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# Logistics Flow Optimization for Advanced Management of the Crisis Situation

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**Abstract**

Our work has been carried out with the aim of providing a solution to decision-making problems encountered in information systems for supply chains in crisis situation. The supply chain represents a competitive advantage that companies seek to perpetuate. It aims to optimize the exchanges, or flows, that the company maintains with its suppliers and its customers. These flows can be of various natures. It can be information flows relating to supplies or product design, financial flows linked to purchases, or even flows of goods. The crisis management logistics is getting more and more attention, especially in the current context of the COVID-19 pandemic. For these systems, where it is never very easy to anticipate the evolution of the environment, the forms of changes undergone are varied and rapid. We aim to provide an answer to these challenges, in an approach that links optimization methods to the paradigm of artificial intelligence. We therefore propose to find mathematical models, and inter-agent cooperation protocols, to minimize the risk of stock shortage in any area of the supply chain.



*Keywords:* *Supply Chain, logistics flow, Multiagent Systems, Crisis situation, modelisation, optimisation*

## 1. Introduction

Crisis management logistics are getting more and more attention, especially the current context of the COVID-19 pandemic. For these systems, where it is never very easy to anticipate the evolution of the environment, the forms of

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changes undergone are varied and rapid. Logistician's decision-making concerns actions that take place in an ever-hectic environment. In addition, responding to an emergency call, by definition, they have no way of predicting what will happen. A Crisis Management Supply Chain CMSC can fall victim to delivery delays, poor consumption estimates, loss of cargo, spontaneous spikes in consumption, and many other unpredictable events at any time. All of these unforeseen events are likely to lead to stock-outs at any point in the supply chain, which can have dramatic consequences that can lead to human loss. These extreme situations are not acceptable, this justifies the need to create a tool that would simulate real and/or probable logistical situations, the objective being to observe the behavior of the different areas in place and identify the best strategies to adopt according to crisis situations.

An increasing number of articles have been published on the subject of disaster management. Most of the current work on crisis management supply chains agrees that future research should focus on methods for improving inventory management, designing distribution systems, cooperation, coordination and performance measurement. Indeed, an increasingly obvious observation is the fact that the crisis management supply chain is not just a dyadic relationship or even a set of relationships limited to one or two ranks. A crisis management supply chain is often a network of geographically distributed entities that is larger and therefore more complex to manage.

In the first section of our paper, we present a state of the art and the context of our research, emphasizing the characteristics of advanced distributed logistics. The second section presents our issue and a focus on the resolution methodology to be adopted in the form of an alliance of multiagent systems and the foundations of optimization, within the framework of artificial intelligence. In the third section, we study the contribution of multiagent systems in the design and implementation of logistics systems. We then propose a multi-agent organization dedicated to modeling and optimizing a CMSC by detailing our architecture and the behaviors of the different agents. The fifth section is devoted to the solutions proposed to optimize the flows of the crisis management supply chain. Finally, we detail the applications of the system adopted to demonstrate the validity of the solutions proposed.

## 2. State of the art

The word "logistics" appeared in France in the 18th century with the appearance of problems of military support, hence the definition of military origin: "Logistics consists in bringing what is necessary, where it is necessary and when it must[5][13]. In the industrial environment, "global logistics" is the set of activities internal or external to the company that bring added value to products and services to customers. There are several types of logistics: supply logistics; production logistics; distribution logistics; military logistics and retro-logistics.

### *2.1. Concepts*

The concept of Supply Chain SC has brought a certain unity to the field of logistics. The supply chain is defined as "The sequence of stages of production and distribution of a product from suppliers to suppliers of producers, to customers of its customers" (Supply Chain Council). For Rota-Franz et al., doing Supply Chain Management SCM consists of integrating all internal and external means to meet customer demand[13]. The aim is to optimize all logistical processes simultaneously, rather than sequentially. The main objective of SCM is to improve industrial competitiveness by minimizing costs[11], ensuring the level of service required by the client and effectively allocating activities on the actors of production, distribution, transport and information; ensuring that actors do not develop antagonistic local behaviors that affect overall performance.

For any type of supply chain, decision-making is divided into three levels:

- Strategic: also called Strategic Management or Strategic Planning, groups together all strategic decisions for long-term[9][10].
- Tactical: is concerned with medium-term decisions which will have to be executed to deploy the strategy decided by the company.
- Operational: The operational level, or Operational Planning according, decisions have a more limited scope in space and time.

### 2.2. Performances

The SCM generally seeks to improve productivity. To achieve this goal, we often use many performance indicators. These indicators can be customer satisfaction, compliance with delivery times, chain flexibility, information sharing, risk management, improved traceability, etc. [4][6][9][10]

Three main supply chain performance indicators are widely used, each corresponding to a type of flow: “cooperation” indicators with regard to the performance of the information flow, “costs” for the financial flow and “delivery times” for the physical flow. The first step in performance monitoring is therefore to “measure performance”. Then, it is necessary to take reengineering decisions and act on the system and the model through decision variables in order to tend towards the set objectives. The implementation of a high-performance system therefore reflects a need for control of the supply chain and improvement of performance.

### 2.3. Logistic decision making

The vision of logistics decision making has changed radically from the conventional centralized perspective to a distributed perspective. This change of perspective is based on new needs in terms of flexibility and responsiveness. Thus, these new systems propose to give an answer to problems such as: distributivity, reconfigurability, interoperability, reusability, etc[2]. Managing a SC made up of several entities is a function that makes it possible to exploit the resources that are available in this supply chain. The information system makes it possible to store, adapt and make available the data on which decision-making centers are based. The role of the information system is to provide each decision center with the information necessary and sufficient for adequate decision-making. We have the conventional centralized systems and the intelligent distributed systems. Several motivations are offered for decentralizing management, such as[8] feasibility; robustness and flexibility; reconfigurability.

### 2.4. Methodological needs for Supply Chains

We quickly present three main areas of research in terms of methodologies and techniques used in the service of supply chain management, namely modeling, optimization and decision support.

1) Modeling : There are different models of supply chains. The choice of model depends directly on the type of problem and structure that we want to study[8][12].

2) Optimization : The optimal quality of service in logistics implies a satisfaction of the users of the proposed system by the integration of the functionalities necessary for the good management of the logistics chain. Optimization was introduced in order to improve the services provided regardless of the area to which they apply. An optimization problem concerns the execution of specific methods in search of an optimum[1]. The latter can be a value that maximizes or minimizes a function f, called the objective function or the cost function; it is also called optimization criteria[13].

3) Decision support : The purpose of decision support techniques is to model the preferences of an expert as faithfully as possible. This modeling will then make it possible to design and build suitable tools capable of assisting or replacing a decision maker on complex problems. Decision support formalizes the expertise obtained after an interview with the decision-maker and the interactions between the decision-maker and his environment. Since we are mainly interested in the expertise of decision-makers in the field of logistics, the model used must be flexible and sufficiently developed to allow the representation of the different decision-making behaviors most commonly encountered in supply chain management crisis management CMSC [2].

## 3. MultiAgent Systems approaches for distributed artificial intelligence.

Agent-oriented methodologies are concerned with the problems of designing multi-agent systems relating to: the identification of agents, the specification of reasoning skills, the organization of the multi-agent system and the representation of interactions between agents. Their objectives are to guide the designer in the analysis and design phases of multi-agent systems.

The research proposal that we are making consists more precisely of a set of tools and approaches allowing the optimization of flows in a CMSC. We opted for a modeling of the CMSC based on communicating agents[1][3][10]. In this model, the agents who represent the various actors in the logistics chain, are in direct contact with what is happening in the field, they pump information continuously from the field layer and compare the real situation to the reference logistics situation (Fig. 1).

### *3.1. MultiAgent System MAS*

We can consider a multiagent system as being a homogeneous or heterogeneous set of agents located in the same environment and which interact. These agents communicate and collaborate to achieve individual or collective goals, or to solve problems that exceed each individual's abilities or knowledge[9]. One of the most important characteristics of an MAS is interaction. It is defined as being a dynamic relationship established between several agents due to their combined and reciprocal actions. Interaction can take many forms: cooperation, coordination, negotiation, collaboration, etc[1][9][13]. Authors propose the modeling given in Fig. 2 in order to schematize all the possible interactions between the agents.

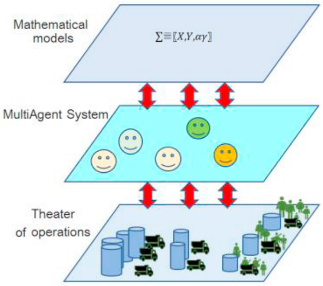


Fig. 1. Architecture of our system

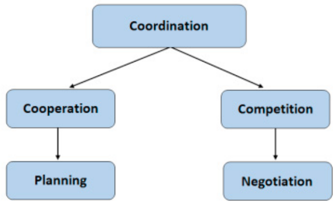


Fig. 2. Types of interactions

Several publications concerning the applications of multi-agent systems in industry have appeared[1][2][9][12]. This emergence can be explained by the ability of MAS to model increasingly complex systems. Among the first applications developed using communicating agents, there is an application for air traffic control[14]. In this application, MAS cooperation strategies have been used to resolve conflicts between the plans of a group of agents. Each agent, representing an aircraft, seeks to build a flight plan which must guarantee a safe distance from each other agent. In the event that the agents are in conflict, they must choose between the agent best able to draw up a new flight plan without creating new conflict situations. This choice is based on the amount of information available to each agent and the number of constraints. Indeed, it is up to the most knowledgeable officer to carry out the new flight plan that resolves the conflict and to the least constrained officer to execute it.

### *3.2. MultiAgent Systems for Optimizing Crisis Management Logistics*

In 1996, the Defense Advanced Research Projects Agency (DARPA), in collaboration with the Defense Logistics Agency (DLA) began a research effort of approximately \$ 80 million called the Advanced Logistics Project: Advanced Logistics Projetc (ALP), aimed at developing the next generation of logistics systems[5][13]. This project is mainly based on the following strategies: Gathering; Supporting; Decomposing; Acting; Delegating; Assessing and Reporting.

The designers use a dynamic workflow engine to build the models, interconnect the representations of the cognitive components and accomplish the tasks. We have opted for an alliance of MAS and optimization in a specific architecture, which we detail in the following sections.

## 4. MAS for advanced modeling of a CMSC

In this section, we study the contribution of multi-agent systems in the design and implementation of logistics systems. We then propose a multi-agent organization dedicated to the modeling and optimization of a crisis management supply chain by detailing the architecture of our system and the behaviors of the various agents[3][4][7].

With the essential aim of countering the problems of exponential complexity, we propose to set up a resolution system which is based on the decomposition of the global process into a set of less complex tasks executing in parallel. The multiagent concept is favorable to the implementation of a dynamic distributed architecture. Thus, in order to establish an efficient and efficient optimized treatment in terms of complexity, we propose to set up a multi-agent system. This system, called OBCA (Optimization Based on Communicating Agents), is equipped with a multitude of functionalities involved in the process of optimizing the functioning of the logistics chain and the response to the crisis.

The proposed MAO (Multi-Agent Organization) is dynamic; it considers each actor of the CMSC as an autonomous agent, capable of exchanging information with the other actors. In our SCM, the actors are many and varied. Multiple models are possible. We propose a dynamic and open system, based on the interaction of several types of software agents which will help the smooth running of exchanges of physical and information flows: Zone Agents, Transport agent, the Integrator/Evaluator Agent, the Weather Agent, the GUI Interfaces Agents and the Watch agent. The Interfaces Agents play the role of interface between the users and the system, the Zone Agents are responsible for the logistic zones and take care of the scheduling of the local delivery tasks, the Transport Agent manages all the transport vectors of the supply chain, the Integrator/Evaluator Agent are responsible for the evaluation and composition of the final delivery plans and the Weather Agent provides information on weather conditions. Another type of agent is involved in the operation of the CMSC: the NEA (Need Estimating Agent), which has the role of estimating consumption at the level of disaster areas.

The organization of our system is illustrated in Fig. 3. As shown in Fig. 4, data flows are exchanged between the various agents helping the system to run smoothly in a context of obvious synchronization.

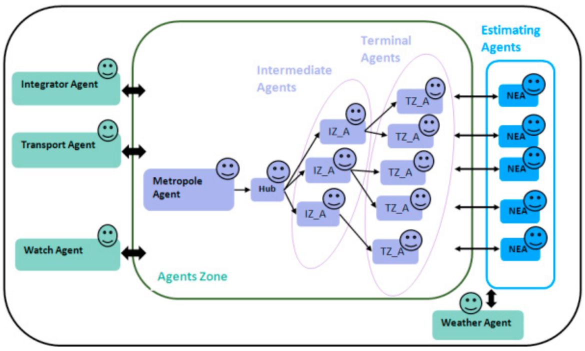


Fig. 3. MAS organisation

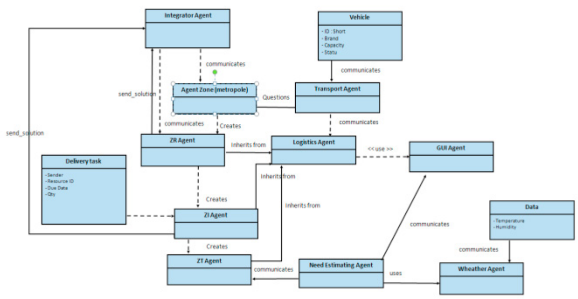


Fig. 4. System architecture

The Zone Agents are of 4 types of a population of Zone Agents:
- Metropole Agent MA : this is a fixed agent who manages all the resources in the Metropolitan area. It has a very large starting stock and plays the role of supplier for the entire CMSC;
- Resource Zone Agent RZ: It is a dynamic agent that is created only in the event of a crisis. At the level of this agent, resources will be pooled to be allocated to the various possible means of transport. It is the second link in the CMSC. The operation of bringing metropolitan resources to the RZ Agent is called pre-routing. These are generally areas for grouping goods awaiting expatriation outside country borders;
- Intermediate Zone Agent IZ:. When the distance between the resource regrouping zone RZ and the disaster zone is significant, an intermediate logistics zone is placed and an Intermediate Zone Agent IZ is created to manage this zone.
- Terminal area Agent TZ: It represents the disaster area and the consumption of resources is the most random.

The Metropole Agent activity diagram is shown in Fig. 5.

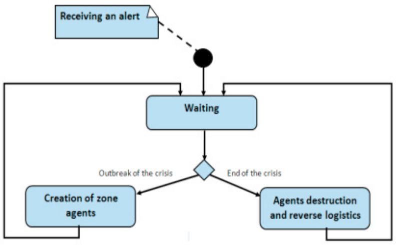


Fig. 5. Activities diagram of Metropole Agent

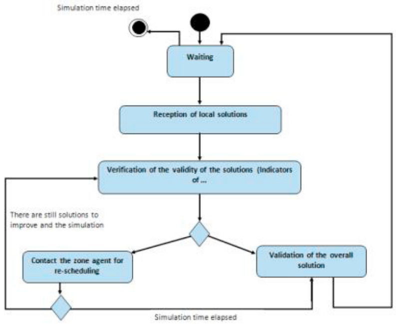


Fig. 6. Activities diagram of Integrator/Evaluator Agent

Transport Agent TA: The Transport Agent takes care of the transport of goods and informs the zones that they have just received a package.

Integrator/Evaluator Agent IEA: This agent's role is to compose a global planning for the routing of resources throughout the CMSC, from local planning received from the zone agents (Fig. 6).

Need Estimating Agents (NEA): The Need Estimating Agent (NEA) is a holonic agent or a multi-agent subsystem whose role is to provide an estimate of consumption coming from a logistics site.

It is important to keep your stocks above a certain critical level. It is possible to have an idea of this consumption, but in the event of modifications of certain parameters, a consumption peak for example in the case which concerns us, this consumption can vary enormously. The mission of NEA is to combine the expertise of people used to determining these consumptions, with corrections according to certain environmental parameters that we obtain from a database retracing the old CMSCs and their conditions. The NEA agent therefore examines, from the field layer, information on the climate and the number of people and uses the estimation models developed in the mathematical layer to simulate and anticipate the variation in the consumption phenomenon at the level of logistics areas.

Weather Agent WA: The Weather Agent is directly linked to the estimating agents; it gives the NEA all the information relating to the environment of their area. Three types of data were selected: the room temperature; the humidity level of the area and the number of persons to be supplied, near the area. The Weather Agent provides an estimate of this data for the same day, as well as the next 6 days, which allows the estimators to be able to make precise estimates on the needs of an area (Fig. 7).

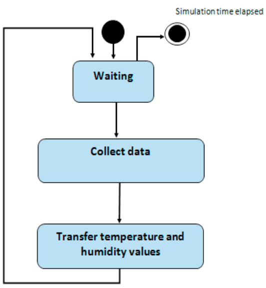


Fig. 7. Activities diagram of Weather Agent

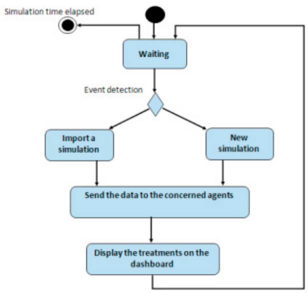


Fig. 8. Activities diagram of GUI Agent

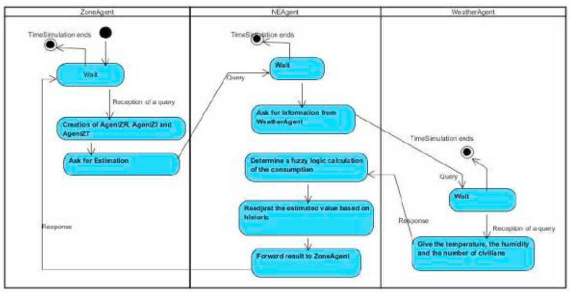


Fig. 9. Interactions between all agents

GUI Agent: The GUI (Graphic User Interface) Agent is an agent directly attached to the control window. He will therefore dialogue with all the agents to give them the desired orders by the user. It is also responsible for retrieving information allowing to have a global vision of the chain on the screen, and finally carrying out a risk study[3][7][8][10]. As soon as it is created, the GUI Agent goes to sleep waiting for any event likely to reactivate it and trigger its own process (Fig. 8).

The interaction between a company of agents, composed of zone agents, NEA agent and the Weather Agent is illustrated by the three-partition activity diagram in Fig. 9.

All of the agents in our crisis management supply chain, because of their different properties (autonomy, communication, cooperation, etc.) can have different modes of activity. Indeed, at a given time t, some agents negotiate among themselves, others transmit orders while others schedule delivery tasks. We have identified four modes of activity : parallel activity, staggered activity, interruption and different duration activity.

Each day, four main steps are used to summarize the operations that can be carried out : i) Receipt of packages; ii) Consumption of goods; iii) Transmission of requests and needs to the superior; and iv) Sending packages to a subordinate area.

## 5. Optimization of flows in the CMSC

### *5.1. Optimizing of areas positioning : Behavior of the Metropole Agent*

We have therefore adapted and developed an algorithm for positioning logistics zones, which will allow us to optimize the structure of our CMSC. In the same way, a distributed scheduling process, and therefore a new scheduling behavior integrated into the core of each zone agent, was developed and implemented.

Several constraints are involved in decision-making relating to the geographic location of the CMSC. In fact, to ensure effective logistical coordination, different points must be taken into account:
- The extent of the damage in the country affected by the disaster.
- The government's internal policy.
- The climate and the local fauna.
- The likelihood of other natural disasters occurring and destroying the facilities.
- The geographical area.

As part of our research, we are proposing to offer the logistician decision-maker a tool that guides him in his decision-making when configuring the CMSC, to choose the geographic location of intermediate logistics bases (Hubs). The goal here is to suggest to the designer the optimal geographic areas that guarantee a rapid and efficient response and response to the crisis. To solve this problem, we offer a decision support module within our OBCA demonstrator which offers the logistician two modes of operation : automatic mode and manual mode.

### *5.2. Scheduling of delivery tasks : Behavior of the Zone Agent*

We propose to introduce optimization agents and scheduling techniques into Zone Agents in order to allow them to facilitate the circulation of CMSC flows and determine a better scheduling solution satisfying a certain number of criteria. Conventional centralized approaches propose to concentrate the resolution of the optimization problem within a single agent who plays the role of mediator. However, this centralization of resolution has problems in terms of fault tolerance and adaptability. In our context, we propose a distributed and cooperative resolution approach that makes all the entities making up our system interact. The scheduling problem under consideration will make it possible to establish resource routing plans along the CMSC. Our scheduling problem is composed, in its most complete representation, of several entities, as illustrated in the Fig. 10.

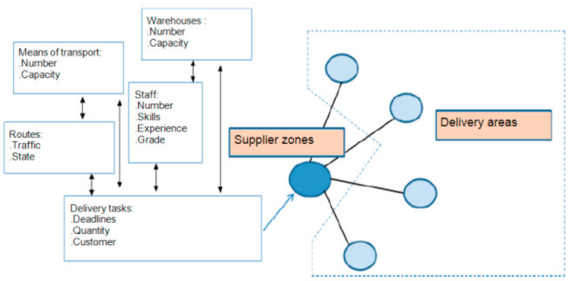


Fig. 10. Model of delivery system scheduling

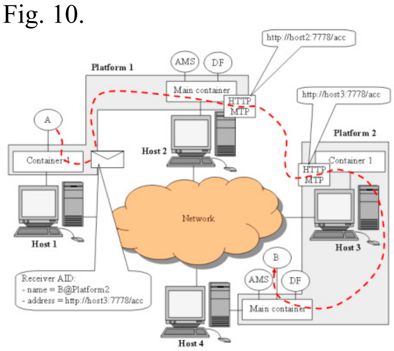


Fig. 11. Running multiple JADE platforms

## 6. Simulations

We chose the JADE platform (Java Agent Development framework) for the development of our system and the simulation of the results of our distributed optimization approaches. JADE is a 4 middleware software-mediator which allows flexible implementation of multi-agent systems communicating through efficient transfer of ACL (Agent Communication Language) messages, in accordance with FIPA specifications. JADE is written in Java, supports mobility, evolves rapidly and is today one of the rare multi-agent platforms that offer the possibility of integrating Web services to optimize the performance of a distributed agent system (Fig. 11).

We simulated the operation of the optimization approaches adopted in our OBCA demonstrator. We had done several simulations to evaluate the performance of our system for crisis management. The simulation results and scenarios show the flexibility and adaptability of the system in the face of the vagaries of the crisis. The OBCA certainly helps logistic decision-makers.

## 7. Conclusion

In this paper, we are interested in decision support solutions to facilitate the work of logistics decision-makers in the event of a crisis as we saw during the current context of the COVID-19 pandemic. We have brought solutions based on a modeling, optimization and simulation approach geared towards logistics flow agents, in a context with strong disruptions, more precisely, in the case of a crisis management supply chain. .

Our contribution covered three areas of investigation: a module to help with the positioning of logistics zones which makes it possible to minimize the distances between zones and to optimize their numbers and this for better circulation of flows, a multiagent oriented approach for the distribution of delivery tasks which provides a solution to a highly distributed flow management problem, and finally a holonic agent whose role is to provide an estimate of the future consumption of a logistics site by combining human expertise in mathematical models.

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