# INTELLIGENT AGENTS IN LOGISTICS: SOME TRENDS AND SOLUTIONS

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**ABSTRACT**

The paper gives an insight into trends and solutions based on intelligent agent paradigm in logistics domain. Three kinds of systems are described: single agents constituting multi-agent systems, holonic systems and multi-multi-agent systems. Single agents and multiagent systems are used in various applications, holons mainly are designed for transportation scheduling while multi-multi-agent systems are the most suitable for supply chain management. The prototype of simulation tool based on holonic agents has been developed and used to simulate four different types of auctions.

Keywords: logistics, intelligent agent, holon, simulation tool

## 1. INTRODUCTION

The logistics domain is complex, decentralized, dynamic (goals, organizations' capabilities and beliefs are continuously changing), and open because organizations may enter or leave the system at any time (Perugini et al. 2003). In this domain a great number of actors are operating. These actors compose supply chains, i.e. networks of suppliers, factories, warehouses, terminals, distribution centers, retailers and customers, as well as various means of transportation, such as trucks, trailers, vans, cargo boats, barges, planes, etc.

Analysis of the available publications reveals that regardless of the fact that traditional mathematical and simulation techniques still dominate for problem solving and optimisation of solutions new approaches start to expand, for example, Web-based, knowledge-based, and mobile systems appear in logistics domain. The paper has focus on agent-based technologies, multi-agent and multi-multi-agent systems which emerge only recently in connection with such relevant complex, and wherewith unsolved, problems as coordination in supply chain management, dispatching of transportation orders, management of, for example, a seaport or a container terminal, etc.

Intelligent agents model organizations' logistics functions, processes, expertise and communications with other organizations, or simulate users involved in traffic, transport units or elements of transport infrastructure (Zhu and Bos 1999, Henoch and Ulrich 2000). Agent technologies and, in particular, multi-agent systems become quite popular for supply chain management (Gerber, Vierke, and Zinnikus 2000; Yuan, Liang, and Zhang n.d.; Fox, Barbuceanu, and Teigen 2000; Zhengping, Low, and Kumar 2003) because they model distributed tasks. Multi-multi-agent systems, in their turn, appear as the next step – integration of multi-agent systems providing reliability of overall supply chain processes (Frey et al. 2003, Stockheim et al. 2004, Nimis and Stockheim 2004).

The objective of this paper is to give an insight into applications of agent-based technologies and to figure out trends in development of such systems for logistics domain. The paper is organized as follows. The next section gives an outline of plethora of intelligent agents already proposed for transportation and logistics systems. Holonic agents are discussed in Section 3. Section 4 is devoted to multi-multi-agent systems. The brief description of the developed prototype of simulation tool based on holonic agents is given in Section 5. Finally, in the last section conclusions are made and future work is outlined.

## 2. INTELLIGENT AGENTS FOR TRANSPORTATION AND LOGISTICS SYSTEMS

The analysis of different information sources allows to conclude that applications of agent-based technologies cover many transportation and logistics problems, for instance, traffic modelling, logistics management and planning, vehicle dispatching, transportation scheduling, and others (Graudina and Grundspenkis 2006). At the moment a plethora of various agents already exists, and many research activities and application projects are carried out. In fact the very nature of logistics domain determines that single agents should be integrated in different kinds of multi-agent systems (MAS).

Logistics management motivates introduction of two generic meta-types of agents, namely, management agents which pursue goals with respect to their environment and defined action space, and service agents which solve well specified tasks autonomously (Henoch and Ulrich 2000). In logistics management agents are software entities for meeting operational goals. These agents to the certain extent are autonomous, proactive, goal directed, take goal responsibility, and make decisions. They act autonomously, but their actions are constrained by the provided information and models. A management agent needs the following information: a goal to pursue, its skills and behaviour, model of environment, its role in the agent community, e.g. a role of supervising and collaborating agent or sub-agent, communication and cooperation protocols. In a logistics domain where the coordination of joint actions plays the most important role, this agent exhibits the following properties: acts in a collaborating manner, applies various problem solving strategies, manifests communication abilities, uses methods for conflict solution among its sub-agents, and shows capabilities for goal and model building, which are used by its sub-agents.

One of the main functions of agents in logistics and transportation systems is collaboration support which is divided into subfunctions: collaborative information sharing, collaborative operation and collaborative configuration (Yuan, Liang, and Zhang n.d.). To provide collaborative support such agents as searching, scheduling, optimisation and negotiation agents are used.

A supply chain is the subarea where intelligent agents are intensively studied and implemented. The new software architecture for managing the supply chain at tactical and operational levels with the purpose to improve its overall quality has been worked out (Fox, Barbuceanu, and Teigen 2000). This architecture is composed from a set of intelligent software agents and actually represents a MAS. Each agent is responsible for one or more activities in a supply chain and is interacting with other agents in planning and executing their responsibilities. The typical set of agents includes six agents. An order acquisition agent is responsible for customers' orders and communication with a logistics agent in cases when orders are modified or cancelled. A logistics agent coordinates and manages movement of materials or products across the supply chain. A transportation agent is responsible for the assignment and scheduling of transportation resources. A scheduling agent is responsible for scheduling and rescheduling activities in the factory, and for resource assignment. A resource agent manages availability of resources. A dispatching agent performs the order release and real-time floor control functions.

A typical logistics scenario (Zhengping, Low, and Kumar 2003) includes a variety of logistics service providers, manufacturers, and suppliers whose actions must be coordinated. Four types of agents, namely, a distribution hub agent, a logistics coordinator agent, a manufacturer agent and a transporter agent represent generic roles in a typical supply chain. An architecture for agent-based logistics coordination has been designed based on the JADE agent platform (http://jade.tilab.com/). Each participant of a supply chain provides the agent platform with a set of agent instances. The agent platforms which include basic management agents and application agents are linked via Internet. Basic management agents embody a registration agent, a communication agent and a directory agent while an application agent includes interface, activation controller, optimisation/planning modules, for example, a demand forecasting or a transportation planning modules, and a knowledge base.

The Distributed Intelligent Agents for Logistics (DIAL) project is an open systems architecture that allows existing models to interface and communicate in a distributed network environment to evaluate and develop logistics plans (Satapathy, Kumara, and Moore 1998). A customer's problem is decomposed and assigned to corresponding intelligent agents which working together generate a logistics plan. Intelligent software agents are built on the top of simulation models to communicate among themselves, and to generate or to assist in generating a correct course of actions. Of course, DIAL is only one example of MAS developed for logistics. Various MASs have been developed and applied due to the growing success of FIPA standardization (http://www.fipa.org/) for MAS, increasing availability of FIPA-compliant frameworks, such as JADE (http://jade.cselt.it/) and open service infrastructures, for instance, Agent Cities (http://www.agentcities.org/) (Stockheim et al. 2004, Nimis and Stockheim 2004). A large number of agent-oriented methodologies have been proposed in recent years, for example, Gaia and its extension SODA, PASSI, AUML, MaSE, Tropos, TAO, CoMoMAS, MAS-CommonKADS, PROMETHEUS, and many others, part of which are described and compared in (Padgham and Winikoff 2004).

Recently the agents' family is supplemented with a new kind of agents. Mobile agents not only can communicate and interact with other agents but also can move from one place to another, and find and process information, as well as can send back results to the users (Schoder and Eymann 2000). Mobile agents provide an innovative concept for distributed systems development. These agents have a great potential for transportation and logistics problem solving, and for supply chain management because global transportation networks and supply chains require distributed global planning of activities.

## 3. HOLONIC AGENTS FOR TRANSPORTATION AND LOGISTICS PROBLEM SOLVING

Design of agent based systems for transport has created a new agent technology, so called holonic agent or a holon (Bürckert, Fischer, and Vierke 1999). A holon is composed from agents working together in order to reach a common goal. A holon interacts with its environment similarly as a single agent. In (Bürckert, Fischer, and Vierke 1998) three kinds of holonic structures are described. First, a holon may be organized as a federation of autonomous agents (Figure 1a). In fact, this structure is just another version of traditional MAS because all sub-holons are fully autonomous agents. A super-holon (composition of subordinate agents) is realized exclusively through cooperation among sub-holons and in reality is just a new conceptual instantiation of the same agent architecture. Second, a holonic agent may be created as a union of all involved agents (Figure 1b), i.e., agents merge into one agent, and merged agents completely give up their autonomy. After termination of super-holon each agent may be reverted into its initial state. Third, a holon as a moderated group is a hybrid way of forming a holon because agents give up only part of their autonomy to a super-holon keeping their own plans, goals and communication facilities. A super-holon is one of agents which coordinates resource allocation within a holon and controls communication with the rest of agent society. Thus, a super-holon becomes a representative, or so called, head of the holon (Figure 1c).

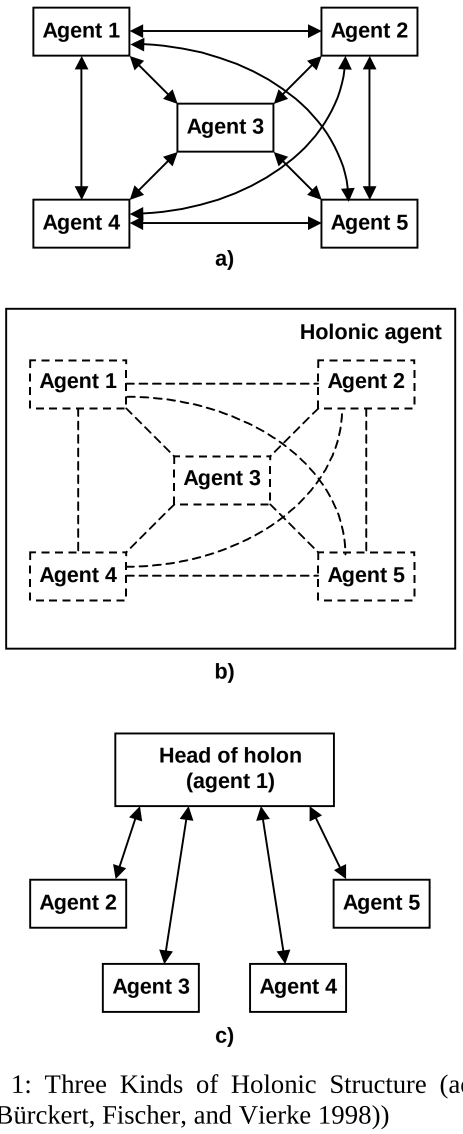


Figure 1: Three Kinds of Holonic Structure (adapted from (Bürckert, Fischer, and Vierke 1998))

The most important requirements for a holonic agent are the structure and cooperation, that is, a domain must be recursively decomposable and must have sufficient cooperative elements between the distinguished problem solvers. It is quite obvious that the holonic approach is suitable for problem solving in transportation and logistics. This approach is successfully used in several projects for transportation scheduling, starting with MAS-MARS (Fischer and Kuhn 1993), followed by TELETRUCK (Bürckert, Fischer, and Vierke 1999; Bürckert, Fischer, and Vierke 1998), its extension TELETRUCK-CC (Bürckert and Vierke 1999) and PLATFORM (Gambardella, Rizzoli, and Funk n.d.). The agents of MAS-MARS represent homogenous trucks and negotiate on incoming orders optimising the distribution and execution of these orders. In contrast, the TELETRUCK system schedules orders using heterogeneous agents modelling different forms of vehicles. The main idea in the TELETRUCK system is to model basic transportation units (drivers, trucks, trailers, chassis, containers, etc.) of transportation domain explicitly by component agents that merge into a holon representing a vehicle for a transportation task. The agent society is implemented as a holonic agent system that acts in a corporate way. The TELETRUCK-CC allows several independent shipping companies to cooperatively optimise their fleet schedules. The PLATFORM architecture consists of the intermodal transport planner that manages planning of the whole intermodal transport chain, and the simulation system that simulates intermodal transport unit transportation process.

Another kind of holonic software agent is realized in the Casa ITN system (Gerber and Klusch 2002). Each member of participant group, namely, producers, buyers, retailers, and logistics companies is represented by an appropriate holonic agent. Holonic agents accomplish hierarchically decomposed tasks and resource allocation, coordinate and control activities and information flows of their sub-agents. There are known also other applications such as scheduling of work in a production plan and coordination of business processes in a virtual enterprise where the holonic agent approach has been successfully used.

To summarize, it is worth to stress, that holonic structures besides such characteristics as hierarchy, decomposability, communication and cooperation have the most important characteristic – an open architecture. This made the design of MAS much more easy because instead of monolith agents with all needed functionality the holonic architecture promotes the design of small units with limited functionality which may be added or deleted from the MAS without impact on the rest of the system. This very relevant characteristic determines that the holonic approach will be widely used in future not only in transportation and logistics but also in other intelligent agent applications.

## 4. MULTI-MULTI-AGENT SYSTEMS FOR SUPPLY CHAIN MANAGEMENT

Multi-agent systems (MAS) support distributed task modelling for supply chains which involves many different independent tasks, i.e., planning, execution and control of production, transportation and warehousing processes (Nimis and Stockheim 2004). Looking at MASs from the viewpoint of supply chain management design these systems depend on each others' input and output, and therefore need to be integrated in heterogeneous systems. Integration of MASs leads to the concept of multi-multi-agent systems (MMAS). The structure of MMAS is designed to inherently meet the requirements of distributed supply chains where information for integrated production planning and control is not available within a whole supply chain. Analysis, design and implementation of MMAS has resulted in the Agent.Enterprise system (Frey et al. 2003, Stockheim et al. 2004, Nimis and Stockheim 2004). The Agent.Enterprise methodology focuses on a distributed and weakly coupled development process. The results of the analysis and design phase are consolidated in functionally restricted prototypes which constitute a test bed for components of MMAS. The project substitutes their prototypes with so called gateway-agents in order to connect their applications to the common scenario. Details of MMAS development process are given in (Stockheim et al. 2004) In brief, the analysis phase includes the role definition and assignment step followed by the use case specification. At the design phase of Agent.Enterprise two central design decisions are united in the gateway-agent concept as it is shown in Figure 2.

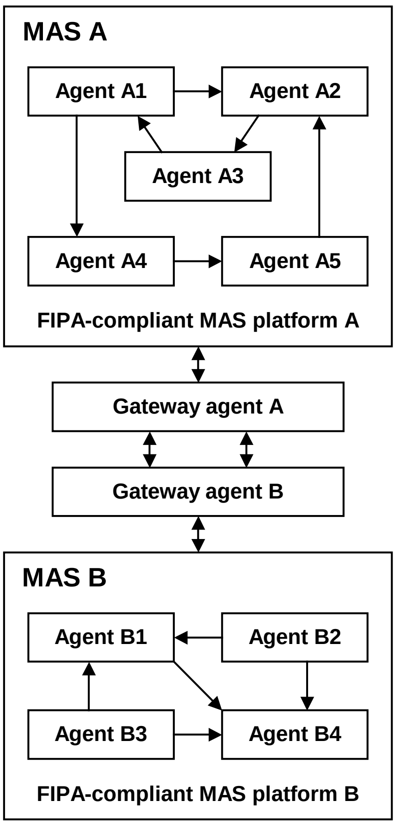


Figure 2: Multi-Multi-Agent Design Concept (adapted from (Nimis and Stockheim 2004))

The use of FIPA-compliant platforms avoids many of communication-related obstacles connected with heterogeneity of knowledge representation and semantics in individual MAS. The gateway-agent concept defines a virtual MAS where agents are scattered across a number of agent platforms such that an ontology can specify semantics of conversations, and ontology expressions are used as means of communication. At the design phase every individual MAS to be integrated should be represented by a single agent that comprises all roles of the corresponding MAS and provides them to the resulting MMAS. The implementation phase starts with the implementation of functionally restricted prototypes. There are some advantages of the gateway-agent concept. Developers can focus on a single agent and only gateway-agents must be available during operation. Moreover, the MMAS provides an integration of different agent platforms. On the other hand, the multi-multi-agent concept may be less flexible then the holonic agent approach because an individual MAS should be represented by a single agent with its full functionality.

The MMAS called the Agent.Enterprise covers services of supply chain scheduling, shop floor production planning and control, as well as pro-active tracking and tracing services. The MMAS provides reliability of overall supply chain processes (Stockheim et al. 2004).

## 5. SIMULATION TOOL BASED ON HOLONIC AGENTS

To gain experience of holonic agent design we have developed the prototype of simulation tool which in details is described in (Grundspenkis and Lavendelis 2006). The purpose of the prototype is to simulate delivery of goods from Asia to Europe using the following supply chain: Asian deep sea port (Shanghai, China) → deep sea shipping lines → deep sea port (Hamburg, Germany) → feeder shipping lines → Baltic and Mediterranean feeder ports (Greece, Finland, Lithuania, Latvia, Estonia) → trains → railway container terminals → customers in the EU and CIS countries. The multiagent system depicted in Figure 3 consists from clients' agent, logistics companies' agents and agents of each carrier. The system is built as follows: each client has his agent and each logistics company has its agent, too. Clients make deals with logistic companies using auctions. Each client is an auctioneer and logistics companies are bidders. A client's agent gets all necessary auction parameters from a client, e.g., a starting point and a destination, an auction type and a starting price per unit. Each logistics company's agent has knowledge base containing all carriers with whom his owner (logistics company) collaborates, and information about routes they operate. After receiving an offer to participate in an auction, a logistics company's agent must calculate its private evaluation. To do it, this agent must find all possible routes between a starting point and a destination. A transport network is modelled by a weighted graph which nodes represent terminals and edges are possible routes. Weights of nodes correspond to costs for keeping units of goods (containers) in terminals, and weights of edges correspond to their transportation costs. After finding the route with minimal total costs (the widely known shortest path algorithm is used), the agent gets its private evaluation which is the sum of the minimal total costs and the minimal company's profit.

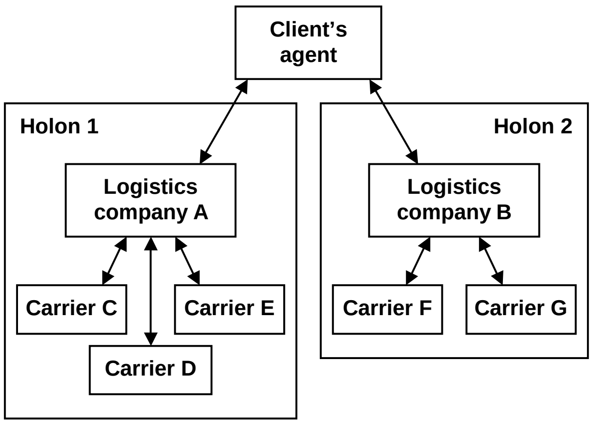


Figure 3: Example of Holonic System for Auction Simulation

The auctioneer starts an auction by sending all auction parameters to bidders. Four well known types of auctions, namely, English, Dutch, first-price sealed-bid and Vickrey auction (Wooldridge 2002) are implemented in the developed simulation tool. Each agent has its strategy for each type of auction captured in its knowledge base. Having its strategy and its private evaluation, an agent makes a decision to bid or not to bid. At the end of auction the auctioneer (the client) can make a deal with the winning agent. Automation of communication between a carrier agents and a logistics company agent can be done using auctions, too. In this case a holonic agent is used because for clients a logistics company and carriers with which it corporates is one whole object (holon) represented by one holonic agent. It is worth to point out that communication of carriers and ships, trains and/or trucks is not based on auctions because they are units of the same company. In fact, instead of deal making coordination is needed in this case (the developed prototype don't support coordination mechanisms).

The interface of the developed simulation tool consists from three main parts: 1) the auction parameters' input part, 2) the knowledge editing part and 3) the bid and winner information output part. The first part allows to input routes and auctions' parameters. The second part allows the user to edit agent lists, their attributes and knowledge bases. The third part consists of Europe's and China's maps where during an auction all terminals and routes are drawn. There is also the result table where information about the price, the route and the time is represented.

The developed simulation tool is used as a test bed to investigate influence of auction protocols on price, i.e. to find an answer to the question which auction gives the lowest price? In fact for risk-neutral bidders the chosen protocol is not important but for risk-averse bidders Dutch and first-price sealed-bid auctions are the best for auctioneers. However, risk-averse auctioneers do better with Vickrey and English auctions (Wooldridge 2002). Results of experiments carried out with the developed simulation tool shows that if both an auctioneer and bidders are risk-neutral there is not big difference which auction protocol is used (variations of the price are not more than 10% in any case). In real world it seems that small companies mainly are risk-averse while big companies may take a risk more willingly because their possible relative losses will not be so crucial for them.

At the moment the prototype can not support simulation of realistic situations because the simulation tool is implemented using Borland C++ Builder and MS Access database and is running on one computer without the Internet connection. A real system should have one server and many client's and logistic company's computers each having one agent. Actually it is only a matter of programming client-server applications to implement a simulation tool for real life situations, and it is one direction of future work.

## 6. CONCLUSIONS

This work is based on analysis of rather large number of information sources. This allows to conclude that in logistics domain there are three kinds of agent architectures. A plethora of single agents already have been developed which are integrated in multi-agent systems (MAS). Holonic systems have found their applications mainly in transportation problem solving, in particular, for scheduling tasks. In the supply chain management MASs and MMASs are widely used.

To get experience we have developed the prototype of simulation tool based on holonic agents. This tool allows to simulate one predefined supply chain for delivering goods from Asia to Europe. The prototype is used for investigation of influence of four different auction protocols on price.

The future work envisages continuation of analysis of existed approaches of applying agent technologies to automate the coordination and decision making in logistics, already proposed methodologies for single agent-based, MAS and MMAS development and the corresponding software. Another direction of future work is the development of holonic agent based simulation tool that is applicable for real life situations.

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