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An agent-based Decision Support System for resources' scheduling in Emergency Supply Chains

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ABSTRACT

We propose a multi-agent-based architecture for the management of Emergency Supply Chains (ESCs), in which each zone is controlled by an agent. A Decision Support System (DSS) states and solves, in a distributed way, the scheduling problem for the delivery of resources from the ESC supplying zones to the ESC crisis-affected areas. Thanks to the agents' cooperation, the DSS provides a scheduling plan that guarantees an effective response to emergencies. The approach is applied to two real cases: the Mali and the Japan crisis. Simulations are based on real data that have been validated by a team of logisticians from Airbus Defense and Space.

1. Introduction

When a disaster occurs, regardless of its type (natural, such as earthquakes, floods, tsunami, etc., or man-made, e.g., wars), detailed plans should be established for people at risk, so that logistics operators are able to answer the needs of survivors in the affected areas. These operations are called emergency logistics and aim at providing the needed supplies with the minimum cost and time. Hence, emergency logistics refers to a set of interacting and coordinating logistics actors aiming at accomplishing emergency logistics requirements (Sauer, 1999). With respect to classical logistics, emergency logistics is characterized by several distinctive features. First, in the aftermath of a crisis, responsive (or automated) emergency logistics systems are needed in the affected areas for efficient disaster relief supply and recovery (Yongsong, Siuming, & Kwokkit, 2011). Second, an assessment of supply resources and workforce should be conducted to adjust to the unexpected difficult circumstances. Third, since the crisis environment is typically uncertain, traditional centralized systems cannot deal with the sudden unexpected variations of needs (Maturana, Shen, & Norrie, 1999). Hence, the Emergency Supply Chain (ESC) objectives for crisis management are: optimal deployment of military units, resources and equipment (personnel, vehicles, planes, etc.); supply of water, food, clothing, etc.; infrastructure reconstruction; medical support.

This paper considers the first two objectives of an ESC, i.e., the optimal allocation of the resources for the supply management during the crisis. In the case of a security threat, immediate operations must be implemented, including the development and maintenance of the ESC to provide logistics support functions. The issue is to implement a suitable procurement policy to deliver the resources avoiding stock-outs that can paralyze the functioning of the whole chain. Therefore, logistics ESC managers have to take into consideration objectives like costs minimizing and constraints such as delivery delays as well as the complexity of the environment characterized by uncertainty and a large number of actors that make the scheduling task highly complex. The described context shows the relevance of developing an automatic tool to model and optimize logistics solutions to answer emergencies and help decision-makers or authorities make the right choices in real time.

To answer the recalled needs, we propose a Decision Support System (DSS) that solves the ESC resources scheduling problem in a distributed setting. More precisely, the DSS uses an optimization and negotiation scheme to solve the resources scheduling in the areas affected by the crisis while taking into account the requirement for a distributed solution to the ESC management by an agent-based approach. The developed tool not only answers the supply needs during or after emergencies, but also supports the decision maker in scheduling resources in a varying environment. The proposed DSS is developed in cooperation with the logistics department of Airbus Defense and Space, a division of the European Aeronautic Defense and Space Company group now rebranded into Airbus Group. This

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paper describes the DSS agent-based architecture, where actors provide smart negotiation in order to execute and control the schedule of delivery tasks. Hence, the paper presents a set of tools and approaches for optimizing logistics flows in the ESC, detailing the optimization models used. The application of the DSS to two simulated case studies based on real data (referring to the Mali crisis and the Japan crisis) validated by military logisticians is also shown.

The remainder of the paper is structured as follows. Section 2 reviews the related literature, motivating and positioning our approach. Sections 3 and 4 respectively describe the ESC structure and the agent-based DSS for the ESC management. Section 5 defines the scheduling problem and presents the optimization model for its solution. Section 6 explains the behaviour of agents. Section 7 presents the agents' communication protocols and analyses the DSS complexity. A comparison with existing alternatives is presented in Section 8. The developed software and its application to two case studies are presented in Section 9. Section 10 summarizes the paper and presents future research directions.

2. Literature review and paper contribution

2.1. Literature review

The literature is rich in papers related to crisis management and ESC. The reader is referred to the surveys by Altay and Green (2006) who describe the various operational research approaches for disaster supply chain management and by Tang (2006) who presents an overview and perspectives in supply risk management.

The recent papers on ESC management include the following works. Ben-Tal, Do Chung, Mandala, and Yao (2011) propose an approach to generate a robust logistics plan that can ease demand uncertainty management in humanitarian supply chains. They apply dynamic linear programming in order to assign emergency response and evacuation traffic flow problems. Sheu and Pan (2014) treat a centralized emergency supply network and propose a method involving three stage multi-objective and mixed-integer linear programming models. Kelle, Schneider, and Yi (2014) study pre-positioning decision and response (evacuation and supply) optimization considering the resources of all stakeholders. Guojun and Caihong (2012) introduce the salvable concept for ESCs and address risk management based on urgent relief service, classifying the crisis areas based on their evaluated salvable degree. Barahona (2013) develops an optimization and simulation framework to manage the distributing relief logistics supplies in a multi-tier supply network. A dynamic fuzzy model for disaster relief response in large-scale problems is proposed by Sheu (2010). Nagurney, Yu, and Qiang (2011) suggest a supply chain network scheme model for critical needs. Nagurney, Amir Masoumi, and Yu (2014) study the management of a (humanitarian) disaster relief ESC and develop a network optimization model. Hale and Moberg (2005) propose a decision process for secure storage facilities efficient network supporting multiple supply chain facilities. Asghar, Alahakoon, and Churilov (2005) propose an approach to the design and the implementation of a dynamic integrated model for disaster management. Wang (2009) introduces a resource-constrained and decision support workflow model able to specify resource consumption and production while executing a task. Sheu (2007) proposes in his work a hybrid fuzzy clustering-optimization approach for quick response to urgent relief demand in disasters.

The recalled works show that authors typically apply to the ESC management (various different) centralized planning approaches, which are not always appropriate for a distributed chain such as an ESC. In fact, a distributed planning approach is in our opinion much more suitable, since an ESC is typically large and distributed in nature. Hence, a distributed approach allows solving in a more efficient way than a centralized approach the ESC management problem.

The literature is rich in papers dealing with classical supply chain management (Costantino, Dotoli, Falagario, Fanti, & & Mangini, 2012; Dotoli, Epicoco & Falagario, in press; Gaonkar & Viswanadham, 2007), and different methods have been suggested to solve distributed problems in classical supply chains. In several models, the supply chain is represented by mathematical equations. However, the provided solutions are typically incomplete because the dynamic characteristics of the supply chain are neglected in the models. On the other hand, simulations allow the evaluation of the supply chain considering it as a single centralized actor while the related large number of entities to be modelled is the first limit of this approach (Luder, Peschke, Sauter, Deter & Diep, 2004). In various studies, distributed models are constructed and locally maintained and joined during the evaluation (Gupta, Ko, & Min, 2002). Moreover, in Lee, Kim, and Moon (2002) the authors present a framework for distributed optimization of SC planning using an augmented Lagrangian decomposition and coordination approach.

An interesting distributed approach consists in managing supply chains using a Multi-Agent-System (MAS) framework, since MAS are distributed in nature and as such they cope well with modelling complex systems. Despite their recent emergence, MAS have found their wide application in numerous areas (Chaib-draa, 1995; Luder et al., 2004). MAS are at the intersection of several scientific fields: distributed computing, software engineering, artificial intelligence, sociology, social psychology, and many more. Hence, not surprisingly, there are several publications on the application of MAS to the logistics industry (Mařík & Lažanský, 2007; Morel, Valckenaers, Faure, Pereira, & Diedrich, 2007; Shen, Hao, Yoon, & Norrie, 2006). Among the first applications developed based on communicating agents, there is an application for air traffic control (Cammarata, McArthur, & Steeb, 1988). In this application, MAS cooperation strategies have been used to solve conflicts between plans of a group of agents. Moreover, Nyugen (1997) introduce the idea of using generating functions for evaluating the effectiveness of a defence system. They study the quantification of benefits from resource allocation for a naval task group having perfect coordination between its assets. Further, the INGENIAS Development Kit is an application based on MAS to manage a city in which a poisonous material is released, and the central services are not enough to heal all the affected people (Garcìa-Magarino, Gutiérrez, & Fuentes-Fernàndez, 2009). In addition, Saint Germain, Valckenaers, Verstraete, and Hadeli (2007) address the supply network control in a multi-agent framework.

Despite the abundance of distributed approaches to classical supply chain management, none of the recalled works addresses the peculiar case of supply chain management under emergency. In cooperation with Airbus Defence and Space, our team published several seminal works on ESC management. In (Kaddouci, Zgaya, Hammadi, & Bretaudeau, 2009), a first version of an agent-based software tool called OBAC (Optimization Based on Agents Communication) is developed and used to improve logistics planning. Moreover, Zoghlami and Hammadi (2006) propose a linear estimation operator for an ESC. Then, Kaddoussi, Zgaya, Hammadi, Duflos, and Vanheeghe (2012) integrate an estimator based on an ARMAX model, a model that is proven to be generic and well adapted to crisis situations. In addition, Kaddoussi, Zoghlami, Hammadi, and Zgaya (2013) treat the problem of scheduling in a crisis supply chain using MAS. Simulations in this work are academic and based on theoretical examples. Subsequently, Othman, Zoghlami, Zgaya, and Hammadi (2014) propose an adaptive distributed scheduling approach.

2.2. Paper contribution

This paper presents a DSS that solves in a distributed way using the MAS concept the scheduling problem for the delivery of resources to crisis-affected areas of an ESC. According to our previous works presented above, estimation and scheduling tools are integrated into an agent-based crisis management system. The various DSS decisions