Multi-Agent Autonomous Waste Collection System

INTRODUCTION TO INTELLIGENT AND AUTONOMOUS SYSTEMS

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Introduction and Context

Objective:

Develop a decentralized waste collection system using Multi-Agent Systems (MAS) using SPADE

Current Scenario:

Large urban areas face growing challenges in managing waste collection.

Common issues include:

- Variable waste production across locations and times.
- Dynamic traffic conditions, including roadblocks and congestion.
- Inefficiencies in centralized systems, leading to redundant routes and high resource consumption.

Overall Sketch: Types of Agents and System Integration

The system consists of two main types of agents: **Truck Agents** and **Bin Agents**, which operate within a dynamic environment. Here's an overview of their roles and interactions:

Bin agent:

Waste Monitoring: Tracks and increases waste levels in bins.

Collection Request: Sends a CFP to Truck Agents when bins are ≥70% full.

Proposal Evaluation: Analyzes truck proposals to choose the best option based on cost, capacity, and availability.

Problem Resolution:
- Resends CFPs if no truck responds.
- If a responding truck breaks down, it notifies the bin to wait for reassignment. After a delay, the bin resends CFPs if there aren't trucks available.

Truck agent:

Proposal Generation: Responds to CFPs with cost, fuel, and capacity estimates.

Route Planning: Calculates the shortest path dynamically using Dijkstra's algorithm, considering real-time traffic conditions.

Waste Collection: Navigates to bins, collects waste, and updates its load status.

Resource Management: Manages fuel, waste load, and capacity; returns to the depot when resources are low.

Fault Tolerance: Reallocates tasks to other trucks during breakdowns or emergencies

Exploration: A truck can choose to explore the environment and go to a bin

Autonomous Truck Agent Behaviors

- **Autonomous Exploration:**

Trucks explore nearby bins (with Waste accumulation >= 40) autonomously if no Call for Proposals (CFP) has been received.

- **Task Allocation:**

If a truck cannot reach a bin, it allocates the task to the next most suitable truck.
Selection based on:

  - **Capacity (priority 1).**
  - **Cost (priority 2).**
  - **Fuel efficiency (priority 3).**
  - **Tie-breaker:** Truck ID.

- **Dynamic Route Adaptation:**

Routes are adjusted dynamically based on traffic conditions and roadblocks:

No two trucks go to the same bin simultaneously (Lists of accessible bins are constantly updated and once a bin is serviced, it becomes accessible again.

Interaction and Communication Protocols

- **Communications between TRUCK1 and TRUCK2:**

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1. **Allocation of other trucks:** If truck1 was on its way to collect the trash from a CFP and in the middle of the path it breaks down, the truck1 communicates with other trucks and they decide wich one should go, if they have availability to do so.
2. **Claims:** When a truck shows interest to go to one bin, the truck sends a Claim to every other truck and he gets an answer from them to check if he is indeed the best truck to complete the collection. The winning truck claims the bin for himself.
3. **Decline Claim :** A truck can deny the acessability of other trucks when they want to claim a bin.
4. **Release Bin :** A truck can indicate to other trucks, after he collects the trash or if the truck for some reason was not able to reach the bin as he planned, that he released the bin that he once claimed .

Interaction and Communication Protocols

For this project we used the **Contract Net Protocol** for the communication between agents

- **Communications between TRUCK and BIN:**

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1. Call for Proposals (CFP): Bin Agents send CFPs to Truck Agents when waste exceeds a threshold (70%.)
Truck Action: Trucks evaluate feasibility based on {Proximity, Fuel and capacity , route accessibility} and decide whether to answer or not, if so they send a proposal.

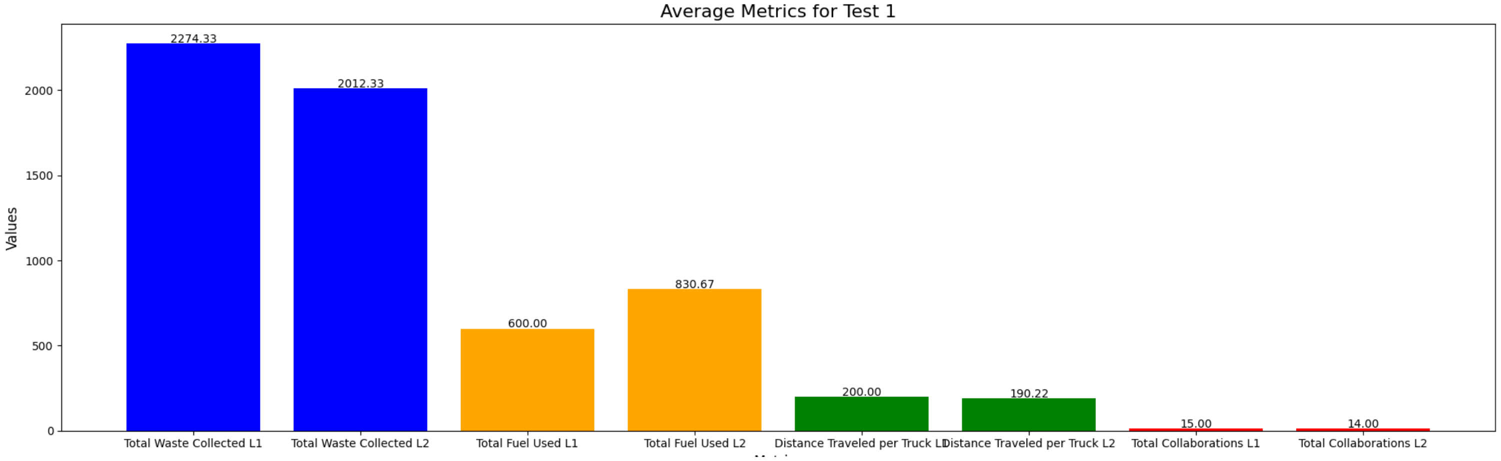
2. Proposal Generation and Evaluation:
Truck: Sends proposals with cost, fuel, path and capacity details.
Bin: Selects the best proposal (highest capacity, lowest cost, sufficient fuel).

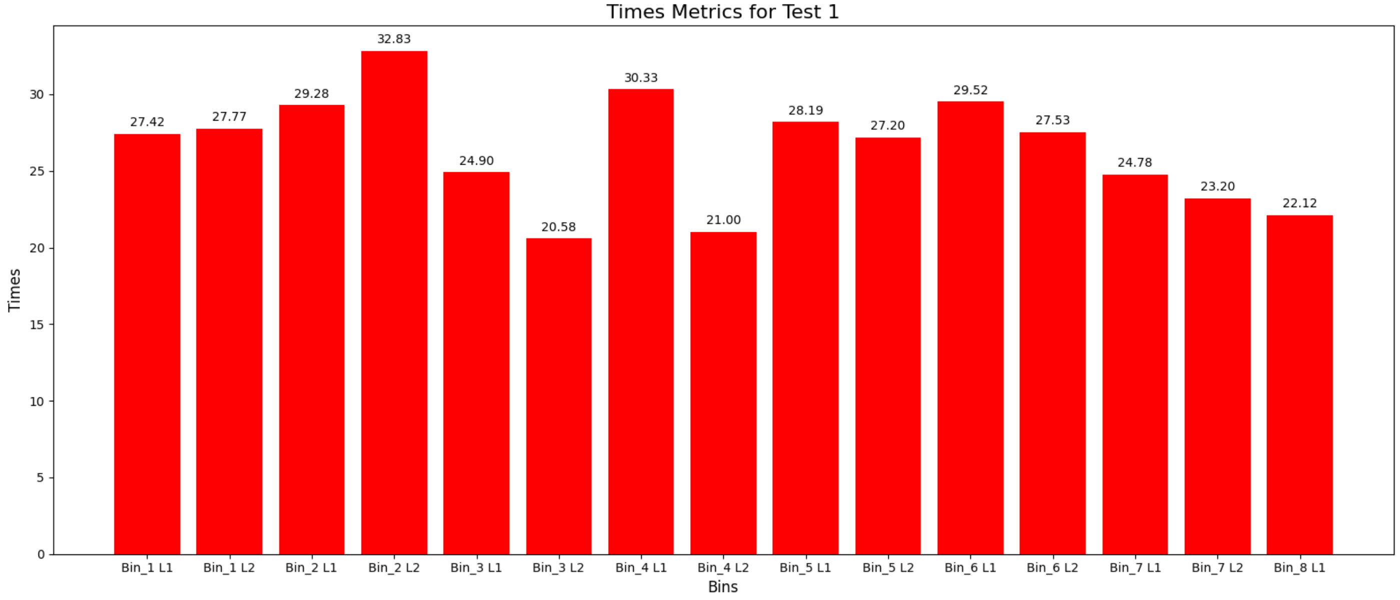
3. Task Allocation and Execution:
Bin: Sends acceptance to selected truck.
Truck: Executes task {Navigates to bin collects waste and updates status}

4. Fault Tolerance:
Truck: Sends release messages to other trucks if it is unable to complete the task (e.g., low fuel, breakdown) and tries to allocate the bin to another truck.
Bin: Resends CFP for task reassignment after x time if no other truck is selected.

Trucks adapt routes dynamically based on updated graphs provided by the environment.

Test 1: Basic Environment with Constant Waste Accumulation

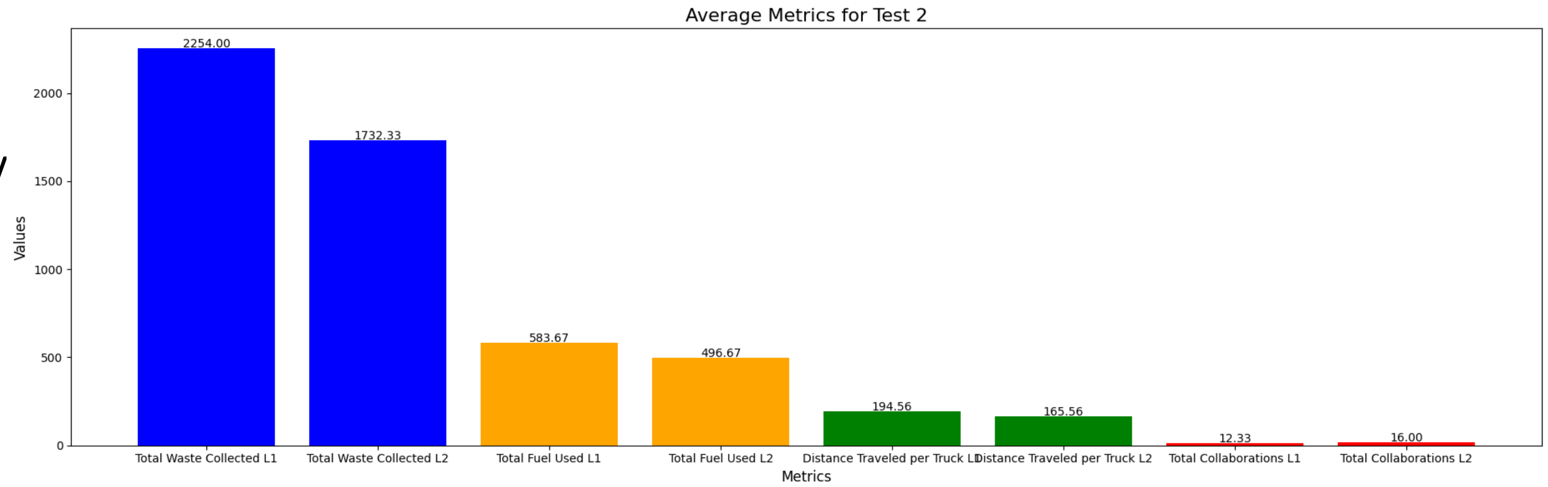


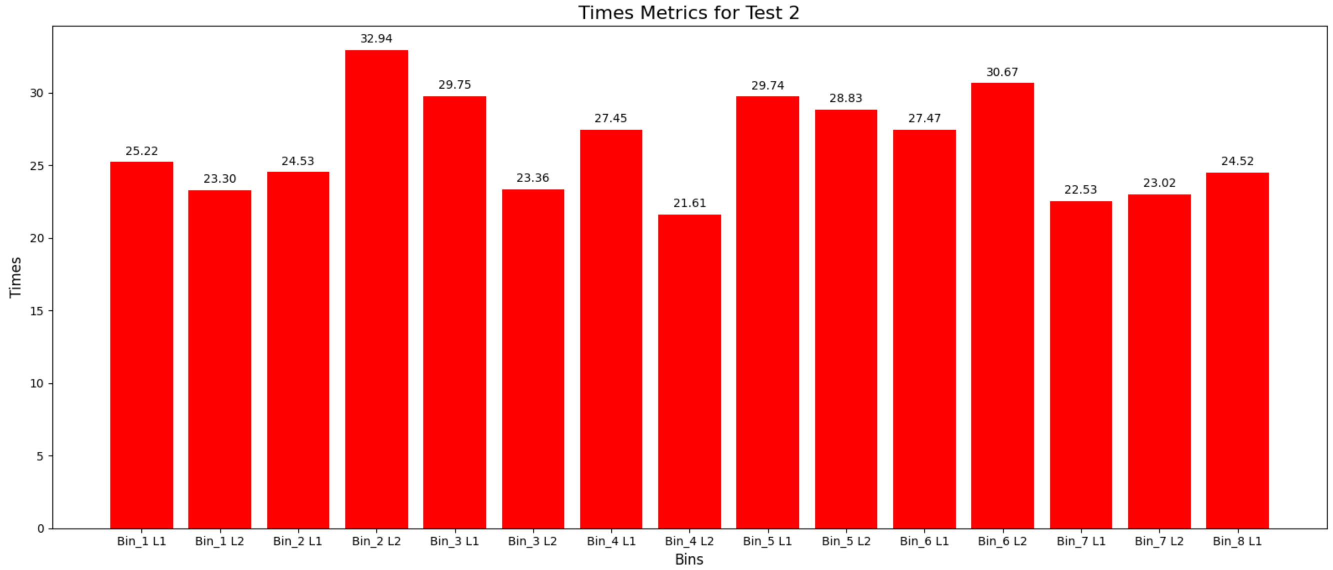


Analysing the graphs we noticed that in general, regardless of the layout, the **time** it takes for the trucks to **collect garbage** is **similar** in both cases, which proves the **effectiveness** of the agents in **different situations** for the same conditions. Furthermore, we also concluded that each truck **travelled** approximately the **same distance**, thus **showing good collaboration** and **distribution of tasks**. Finally, we detected that there was a small **discrepancy** between the values of **fuel spent** and **garbage collection** for the different layouts, which could occur due to the **arrangement** of the **bins**, which in one of them are more concentrated on one side of the map.

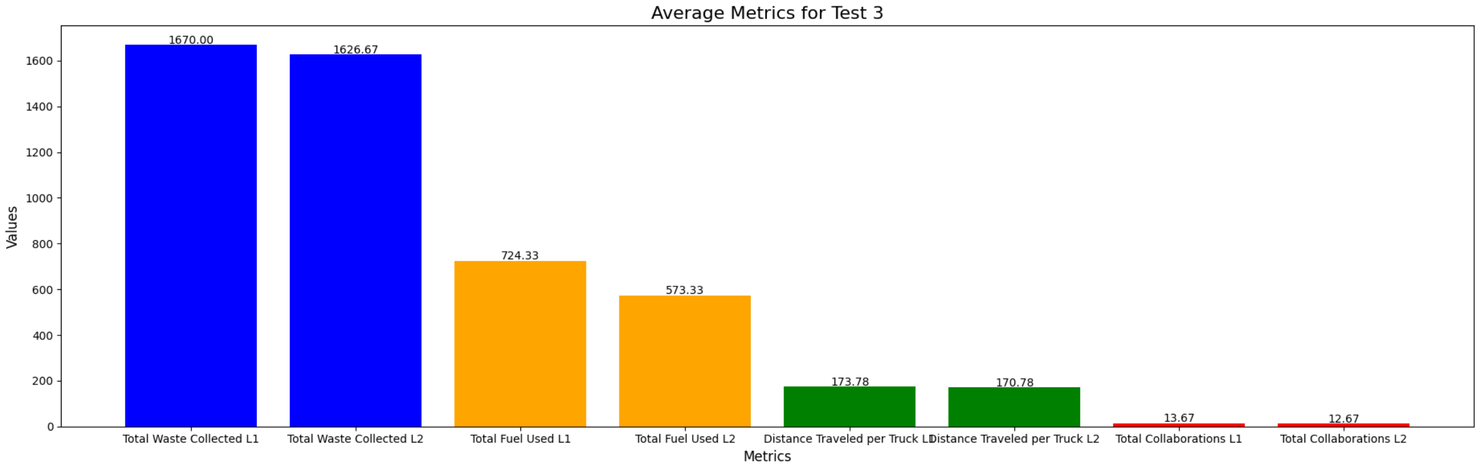
Test 2: Basic Environment with Different Waste Accumulation

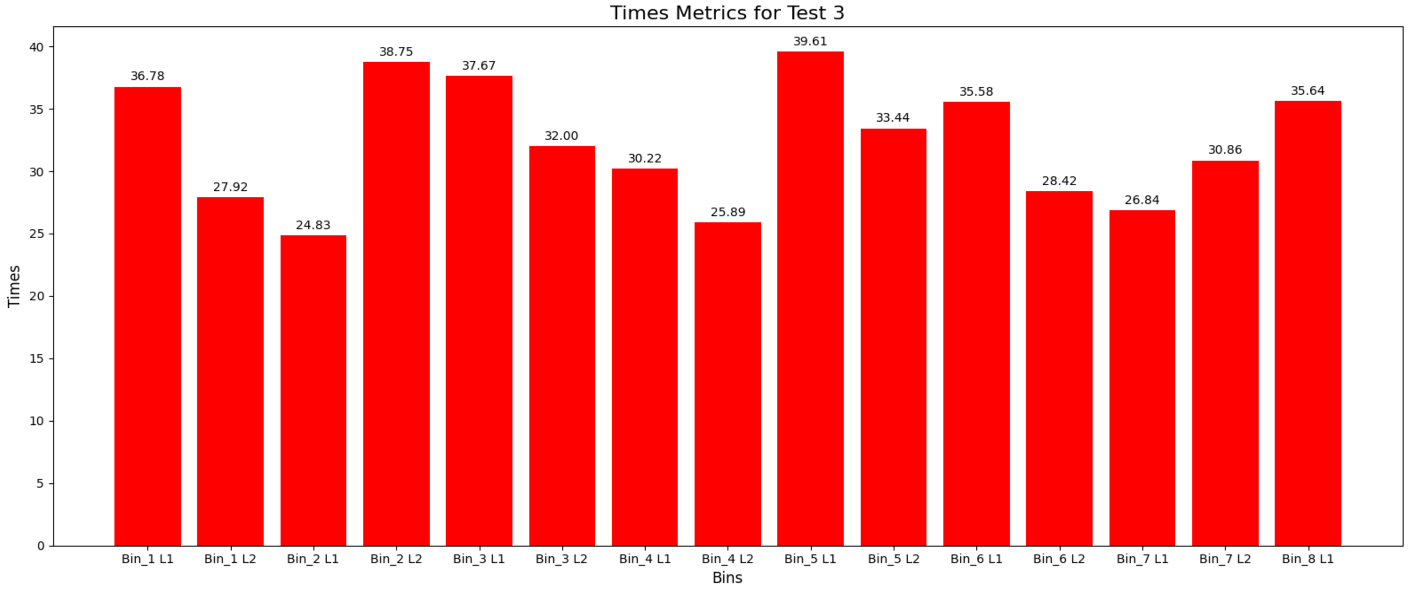
When we start to have **different garbage accumulation** rates, we notice that in general the amount of **fuel spent decreases**, which may be related to the fact that the different accumulation rates **allow the bins to reach higher garbage accumulation levels**, thus making trucks prioritize CFP's over Exploration, collecting more garbage for lower fuel costs. In terms of **garbage collection times**, we noticed that there were **more differences** here, but this could be related to the management of random accumulation rates, as it can mean that **trucks** have to **constantly move from one end of the map to the other**. In relation to the average distances covered by the trucks and the collaborations between them, there were no major changes.





Test 3: Dynamic Environment with Different Waste Accumulation





When we introduce **environmental changes** into the system, such as **traffic** and **road blocks**, we would expect the bin **collection time to increase**, as can be seen in the graphs. Additionally, since **trucks take longer to reach the bins**, the amount of **trash they have increases**, causing them to **collect larger quantities** at once. However, **fuel costs increased drastically**, as trucks had to make **detours** from the original route and spend fuel **'sitting' in traffic**.

CONCLUSION

In general, we can conclude that the system created proves to be quite efficient for the situations tested, namely: simple environments, changes in the level of waste accumulation and changes in the environment, thus proving to be effective for everyday challenges. Furthermore, the collaboration between agents during tests and the planning of new routes in real time with the aim of avoiding environmental changes, allowed the trucks to save more resources. Furthermore, negotiation between the trucks also made it possible that when an agent broke down, the bin he was going to, would not be left with no one to go there.