

Collaborative System Design for Urban Crisis: Resolution Using Multi-Agent Technology

Sheena Maria Lang, Antonio Lobo Santos, Zachary Parent,
María del Carmen Ramírez Trujillo and Bruno Sánchez Gómez

November 3, 2024

Contents

1	Introduction	2
1.1	Related Work	2
2	City Selection	2
2.1	Criteria	2
2.2	Candidate Cities	2
2.3	Evaluation	3
2.4	Selection: Lloret de Mar	4
3	Environment	4
3.1	Accessibility	4
3.2	Determinism	5
3.3	Episodicity	5
3.4	Static vs. Dynamic	5
3.5	Discrete vs. Continuous	5
4	Agent Crews	5
4.1	Emergency Services	6
4.1.1	Emergency Call Agent	6
4.1.2	Notification Agent	6
4.2	Firefighters	7
4.2.1	Fire Chief	7
4.2.2	Equipment Technician	7
4.2.3	Firefighter	8
4.3	Medical Services	8
4.3.1	Medical Services Operator	8
4.3.2	Hospital Coordinator	9
4.3.3	Paramedic	9
4.4	Forensics Team	10
4.4.1	Forensics Operator	10
4.4.2	Forensics Coordinator	10
4.4.3	Coroner	11
4.4.4	Investigator	11
4.5	Public Communications	12
4.5.1	Communication Operator	12
4.5.2	Archive keeper	12
4.5.3	Article Writer	12
4.5.4	Mayor	13
4.5.5	Social Media Commentator	13
5	Conclusion	14

1 Introduction

In this study, we model a multi-agent system to manage fire-related emergencies in Lloret de Mar, Girona. For this purpose, we have designed five specialized response teams using CrewAI¹: **emergency services**, **firefighters**, **medical services**, **forensics team**, and **public communications**.

The report is structured as follows:

- In **Section 2**, we detail our selection process for the city in which our model takes place.
- In **Section 3**, we analyze the environmental characteristics affecting this system.
- In **Section 4**, we discuss the distinct agent crews and the attributes of their individual members.

1.1 Related Work

The increasing capabilities of Large Language Models (LLMs) have sparked greater interest in this area, as these models demonstrate early signs of general intelligence [3] and adaptability to novel situations [5]. These advancements have driven diverse approaches and applications of autonomous agents, such as the work by Wang et al. [7].

However, new challenges accompany these advancements, including the optimization of **task allocation** to leverage agents' unique skill sets, enhancing intermediate outcomes through agent discussions, managing complex **context** layers related to tasks, agents, and shared knowledge, and handling multiple **memory types** essential for effective multi-agent collaboration [4].

While not within the scope of our current study, future work might benefit from exploring related topics such as Berthon et al.'s work on modeling environmental uncertainty [1] and Morales et al.'s research on synthesizing norms for multi-agent systems (MAS) [6].

Finally, for the design of our system, we reference key principles in Chapter 2 of [8] and insights from Michael Wooldridge's video on agent properties².

2 City Selection

This section presents an explanation of the city selection process.

2.1 Criteria

We carefully selected among several candidate cities, using the following criteria:

- A city the team is familiar with, so that we can better understand the practical implications of our work.
- A city with well-defined borders, so that we can easily define a realistic environment.
- A city with reasonable complexity, not too big and not too small.

2.2 Candidate Cities

We selected the following cities for consideration:

1. **Barcelona, Spain:** Our city, but relatively dense and complex.
2. **Seville, Spain:** Similarly very dense and complex.
3. **Salamanca, Spain:** Not as dense or complex, but lacks well-defined borders.
4. **Tossa de Mar, Spain:** Small and very compact. Includes a long single road.
5. **Lloret de Mar, Spain:** Relatively small, but includes densely connected city areas.
6. **New York, NY, USA:** Prohibitively large and complex.

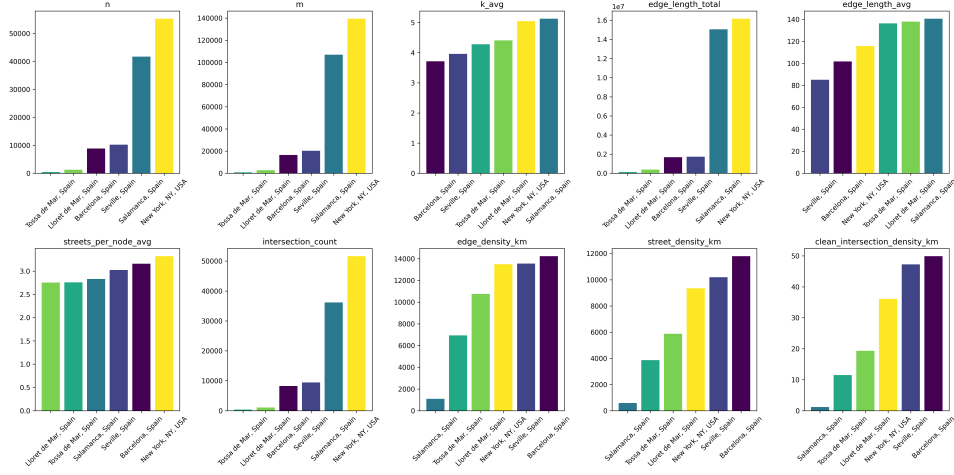


Figure 1: Map Complexity Statistics

2.3 Evaluation

We pulled 10 metrics from the OSMnx package [2] for each city. Plots of these metrics are shown in Figure 1.

- **n**: Number of nodes in the graph
- **m**: Number of edges in the graph
- **k_avg**: Average node degree
- **edge_length_total**: Total length of all edges in meters
- **edge_length_avg**: Average edge length in meters
- **streets_per_node_avg**: Average number of streets per node
- **intersection_count**: Number of intersections
- **edge_density_km**: Kilometers of edge per square kilometer
- **street_density_km**: Kilometers of street per square kilometer
- **clean_intersection_count**: Number of intersections (cleaned)

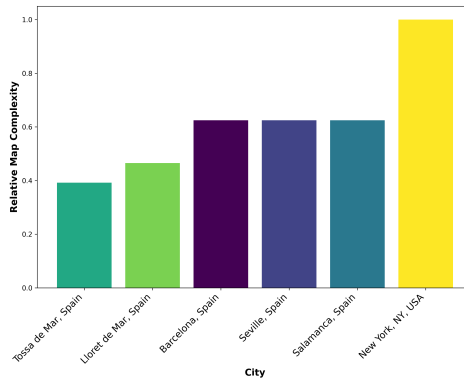


Figure 2: Relative Map Complexity

¹<https://www.crewai.com/>

²https://www.youtube.com/watch?v=vID-_uIfAvg&feature=youtu.be

We ranked each city based on each metric, and then added the ranks, inverted them, and normalized them to derive a relative complexity score. As you can see in Figure 2, **New York** is by far the most complex city, and **Tossa de Mar** is the least complex. **Barcelona**, **Seville**, and **Salamanca** are of similar moderate complexity.

2.4 Selection: Lloret de Mar

We decided to select **Lloret de Mar** because it has a more interesting structure than the other large Spanish cities, but has a more standard layout and complexity than **Tossa de Mar**. This makes it a nice, well-balanced case study (see Figure 3).

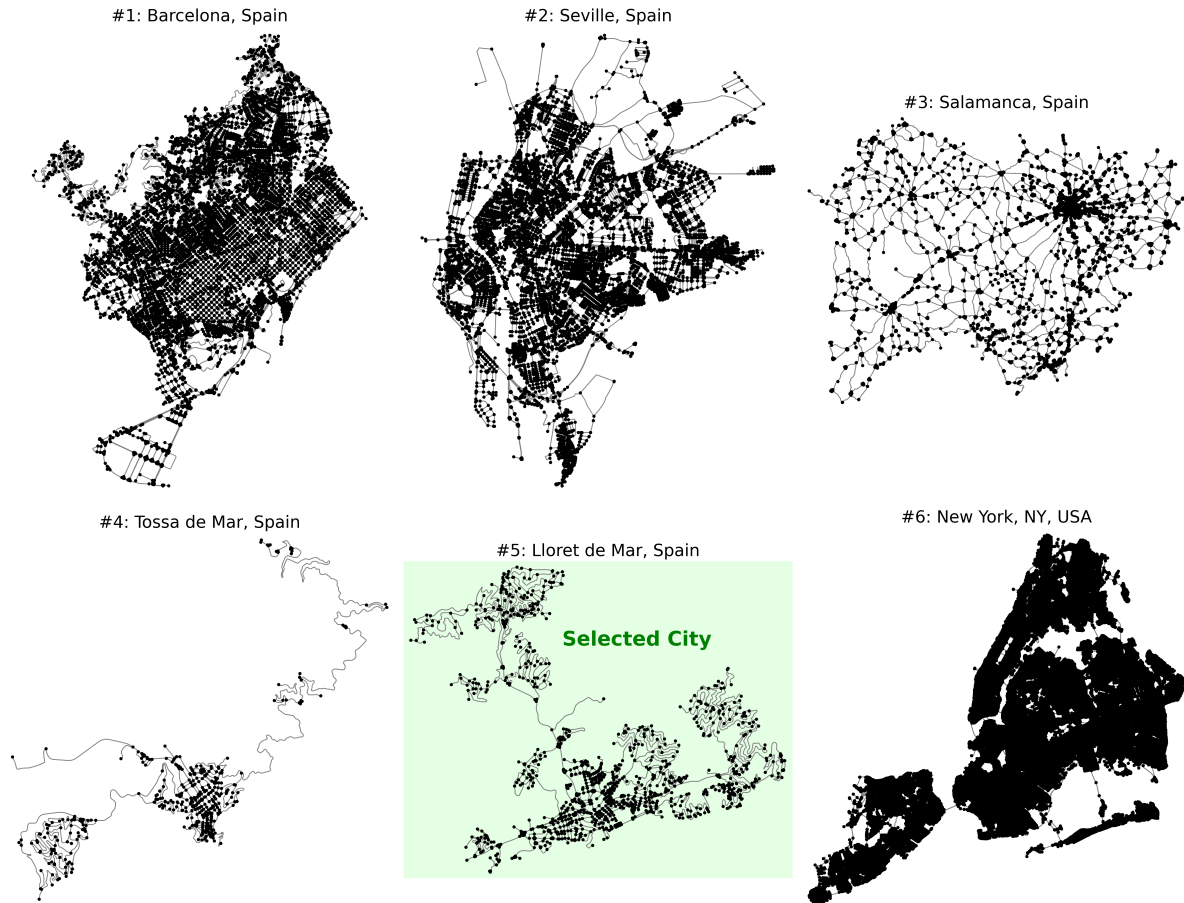


Figure 3: Maps of Candidate Cities

3 Environment

This section presents an analysis of the multi-agent system environment in the context of emergency response.

3.1 Accessibility

The environment is **partially observable**. In a partially observable environment, agents cannot obtain complete, accurate, and up-to-date information on all aspects of the environment. Here, each agent may have limited knowledge about the current state of other agents, such as their exact locations or the resources they are carrying at any given time. For example, a fire truck may not know the precise location or availability of ambulances in the vicinity. This limitation requires agents to operate with incomplete information and make decisions based on their local observations and periodic updates.

3.2 Determinism

The environment is **non-deterministic**. Although agents follow specific instructions, the outcomes of their actions are uncertain due to unpredictable environmental changes and external factors. For example, the fire may spread or intensify, and resource availability (like ambulances or fire trucks) may vary. This requires agents to continuously adapt to changing conditions, as there is no guaranteed single effect from each action.

3.3 Episodicity

The environment is **non-episodic**. Actions taken by agents have interdependent consequences. For instance, dispatching a fire truck to one location affects its availability for future incidents. This interconnectedness means agents must consider the consequences of their actions over time, as each decision affects future outcomes in a continuous sequence rather than isolated episodes.

3.4 Static vs. Dynamic

The environment is **dynamic**. Fires can evolve, spread, or be partially contained over time. Additional injuries may occur, and the status of resources (such as the availability of hospital beds or medical staff) can change unexpectedly. The dynamic nature of this environment necessitates that the system's agents are capable of frequent plan updates and re-coordination to respond effectively to evolving situations.

3.5 Discrete vs. Continuous

The environment is **continuous**. The city is represented as a graph with coordinates, which means agents have a wide range of possible positions, paths, and interactions. Additionally, factors such as fire severity and the capacity of resources are continuously changing, requiring agents to process ongoing updates and adjust their actions accordingly.

In summary, the emergency response environment for this multi-agent system is partially observable, non-deterministic, non-episodic, dynamic, and continuous. The agents operating within this system must be designed for adaptability and responsiveness, capable of handling incomplete information, and prepared to respond to a sequence of interconnected events across a continuously changing city landscape.

4 Agent Crews

In this section we will describe the five agents crews of our model:

1. Emergency Services.
2. Firefighters.
3. Medical Services.
4. Forensics Team.
5. Public Communications.

We will discuss the main tasks, tools, types, and properties of each agent that comprises the crews. Figure 4 illustrates the interactions between crews of agents as well as among agents within the different crews. Communication between crews is carried out through a communication channel, which only one agent per crew has access to.

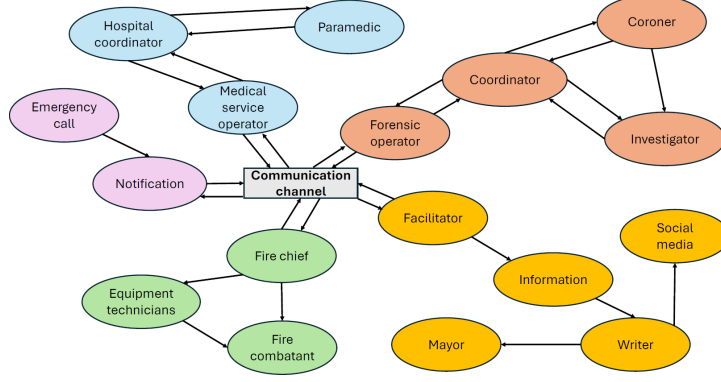


Figure 4: Diagram of the interaction between the crews of agents and the agents within the different crews. Emergency services: purple, firefighters: green, medical services: blue, forensic team: red and public communication: orange.

4.1 Emergency Services

This crew is responsible for handling emergency calls and coordinating communication responses with the appropriate teams. The members of the crew are: an **emergency call agent** and a **notification agent**.

4.1.1 Emergency Call Agent

The Emergency Call Agent serves as the main point of contact for incoming emergency calls, responsible for collecting essential information from the caller and assessing the severity and nature of the incident.

- **Main task:** To receive, assess, and categorize emergency calls, and subsequently notify the appropriate response units.
- **Tools:**
 - *Database management:* A computer system or software for systematically entering and recording emergency details.
 - *GPS:* A map to quickly locate and verify the caller’s position and assess the scene, potentially including software for prioritizing the severity of the incident if necessary.
- **Type:** Interface agent: This agent emphasizes autonomy and learning to support users. In this case, the Emergency Call Agent acts as a user interface for emergency call handling, gathering caller input and making proactive decisions on incident categorization.
- **Properties:**
 - *Reactivity:* The Emergency Call Agent continuously interacts with the environment (incoming calls) and rapidly assesses each situation to provide an appropriate response.
 - *Proactiveness:* While primarily reactive, the Emergency Call takes initiative by categorizing and prioritizing incidents, ensuring the most urgent cases receive immediate attention.
 - *Social Ability:* Capable of basic communication with other agents and potentially human responders, using a structured communication protocol for efficient incident coordination.
 - *Autonomy:* Operates independently once set up, requiring minimal external input to manage call processing and categorization.

4.1.2 Notification Agent

A bridge agent that ensures timely and accurate transmission of information between the Emergency Call Agent and emergency response teams.

- **Main task:** To relay details about the incident to the respective emergency teams and manage ongoing updates throughout the response.

- **Tools:**
 - *Communication channel:* Passes the information collected by the Emergency Call Agent to the rest of the crews. It can then continue to relay new updates or details as they come in, ensuring no one is left out of important updates.
- **Type:** Facilitator agent: This type emphasizes communication and interaction, managing the connections and information flow between agents. The Notification Agent serves as the coordinator in the emergency response communication network.
- **Properties:**
 - *Reactivity:* Monitors changes from both Emergency Call inputs and emergency response team feedback, adjusting notifications and updates based on dynamic incident progress.
 - *Social Ability:* Engages in continuous communication with multiple agents in real-time, ensuring all parties are kept informed and aligned on incident status.
 - *Temporal Continuity:* Remains active throughout the duration of an incident, managing and providing updates until the situation is resolved.
 - *Flexibility:* Adapts to various communication protocols and priority levels, adjusting its actions according to the severity of the situation and the availability of response teams.

4.2 Firefighters

This agent crew is responsible to move to the location of a fire and to extinguish the fire.

The agents that are part of this crew are: a **fire chief**, one **equipment technician** and a team of **fire combatants**.

4.2.1 Fire Chief

Takes calls from the emergency services and reports back.

- **Main task:** The fire chief receives a call from the emergency service operator and relays the information to its agent crew members. Once the firefighter crew arrives at the fire scene, the fire chief provides updates on the situation back to the emergency service operator.
- **Tools:**
 - *Communication Device:* A device for effective communication with the other crews.
- **Type:** Facilitator agent.
- **Most relevant properties:**
 - *Flexibility:* The fire chief must be able to adapt to changing circumstances and new information, ensuring that the crew can respond effectively to dynamic situations on the fire scene.
 - *Reactivity:* The fire chief needs to respond promptly to incoming information and evolving conditions during emergencies, ensuring that the crew is informed and can adjust their actions accordingly.
 - *Social Ability:* Effective communication and collaboration with both the emergency service operator and other crews are crucial for the fire chief to facilitate coordination and ensure that all parties are updated on the situation.

4.2.2 Equipment Technician

Manages material required to extinguish a fire.

- **Main task:** Based on the information received from the fire chief, the equipment technician needs to determine which materials are necessary, such as fire hoses, personal protective equipment (PPE), and fire extinguishers, and packs these items and loads them on the fire truck before the agent crew moves to the location of the fire. It is crucial that sufficient materials are packed to ensure a safe and effective response.

- **Tools:**
 - *Material Management Software:* Has a database of all the available material, which can be modified when resources are used for the emergencies.
- **Type:** Information agent.
- **Most relevant properties:**
 - *Flexibility:* The agent must adapt to different emergency scenarios and equipment needs quickly.
 - *Reactivity:* The technician must respond promptly to changing conditions and requirements during firefighting operations.
 - *Rationality:* The agent needs to make logical decisions about what materials to prioritize and pack based on available information.

4.2.3 Firefighter

Extinguishes the fire.

- **Main task:** The firefighting combatants unload the required equipment from the fire truck at the fire scene. They then assess the most effective strategy to extinguish the fire by coordinating with their fellow firefighters.
- **Tools:**
 - *GPS:* Can access a real-time map of the city to locate the location of the incident and calculate the best route to get there.
- **Type:** Collaborative agent.
- **Most relevant properties:**
 - *Reactivity:* This property is crucial as firefighting involves rapidly changing situations that require immediate responses to new developments, such as flare-ups or structural shifts.
 - *Proactiveness:* The combatant must anticipate potential challenges and take initiative in strategizing the best approach to extinguishing the fire, helping to prevent escalation and ensure successful outcomes.
 - *Social Ability:* Strong social ability is essential for effective teamwork, enabling the combatant to communicate and collaborate with fellow firefighters to coordinate efforts and ensure safety.

4.3 Medical Services

This agent crew is responsible for treating those injured in the fires. They manage the available health and first-aid services, such as hospitals and ambulances. The agents that are part of this crew include a **medical services operator**, one **hospital coordinator** per hospital, and multiple teams of **paramedics**.

4.3.1 Medical Services Operator

The medical services operator takes calls from emergency services and reports back.

- **Main task:** Receives information from other crews and relays the relevant information to the rest of the Medical Services agents. Also gathers information from its own crew and sends it to other crews who might be interested.
- **Tools:**
 - *Communication Channel:* Is capable of receiving and sending information with the facilitator agents of other crews.
- **Type:** Facilitator agent.

- **Most relevant properties:**

- *Reactivity*: This agent is in constant contact with its own crew, as well as with the other crews, reacting to events that occur during the emergency.
- *Proactiveness*: As a facilitator, this agent maintains a two-way communication channel between crews at all times without needing to be called into action.
- *Social Ability*: The primary task of this agent is communication between agents, making it essentially social in nature.
- *Temporal continuity*: The *medical services operator* is constantly receiving and sending messages to update other agents about the current status of the emergency.

4.3.2 Hospital Coordinator

The hospital coordinator manages the available resources of its corresponding hospital and coordinates with other *hospital coordinators* to discuss the distribution of resources and patients.

- **Main task**: Manages knowledge of available beds, ambulances, and paramedics at the hospital. Assesses the hospital's capacity to treat the injured and deploys aid teams to fire sites. Communicates this information to other *hospital coordinators*.

- **Tools:**

- *Hospital Resource Management*: Can read a database detailing the resources of the hospital, and modify it to keep track of those available or in use.

- **Type**: Information agent.

- **Most relevant properties:**

- *Social Ability*: Communication with the *medical services operator* and other *hospital coordinators* is crucial to properly allocate and manage Medical Services resources.
- *Rationality*: This agent understands the limitations of its hospital and will not trigger a call to action if the necessary resources are unavailable.
- *Reasoning*: Real-time knowledge of available resources and communication with other *hospital coordinators* enable sound response plans during emergencies.
- *Learning*: As an information agent, the *hospital coordinator* must continuously update its knowledge based on world changes and performance of emergency response plans.

4.3.3 Paramedic

Paramedics provide medical care in the field and transport people to hospitals as needed. They work in teams of multiple *paramedics* to manage emergency site situations.

- **Main task**: Takes an ambulance to the scene to treat individuals with minor injuries on-site. Decides when critically injured persons need hospital transport. Each *paramedic* has specialized knowledge, applied collaboratively depending on the situation, and reports the health status of treated individuals after deployment.

- **Tools:**

- *Specialized Knowledge*: Has access (read) to a database of specialized medical knowledge.
- *GPS*: Can calculate distances between points of the city and draw routes in order to efficiently get where it's needed.

- **Type**: Collaborative agent.

- **Most relevant properties:**

- *Flexibility*: This agent must adapt to unpredictable issues at the emergency site.
- *Reactivity*: During deployment, this agent continuously reacts to unfolding events and makes decisions in a chaotic environment.

- *Social Ability*: Since *paramedics* are deployed in teams, they must collaborate to manage the situation effectively.
- *Reasoning*: Each *paramedic* leverages specific medical abilities to determine treatment and prioritize patients based on their conditions.
- *Autonomy*: Once in the field, this agent independently decides actions based on the situation.

4.4 Forensics Team

This agent crew is responsible for determining the cause of fires. Some actions are taken on-site shortly after the fire, while others occur later, at locations such as the coroner’s office or the police station. The agents that are part of this crew are: a **forensics operator**, a **forensics coordinator**, a **coroner**, and an **investigator**.

4.4.1 Forensics Operator

Takes calls from the emergency services and reports back, providing information about ongoing and finished investigations to the *public announcements* crew.

- **Main task**: Receives information from other crews and relays relevant information to the other agents of the Forensics Team. Gathers information from its own crew and sends it to other crews who might be interested.
- **Tools**:
 - *Communication Channel*: Can communicate with the rest of agent crews.
- **Type**: Facilitator agent.
- **Properties**:
 - *Reactivity*: This agent is responsible for communication between the *forensics team* and the rest of the emergency services, reacting to messages from other crews and crew members.
 - *Proactiveness*: This agent is not proactive, only relaying information from other agents.
 - *Social Ability*: This agent is social, managing communication between the *forensics team* and other crews.
 - *Temporal Continuity*: Constantly communicates with other agents of the *forensics team* and the emergency services, thus maintaining temporal continuity.

4.4.2 Forensics Coordinator

Manages the team, resources, and knowledge for the forensics team. Communicates with other *forensics coordinators* to discuss resource distribution and ongoing investigations, and stores case files for recent and old fires.

- **Main task**: Manages the knowledge of available coroners and investigators, assesses the forensics team’s capacity for new cases, and assigns coroners and investigators to fire sites. Also gathers, compiles, and stores case files for current and previous fires, sharing this information with other *forensics coordinators*.
- **Tools**:
 - *Case Files Database*: Accesses a database (CSV) of case files, allowing reading and writing capabilities.
- **Type**: Information agent.
- **Properties**:
 - *Reactivity*: Responds to requests from other *forensics team* agents.
 - *Proactiveness*: Responds only to requests from other agents within the *forensics team*.
 - *Social Ability*: Manages the *forensics team* resources and information.

- *Rationality*: Allocates resources based on available information and determines which details may be relevant to an investigator’s case when responding to requests.
- *Reasoning*: Allocates resources and investigators by reasoning about information, negotiating with other *forensics coordinators*.
- *Learning*: Stores learned information in the case files database, improving future decision-making.
- *Temporal Continuity*: Communicates continuously with agents of this team and other *forensics teams*.

4.4.3 Coroner

Retrieves bodies from fire sites, brings them to the morgue, and performs further analysis to assist the investigator.

- **Main task:** After a fire is extinguished by the *firefighters crew*, the **coroner** goes to the fire site with the *investigator* to assess the victims’ bodies. After the *investigator* completes on-site forensics, the **coroner** retrieves bodies and performs further analysis in the morgue to assist the investigation.
- **Tools:** Has no special tools.
- **Type:** Collaborative agent.
- **Properties:**
 - *Reactivity*: Responds to requests from the *forensics coordinator* and provides information to the *investigator* at scenes.
 - *Social Ability*: Works closely with the *investigator* at scenes and communicates findings to the *forensics coordinator*.
 - *Rationality*: Makes decisions on body retrieval and examination procedures based on scene conditions and investigation needs.
 - *Reasoning*: Evaluates cause and time of death, injury patterns, and forensic evidence to support the investigation.

4.4.4 Investigator

Conducts on-site forensics and off-site research to determine the cause of the fire.

- **Main task:** After a fire is extinguished by the *firefighters crew*, the **investigator** assesses victims’ bodies with the *coroner*, interviews witnesses, and collects evidence. Later, the **investigator** gathers research from the *forensics coordinator* and performs further analysis to determine the cause of the fire. This information is shared with the *forensics coordinator* for storage in case files and with the *forensics operator* to inform other crews.
- **Tools:**
 - *Specialized Knowledge Database*: Has read access to a database holding specialized knowledge about the apparition signs and propagation of fire.
- **Type:** Collaborative agent.
- **Properties:**
 - *Flexibility*: Adapts to various situations, including new types of fires.
 - *Reactivity*: Responds to requests from other *forensics team* agents.
 - *Proactiveness*: Takes initiative for further analysis of collected information.
 - *Social Ability*: Works in a team with the *coroner* and the *forensics coordinator*.
 - *Rationality*: Makes decisions based on the information available and investigation needs.
 - *Reasoning*: Makes case decisions by reasoning about available information and investigation requirements.
 - *Autonomy*: Once assigned to a case, independently makes decisions about investigation steps.

4.5 Public Communications

This agent crew is responsible for managing public communications regarding incident zones, summarizing weekly reports, and analyzing societal behavior. The agents in this crew are: a **communication operator**, an **archive keeper**, an **article writer**, a **mayor**, and a **social media commentator**.

4.5.1 Communication Operator

Serves as the main point of contact, bridging communication between other emergency crews (firefighters, police, etc.) and updating the Public Communication Team on all pertinent activities.

- **Main task:** Receives updates from other emergency crews and relays the necessary information to agents within the Public Communication Team. Additionally, gathers insights from the team to share with other relevant crews when needed.
- **Tools:**
 - *Communication Channel:* Can communicate with the facilitators of the other agent crews.
- **Type:** Facilitator agent.
- **Properties:**
 - *Flexibility:* Must adapt to and handle varied formats of incoming information from multiple sources.
 - *Reactivity:* Responds to new messages and incidents promptly.
 - *Proactiveness:* Initiates communication with other agents and emergency crews as necessary.
 - *Social Ability:* Facilitates collaboration within the team and interacts effectively with external agents.

4.5.2 Archive keeper

Acts as the central information repository for the team, handling data storage and retrieval as required.

- **Main task:** Manages a well-organized database of factual data, ensuring timely access to accurate information for other agents.
- **Tools:**
 - *Long-Term Memory:* A structured database for reliable information storage and retrieval.
- **Type:** Information agent.
- **Properties:**
 - *Reactivity:* Responds promptly to data requests from the facilitator and article writer, efficiently storing and retrieving information as needed.
 - *Social Ability:* Engages with both the facilitator and article writer to ensure access to necessary details.
 - *Learning:* Continuously updates knowledge of city-wide incidents and facts.

4.5.3 Article Writer

Responsible for drafting, organizing, and refining articles to provide the public with clear and concise updates.

- **Main task:** Plans and develops well-structured, informative articles, ensuring consistency in public announcements based on current reports.
- **Tools:** Has no specialized tools.
- **Type:** Collaborative agent.

- **Properties:**

- *Proactiveness*: Independently decides when to begin and publish articles based on recent events.
- *Social Ability*: Collaborates with the information agent to acquire data on specific neighborhoods or timeframes.
- *Reasoning*: Applies logical structure and clarity when crafting announcements.

4.5.4 Mayor

Represents the city officially, approving important articles for public release and maintaining the city's voice in communications.

- **Main task:** Reviews significant articles for release, ensuring they align with the city's position and information standards.

- **Tools:**

- *Official Communication Channels*: Direct access to official public announcement platforms.

- **Type:** Collaborative agent.

- **Properties:**

- *Reactivity*: Responds to articles slated for publication to approve or request revisions.
- *Proactiveness*: Can halt articles and issue a modified announcement directly if necessary.
- *Social Ability*: Coordinates with the article writer to ensure messaging aligns with city standards.
- *Reasoning*: Assesses news content for potential public impact, adjusting as needed for public communication strategy.

4.5.5 Social Media Commentator

Offers lighthearted, constructive commentary on emergency operations to boost public morale and encourage positive feedback.

- **Main task:** Provides insights on emergency crew operations in a casual, humorous style to foster constructive improvements in a relaxed format.

- **Tools:**

- *Social Media Platforms*: Direct access to platforms like "Twitter" for posting feedback.

- **Type:** Collaborative agent.

- **Properties:**

- *Flexibility*: Adapts tone and style to maintain a balanced, lighthearted approach.
- *Reactivity*: Responds to public and team updates with timely commentary.
- *Proactiveness*: Actively comments on recent activities, providing feedback in a humorous way.
- *Social Ability*: Communicates with a friendly, approachable tone.
- *Reasoning*: Crafts feedback to be constructive and engaging.

5 Conclusion

This report offers an overview of the environment and agents in the multi-agent system designed for fire-related emergencies. The insights gathered will guide the next phase of our project, which focuses on establishing effective cooperation and coordination mechanisms to improve emergency response capabilities.

This phase will involve defining the processes each crew will follow, whether sequential or hierarchical, while considering task execution and relevant properties like human input. We will also implement Pydantic outputs for tasks that can benefit from structured data formats. Lastly, we will outline the interaction protocols between agent crews using flow diagrams and routing mechanisms to facilitate seamless information exchange.

By addressing these components, we aim to develop a framework that ensures all agents collaborate effectively to handle outbreaks of fire in Lloret de Mar.

References

- [1] Raphaël Berthon, Joost-Pieter Katoen, Munyque Mittelman, and Aniello Murano. Natural strategic ability in stochastic multi-agent systems, 2024.
- [2] G. Boeing. Modeling and analyzing urban networks and amenities with osmnx, 2024. Working paper.
- [3] Sébastien Bubeck, Varun Chandrasekaran, Ronen Eldan, Johannes Gehrke, Eric Horvitz, Ece Kamar, Peter Lee, Yin Tat Lee, Yuanzhi Li, Scott Lundberg, Harsha Nori, Hamid Palangi, Marco Tulio Ribeiro, and Yi Zhang. Sparks of artificial general intelligence: Early experiments with gpt-4, 2023.
- [4] Shanshan Han, Qifan Zhang, Yuhang Yao, Weizhao Jin, Zhaozhao Xu, and Chaoyang He. Llm multi-agent systems: Challenges and open problems, 2024.
- [5] Allyson I. Hauptman, Beau G. Schelble, Nathan J. McNeese, and Kapil Chalil Madathil. Adapt and overcome: Perceptions of adaptive autonomous agents for human-ai teaming. *Computers in Human Behavior*, 138:107451, 2023.
- [6] Javier Morales, Michael Wooldridge, Juan A. Rodríguez-Aguilar, and Maite López-Sánchez. Synthesising evolutionarily stable normative systems, 2017.
- [7] Lei Wang, Chen Ma, Xueyang Feng, Zeyu Zhang, Hao Yang, Jingsen Zhang, Zhiyuan Chen, Jiakai Tang, Xu Chen, Yankai Lin, Wayne Xin Zhao, Zhewei Wei, and Jirong Wen. A survey on large language model based autonomous agents. *Frontiers of Computer Science*, 18(6), March 2024.
- [8] Michael Wooldridge. *An Introduction to MultiAgent Systems*. John Wiley & Sons, 2nd edition, 2009.