AGENT-BASED OPTIMISATION OF LOGISTICS AND PRODUCTION PLANNING

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Abstract: Manufacturing and logistics service provision enterprises are now moving towards open architectures for integrating their activities with those of their suppliers, customers and partners within wide supply chain networks. Agent-based technology provides a natural way to design and implement such environments.
This paper presents an agent-based approach for optimising logistics and production planning whilst taking into account availability and cost of logistic providers. Emphasis is given on efficient negotiation mechanisms based on extended contracting protocol. The agent infrastructure is being developed within the context of Agentcities, a successful EU funded agent system interoperation initiative.
The proposed approach is demonstrated in a case study concerning optimisation of production planning of a virtual manufacturing enterprise in relation to sub-contracted logistic services used to transport the materials between the enterprise units.

Keywords: Agents, Enterprise Integration, Manufacturing Systems

1. INTRODUCTION

1.1 Background and Motivation

Manufacturing and logistic service provision enterprises are trying to organise and optimise their existing supply chains, using software that supports negotiations at different levels of automation. E-marketplaces are examples of such software. In contrast to these centrally organised software solutions, systems using the agent paradigm are build to reflect the distributed and autonomous nature of real enterprises and thus provide a natural way to design and implement such environments.

An emerging view of manufacturing enterprises is based on the holonic paradigm (Vancza and Markus, 1998). The idea of holonic business is based on the collaboration of autonomous and cooperative business agents (*holonic agents* or *holons*). A holonic agent is an agent is composed of sub-agents acting as a whole. A (dynamic) business network can be seen as a temporarily existing holon where the sub-holons are the necessary service providers (business partners) within the network. The holonic relationships can be extended to many levels inside an enterprise, creating heterarchies of holons known as *holarchies* (Koestler, 1967).

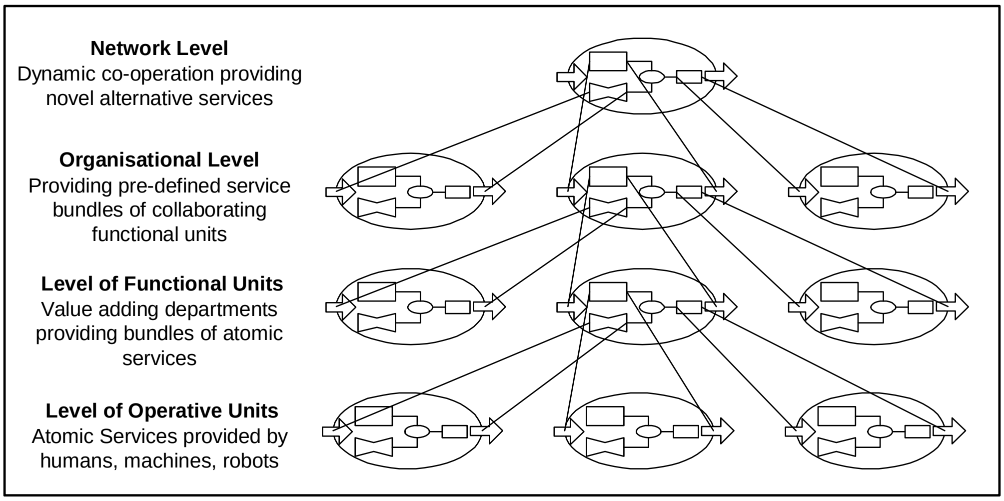

Fig. 1. Enterprise Holarchy

Providing an agent-based infrastructure where holonic agents will be able to interoperate is currently an open issue (Gou, et al., 1998). Major obstacles towards this goal are the lack of standardised technologies that would enable (possibly heterogeneous) agents corresponding to different enterprises to advertise their services, locate each other and interact in a dynamic manner using commonly shared domain knowledge.

A successful agent-based systems interoperation initiative is *Agentcities* (Willmott, et al., 2001). The Agentcities initiative works towards the vision of an ambient proactive environment where heterogeneous, autonomous and increasingly intelligent systems, which represent businesses, services and individuals, are able to interact with each other and enable flexible and dynamic composition of services. In the first year of its operation, the Agentcities initiative has resulted in an experimental open infrastructure providing “white-” and “yellow pages” information concerning available agent platform locations and agent service types.

The main goal of the project described in this paper is to develop an agent-based approach for optimised intelligent logistics and production planning, which would allow dynamic interaction of holonic business agents. The view was that this infrastructure should be exploiting the progress made in the Agentcities initiative in terms of agent interoperation. The design of the infrastructure is based on the holonic paradigm.

The primary objective of the project is to develop a demonstrator and evaluate the proposed infrastructure using a number of scenarios drawn from a case study. The case study discussed in this paper concerns a virtual enterprise including a number of manufacturing units, requesting external logistics services. The term virtual enterprise refers to a temporary alliance of enterprises that come together to share skills or core competencies and resources in order to better respond to business opportunities, and whose cooperation is supported by computer networks (Goletz and Ferreira, 2000). Similarly to other industrial sectors, a distributed network of manufacturing and logistic service providers organizations can be modelled as a VE.

The virtual enterprise receives orders from a wholesale distributor. The planning of the production batches will depend on the orders, the abilities and workload of manufacturing units and on the availability and pricing of logistic services to move the products between the two units and to the wholesale distributor. Logistic service providers will in turn be selected depending on the dynamic transport requirements arising from the production plan.

The rest of this paper is organized as follows: An intelligent production and logistics planning scenario is described in Section 1.2. The system architecture is described in Section 2. Furthermore, the extended contracting protocol used for production and logistics planning optimisation is described in Section 3. Section 4 discusses the advantages of the proposed approach in comparison with relevant work and Section 5 concludes the paper.

1.2 The Scenario

In our case study we regard several static Virtual Enterprises (VE) consisting of two Manufacturing Facilities (MF). The geographical distribution of the

VE is reflected in the Agentcities demonstrator, where one MF will run on an Agentcities node in Manchester, the other MF will run in Steyr. Each MF is part of several VEs. The services provided by the MF are the following:

- MF1 is able to manufacture the basic products MUN and TSCHA,
- MF2 is able to manufacture the basic products MAN and TSCHA.

Basic products may be combined to form more complex products. A wholesaler requesting products from the VE therefore has the choice between:

- MUN
- MAN
- TSCHA
- MUNTSCHA
- MANTSCHA
- MUNTSCHA-MANTSCHA.

There are constraints when producing MUNTSCHA and MANTSCHA which require MUN (MAN) to be produced first, and TSCHA be then applied. In case of MUNTSCHA-MANTSCHA both subparts can be produced in parallel, and get assembled at either facility.

2. SYSTEM ARCHITECTURE

Agent technology has been considered as an important approach for developing industrial distributed systems (Fox, et al., 2000). A number of researchers have attempted to apply agent technology to manufacturing enterprise integration, supply chain management, manufacturing scheduling and control, material handling, logistics service provision and holonic manufacturing systems, e.g. (Bürckert, et al., 1998; Bussmann, 1998; Camarinha-Matos and Afsarmanesh, 2001; Fischer, et al., 1998; Goletz and Ferreira, 2000; Gou, et al., 1998; Ulieru, et al., 2001). In this section, we motivate our holonic approach to integrated logistics and production planning across companies and outline the resulting system architecture.

1.3 A holonic approach

When planning, we also work with a holonic view of business networks. A (dynamic) business network can be seen as a temporarily existing holon, where the sub-holons are the necessary service providers (business partners) within the network. A holonic agent (holon) is an agent which is composed of sub-agents acting in a corporate way (Bürckert, et al., 1998). The holonic picture can be extended to lower levels inside an enterprise, giving rise to the notion of an “enterprise holarchy”, for example a recursively structured agent society naturally reflecting the nested service structure, (Fig. 1). Each level decomposes services into sub-services. The holonic architecture reflects the mapping between (sub)-services and (sub)-holons.

The network level in Fig. 1 focuses on bringing independent organisations together and on forming dynamic virtual enterprises. At the organisation level, the units that form that holon, are interconnected in a rather static way. These units could be departments of an organisation or organisations, forming what we consider as static virtual enterprise. At the level of functional units the focus is on completing a concrete task or function. The lowest level is representing the machines or humans that do the actual work.

The Application developed in this project focuses on the Organisation layer integrating the functional and operative levels. We have in mind that this application could be extended to allow the dynamic formation of temporary virtual enterprises. The constraints of this project, however, require us to consider virtual enterprise formation as a totally separate activity preceding the planning stage. Mixing these two activities into a three-way optimisation will be a subject of further research work outside of the scope of this project.

1.4 The case study – implementing a holonic architecture

Resource agents represent the active system components in the Virtual Enterprise scenario. The top-level resource agent is the Virtual Enterprise itself. It is responsible for managing incoming customer requests, decomposing manufacturing and logistics tasks based on product specific process plans, allocating tasks to lower level resources (manufacturing facilities and logistics providers) and placing offers to customers.

Manufacturing facilities and (optionally) logistics providers are resources inside a Virtual Enterprise. They are responsible for further decomposing tasks and for local planning and scheduling of manufacturing and logistics tasks by allocating tasks to machines (or trucks).

Machines are resources inside manufacturing facilities actually processing the work-pieces. They manage their internal production plans and interact

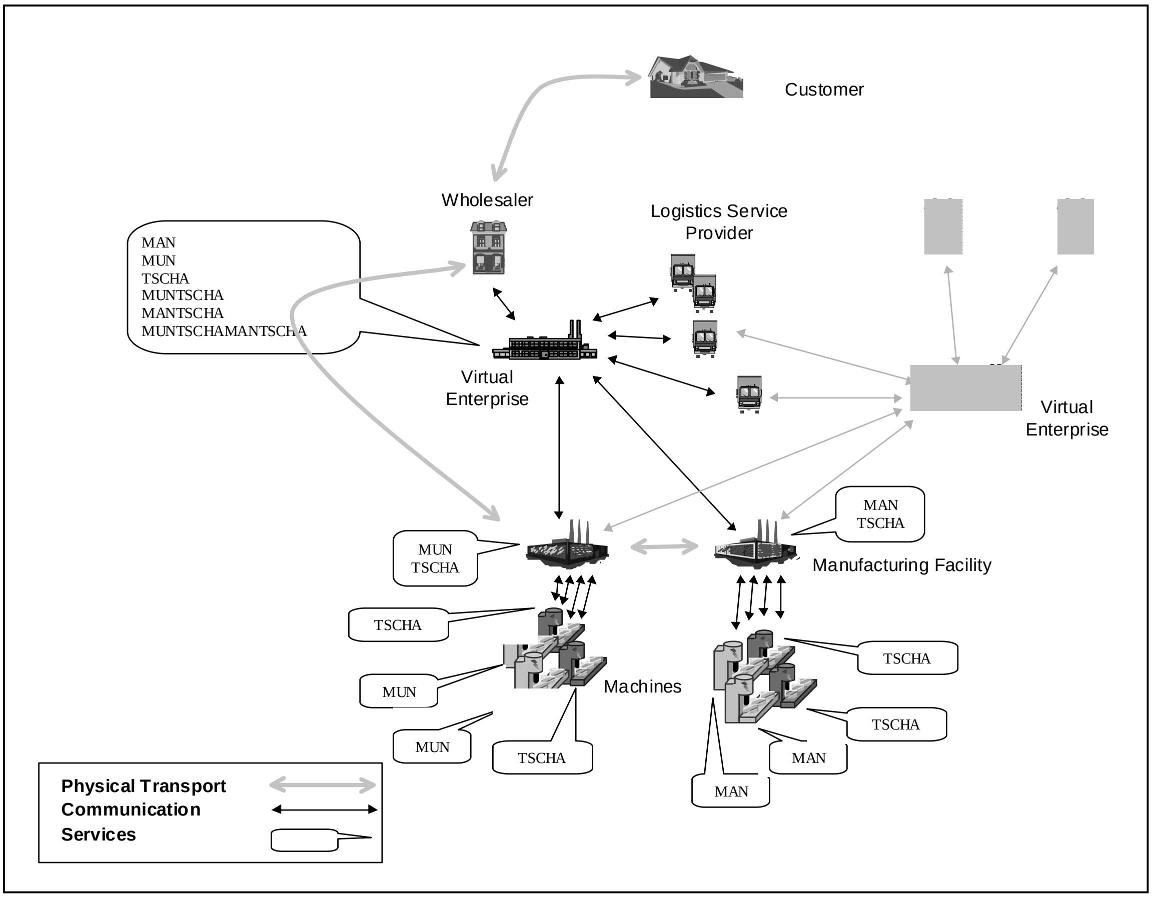

Fig. 2. Case study system architecture

with the manufacturing facility to generate global production plans.

The resource agents build up a recursively structured agent society, implementing the holonic approach presented above. The described structure is based on the case study and illustrated in Fig. 2. In other scenarios, additional resource level types may be involved, for example (production) departments and work cells.

2. NEGOTIATION-BASED PLANNING

This project is along the lines of our general effort to provide a software infrastructure that would enable integration of manufacturing virtual enterprise's activities such as design, planning, scheduling, simulation and execution, with those of its suppliers, customers and partners into a distributed intelligent open environment. The main innovations of the proposed agent-based infrastructure include introducing mechanisms for optimising production planning by extended contracting protocols.

2.1 Nested Contract Net Protocol

The Contract Net is a negotiation protocol proposed by Smith (Smith, 1980), which facilitates distributing subtasks among various agents. The agent wanting to solve the problem broadcasts a call for bids, waits for a reply for some length of time, and then awards a contract to the best offer(s) according to its selection criteria. This protocol has been widely used for multi-agent negotiation. Some researchers have proposed modified versions of Contract Net protocol for special applications, such as the Extended Contract Net Protocol (ECNP) proposed by Fischer et al (Fischer, et al., 1995). The recursive nature of the holonic architecture allows us to define a recursive or "Nested" Contract Net protocol:

A Query from the customer, which is outside our system, arrives at the Wholesaler. The Wholesaler uses the Directory Facilitator provided by the FIPA compatible platform to find all Virtual Enterprises able to provide the appropriate services. Subsequently, he sends them a Call For Proposals (CFP).

Each Virtual Enterprise splits the request into basic products. This separation of the task into subtasks reduces computational complexity. The Manufacturing Facilities are allowed to strive for an optimal solution of the subtask. The Virtual Enterprises later on just combines the proposed solutions of subtasks. On the one hand this limits the number of possibilities that have to be evaluated, on the other hand this does in most cases not result in a global optimum. The Virtual Enterprise also considers time and precedence.

Manufacturing Facilities, which are part of the Virtual Enterprise, receive one or more CFPs for producing basic products. Here the CFP is forwarded to the Machines, where the local machine-usage plan is checked and a Propose message is returned. The information returned with the message includes the earliest start time, the estimated finish time, and the costs.

The Manufacturing Facility now chooses the proposals to combine them in a way to have a optimum solution of the subtask requested by the Virtual Enterprise, and proposes this to the Virtual Enterprise. The proposals that are not amongst the chosen ones are rejected right after a solution is chosen. This is a slight change of the original Contract Net Protocol, which is rather a technical optimisation in terms of freeing system resources, than a semantic modification.

2.2 Using the Nested CNP for planning optimisation

The VE in turn calls the logistic service providers for proposals on the transport between the facilities and to the wholesaler. If one facility is able to produce the whole desired product, then of course only transport from the facility to the wholesaler is necessary. When the Virtual Enterprises receive the proposals from the logistic service providers, it combines the subtasks. This is proposed to the wholesaler, which accepts or rejects the proposal.

The decision gets propagated down to the machines. If it was an accept message, the machines after having finished inform the Manufacturing Facilities which after having received all messages, in turn inform the Virtual Enterprise, which again wait for all sub-holons to finish and then informs the wholesaler upon completion. In case of an error, a failure message is propagated.

3. PROTOTYPE IMPLEMENTATION

We have used JADE as a development platform, and will endeavour to create a generic library that enhances JADE with services and components for building holonic supply chain management systems. The Holonic architecture allows us to start with the enterprise level, dealing with a fixed set of parties forming a static Virtual Enterprise. We will develop it so that later on it could be extended both outwards to the dynamic Network level, where Holons are dynamically formed, and inwards to the level of functional units.

The selection of JADE was done primarily because a considerable amount of ready-to-use infrastructure components is built in. The application programmer basically concentrates on customized interaction protocols and ontologies.

We will also develop a bridge from FIPA to Web Services to link our agent-based holonic system with a simulated e-marketplace of logistics services. The system will seek logistics services and obtain simulated results regarding their availability and pricing, thus demonstrating integrated supply chain management using heterogeneous technologies.

4. DISCUSSION – RELEVANT WORK

Examples of relevant approaches include the Teletruck logistics planning and Holonic Manufacturing Systems.

DFKI have developed a prototypic software system TeleTruck (Bürckert, et al., 1998) for planning, optimising, and monitoring of road haulage. The underlying approach is based on multi–agent technology, where physical objects of the transport domain (trucks together with their drivers, trailers, and load spaces) are modelled by active software processes (intelligent agents). Those agents are able to reason and plan on the basis of their individual resources and means provided by the corresponding physical objects. They are embedded in a common environment (a multi–agent system) — potentially distributed in a network of several computers which could be located at different transport departments — reflecting the communication and other interaction structure of the agents. The major difference between TeleTruck and our approach is that TeleTruck only focuses on logistics planning and does not consider manufacturing co-scheduling.

Agent technology is also used in the holonic manufacturing systems (HMS) approach (Gou, et al., 1998) which view manufacturing systems from a holonic perspective. In this type of systems, intelligent agents called 'holons' have a physical part as well as a software part. This type of architecture allows integration of appropriate elements of hierarchical and heterarchical systems into an intelligent and open structure. The problem with Holonic Manufacturing Systems is that they do not consider planning of the transportation scheduling between units.

In our approach, we address both issues in the aim of demonstrating advantages of agents into co-optimisation of production and logistics planning.

5. SUMMARY – CONCLUSIONS

This paper has presented a simple but efficient manufacturing and logistics service planning integration infrastructure using agent-technology. The enabling mechanism for realising agent-interoperation was the Agentcities agent-platform interoperation infrastructure.

Based on our previous research work, we are now working towards integrating the manufacturing enterprise's activities with those of its suppliers, customers and partners through an open, distributed integrated intelligent manufacturing environment. Therefore, this work could be extended in the following ways:

- Dynamic formation of the virtual enterprise, demonstrating the open nature of agent systems.

- Re-planning when plan is broken, using constraints and information provided in formally defined contracts and service level agreements.

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