Application of a multiagent system for resource distribution in humanitarian logistics

Aplicación de un sistema multiagente para la distribución de recursos en logística humanitaria

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ABSTRACT

In humankind's history, many natural and man-made disasters have happened and will continue to happen. In a post-disaster scenario, many processes and actors must be organized to provide the needed supplies to the affected people. Although it is similar to a supply chain, it is called Humanitarian Logistics in a disaster context. Many papers present centralized approaches to organizing different aspects of humanitarian logistics. However, a centralized approach is not always appropriate due to the dynamics and uncertainty present in a post-disaster scenario. This paper describes a distributed approach based on Multiagent Systems (MAS) to organize the elements of humanitarian logistics in a post-disaster scenario (MAS-HL). Intelligent agents in the MAS-HL, represent real-world elements, such as affected zones, distribution centers, donors, and trucks. The agents negotiate among themselves using a Contract-Net Protocol (CNP) to organize the operations of the elements represented. Due to dynamics and uncertainty in a post-disaster scenario, the agents must reorganize the operations of the elements. The MAS-HL is evaluated by simulating and evaluating a case study focused on bottled water delivery in post-disaster scenarios, they represent when major changes occur. The computational results confirmed that the MAS-HL quickly generates plans to organize the elements of humanitarian logistics and reorganize the plans when the environment changes.

Keywords: Humanitarian Logistics, Disaster Relief, Multiagent Systems.

RESUMEN

En la historia de la humanidad han ocurrido y seguirán ocurriendo muchas catástrofes naturales y de origen humano. En un escenario posterior a una catástrofe, hay que organizar muchos procesos y actores para proporcionar los suministros necesarios a las personas afectadas. Esto es similar a una cadena de suministro, pero en un contexto de catástrofe se denomina Logística Humanitaria. Muchos documentos presentan enfoques centralizados para organizar diferentes aspectos de la logística humanitaria. Sin embargo, un enfoque centralizado no siempre es adecuado debido a la dinámica y la incertidumbre presentes en un escenario posterior a una catástrofe. Este artículo describe un enfoque distribuido basado en sistemas multiagentes (MAS) para organizar los elementos de la logística humanitaria en un escenario post-catástrofe (MAS-HL). En el MAS-HL, los agentes inteligentes representan elementos del mundo

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real como las zonas afectadas, los centros de distribución, los donantes y los camiones. Para organizar las operaciones de los elementos representados, los agentes negocian entre ellos aplicando un protocolo de red de contratos (CNP). Debido a la dinámica y la incertidumbre en un escenario post-catástrofe, los agentes deben reorganizar las operaciones de los elementos que representan cuando se producen cambios importantes. Para evaluar el MAS-HL, se simuló y evaluó un caso de estudio centrado en la entrega de agua embotellada en escenarios post-catástrofe. Los resultados computacionales confirman que el MAS-HL genera rápidamente planes para organizar los elementos de una logística humanitaria y los reorganiza adecuadamente cuando el entorno cambia.

Palabras clave: *Logística humanitaria, ayuda en catástrofes, sistemas multiagentes.*

INTRODUCTION

In humankind's history, many natural and man-made disasters have happened and will continue to happen. The disasters that have occurred in recent times have left innumerable material losses and hundreds of thousands of human casualties. Moreover, there is a growing trend in the frequency and intensity of these events [1, 2]. Due to this, it is necessary to increase efforts and improve activities to respond to disasters [2].

From an academic viewpoint, humanitarian logistics refers to the processes of storage, transport, distribution, and coordination of people, goods, and services required to serve the population affected by a disaster [3, 4]. In this context, Hasanzadeh and Bashiri [5] mention that the main objective of humanitarian logistics is to provide the needed supplies as soon as possible to the affected people. Figure 1 shows elements present in humanitarian logistics.

Many authors have proposed different solutions to organize actors and operations in humanitarian logistics [1, 7]. Most of them follow a centralized approach [1, 7] which is not always fitting in humanitarian logistics since the humanitarian logistics is large and distributed in nature [6]. Due to the fact that a post-disaster scenario is uncertain, centralized systems cannot deal with sudden unexpected variations in the environment.

Alternatively, a distributed solution based on multiagent systems would allow the elements in humanitarian logistics to be organized closer to reality and overcome the problems in the centralized approach. This approach has been applied in classical supply chains but not much for humanitarian logistics [6]. This paper describes the MAS-HL as a distributed approach to humanitarian logistics.

The remainder of this paper is structured as follows: Section 2 presents related work. Section 3 describes the MAS-HL. Section 4 presents the evaluation

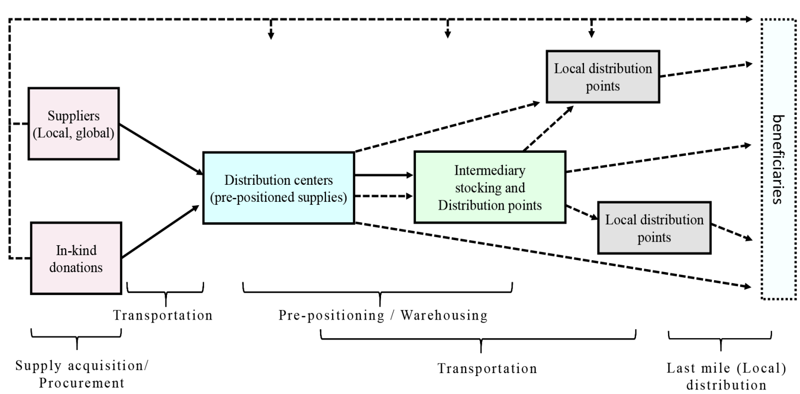

Figure 1. Relief chain structure proposed by Balcik, Beamon, Krejci, Muramatsu, and Ramirez [7].

and discussion of the MAS-HL in a case study. Finally, the conclusions and outlook are presented in Section 5.

RELATED WORKS

In the literature, many papers deal with humanitarian logistics [6]. Leiras, Brito, Queiroz Peres, Rejane Bertazzo, and Tsugunobu Yoshida Yoshizaki [1], present trends and gaps in the research on logistics and supply chain management in a crisis. Balcik, Beamon, Krejci, Muramatsu, and Ramirez [7] provide the challenges in coordinating humanitarian relief chains and describes the coordination practices in disaster relief. They also provide an overview and background on the coordination among the actors present in humanitarian logistics. Lopez-Vargas and Cárdenas-Aguirre [2] present a review that aims to identify the main positive and negative factors that influence the coordination of the actors involved in the logistical processes of preparation and response to disasters. Othman, Zgaya, Dotoli, and S. Hammadi [6] propose a multiagent-based architecture for managing supply chains. The MAS states and solves the scheduling problem for the delivery of resources from the supply zones to the affected areas.

In the classical supply chains field, there are several works that apply multiagent systems. Krejci and Beamon [8] highlight some of the challenges modelers face in deciding on the appropriate methods for representing the elements of a food supply chain in a MAS model. Dominguez [9] reviews on the development of multiagent systems applications for supply chain management. The paper gives a general picture of the state of the art, showing the main applications developed using MAS. Terrada, ElKhaïli, and Ouajji [10] describe a MAS-based solution for decision-making problems in information systems used in Supply Chain Management. In this solution, each phase of the Supply Chain is developed as an agent.

A common gap mentioned in the previous works is the lack of studies that address the cooperation and coordination of stakeholders [1, 6]. This paper aims to reduce this gap by proposing a distributed approach based on a MAS (MAS-HL). The MAS-HL coordinates the stakeholders to distribute needed resources to the affected people.

THE MULTIAGENT SYSTEM FOR HUMANITARIAN LOGISTIC

A multiagent system is a system collection of intelligent agents that interact with each other to accomplish their objectives or to perform some tasks [11]. The agents act autonomously and make decisions to reach their objectives using their specific data, communication mechanisms, and sharing their knowledge.

The MAS-HL objective is to organize the elements of humanitarian logistics to provide required resources to affected people in a post-scenario disaster. In the MAS-HL, the agents represent elements of humanitarian logistics and interact with each other to organize the operations of the elements that they represent. Applying this approach allows us to model humanitarian logistics in a way that is closer to reality than the centralized approach.

The following subsections describe the agents implemented in the MAS-HL, the interactions among them to accomplish their objectives, and the agents' decision-making process.

Agents

The agents implemented in the MAS-HL include the following ones:

- *LocalDistributionPointAgent:* This agent represents a local distribution point of the real world located in an affected zone. Its objective is to keep enough resources required for the affected zone's people. The main specific data used are the number of affected people in the zone, the stock of resources, and its geographic location.
- *DistributionCenterAgent:* This agent represents a distribution center of the real world located in a non-affected zone. Its objective is to keep enough required resources to supply local distribution points. The main specific data used are the required resources stock, and its geographic location.
- *DonorAgent:* This agent represents a donor of the real world. Its objective is to donor resources when it is required. The main specific data used are the stock of resources and their geographic location.
- *TransportAgent:* This agent represents a freight company in the real world. Its objective is to

manage a fleet of trucks efficiently. The main specific data used are a schedule of the fleet operations.
- *TruckAgent:* This agent represents a truck of the real world. Its objective is to transport the required resources in the shortest time and as soon as possible. The main specific data used are a distance matrix, truck capacity, velocity loaded and empty, and its location.

Interactions among Agents

The agents must interact with each other to organize the elements of humanitarian logistics. The interaction includes three negotiations based on the Contract-Net Protocol (CNP) [12]. The CNP is a well-known mechanism for task sharing. It has proved to be a flexible and low communication interaction protocol. The main idea of the protocol is the following: a manager agent announces to contractor agents that there is a task expected to be executed and waits for the offers of the contractor agents. A contractor agent who receives the announcement evaluates its skills and availability to perform it. If the contractor agent can perform the task, it makes an offer. After receiving the offers from the contractor agents, or until a deadline is expired, the manager selects the most appropriate offer and assigns the task to the contractor agent that sent the offer. When a contractor agent has won a bid, it must reserve the resources required for its execution, perform the task assigned, and generate reports about the progress of the task and its final result.

Figure 2 depicts the Contract-Net protocol standardized by FIPA (Foundation For Intelligent Physical Agents [13]).

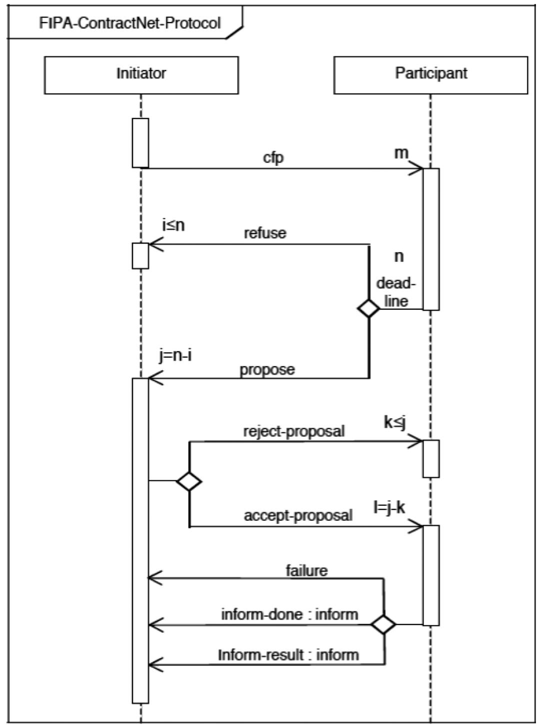

Figure 2. The Contract-Net Protocol (CNP).

In the MAS-HL, the interaction among agents starts when the *LocalDistributionPointAgents* informs the *DistributionCenterAgent* of the number of required resources and the location of the local distribution center that represents. When the *DistributionCenterAgent* receives requirements, it sorts and stores the requirements received in a list. Then, it starts a loop to fulfill the requirements in the list. In each iteration of the loop, one requirement is managed.

The *DistributionCenterAgent* checks its stock of required resources to fulfill the requirement. If it does not have enough stock, it negotiates with the *DonorAgents* to get resources by applying for the CNP. The *DistributionCenterAgent* sends a *call-for-proposal* message to the *DonorAgents* and the *call-for-proposal* points out the resources required. Each *DonorAgent* sends a *propose* or a *refuse* message. A proposal from a *DonorAgent* points out the location of the donor. Then, the *DistributionCenterAgent* selects the best proposal received. If the negotiation with the *DonorAgents* is unsuccessful (it means no *DonorAgent* sends a proposal), the *DistributionCenterAgent* informs *LocalDistributionPointAgent* that it cannot fulfill its requirement, and the iteration finishes.

Should the *DistributionCenterAgent* have the necessary resources (or obtain resources from a *DonorAgent*), a negotiation process is initiated with the *TransportAgents* to find a truck (or trucks) to transport the necessary resources from the distribution center (or donor) to the local distribution point. This negotiation is based on the CNP. The *DistributionCenterAgent* sends a *call-for-proposal* to the *TransportAgents,* pointing out the number of required resources to transport, the location of the loading point, and the location of the local distribution point.

When a *TransportAgent* receives a *call-for-proposal* message from the *DistributionCenterAgent*, it negotiates with their respective *TruckAgents* by applying the CNP. The *TransportAgent* sends a *call-for-proposal* message to its *TruckAgents,* pointing out the required transportation resources and the locations of the loading and the local distribution points. When a *TruckAgent* receives a *call-for-proposal* message from a *TransportAgent*, it sends a *propose* or *refuses* message. The proposal indicates the required resources that can be hauled by truck, the time when the required resources would be picked up, and the time of delivery.

If the *TransportAgent* receives proposals, it selects the best option and sends a *proposed* message to the *DistributionCenterAgent*. Otherwise, it sends a *refuse* message. A proposal from a *TransportAgent* indicates the truck (or trucks) and the time required to transport the required resources. The *DistributionCenterAgent* receives the proposals from the *TransportAgents* and selects the best option. If the negotiation with the *TransportAgents* is unsuccessful (it means no *TransportAgent* sends a proposal), the *DistributionCenterAgent* informs *LocalDistributionPointAgent* that it cannot fulfill its requirement, and the iteration finishes.

If the negotiation with the *TransportAgents* is successful, the *DistributionCenterAgent* informs the awarded *TransportAgent* (and the *DonorAgent* if the required resources are transported from it). Both add the operations to their respective plans. Then, the *TransportAgent* informs the awarded *TruckAgent* (or *TruckAgents*), and they add the operations to their plans. Finally, The *DistributionCenterAgent* informs the *LocalDistributionCenterAgent* of the estimated arrival time of the required resources in its area.

The *DistributionCenterAgent* repeats this procedure to manage all requirements in a sorted list. Figure 3 depicts the sequence diagram that describes this interaction. Table 1 shows an example of the operation planned for the distribution center, and Table 2 shows an example of the operation planned for a truck. The column "Quantity of Bottled Water" is an example of required resources and indicates the number of bottles of different sizes. For instance, "Bottles{500, 50}" means 50 bottles of 500cc.

Decision Making

A *LocalDistributionPointAgent* must decide on whether to send a resource requirement to the *DistributionCenterAgent*. In this decision-making process, the company considers its current resources and future demands. If its current stock is lower than a predefined threshold, it informs *DistributionCenterAgent about* about the number of the resources required.

A *DistributionCenterAgent* makes two decisions: First, it decides on the best proposal received from the *DonorAgents*, and second, it decides on the best proposal received from the *TransportAgents*. The number of resources required and the distance from the donor's location to the local distribution point location are relevant in selecting the best proposal received from the *DonorAgents*. The best proposal from *TransportAgents* considers the time needed to transport the required resources from the loading site to the local distribution site.

A *DonorAgent* decides on whether to send or not a proposal to the *DistributionCenterAgent.* As part of this decision, the *DonorAgent* compares the resources needed for the *DistributionCenterAgent* with its current stock. If its current stock is higher than the resources required, it sends a *propose* message. Otherwise, it sends a *refuse* message.

A *TransportAgent* makes two decisions. The first decision is to select the best proposal (or proposals) received from the *truckAgents*. This decision is made based on the time needed to transport the required resources by truck and the truck's capacity. The second decision is on whether to send a proposal to the *DistributionCenterAgent*. If the selects a proposal (or proposals) received from the *truckAgents*, it generates a proposal for the *DistributionCenterAgent.* Otherwise, it sends a message.

A *truckAgents* decides on whether to send a proposal to the *TransportAgent*. This decision is based on whether the time to perform the operations (loading, travel, delivery) to transport the required resources fits its plan.

EVALUATION AND DISCUSSION

The proposed MAS-HL was validated by simulating different scenarios using a case study. The aim

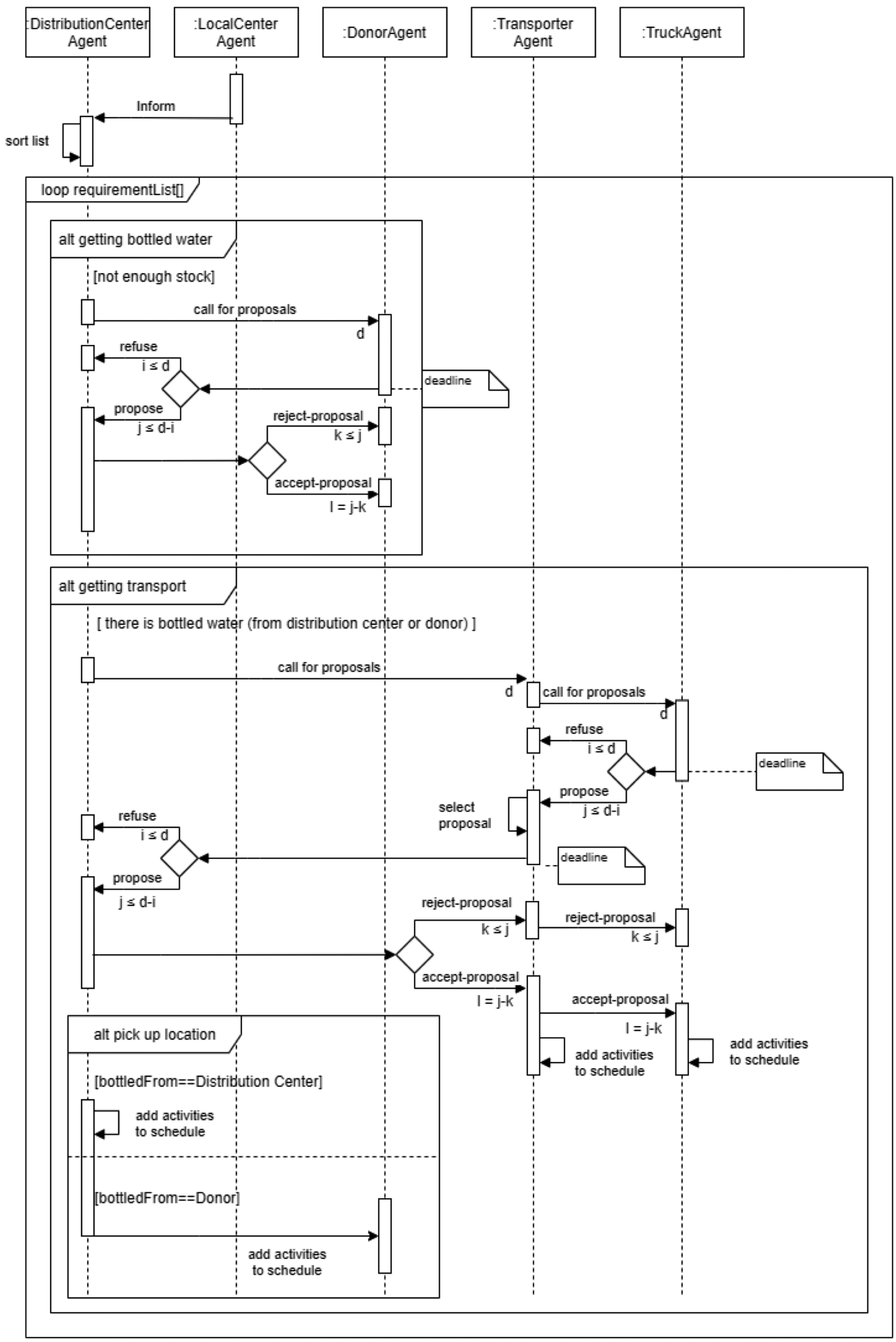

Figure 3. Interaction protocol among Agents. The agents negotiate by applying the Contract Net Protocol.

Table 1. Example of a distribution center schedule generated by the agents.

Time	Activity	Truck	Quantity of Bottled Water
11:02:36	Loading	Truck 1	Bottles{500, 80}, Bottles{1000, 100}, Bottles{2000, 200}
12:28:36	Loading	Truck 3	Bottles{500, 50}, Bottles{1000, 200}, Bottles{2000, 100}
13:25:45	Loading	Truck 8	Bottles{500, 150}, Bottles{1000, 0}, Bottles{2000, 250}
15:06:07	Loading	Truck 9	Bottles{500, 50}, Bottles{1000, 200}, Bottles{2000, 100}

Table 2. Example of a truck schedule generated by the agents.

Starting Point	Destination	Activity	Start Time	End Time	Quantity of Bottled Water
Freight Company	Distribution Center	Empty Travel	10:35:00	10:55:25	
Distribution Center	Distribution Center	Loading	11:02:36	11:25:36	Bottles{500, 50}, Bottles{1000, 200}, Bottles{2000, 100}
Distribution Center	Local Distribution Point 1	Loaded Travel	11:25:40	11:45:21	Bottles{500, 50}, Bottles{1000, 200}, Bottles{20000, 100}
Local Distribution Point 1	Local Distribution Point 1	Delivery	11:45:21	12:02:54	Bottles{500, 50}, Bottles{1000, 200}, Bottles{20000, 100}
Local Distribution Point 1	DonorAgent 3	Empty Travel	12:25:53	13:28	

of the simulations was to determine the required time by the MAS-HL to organize the elements in humanitarian logistics. The proposed MAS-HL and the simulations run on the JADE platform. The following subsections describe how the MAS-HL is implemented, the case study on which the simulated scenarios are based, and the validation results.

MAS-HL Implementation

The MAS-HL is developed with the JADE (Java Agent DEvelopment framework) platform [14]. JADE is an appropriate agent toolkit for implementing MASs due to providing several interaction protocols, behaviors, and graphical tools to analyze the agent comportment and performance of a MAS. All operating systems support JADE because it is developed in JAVA. All simulations were run on a laptop computer with an Intel Xeon 3 gigahertz CPU, 32 gigabytes of RAM, and Windows 10.

Simulation Setup

The simulated scenarios to evaluate the MAS-HL are based on the case study provided by Zuñiga, Icarte, Griffiths, Lopez, and Quezada [15]. The case study corresponds to the last earthquake and tsunami in Iquique City - Chile, in 2014. Iquique is a port city in the north of Chile with around 200,000 residents. In April 2014, an earthquake measuring 8.2 on the Richter scale occurred near Iquique. A few hours later, the megathrust earthquake triggered a tsunami of up to 2.11 meters that hit Iquique. Many small and large earthquakes followed the main event, including another one the following day registering 7.7 on the Richter scale. This case study is interesting because the post-disaster scenario changed often. For instance, new affected zones arose, and some elements of humanitarian logistics (such as local distribution points and trucks) became unavailable. In this context, we simulated different scenarios for bottled water delivery. Table 3 describes the different scenarios simulated.

Results and Discussion

Table 4 shows the time that the MAS-HL requires to organize the elements in this case study of humanitarian logistics. Also, it shows the minimum and maximum duration of a negotiation to fulfill a bottled water requirement. The simulations run until they satisfy the 100 bottled water requirements.

Table 3. Scenario simulated.

Scenario Description	Distribution Center Agents	Local Distribution Point Agents	Donor Agents	Transport Agents	Trucks Agents
Before main earthquake	1	0	10	10	100
After main earthquake	1	10	8	8	90
After several small earthquakes (a few hours after the main earthquake)	1	15	7	7	85
After Tsunami	1	18	6	6	75
After second main earthquake	1	23	3	3	50

Table 4. Times required to generate the plans.

Scenario Description	Number of Negotiations	Minimum Processing Time (ms)	Maximum Processing Time (ms)	Average Processing Time (ms)	Total Time to generate plans (ms)
Before main earthquake	0	0	0	0	0
After main earthquake	100	413	614	518	12,965
After several small earthquakes (a few hours after the main earthquake)	100	402	587	503	12,625
After Tsunami	100	375	513	455	11,798
After second main earthquake	100	303	473	413	10,563

The results show that the MAS-HL organizes the elements for 100 bottled water requirements in less than one minute in each one of the simulated scenarios. The difference between the minimum and maximum duration of the negotiations is that some negotiations are shorter than others, as fewer agents participate. For instance, if a distribution center has enough bottled water to fulfill a requirement, it is optional to negotiate with the *DonorAgents*. The results also show that the time required to organize the elements decreases when the number of agents decreases due to fewer agents participating in negotiations.

One aspect that influences the processing time of the MAS-HL to organize the elements of humanitarian logistics is the deadline to receive proposals in the negotiation process. In the MAS-HL, there are three negotiations and, therefore, three deadlines. Short deadlines would decrease the processing time; however, the quality of the plans generated by MAS-HL could decrease. In contrast, extended deadlines would increase the processing time, but the quality of the plans could be better. In this context, it is necessary to find appropriate values for the deadlines to generate high-quality plans in a short time. In addition, to find appropriate values for deadlines is noteworthy to consider the number of agents.

The fast organization of the elements in this case study of humanitarian logistics is due to the characteristics of the MAS technology, such as distributed organization, parallel processing, and a low computational power requirement.

CONCLUSIONS

This paper presents a Multiagent System (MAS) for humanitarian logistics (MAS-HL). In the proposed MAS-HL, agents represent elements from a relief chain and organize their operations by interacting with each other. MAS-HL was validated by simulating scenarios based on a case study. The simulation results show that the proposed MAS-HL organizes the elements very fast. In addition, the agents react appropriately when changes occur in the environment. Several characteristics of the agent technology, such as robustness, flexibility, and autonomy, allow the agents to properly organize the elements of humanitarian logistics.

In our further research, we will follow three aspects. The first one is to extend the MAS-HL to increase the size of the relief chain. The aim is to compare the plans generated by MAS-HL with those generated by another method, such as the plans generated by a Tabu search or mathematical programming. The second aspect is related to the quality of the plans generated by the MAS-HL. This means comparing the plans generated by MAS-HL against those generated by another method, such as plans generated by a Tabu Search or mathematical programming. The third aspect is related to the negotiation process among the agents. Due to the negotiation processes being performed in parallel, the agents must discard some negotiations and could generate inefficient plans. Therefore, it is necessary to evaluate different mechanisms to face the parallelism of the negotiation process.

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