Pareto-Huff Model

- Competitive Facility Location Problems (CFLPs) focus on the **strategic placement of facilities** considering the **presence of competitors**.
- These problems analyze how facility locations can influence **market share**, **customer** capture, and overall **competitive advantage**.

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Agent Models

Binary Agent (All-or-Nothing)

- **Concept:** Each demand point chooses a single facility with the highest attractiveness.
- **Formula:** Attraction=Quality/Distance+1

demand point's entire population goes to the facility with the maximum attraction (ties split by a predefined fraction).

- **Behavior:** Captures scenarios where customers make exclusive choices.

Proportional Agent (Demand-Splitting)

- **Concept:** Each demand point distributes its demand among all facilities in proportion to their attractiveness.
- Proportional Demand=∑(All Attractions)/ ∑(Candidate Attraction)

The candidate's share of demand is the ratio of its total attraction to the sum of attractions from both candidate and existing facilities.

- Behavior: Reflects more nuanced customer behavior where loyalty is split among multiple facilities.

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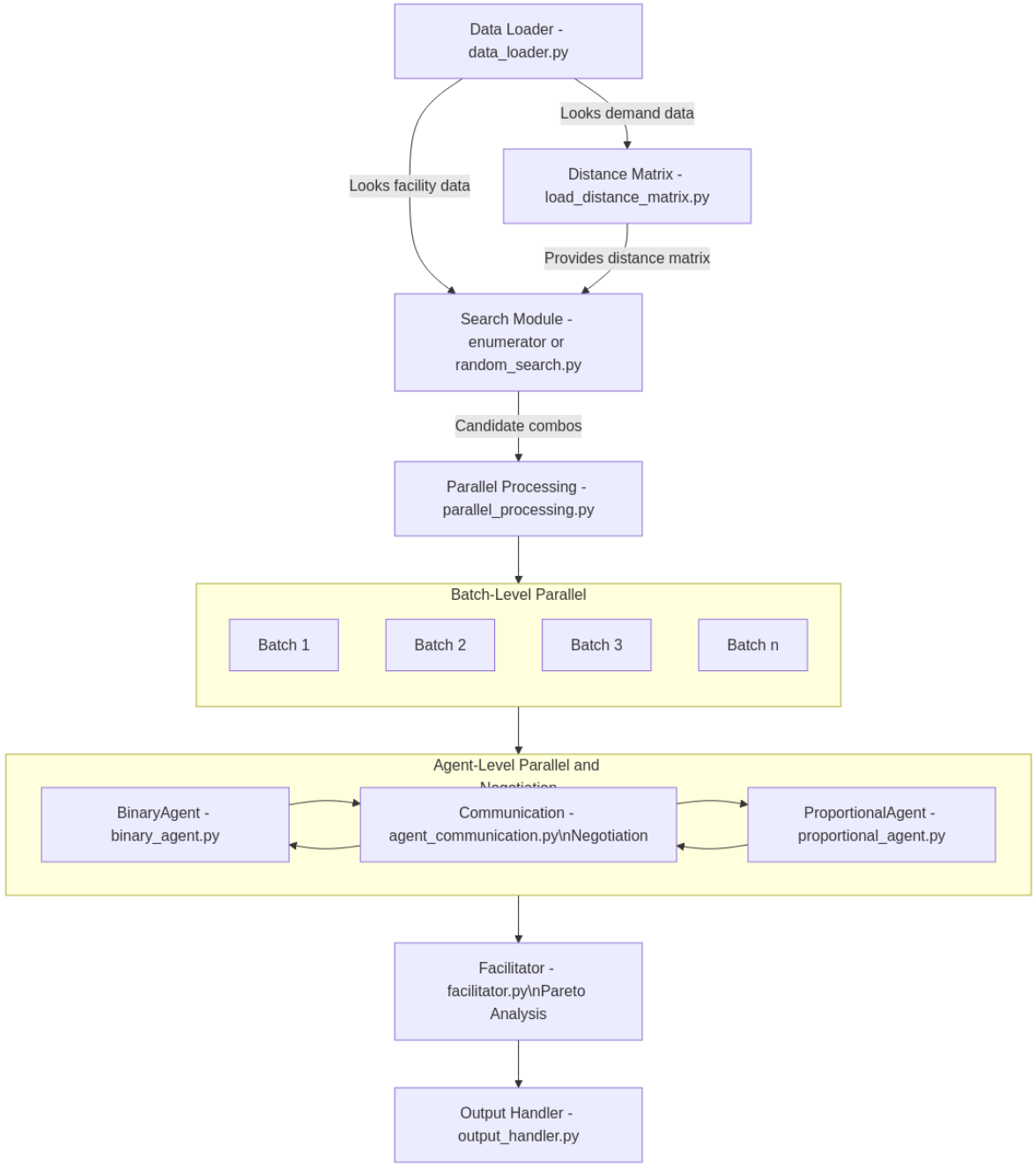
System Design



Data Loader: Loads demand points and facility site data.
Distance Matrix (OSRM/Haversine): Computes distances.
Search Module: Generates candidate solutions; supports Random or Enumeration methods.
Parallel Processing: Batch-level and agent-level parallel execution.
Agents: BinaryAgent and ProportionalAgent run concurrently.
Facilitator: Integrates agent utilities, manages iterative Pareto refinement.
Output Handler: Generates CSV/Text results, visualizes Pareto Front.
Agent Communication: Enables agent interaction and negotiation via iterative refinement.
Pareto Optimal Solution

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Results and Discussion

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Best Utility Values for both models

binary_results - Notepad

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Best BinaryAgent Result:
Combination: (53, 59, 88)
Utility: 1944824.4506226834
Percentage: 79.92%

All BinaryAgent Results (Descending Order):
Combination: (53, 59, 88), Utility: 1944824.4506226834, Percentage: 79.92%
Combination: (10, 53, 59), Utility: 1939201.781070665, Percentage: 79.69%
Combination: (30, 31, 59), Utility: 1937886.20429879, Percentage: 79.63%
Combination: (4, 30, 59), Utility: 1937241.6122847924, Percentage: 79.61%
Combination: (18, 53, 59), Utility: 1932340.6827673446, Percentage: 79.41%
Combination: (30, 59, 88), Utility: 1931323.5470224228, Percentage: 79.36%
Combination: (6, 53, 88), Utility: 1927779.8136037376, Percentage: 79.22%
Combination: (6, 10, 53), Utility: 1923592.5032765893, Percentage: 79.05%
Combination: (59, 79, 88), Utility: 1921239.4886491152, Percentage: 78.95%
Combination: (10, 30, 59), Utility: 1920830.401118972, Percentage: 78.93%
Combination: (13, 59, 88), Utility: 1919285.410496446, Percentage: 78.87%
Combination: (6, 30, 31), Utility: 1918969.7126754173, Percentage: 78.86%
Combination: (4, 6, 30), Utility: 1917908.9273925396, Percentage: 78.81%
Combination: (18, 30, 59), Utility: 1915852.3235809512, Percentage: 78.73%
Combination: (6, 18, 53), Utility: 1915571.1393480734, Percentage: 78.72%
Combination: (0, 53, 88), Utility: 1914911.3207510682, Percentage: 78.69%
Combination: (10, 59, 79), Utility: 1914776.3117150657, Percentage: 78.68%
Combination: (6, 30, 88), Utility: 1914278.910003477, Percentage: 78.66%
Combination: (18, 59, 79), Utility: 1912823.2486679303, Percentage: 78.60%
Combination: (10, 13, 59), Utility: 1912391.828816042, Percentage: 78.59%
Combination: (13, 18, 59), Utility: 1910869.1705152611, Percentage: 78.52%
Combination: (0, 10, 53), Utility: 1910075.3579877869, Percentage: 78.49%
Combination: (0, 30, 31), Utility: 1906101.2198227479, Percentage: 78.33%
Combination: (6, 10, 30), Utility: 1905221.1233248964, Percentage: 78.29%
Combination: (0, 4, 30), Utility: 1904391.7821037374, Percentage: 78.26%
Combination: (6, 79, 88), Utility: 1904194.85163017, Percentage: 78.25%
Combination: (6, 13, 88), Utility: 1902240.7734775005, Percentage: 78.17%
Combination: (0, 18, 53), Utility: 1902053.9940592712, Percentage: 78.16%
Combination: (0, 30, 88), Utility: 1901410.4171508078, Percentage: 78.13%
Combination: (6, 10, 79), Utility: 1899167.03392099, Percentage: 78.04%
Combination: (6, 18, 30), Utility: 1899082.7801616802, Percentage: 78.04%
```

proportional_results - Notepad

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Best ProportionalAgent Result:
Combination: (0, 2, 98)
Utility: 1394599.7861817752
Percentage: 57.31%

All ProportionalAgent Results (Descending Order):
Combination: (0, 2, 98), Utility: 1394599.7861817752, Percentage: 57.31%
Combination: (0, 4, 98), Utility: 1386092.2701628876, Percentage: 56.96%
Combination: (0, 2, 49), Utility: 1361997.1238370647, Percentage: 55.97%
Combination: (0, 20, 98), Utility: 1359349.6796852848, Percentage: 55.86%
Combination: (0, 1, 2), Utility: 1357856.6808925779, Percentage: 55.80%
Combination: (0, 1, 4), Utility: 1356226.6903407017, Percentage: 55.73%
Combination: (0, 4, 49), Utility: 1355522.2287695615, Percentage: 55.70%
Combination: (0, 88, 98), Utility: 1342123.7023401745, Percentage: 55.15%
Combination: (0, 10, 98), Utility: 1341331.3566452612, Percentage: 55.12%
Combination: (0, 18, 98), Utility: 1338316.55712764, Percentage: 55.00%
Combination: (0, 3, 98), Utility: 1332251.1573554387, Percentage: 54.75%
Combination: (0, 20, 49), Utility: 1327092.2774854994, Percentage: 54.53%
Combination: (0, 1, 20), Utility: 1323917.8407884855, Percentage: 54.40%
Combination: (0, 40, 98), Utility: 1323793.66470986, Percentage: 54.40%
Combination: (0, 19, 98), Utility: 1321778.9226785062, Percentage: 54.32%
Combination: (0, 7, 98), Utility: 1317504.1860619192, Percentage: 54.14%
Combination: (0, 89, 98), Utility: 1316201.8036895038, Percentage: 54.09%
Combination: (0, 31, 98), Utility: 1313160.4626578963, Percentage: 53.96%
Combination: (0, 53, 98), Utility: 1312919.2578818288, Percentage: 53.95%
Combination: (0, 65, 98), Utility: 1310942.155586279, Percentage: 53.87%
Combination: (0, 49, 88), Utility: 1310427.8787980475, Percentage: 53.85%
Combination: (0, 1, 88), Utility: 1310391.6266474167, Percentage: 53.85%
Combination: (0, 10, 49), Utility: 1309079.8894777466, Percentage: 53.79%
Combination: (0, 6, 98), Utility: 1308901.7124467727, Percentage: 53.79%
Combination: (0, 1, 10), Utility: 1308412.4512124646, Percentage: 53.77%
Combination: (0, 2, 4), Utility: 1306963.8123951328, Percentage: 53.71%
Combination: (0, 18, 49), Utility: 1306107.8916439868, Percentage: 53.67%
Combination: (0, 1, 18), Utility: 1305281.8327939447, Percentage: 53.64%
Combination: (0, 67, 98), Utility: 1303318.2334246293, Percentage: 53.56%
Combination: (0, 49, 98), Utility: 1301918.6111437115, Percentage: 53.50%
Combination: (0, 30, 98), Utility: 1297300.9244254758, Percentage: 53.31%
```

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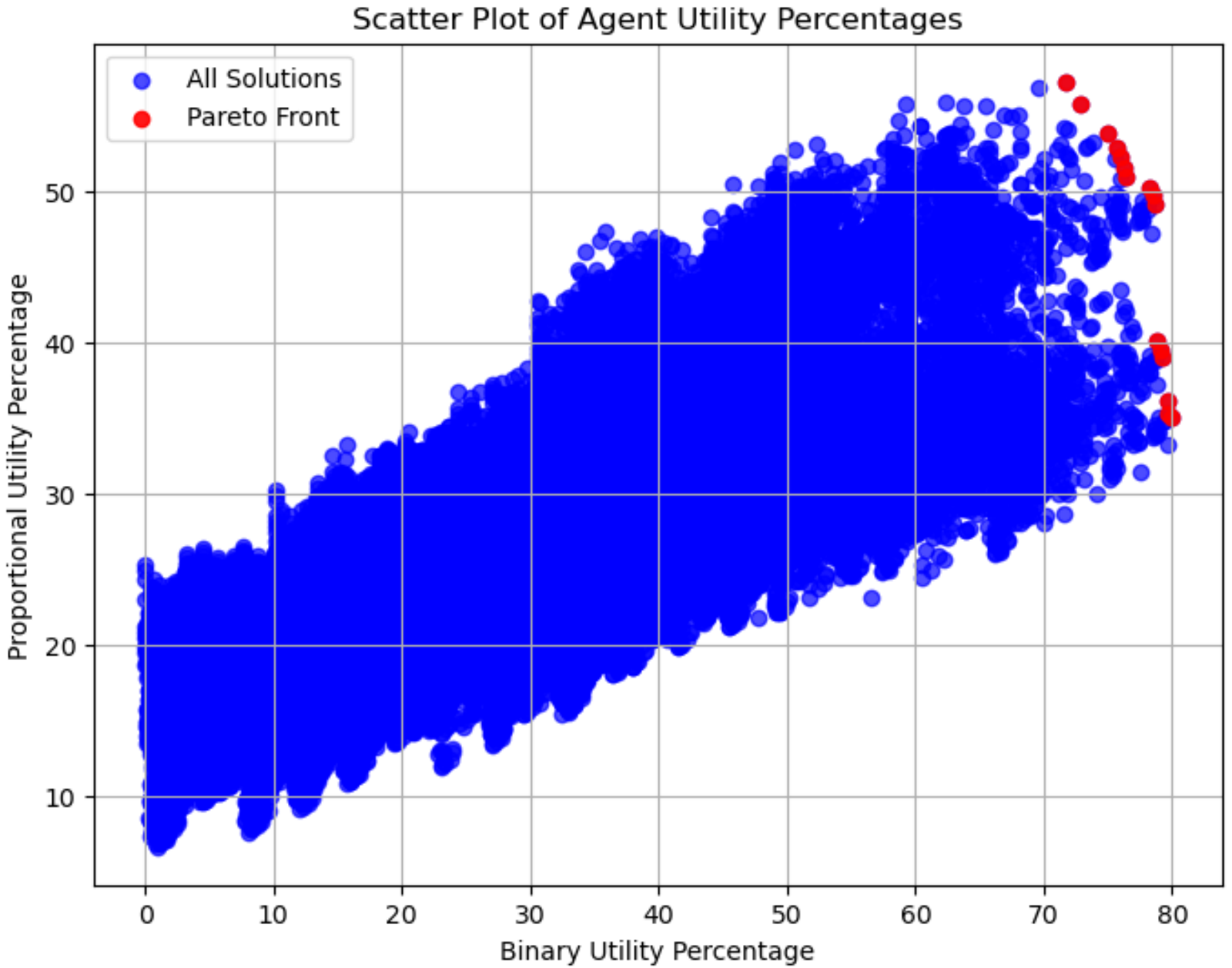
CSV File

	A	B	C	D	E
1	Combination	Binary Utility	Binary Percentage	Proportional Utility	Proportional Percentage
2	(53, 59, 88)	1944753.205	79.91608793	853714.3138	35.08183352
3	(10, 53, 59)	1939130.741	79.68504304	860407.5322	35.35687913
4	(30, 31, 59)	1937815.213	79.63098379	810006.1751	33.28572723
5	(4, 30, 59)	1937170.644	79.60449643	878188.7587	36.08756622
6	(18, 53, 59)	1932269.894	79.40310904	848133.7277	34.85250951
7	(30, 59, 88)	1931252.796	79.36131324	846067.8193	34.76761477
8	(6, 53, 88)	1927709.192	79.21569531	950491.6691	39.05872253
9	(6, 10, 53)	1923522.035	79.04363172	960408.038	39.46621763
10	(59, 79, 88)	1921169.107	78.94694242	829145.7431	34.07223289
11	(10, 30, 59)	1920760.034	78.93013233	852776.057	35.04327757
12	(13, 59, 88)	1919215.1	78.86664608	826066.8549	33.9457116
13	(6, 30, 31)	1918899.414	78.85367353	906339.4894	37.24436918
14	(4, 6, 30)	1917838.668	78.81008409	975288.7352	40.07771275
15	(18, 30, 59)	1915782.139	78.7255748	840524.3274	34.53981507
16	(6, 18, 53)	1915500.965	78.71402047	946513.9579	38.89526573
17	(0, 53, 88)	1914841.171	78.68690742	1198071.655	49.23257075
18	(10, 59, 79)	1914706.167	78.68135967	836288.3427	34.365745
19	(6, 30, 88)	1914208.783	78.66092061	942833.6947	38.74403203
20	(18, 59, 79)	1912753.175	78.60110505	823537.747	33.84178251
21	(10, 13, 59)	1912321.771	78.58337729	833295.201	34.2427473

Combination	Binary Utility	Binary Percentage	Proportional Utility	Proportional Percentage
(53, 59, 88)	1944824.451	79.91901565	853745.5895	35.08311874
(10, 53, 59)	1939201.781	79.68796229	860439.0531	35.35817442
(4, 30, 59)	1937241.612	79.60741273	878220.931	36.08888828
(6, 53, 88)	1927779.814	79.21859736	950526.4902	39.06015343
(6, 10, 53)	1923592.503	79.04652747	960443.2224	39.46766347
(4, 6, 30)	1917908.927	78.81297128	975324.4647	40.07918099
(0, 53, 88)	1914911.321	78.6897901	1198115.546	49.23437438
(0, 10, 53)	1910075.358	78.49106503	1212021.433	49.80581142
(0, 4, 30)	1904391.782	78.25750884	1222703.651	50.24477771
(0, 20, 88)	1860286.462	76.4450811	1241009.183	50.99701017
(0, 10, 20)	1855867.707	76.26350044	1254259.897	51.54152413
(0, 2, 88)	1847724.531	75.92887144	1274076.011	52.35583122
(0, 2, 10)	1841792.254	75.68509534	1287349.809	52.90129375
(0, 53, 98)	1826105.828	75.04049027	1312919.258	53.95202363
(0, 20, 98)	1771480.969	72.79578126	1359349.68	55.85999718
(0, 2, 98)	1744742.074	71.69699512	1394599.786	57.30853605

Pareto Front



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Insights

- **Model Comparison:**
  - **Binary Agent:** Captures high demand by selecting a single best facility.
  - **Proportional Agent:** Distributes demand among facilities for a more balanced approach.
  - The differences illustrate how varying customer behavior affects market capture.
- **Search Trade-offs:**
  - **Exhaustive Search:** Guarantees the global optimum but is computationally heavy.
  - **Random Search:** Offers near-optimal solutions quickly with lower computational cost.
- **Parallel Processing Impact:**
  - Batch-level and agent-level parallelism significantly reduce evaluation time.
  - Enables efficient handling of large-scale problems and real-time processing.
- **Real-World Implications:**
  - The MAS framework provides decision-makers with a spectrum of robust facility location options.
  - Balances aggressive market capture with balanced service distribution under diverse customer behaviors.
  - Offers scalability and adaptability to dynamic market conditions.

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Conclusion & Future Work

Main Findings & Contributions:

- Developed a robust multi-agent system (MAS) that integrates distinct customer behavior models (binary and proportional) for competitive facility location.
- Achieved significant computational efficiency using batch-level and agent-level parallel processing.
- Employed iterative Pareto refinement to produce a spectrum of balanced, non-dominated solutions.
- Integrated realistic distance calculations using OSRM (with a fallback to Haversine).

Final Remarks:

- The MAS framework demonstrates promising potential for scalable and adaptive facility location.
- We invite questions and feedback to advance this research further.

Future Directions:

- **Expand Agent Diversity:**
  - Introduce additional agents to model other customer behaviors (e.g., logit, Huff).
- **Enhance Inter-Agent Communication:**
  - Develop advanced negotiation protocols and communication frameworks to further refine candidate solutions.
- **Adopt Advanced Search Algorithms:**
  - Explore heuristic/metaheuristic approaches (e.g., genetic algorithms, simulated annealing) to replace or complement complete enumeration for large-scale problems.
- **Robust Optimization:**
  - Integrate methods to handle uncertainty in demand, cost, and competitor behavior.
- **Real-World Validation:**
  - Test the system with real datasets and dynamic market conditions for broader applicability.

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Thank you