



An argumentation-oriented multi-agent system for automating the freight planning process

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ABSTRACT

This paper advocates the use of multi-agent systems in the freight forwarding industry. We propose an intelligent mobile agent system to cope with a dynamic freight forwarding environment where up-to-date information is crucial but time-consuming to obtain. A key component of our system is an agent argumentation mechanism that allows decision support agents to discuss, argue, and come to a compromise in order to derive well-explained freight planning solutions. A number of artificial intelligence mechanisms are implemented, namely: (1) a mobile-agent-based automated information gathering mechanism, where designated mobile agents access various websites automatically to gather information (e.g., weather conditions on a candidate route) critical for cargo consolidation and route planning, (2) a fuzzy logics engine for risk evaluation, and (3) a simulated annealing engine for optimizing cargo consolidation. A system prototype is developed and the feasibility of our approach is demonstrated in a case study. A series of experiments are also conducted to evaluate the system's performance.

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1. Introduction

With the rapid development of the Internet and relevant information and communication technology, a new business model called e-business has emerged. The distinctive characteristic of this model is that it allows people to trade without geographical limitations. To ensure fast and efficient global delivery of products, the demand for air cargo has been growing during the last 20 years.

One important but frequently overlooked group of companies in the field of air cargo logistics are the air freight forwarders. Air freight forwarders are third party logistics companies that coordinate, consolidate, and arrange the delivery of cargo shipments for their shipping clients (Wong, Leung, & Hui, 2009). The primary task of an air freight forwarder is to construct freight plans with the target of minimizing the overall operations cost while fulfilling shipment deadlines and other conditions specified by their customers, then execute the plans accordingly. This problem is called the route planning problem. In reality, freight forwarders need to consider a large amount of additional information during their planning process, for instance, the weather conditions along the cargo route, the political situation in transit countries, or other possible causes of delays (e.g., imminent industrial actions, the start of major national holidays or religious festivals, etc.). As these factors can all affect the delivery schedule, information regarding such events must be kept up-to-date. Also, the freight planning process is

becoming more and more complex as freight forwarders often need to consolidate cargo items from multiple customers in order to optimize the loading of the cargo containers (known as unit load devices, or ULDs). This second problem is known as the cargo consolidation (or cargo loading) problem.

During the past decade, much research effort has been expended on the cargo consolidation and route planning problems (collectively labeled the *C and R problem*). Most of these studies aimed to optimize the consolidation and route planning process by constructing mathematical models and by using various intelligent optimization techniques. However, consolidation and route planning is just one part of the freight planning process. To minimize the work involved in collecting information, in recent years many researchers have proposed the use of a multi-agent technology system in logistics. A review of studies on multi-agent systems in air freight forwarding and related disciplines is given in Section 2.

In this paper, we present a novel argumentation-based multi-agent decision support system for freight planning. The system has several distinctive research features. First, our system supports the automatic collecting and updating of information relevant to the freight planning process. By using information gathering mobile agents, our system can collect and monitor useful information from various sources including airline agent platforms, third party websites, and client platforms. Second, an argumentation mechanism is implemented for determining the best freight plan based on the principles of both cost minimization and risk reduction. Two agents are defined, namely the financial agent (FA) and the risk

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management agent (RMA). During the freight planning process, each of the two agents first proposes a freight plan according to their own goals and criteria: the FA plan is based on cost-minimization and the use of simulated annealing techniques, whereas the RMA plan is based on risk reduction using a fuzzy logic engine. Should the two paths not be the same, an argumentation process is executed, where the two agents challenge the other's decision, exchange dialogs, and provide evidence justifying their proposed freight path. This continues until the difference is resolved. The output is a freight plan with well-explained rationales. A case study is given to demonstrate the feasibility of the proposed system.

This paper consists of six sections. Section 1 is the introduction. A review of studies on the development of software agent systems in the air freight forwarding industry is found in Section 2. The system architecture of the agent system and details of the operating mechanism of each agent are described in Section 3. In Section 4, a case study is illustrated to show how the proposed system can be used to construct freight plans. Section 5 provides an evaluation of system performance. Section 6 concludes this paper.

2. Background: software agents and cargo logistics

In recent years, there has been much interest in applying multi-agent technology to deal with various problems in the field of logistics. Software agents have traditionally been defined as software entities with a high degree of autonomy, meaning that they can complete their assigned goals with minimal human supervision. Intelligent agents also have a number of desirable properties. Apart from being autonomous, agents are able to act *proactively* toward some goals, while also being *reactive* to dynamic environmental changes (Wooldridge & Jennings, 1995). This makes them particularly suitable for applications where the problems are (1) modular in nature, (2) can be solved by a decentralized approach, (3) ill-structured, (4) such that frequent changes are expected and, most importantly, (5) complex and dynamic in nature (Parunak, 1999). It is not hard to see that cargo logistics fits many of these prerequisites: it is a complex problem involving multiple parties spread across many locations around the world, and the problem consists of many interdependent sub-tasks such as route planning, ULD booking, and monitoring. Additionally, for practical reasons, it is also desirable that the proposed solution should be comprehensible (Himoff, Skobelev, & Wooldridge, 2005), that is, the reason behind the decisions should be understandable to humans. A cargo logistics problem is a very dynamic one, as information on matters such as road conditions, flight and container availability, and cargo supplies changes dynamically throughout the process. Negotiation-based multi-agent solutions are good candidates given these requirements. A desirable cargo logistics system must be highly autonomous so as to ease the burden of human operators, and readily react to any changes or unforeseen conditions, making software agents particularly attractive.

For these reasons, various multi-agent based solutions have been proposed in cargo logistics, starting from some early studies that provided conceptual frameworks or platforms for distributed intelligent problem solving in logistics. One early example is the work of Satapathya, Kumaraa, and Moore (1998). In this work, a framework is proposed for decomposing a logistical task into sub-tasks, with each sub-task being taken up by a task agent. Although no specific implementation is described in detail, mechanisms for agent communication (with human or with other agents), collaboration, and task delegation are discussed. Later, in Himoff et al. (2005), Magenta, a commercial platform for building multi-agent based applications in logistics, is described.

In this paper, we propose an argumentation-based multi-agent approach for cargo-logistics (specifically, for the C and R problem

in air-freight forwarding). A *purely cooperative* multi-agent approach is taken, where all of the proposed agents belong to one single organization and jointly work toward a common objective. Many related works in the literature also belong to this category. For example, Chan, Chow, So, and Chan (2012) proposed a software agent and RFID-based approach for the C and R problem and for a problem known as “equalization.” Four task agents are defined for the respective tasks of flight planning, data-retrieval from airlines, equalization, and consolidation, which are overseen by an RFID Cargo Agent. Software agents are employed for autonomous background processing as well as for automatic information gathering (e.g., the latest flight schedules). Baykasoglu and Kaplanoglu (2011) tackled the C and R problem using a negotiation mechanism between order agents (which represent the cargo items to be delivered) and truck-agents (which represent the cargo delivering units). Xu, Wijesooriya, Wang, and Beydou (2011) proposed a cargo monitoring system for outbound logistics. They implemented a multi-agent framework for detecting and monitoring exceptional conditions at various stages of the logistics process (e.g., a cargo item that cannot be delivered). Chow, Choy, and Lee (2007) described a real-time process management system based on RFID and software agents to supply front-line operators with updated information (e.g., handling instructions for cargo items). In the work of Adler, Satapathy, Manikonda, Bowles, and Blue (2005), cooperative agents are defined to represent cargo truck operators and a centralized route planner. The routes are decided by a process of negotiation and the results are communicated to the truck drivers. Note that it is also possible to use seemingly competitive agents for purely cooperative tasks. Examples of this approach include the work of Zhu, Ludema, and van der Heijden (2000), which described a coalition formation approach for the C and R problem in air cargo logistics, and the work of Perugini, Lambert, Sterling, and Pearce (2005), which proposed a provisional agreement protocol to support the scheduling of global transportation.

There are also other works with agents that are competitive (non-cooperating) in nature. Typically, such a design is used where the agents represent the interests of more than one party (e.g., a shipping customer and a freight forwarder, or more than one competing logistics company at various parts of a cargo-supply chain). Examples of such systems include the work of Wang, Vogel, Kumar, and Chiu (2009), where agents representing third party logistics companies (3PLs) interact at various stages of the cargo logistics supply chain of some shipping customer. Jung, Chen, and Jeong (2008) tackled this problem by defining software agents for the manufacturers and for the 3PL providers. In Robu, Noot, Poutré, and van Schijndel (2011), an auction-based platform is implemented to process bids from both 3PL agents and human 3PL bidders.

In this paper, we describe a novel multi-agent approach for the C and R problem. There are two major contributions. First, in our system, an agent argumentation based mechanism is proposed. While the art of argumentation has been studied in philosophy since the classical period, it is a relatively new one for multi-agent systems mechanisms (McBurney & Parsons, 2009), and certainly for cargo logistics decision support. Recall from the above that in cargo logistics it is often desirable that the rationale behind any system-proposed solutions should be explainable and understandable to the human operators, and yet this is an area currently not well explored in the literature. In agent argumentation, multiple solutions are concurrently proposed by agents with diverse areas of expertise and any solutions are subjected to challenges by other agents. The challenged agent must then provide the supporting evidence and rationale for his decision. (As a simple example, a low-cost solution can be challenged by a risk-sensitive agent raising concerns about the presumed risk of possible delays along a route.) This way, any final solution will be clear and well explained.

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