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A Negotiation-Based Multi-Agent System for Supply Chain Management

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***Abstract* - A supply chain is a key definition in logistics. The supply chain is a set of logistics system nodes that is linearly ordered by the material, information or financial flow in order to analyze or synthesize a specific set of logistic functions and (or) costs. Multi-agent systems are suitable for the domains that involve interactions between different people or organizations with different (possibly conflicting) goals and proprietary information. They view the supply chain as a set of intelligent agents, each responsible for one or more activities in the supply chain. The ontology, in turn, describes the domain area and becomes a mechanism to aid in understanding and analyzing the information flow between agents. The use of ontologies for multi-agent system provides the following benefits: the ontology enables knowledge structuring and sharing, increases the reliability of agent system and provides the basis for the interaction between the agents. This paper proposes a method of multi-agent system application for supply chain node cooperation and shows the interaction between agents inside one of the supply chain nodes – manufacturer node.**

***Keywords* – negotiation, ontology, software agents, supply chain**

I. INTRODUCTION

A supply chain is a key definition in logistics. The supply chain is a set of logistics system nodes that is linearly ordered by the material, information or financial flow in order to analyze or synthesize a specific set of logistic functions and (or) costs. Supply chain reflects the entire product path, starting from acquisition of raw materials and their transformation into finished product to its delivery to the end consumer. This path passes through raw material suppliers, manufacturers, logistics centers, warehouses, brokers, transport companies, wholesalers, retailers and others [1].

Supply chain management involves the following stages: planning, procurement, production, delivery and return. It has its own processes, problems and solutions at each stage [2].

The procurement and inventory management tasks are to analyze residues in storage, and analyze sales by customer group, sales in the previous period and the seasonality in the past, order placement, matching the quantity and terms with suppliers, the implementation of movement of goods between warehouses, and distribution of flows of goods in warehouses. It provides timely and sufficient saturation of commodities in stock in order to avoid situations of overstock (excess inventory), and out-of-stock (lack of goods in warehouses).

Multi-agent systems are suitable for the domains that involve interactions between different people or organizations with different (possibly conflicting) goals and proprietary information. It views the supply chain as a set of intelligent agents, each responsible for one or more activities in the supply chain.

"An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors" [3].

This paper proposes to use software agents that have knowledge about the functioning of the environment that allows them to make decisions in case of changes in parameters of functional environment. The classification of agents is presented in [3, 4].

A set of autonomous agents in multi-agent systems acts in the interests of different users and agents interact with each other in the process of solving tasks, sharing information, performing tasks and achieving common goals. The ability to negotiate is the unique feature of agents that distinguishes them from other software.

The ontology, in turn, describes the domain area and represents a mechanism to assist in understanding and analyzing the information flow between agents. The use of ontologies for multi-agent system provides the following benefits: the knowledge structuring, its sharing, increases the reliability of agent system and provides the basis for the interaction between the agents.

A model consisting of a set of agents is offered for electronic supply chain management in [5]. Its processes can be divided into sub-processes, where each agent is responsible for a particular sub-process. It is possible to implement all features in one single agent, but a set of agents is the best solution. Agents use the ontology to understand the domain area and communicate with each other.

A multi-agent system is proposed in [6] as a set of intelligent software agents where each agent is responsible for one or more actions in the supply chain related to the problem of steel pipe production. Agents interact with each other in planning and carrying out their functions.

The agent-oriented approach is considered for supply chain management in [7]. The carried out supply chain activities are distributed among agents, thereby improving the quality of supply chain management.

The authors note the importance of communication between agents, through which the quality of decisions can be improved, and the uncertainty avoided. The distribution of functions of the supply chain into a set of agents makes the system decentralized; thus making the whole system determined by the individual behaviour of each agent. The process of communication between agents in one company, in turn, has not been described in the publications yet.

This paper proposes a method of multi-agent system application for supply chain node negotiation, as well as the negotiation between agents inside one of the supply chain nodes – manufacturer node. The domain area of the system is the microchip assembly line. It consists of manufacturer node, crystal supplier node and microchip buyer node.

The paper is organized as follows: Section 2 presents the proposed method, Section 3 shows the multi-agent system architecture, Section 4 addresses multi-agent system construction, Section 5 provides multi-agent system implementation and Section 6 discusses the results.

II. The Proposed Method

One of the features of multi-agent system is that it offers a decentralized system. Global behaviour of the whole system is determined by the individual behaviour of a set of agents who follow their own rules of behaviour, exist in a shared environment and interact with the environment and other agents [8]. This makes the multi-agent systems best suited to the task.

The proposed multi-agent system consists of a CrystalBuyer Agent, Procurement and Inventory Management Agent, Production Agent, MicrochipSeller Agent and common ontology, and also CrystalSeller Agent and MicrochipBuyer Agent with common ontologies with CrystalBuyer Agent and MicrochipSeller Agent respectively (Fig. 1).

A. Description of the Proposed System's Parts

CrystalBuyer Agent

CrystalBuyer Agent makes a request to purchase raw materials; the agent negotiates with the CrystalSeller Agent about the price and delivery time. The interaction between the above-mentioned agents is through a common *CrystalTrading* ontology.

Procurement and Inventory Management Agent

Procurement and Inventory Management Agent decides when and how much raw materials to buy.

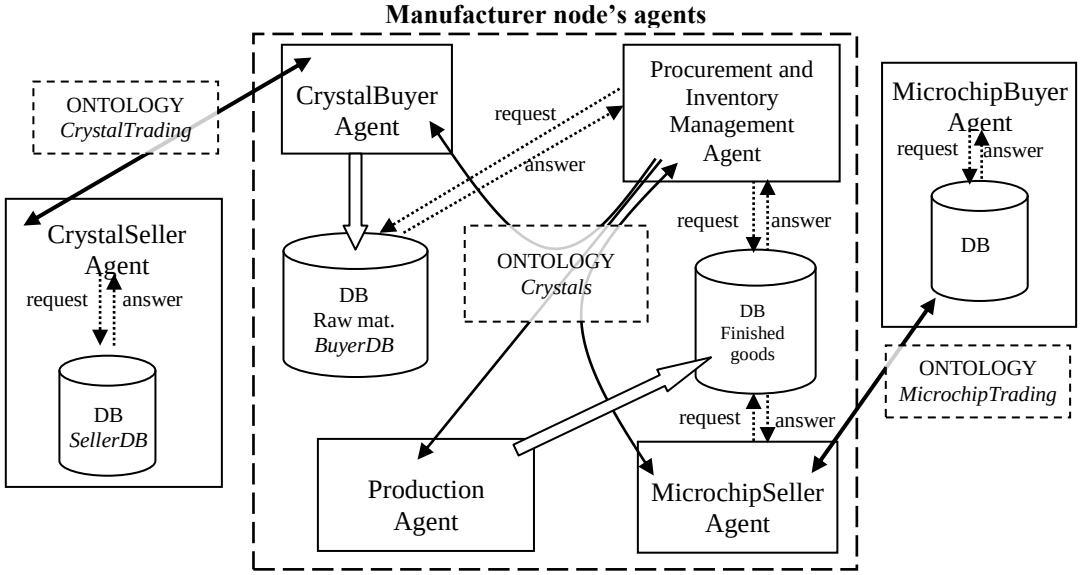

Fig. 1. Multi-agent system's architecture

The interaction of agents with a discussion
The agent commands
Information flow

It possesses the knowledge of the possible minimum reserves and of production capacity, as well as has an algorithm for forecasting future implementations.

Production Agent

Production Agent is engaged in assembling microchips from raw materials. The purpose of this agent is to assemble finished products from the raw materials according to the production technology and to transfer them to the finished goods storage. It does not have any knowledge about the subsequent sale of the finished products, as well as the future order forecast. Production Agent has lower layer agent - clean room agent, which is responsible for proper performance of the premises of the workshop.

MicrochipSeller Agent

MicrochipSeller Agent decides at what price to sell the microchip, takes orders from MicrochipBuyer Agent and takes care of sending the ordered goods to the buyer.

Ontology

The common ontology *Crystals* is used for agent negotiation inside one node (CrystalBuyer Agent, Procurement and Inventory Management Agent, Production

Agent, MicrochipSeller Agent). The use of ontology may lead to a discovery of new knowledge in the system.

The *CrystalTrading* and *MicrochipTrading* ontologies are the basis for the cooperation between agents, clarifying the information received in messages during negotiations between agents.

CrystalSeller Agent and MicrochipBuyer Agent

Both of these agents are not part of the manufacturer company, they belong to other companies. With the help of these agents raw materials are bought and finished products are sold. With these agents, CrystalBuyer Agent and MicrochipSeller Agent (respectively) negotiate on the quantity, price and delivery time of products. The interaction of agents is based on ontologies of *CrystalTrading* and *MicrochipTrading*, which are common for CrystalBuyer and CrystalSeller agents - *CrystalTrading*, and the MicrochipSeller and MicrochipBuyer agents - *MicrochipTrading*.

III. Multi-Agent System Architecture

The roles of individual entities in supply chain are implemented as distinct agents. Agents cooperate with each other in order to implement system functionality.

The multi-agent system consists of heterogeneous types of agents, which implement some functionality of the supply chain management, called functional agents. All of them have some understanding of system ontology and use Agent Communication Language to start a conversation [9].

The architecture of the proposed multi-agent architecture is depicted in Fig.2. It consists of three layers: management layer, functional layer and lower layer. The management layer is represented by one agent – supply chain management agent, which initiates the multi-agent system in case of a request occurrence from one of the nodes of the supply chain.

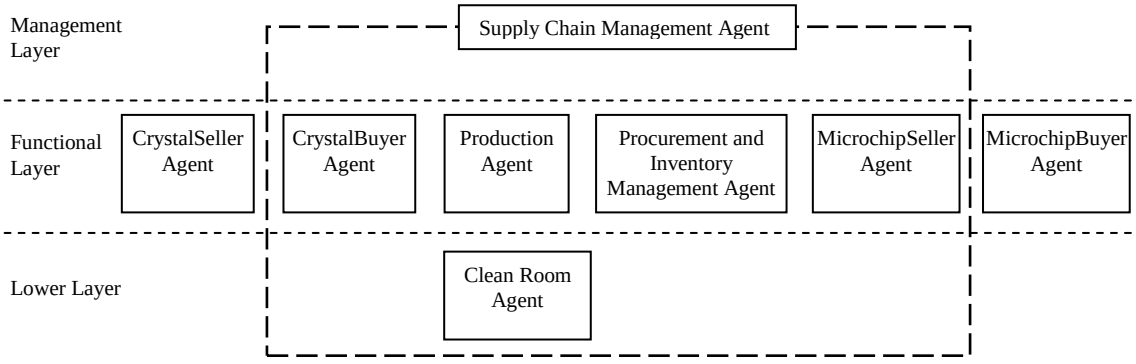

Fig. 2. Multi-agent system architecture

The functional layer is represented by six agents. Four of them are the manufacturer node agents, one of them represents the supplier node and the last one is the retailer node. The structure of the functional agent based on the example of CrystalBuyer Agent is shown in Fig. 2.

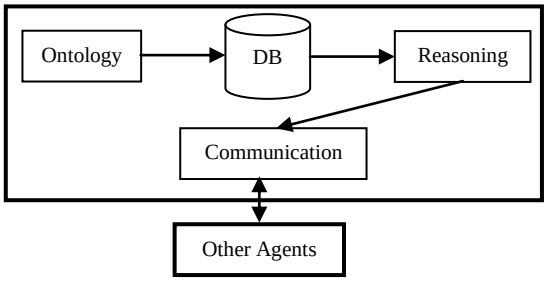

Fig. 3. CrystalBuyer Agent's structure

The lower layer is represented by one agent – Clean Room Agent (see Fig. 4). It cooperates with only one agent in this system – Production Agent. Clean Room Agent is visible to workers in the workshop; it uses its sensors for defining proper performance in workshops because of a strict standard on the quantity of dust per one m^2.

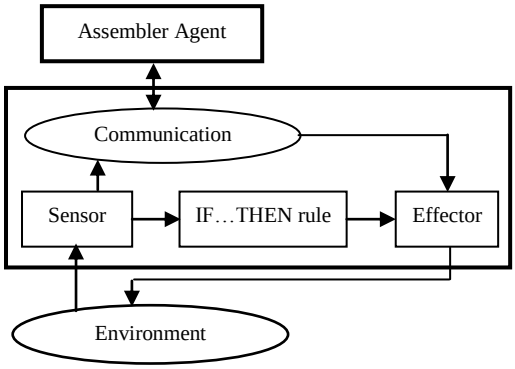

Fig. 4. Clean Room Agent's structure

IV. Supply Chain Construction

For the construction of the supply chain the following infrastructure was used: Java and JADE - a platform in which agents exist and interact, it gives to agents the basic services necessary for their existence, Protégé and Ontology Bean Generator to create a domain ontology and to transform it into JADE classes, MySQL to support the database, Apache Ant to compile the code, NetBeans IDE as Integrated Development Environment, ACL messages to transfer

information, share knowledge and negotiate with each other using FIPA negotiation protocols.

For the system implementation, the following steps were done:

1) three ontologies for the domain areas were constructed and represented in forms suitable for use in JADE;

2) A multi-agent system was constructed in the JADE environment.

V. Supply Chain Implementation

Agents of the manufacturer company are cooperating with each other during all the period of time in order to assemble microchips (see Fig.5.):

1) The procurement and inventory management agent decides when and how to launch microchips (communication with the Assembler Agent);

2) The Assembler Agent initiates the assembly of microchips, and also requests from the Clean Room Agent to confirm proper performance of the premises of the workshop (communication with the agent clean room).

The CrystalSeller or MicrochipBuyer agents take part in this system if:

1) a request is received from CrystalBuyer to buy crystals in case of the deficiency of crystals in raw material stock for the production process in the planned period:

Step 1. The Procurement and Inventory Management Agent triggers the management layer agent.

Step 2. The management layer agent triggers the multi-agent system initialization.

Step 3. The CrystalBuyer Agent looks for a cooperation partner.

Step 4. As soon as the potential seller becomes known, the CrystalBuyer Agent will negotiate with the CrystalSeller Agent directly and find the most suitable one for its own interests: negotiates about the price, quantity and delivery time of the crystals.

The CrystalBuyer agent starts negotiation by sending a Call for proposals (CFP) message to other agent. After several rounds of conversation in which proposals and counter-proposals are exchanged, negotiation between two agents will end when one side accepts or rejects the other side's proposal.

2) a request is received from MicrochipBuyer Agent to buy microchips from MicrochipSeller Agent.

In this case, the MicrochipBuyer Agent negotiates with the MicrochipSeller Agent about the price, quantity and delivery time of microchips to buyer.

Communication of agents from different supply chain nodes is postponed until the next request.

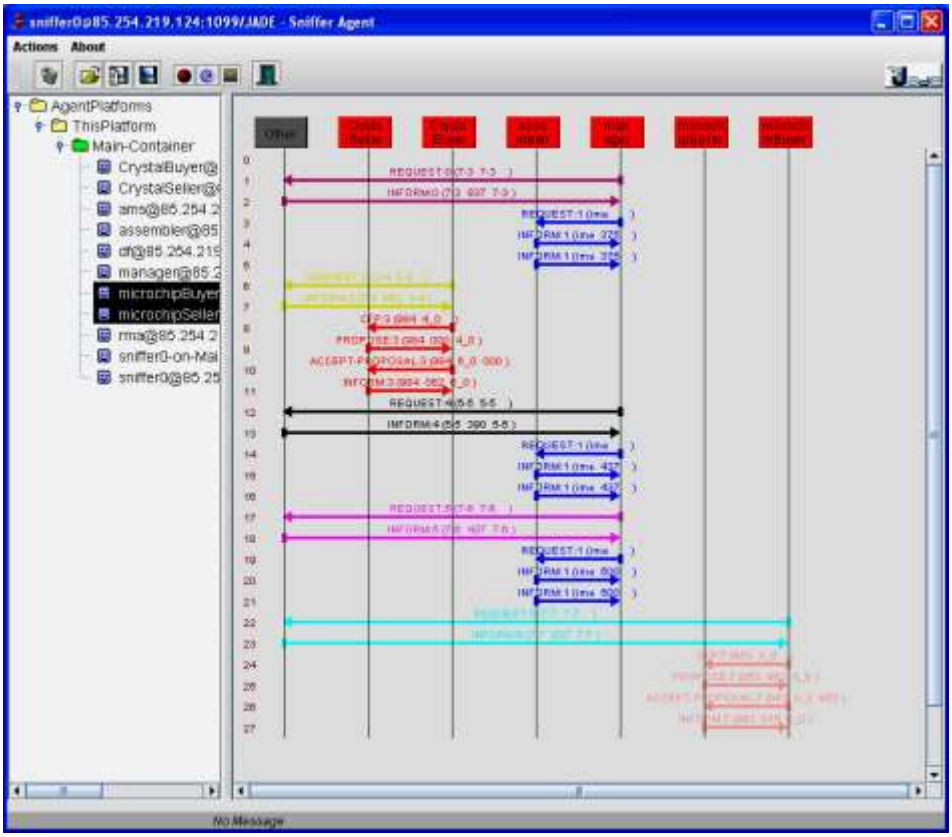

Fig. 5. Screenshot of JADE, negotiation of agents

Figure 5 shows that manufacturer node agents work and cooperate all the time, in case of crystal deficiency the negotiation of supplier and manufacturer nodes occurs. When microchip retailer orders microchips from manufacturer's seller agent, the negotiation between manufacturer and retailer nodes occurs.

VI. Results

The multi-agent system was constructed using the above mentioned architecture and agent structure. The implementation of multi-agent system is realized in JADE platform, using FIPA negotiation protocols. The agents use ACL messages for the negotiation between them, where ontology is considered as knowledge and information interpreter of these messages. The results show that multi-agent system application is suitable for this domain area, where there are different organizations (nodes) with different goals, and agents have to negotiate to achieve their own goals.

VII. Future Research

The negotiation between agents in one supply chain node, as well as in different supply chain nodes is shown in this paper. The idea of applying the possibility of using the auction is taken for the future research. The possibility of searching the best price is considered as appropriate.

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Darja Plinere, Arkādijs Borisovs. Pārrunās bāzētā daudzaģentu sistēma piegādes ķēdes vadībai
Piegādes ķēde ir viens no galvenajiem jēdzieniem loģistikā. Piegādes ķēde - loģistikas sistēmas mezglu kopa, kas ir lineāri sakārtota pēc materiāla, informācijas vai finanšu plūsmas ar specifisku loģistikas funkciju un (vai) izmaksu analīzes vai sintēzes nolūku. Daudzaģentu sistēmas ir piemērotas jomās, kas ietver sevī mijiedarbību starp dažādiem cilvēkiem vai organizācijām, ar dažādiem (iespējams, pretrunīgiem) mērķiem un pieejamo informāciju. Daudzaģentu sistēma uzskata piegādes ķēdi par intelektuālu aģentu kolektīvu, kur katrs no aģentiem ir atbildīgs par vienu vai vairākām darbībām piegādes ķēdē. Savukārt ontoloģija, kas apraksta priekšmeta apgabalu, ir mehānisms, lai palīdzētu saprast un analizēt informācijas plūsmu starp aģentiem. Ontoloģijas izmantošana daudzaģentu sistēmās sniedz šādas priekšrocības: tā ļauj strukturēt zināšanas, kopīgi pielietot tās, palielina aģentu sistēmas uzticamību, kā arī nodrošina pamatu mijiedarbībai starp aģentiem. Šajā publikācijā tiek piedāvāta daudzaģentu sistēmas pielietošanas metode saziņai starp dažādiem mezgliem piegādes ķēdē, un parāda mijiedarbību starp aģentiem vienā no piegādes ķēdes mezgliem - ražošanas mezglā. Piegādes ķēdes konstruēšanai tika izmantota sekojoša infrastruktūra: Java un JADE – platforma, kurā aģenti eksistē un mijiedarbojas, tā piedāvā aģentiem bāzes servisus, kas nepieciešami aģentu eksistēšanai, Protégé un Ontology Bean Generator - priekšmeta apgabala ontoloģijas izveidošanai un to pārveidošanai JADE klasēs, MySQL - datu bāzes atbalstīšanai, Apache Ant - programmas koda kompilēšanai, NetBeans IDE – kā integrētā izstrādes vide, ACL ziņojumi informācijas pārraidei, zināšanu koplietošanai un mijiedarbībai starp aģentiem, izmantojot FIPA protokolus.

Дарья Плинер, Аркадий Борисов. Основанная на переговорах многоагентная система для управления цепями поставок
Цепь поставок является одним из ключевых понятий логистики. Цепь поставок - множество звеньев логистической системы, линейно упорядоченное по материальному, информационному или финансовому потоку с целью анализа или синтеза определенного набора логистических функций и (или) затрат. Многоагентные системы являются подходящими для областей, которые включают взаимодействия между различными людьми или организациями с разными (возможно, противоречивыми) целями и имеющейся информацией. Многоагентная система рассматривает цепь поставок как коллектив интеллектуальных агентов, где каждый из агентов отвечает за одно или несколько действий цепи поставок. В свою очередь, онтология, описывая предметную область, представляет собой механизм помощи в понимании и анализе информационного потока между агентами. Использование онтологии для многоагентных систем предоставляет следующие преимущества: онтология позволяет структурировать знания, совместно их использовать, увеличивает надежность агентной системы и обеспечивает основу для взаимодействия между агентами. В этой публикации предложен метод применения многоагентной системы для взаимодействия между различными звеньями цепи поставок, а также показано взаимодействие агентов внутри одного из звеньев цепи поставок – в звене производства. Для построения цепи поставок была использована следующая инфраструктура: Java и JADE – платформа, в которой существуют и взаимодействуют агенты, она предоставляет агентам базовые сервисы, необходимые для их существования, Protégé и Ontology Bean Generator для создания онтологии предметной области и ее преобразования в JADE классы, MySQL для поддержки базы данных, Apache Ant для компиляции программного кода, NetBeans IDE в качестве интегрированной среды разработки, ACL сообщения для передачи информации, совместного использования знаний и взаимодействия между агентами, используя протоколы FIPA.