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ExPlanTech and ExtraPlant: multi-agent technology for production planning, simulation and extra-enterprise collaboration

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This paper presents a unified multi-agent technology for decision-making support in production planning and scheduling, manufacturing simulation and collaboration among enterprises. We distinguish intra-enterprise and extra-enterprise levels of production planning problem. Two technologies covering both levels have been developed, ExPlanTech for intra-enterprise level and ExtraPlanT for extra-enterprise level. Developed technology implementing prototypes can be used separately, be connected to other systems or together to maximize utility. The technology has been tested on industrial cases.

Keywords: multi-agent technology, production planning, decision making support, ExPlanTech, ExtraPlanT

1. INTRODUCTION

Not only highly flexible production processes require the proper production planning to ensure high effectiveness. But especially the high flexibility makes the production planning and acquisition of relevant data completely complicated. The need of on-line join to supply chain multiplies the planning problem in consequence of tasks processed for the partners, tasks that may be processed by partners, and partners' plans actualizations.

The fast and precise cooperation with the suppliers can shorten the production lead-time and it also can increase utilization of the factory. From the planning perspective it is irrelevant whether the system reasons about in house manufacturing workshop or about a subcontracting company. There is strong demand for universal and flexible technology for the production planning that is able to increase utilization of resources and supports a decision making in a selection of orders. The flexibility of the technology should allow to adapt the system to changes in the production structure, and to allow collaboration with partners. The system should consider differences between intra-enterprise collaboration, which can be seen altruistic from the general view of the planning tool, and the extra-enterprise cooperation, which is between self-interested individuals (without any central point having their internal knowledge). The system also should use a universal description of resources, including product design and development, production, stores and transport. The system has to be able to support not only internal production processes and integration of external business processes, but also universal secure access to the data.

We focus the production planning support technology having a need of following elements:

- **Existing software integration** – the already existing software solutions, which can be still exploited, can be integrated into new system.

- **Complex data representation, collection and maintenance** – the production data and its flow are complex process. There is strong demand to collect, store and use existing data in the most suitable way,
- **Extra-enterprise access** – the need of access the production data anytime from anywhere is required.
- **Supply-chain integration** – not only access, but also integration of the outside processes is needed. Linking the suppliers, customers and other collaborators is very crucial problem.
- **Security** – all the parts of the system have to use the appropriate security politics. The factory business data are very important and have to be properly secured.
- **Visualization** – complex data and production processes generates the need of centralized view. This view has to be adjustable to the user and have to be accessible from the place, where the user needs to see the information.
- **Emulation and simulation** – not just planning problem is solved in the complex production. The simulation of the processes helps to find better configuration of the production, and recognize and analyze the possible problems.

The needs of the nowadays enterprises cannot be covered by conventional solutions anymore. New technologies that deal with all the requests described above have to be adapted. In this text we present the ExPlanTech and ExtraPlanT multi-agent technologies for supporting the production processes. They are developed to offer the solution for the requirements of the present and future days. They can be used separately or together. The former one applies in intra-enterprise planning and the latter one in extra-enterprise cooperation. We understand the intra-enterprise level as inside the enterprise (in the means of resources and secure infrastructure) and extra-enterprise level outside of the enterprise.

1.1 Multi-agent technology

Agent technologies and the concept of multi-agent systems is coming from the field of artificial intelligence and computer science, using principles of component-based software engineering, distributed decision making, parallel and distributed computing, autonomous computing, advanced methods of interoperability and software integration. Operation of an agent-based system is based on interactions of autonomous, optionally self-interested, and loosely coupled software or hardware entities – agents. The processes, which are characterized by natural decomposition or possible computation distribution, can be solved by multi-agent systems very well [1]. Moreover, the multi-agent system offers superb run-time integration capacity and dynamic reconfiguration, and autonomous delegation abilities. They are robust and provide easy integration of humans, existing software and hardware.

Agents technologies are suitable for domains that posses either of the following properties:

- highly complex problems need to be solved or highly complex systems to be controlled,
- the information required for solving problems or controlling systems is distributed and is not available centrally,
- in domains with dynamically changing environment and problem specification,
- high number of heterogeneous software (and possibly hardware) systems needs to be integrated in an open and heterogeneous way, or
- the cooperation of independent units (e.g. in virtual organization) is coordinated.

There are several typical application areas of the agent technologies that relate to manufacturing [2]. In production we need highly complex planning problems to be solved, we need to control dynamic, unpredictable and unstable processes. In production there is also a potential for agent-based diagnostics, repair, reconfiguration and replanning. In the domain of virtual organizations [3] and supply chain management there are requirements for forming business alliances, planning long-term/short-term cooperation deals, and managing (including reconfiguration and dissolving) supply chains. Here we also can use various agent technologies for agents' private knowledge maintenance, specification of various ontologies and ensuring service interoperability across the supply chain. In the domain of internet-base business agent technologies can be used for intelligent shopping and auctioning [4], information retrieval and searching, remote access to information and remote system control. Another important application domain is logistics. Multi-agent systems can be used for managing transportation and material handling, optimal planning and scheduling, especially in cargo transportation, public transport but also peace-keeping missions, military maneuvers, etc. There is a nice match of the agent technologies and managing of the utility networks such as energy distribution networks, mobile operators networks, cable provider networks. Here the concept of distributed autonomous computation can be used for simulation and predication of alarm situations, prevention to blackout and overload and intrusion detection.

1.2 Multi-agent planning systems

For the production support the agentification process can be successfully used for an integration of the software and hardware equipment already existing in the enterprise. These existing facilities can be extended by newly designed agents for planning, data-management and visualization. For physically distributed production units, it's advantageous to decompose and distribute the planning problem [5,6]. System can utilise some algoritm for distributed planning and replanning (for example, Partial Global Planning [7]). Agents usually form local plans, optimize them loccaly and later merge them (e.g. by negotiation and voting).

Another advantage of agent-based approach is its ability to process relevant production data, distributed across the entire enterprise or supply chain. The classical approach when data are collected and processed centrally is difficult especially when data are voluminous and changes frequently. Distributed approach allows proactive data processing at the place of their origin and to exchange only necessary results. The agent-based technology certainly does not provide an uncomplicated solution of NP-hard planning problems. However the concept allows integration of heavy-duty AI problem solver (such as constrain satisfaction systems, linear programming tools, genetic algorithms, etc.) by its agentification into a specialized agent.

Multi-agent solutions exist for low-level scheduling or control systems as well as product-configuration and quotation phases. It can be used for short- and long-term production planning and supply chain management [8,9].

Three main domains exist for applying of multi-agent systems in the production support:

- intra-enterprise production planning,
- extra-enterprise production planning, and
- production simulation.

Individual research efforts often works with a combination of these domains.

Multi-agent systems on intra-enterprise level and extra-enterprise level are independent in the communities' point of view. Agents used on intra-enterprise level are operating inside an enterprise and represents various units or processes in the company. On extra-enterprise level, whole company is represented by a single agent, providing all abilities and services, available in the company. If agents on both levels are used, a special agent can exists that bind both levels together. For research purposes, both levels can be modeled together to study and improve their abilities

Multi agent systems can be used also for a simulation and modeling of the production process or the supply chain, where they easily simulate an independence of involved parts. These tools can help to answer non-trivial tasks – how various changes in single component will affect the production process or supply chain as a whole.

An example of production control and scheduling technology combining intra-enterprise and extra-enterprise levels is AARIA [10]. In AARIA each agent interoperates with other agents in and outside its own factory. AARIA uses a mixture of heuristic scheduling techniques: forward and backward, simulation, and intelligent scheduling. AARIA also adopted the classical contract-net bidding technology. Another system – PAMAS [11] covers the process from production to transportation. It integrates information from partners as needed. This system is based on a FIPA compliant FIPA-OS platform.

Another example of incorporation of various domains is the RealAgentS (Realistic Agent Application Scenarios) [12] research initiative. RealAgentS incorporates several research sub-groups. One of them is Agent.Enterprise [13] consisting of five multi-agent systems from the manufacturing logistics domain.

DISPOWEB [14] aims SCM scheduling, shop floor production planning and control is a domain of KRASH [15] (assembling industries), FABMAS [16] (batch production) and IntaPS [17] (discrete manufacturing). IntaPS is also important for agent architecture based on BDI and the electronic marketplaces where the agents negotiate about their tasks. Agent.Enterprise projects ATT/SCC [15] work in proactive tracking and tracing services.

Distributed intra-enterprise production control is a traditional domain of holonic systems [18,19]. The role of multi-agent systems and holons in manufacturing was previously studied e.g. by the IMS (Intelligent Manufacturing Systems) consortium [20]. The reference planning and scheduling architecture for holonic manufacturing control is PROSA (products-resource-order-staff architecture) [21], which defines three main classes of holons and agents: product, resource, and order.

MetaMorph [22] is a research prototype of generic multi-agent architecture for intra-enterprise production control. PROSA and MetaMorph also support simulation.

Some of intra-enterprise systems generates dedicated agents that accompany on concrete product with respect to its production plan during whole its product-life spent in the enterprise. The agent is void at the moment of the product release. Examples of such system are PABADiS [23] and the Cambridge Holonic Packing Cell [24]. This agent navigates and processes itself within the community with respect to its production plan.

Based on PROSA architecture, FABMAS [16] is a system aiming production control of the wafer fabrication process. The specifics of integrated circuits on silicon wafers manufacturing are high number of process steps, lot of different types of machines, and batch processes. FABMAS uses a hierarchical multi-layer approach and agent runtime environment inspired by the FIPA Abstract Architecture.

Dynamic supply chain creation and extra-enterprise coordination systems usually do not affect the intra-enterprise level. Example of such system is MASCOT [9] that solves the problem of dynamic reconfiguration and supply-chain creation and adequately covers demands on integration and enterprise cooperation.

2. EXPLANTECH TECHNOLOGY

The ExPlanTech technology is designed for the purposes of intra-enterprise production planning in the project oriented manufacturing environment. It focuses mainly on resource management and possible delivery times and costs estimation. ExPlanTech technology is based on a community of planning agents, resource agents and supporting agents that describes one enterprise and has no ability to interact with other systems outside the enterprise. The plan is created as a result of negotiation among agents that are able to contribute to the task. Each task is de-composed into several parts and each part is in responsibility of one agent. This agent maintains the plan for its part. To see the whole plan, local plans of all involved agents must be collected and combined.

ExPlanTech is an outcome of the series of European Union RTD and Trial projects in the area of agent-based production planning [25]. ExPlanTech extends on the original ProPlanT [26] technology, and consists of several components, which can be combined in order to develop a custom-tailored decision support system. For proving technology abilities several prototypes were employed.

From the user perspective the prototypes is supposed to provide the support for sizing the resources and time requirements for a particular order, creating the production plans, optimizing manipulation with material resources and visualizing and analyzing the manufacturing process. Prototype is intended to be used for planning in middle and long terms.

ExPlanTech supporting agents provide means for an integration of existing software, for a complex data representation, data-collection, maintenance and visualization. ExPlanTech does not feature any components for control and real-time diagnostics at the moment, but it can process production feedback (e.g. real progress of planned activities or changes in the capacities of resources). ExPlanTech contains simulation environment, which can be used for verification

of the plans or for modeling and simulation of the production process.

2.1 ExPlanTech technology architecture

ExPlanTech technology architecture is shown on Figure 1. Each logically separable unit like workshop is represented by one agent, which has collected description of all services, capacities and occupancy of represented unit. The heart of the ExPlanTech is set of planning agents using various case-specific approaches (decomposition based planners or heavy duty planners) and set of resource agents. Supporting agents like Cockpit agent and meta-agent complete the set of ExPlanTech technology. The following part describes roles of individual agents.

2.1.1 Planning Agent

The core of the any ExPlanTech based system is usually a community of planning agents. These agents are in charge of making production plans for individual orders, taking care of conflicts and managing re-planning and plan reconfiguration. For different types of production, different planning engines are available or can be developed:

- **Linear planning:** This approach fits for planning problems with limited computation requirements, caused by limited plan variability, or restrictive external constrains (e.g. predefined priorities or ordering). Single planning agent has been developed, that uses forward chaining or backward chaining linear planning (see LPA – Linear Planning Agent on Figure 1).
- **Mathematical programming:** For cases with an explosive variability of possible plan configurations, engines based on the linear programming method, constrain-satisfaction or genetic-algorithm can be extremely efficient. These engines are however very domain specific and often need to be re-developed in case of new formulation of planning problem. Within ExtraPlanT prototypes, a linear programming engine has been developed and possibilities of genetic-algorithm engine have been analyzed. (see CLP – *Constrain Logic Programming agent* and GAA – Genetic Algorithm Agent on Figure 1).
- **Distributed planning:** Some complex problems, like those employing a multi-criteria optimization, can be solved by distributed planning. The plan is created collectively by a community of simple planning agents that use a sophisticated auction-based negotiation, supported by use of the social knowledge and acquaintance models (see PPA - *Production Planning Agent* and PMA – *Production Managing Agent* on Figure 1).

2.1.2 Resource Agents

Typically, there are many resource agents running that carry out data gathering and specific data pre-processing and that directly interact with the planning agents (see PA – *Production Agent* on Figure 1). We provide two types of agents for an integration or representation of various resources. ExPlanTech features (i) agents that integrate/simulate a specific machine, workshop or department (e.g. CNC machine, CAD department), and (ii) agents that integrate a factory software system (e.g. an implemented bridge to MRP system that administers material resources handling in the factory). The main advantage of such an agent is close binding to the resource so the response to the problems and real-time changes can be very fast and solution can be directly applied.

2.1.3 Cockpit Agents

There may be several different users interacting with the planning agents at the same time. In order to allow such an access and to control possible conflicts, we have designed a specific agent – a Cockpit Agent (see Figure 1). The Cockpit Agent presents the user in a user friendly way with the state of production processes, plans, loads of given resources etc. Cockpit Agent also provides a possibility to interact with the system, and according to access rights change the plans and parameters of the resources.

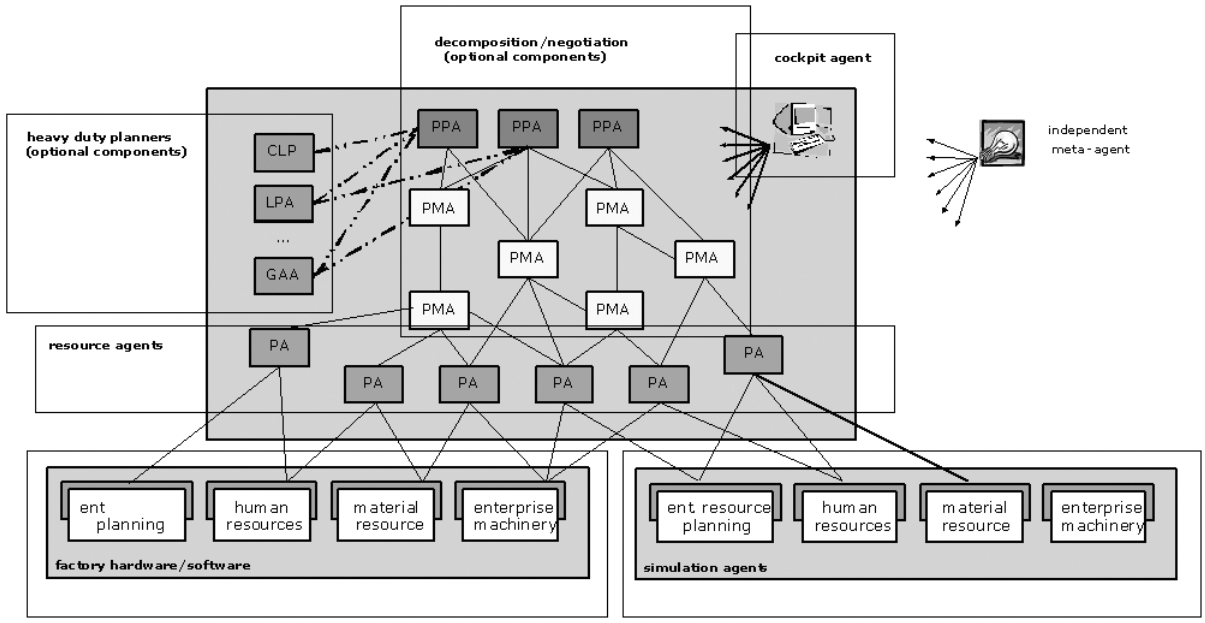

Figure 1 ExPlanTech Intra-Enterprise architecture

2.1.4 Simulation Agent (ExPlanTech Real-Time Planning Simulation)

For the purpose of simulation and modeling of the production process and evaluation of plans, it is possible to simulate the behavior of the real production. The Simulation Agent (see Figure 1) represents an interface between the planning system and a community of agents emulating the real machines or human resources. These agents can model various properties of simulated resources such as production times or failure rates. They follow production schedule simulating a realistic production process. Consequently they provide a feedback to the planning system by means of the Simulation Agent, announcing to the planner the actual time spent on the plan realization. If the actual time differs from the plan, the planner initiates a re-planning. Simulation runs in user defined time scale, so it can be faster or slower then a real production.

The agent-based architecture of the simulation offers the modularity of the whole model, so it is possible to replace each Simulation Agent by an agent with different parameters or by an agent bound to the real resources. On the other hand it is possible to provide the one emulation with two different schedulers.

2.1.5 Meta Agent

Meta Agent is an independent agent, designed to monitor the information flow among the agents and suggest possible operation improvements. Meta Agent can for example recognize workflow bottlenecks, inefficient parts or unused components in the production process. To fulfill given tasks, agent can use sophisticated methods of meta-reasoning as well as measuring and evaluation of the production plans. Obtained results can be presented to the user in the form of tables or charts.

2.2 On implementation

The ExPlanTech technology prototype is implemented using the FIPA [27] compliant JADE [28] multi-agent development environment. This decision affects many features of the system and implicates many assets of the ExPlanTech technology. Brief discussion of some examples of these assets follows.

JADE platform and thus whole ExPlanTech is implemented in JAVA2 language, which offers a platform independence and openness. Agents can run on each supported platform (MS Windows, Windows CE, LINUX, even PLC) and cooperate without care of low level platform specific problems. The same implementation of the agent can be used on different platform.

The first advantage of the JADE is not directly visible to the end user, although it influences whole the system – JADE development environment is easy to use and allows rapid development of sophisticated and reliable MAS. Predefined agent core with already implemented control and message transport protocols frees the author of MAS from low-level programming and resource management. The designer is allowed to focus on high level functions and can easily build user targeted application.

The second highly important advantage is that an application build on JADE platform complies with FIPA interoperability standards for implementing of independent software agents. This feature facilitates an easy integration of new and third party agents as well as use of independent meta-agents for the communication evaluation and optimization.

In comparison with other FIPA compliant agent platforms (e.g. FIPA-OS, ZEUS…), JADE is efficient, flexible and with good system support [29]. Also the fact, that JADE is popular and widely used, supports the possibility of ExPlanTech extension by external or third party agents.

JADE also offers two models of addressing – intra-platform and inter-platform. When the intra-platform addressing is used, the agent is identified by its unique name and the AMS (Agent Management System) agent is responsible for finding of the and for delivering of the message using JAVA RMI technology. In addition to that, when the inter-platform addressing is used, the agent's identification contains a valid address in used message transport protocol (e.g. IIOP, HTTP) and AMS agent uses an appropriate protocol to deliver the message to a computer outside the agent platform. In ExPlanTech, all computers inside one enterprise are organized as one agent platform and so all intra-enterprise communication uses intra-platform addressing.

3. EXTRAPLANT TECHNOLOGY

The ExtraPlanT technology addresses the concept of the extra-enterprise production planning in order to manage efficient resource allocation not only within the enterprise, but also at the company external environments (e.g. suppliers, co-operators involved in the supply chain or virtual organization environments). ExtraPlanT demonstrates the ability of multi-agent systems to improve business processes on the extra-enterprise level and to bring the virtual organization ideas to the real life. If both technologies are connected together ExtraPlanT agents enriches the ExPlanTech community by powerful capability for coordination and planning on the extra-enterprise level.

3.1 ExtraPlanT architecture

The main idea of ExtraPlanT is to extend the intra-enterprise planning system by a tool for cooperation and collaboration on the extra-enterprise level (Figure 2 shows the advanced ExtraPlanT architecture). The architecture of ExtraPlanT is based on following agents:

3.1.1 Extra-Enterprise Agent

As the basement for extension of the ExPlanTech over the boundaries of the enterprise, the Extra-Enterprise Agent (EEA) was designed. Extra-Enterprise Agents allow to human user an access to the system from outside the enterprise. We recognize two classes of Extra-Enterprise Agents – passive and active agents (see Figure 2). The Passive EEA can only read the data from the systems, while Active EEA offers to the user a full access to the data, like if he is working inside the enterprise. As the environment outside the enterprise is variable, also the technology for Extra-Enterprise access must be very flexible and platform independent. To satisfy this requirement, an Extra-Enterprise Agent has been integrated with application server that allows internal

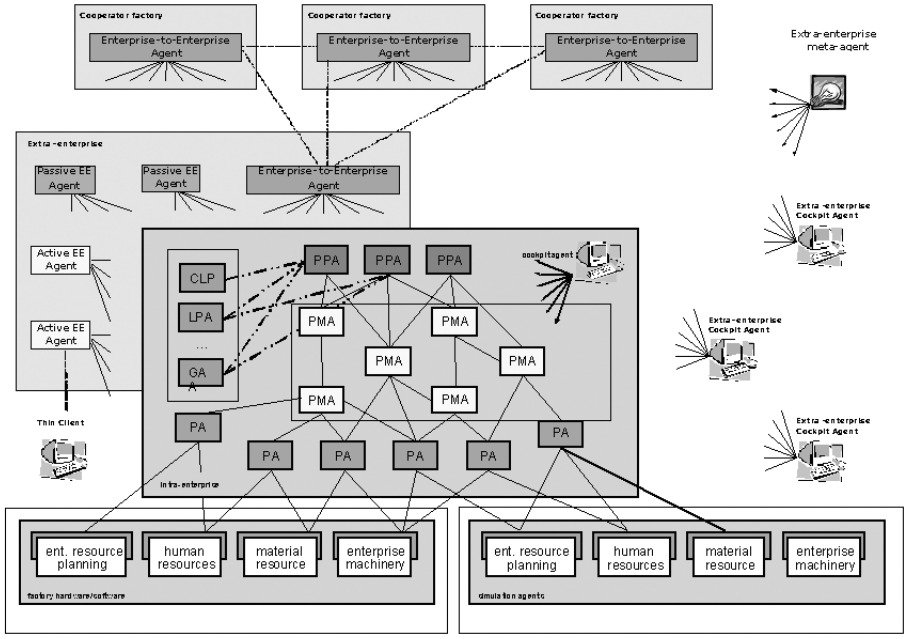

Figure 2 ExtraPlanT Extra-Enterprise architecture

data to be accessible via the WEB browser or WAP-enabled phone [30] using thin client approach. Secure connection protocol and a system of user access rights protects the system against an unauthorized access.

3.1.2 Enterprise-to-Enterprise Agent

Enterprise-to-enterprise (E2E) Agent is the main part of the ExtraPlanT technology (see Figure 2).

This agent makes the intra-enterprise planning tool (e.g. ExPlanTech based system) accessible for external software systems. The main mission of the E2E Agent is to support extra enterprise cooperation and collaboration by proactively connecting external agents (such as E2E Agents in partner enterprises or agents of material resources suppliers), exchanging data with them, and using them for decision support. This technique helps to find possibilities of tasks outsourcing in case of exhausted local resources, it advertises free local capacities to the cooperators or it can search for optimal material resource suppliers.

Each enterprise operates one E2E Agent and these agents connect together on pear-to-pear base and provide the community of cooperating but still independent enterprises. The background of E2E Agents is hidden for the others so that the cooperation do not dependent on the agents' background.

The social model helps E2E Agents to decide which partner could cover agent's needs best. Agent can take into account various aspects of cooperation and make decision upon many criteria (such as reputation, history of cooperation, recommendation, due dates, price, expected quality, etc.). This model is continuously updated with every new contract or information. E2E Agents are designed to cooperate with other agents in the secure and robust way provided by XSecurity tool [31] for inter-agent communication.

3.1.3 Remote Cockpit Agent

This agent is based on the intra-enterprise cockpit's user interface and functionality, but it is connected via the Extra-Enterprise Agent to access data from outside the enterprise. Depending on the implemented interface (Active or Passive EEA) the features of remote cockpit comply with ExPlanTech Cockpit Agent or functionality are limited to only reading available data (still, the authenticated user role can vary). Using this technology, the appropriate data is accessible by the off-site user in any place connected to the Internet by the tool that is very similar to that, used inside the enterprise. This approach uses the security and authentication mechanisms inherited from Extra-Enterprise Agents.

3.1.4 Material Resource Agent

Material resource management poses another big task of supply chain or virtual organization management. Obviously a material resource handling differs from free capacities sharing (material resources are storable, often requires precise specification…) and that is a reason, why a separate agent has been developed for this task. Material Resource Agent (MRA) is a basic extension of the E2E Agent, demonstrating general abilities and extensibility of the basic E2E Agent's concept. This extension is implemented both on intra-enterprise and enterprise-to-enterprise level. On intra-enterprise level, the MRA is equipped with an adequate user interface or a database connection, to be able to obtain data from case specific data sources. On the enterprise-to-enterprise level the communication abilities has been enriched to allow exchange of relevant data in a community of MRA and E2E Agents.

3.1.5 Extra-Enterprise Meta-Agent

Extra-Enterprise Meta-Agent has a similar task as Intra-Enterprise Meta-Agent – independent monitoring, measurement and evaluation of information flow among the agents. But as it operates on a different level of the system operation, it must utilize different means to access data. Meta-Agent periodically asks other agents for their communication logs, merges logs from different sources and stores them in local database. It thereby provides a centralized entry point for a further analysis or visualization.

In comparison to the intra-enterprise communication, the extra-enterprise communication is much more heterogeneous, variable and available logs are possibly incomplete. Therefore it is much more difficult to analyze it automatically. For that reason, an Extra-Enterprise Meta-Agent is more focused on synoptic visualization of obtained data and leaves a bigger part of evaluation on the user. The Meta-Agent employs the same security module as ordinary E2E Agents, thus it strictly conforms the same security rules.

3.2 Look inside

As the ExtraPlanT system is technological extension of the original ExPlanTech, it uses the same technologies like JADE, JAVA, and message transport protocols. But not all enterprises involved in the cooperation need to be equipped by the intra-enterprise multi-agent community. In such a case, E2E Agent can be used as a standalone application equipped with an appropriate interface for accessing company information system (or at least simple user interface when suitable information system is not available).

As already stated (see section 2.2) ExPlanTech uses intra-platform addressing and default intra-platform communication protocols. Extra-enterprise communication, introduced by ExtraPlanT, uses inter-platform addressing and HTTP protocol. For running of thin clients (e.g. web-based EEA, see Figure 2) application server Tomcat [32], developed within Jakarta project of The Apache Software Foundation is employed. Tomcat server uses Servlets or a JSP (Java Server Pages) technology to generate documents.

The XSecurity [31] component for JADE the ExtraPlanT technology covers the basic security and authentication issues needed for the communication in the open Internet environment. The exchanged data are encrypted and signed to minimize possibility of important business data lost. To overcome possible periods of agent's inaccessibility, caused by failures in Internet connection, special failure proof protocol for E2E communication has been implemented. This protocol uses intelligent change tracking, so the agents communicate only changes in data. When the agents are inaccessible, changes are buffered and exchanged after the communication link is established again.

E2E Agents' negotiation is based on two main protocols: contract-net protocol and subscribe-advertise protocol. Traditional subscription mechanism is used for exchange of general information of agents' capabilities and cooperation progress. Contract-net protocol serves for contracting partners for specific task.

3.3 Negotiation on enterprise-to-enterprise level

This section minutely describes single Phases of cooperation life-cycle on Enterprise-to-Enterprise level.

Phase 1 – searching of the possible collaborators
First, agents have to contact possible partners. There is wide field for future research in the domain of automatic searching and contacting possible partners [3]. In ExtraPlanT each E2E Agent knows a basic set of possible collaborators' E2E agents. This approach ensures the trustworthiness of the partners transferred from real-life to the agents' cooperation. Each agent is equipped by the addresses and the security certificates and every partner can be authenticated using standard asymmetric keys methods. Every agent can be connected to many partners' agents according to defined internal cooperation rules.

Phase 2 – capabilities exchange (service synchronization)
Once the agents are connected together, each agent provides the list of available capabilities to partners (it is possible to propose different capabilities to different partners). During this phase, the E2E Agents form basic cooperation network (also called Virtual Breeding Environment [3]). Every E2E Agent receives information suitable for effective collaboration in the next phases. During the life-cycle of the cooperation, agents subscribe information of the changes on interesting resources (and off course on already established cooperation).

Phase 3 – planning and negotiation
The agent that discovers a need for outsourcing of a part of their activities starts looking for the best possible partner for the cooperation. First, the agent searches its local social database for all cooperators, which are potentially able to agree on collaboration. Secondly it negotiates with selected partners about details of a possible collaboration. Ones the cooperation is agreed by both sides, virtual organization is established and contract become obligatory for all involved partners. The originator is responsible for using of (and paying for) agreed capacities and the cooperator is responsible for providing it. Even if the conditions are changed by one of the partners, agents tries to keep the contract.

Phase 4 – production management and re-planning
Once the cooperation is settled, agents inform each other about every relevant change. If the initiator requires a change of contract conditions, it informs the subcontractor about its requirements and subcontractor tries to meet the new specification. As well, if the subcontractor can finish its sub-task sooner or later then agreed, it immediately informs the task originator. When one of agents goes off-line, the synchronization is delayed and during a next successful connection all accumulated changes are exchanged.

Phase 5 – feedback and evaluation
Any partner as well as some kind of independent organization can run meta-agent to monitor and evaluate any cooperation. Meta-agent asks each known E2E Agent for a communication logs, and each E2E agent can or may not provided them. Available data can be used for evaluation, measurement and future optimization of cooperation.

3.4 Experimental E2E scenario

Experiment environment presented in this section is based on real data and verifies possible application on the small peace of supply chain of Modelarna Liaz (middle size pattern shop enterprise in the Czech Republic) that is one of enterprises having implemented ExtraPlanT technology to their information system (see section 4.1). The experiment

contains two virtual enterprises equipped by ExPlanTech based intra-enterprise planning system extended by ExtraPlanT functionality (E2E agents). The first enterprise is Modelarna Liaz, which uses ExPlanTech for daily production planning and the second one is ACR Czech, partner of the first enterprise. Each of experimental enterprises uses ExPlanTech prototype consisting of Planning Agent, several Resources Agents and one E2E Agent, representing the enterprise to external partner. From the point of view of other ExPlanTech agents, the E2E Agent behaves as another Resource Agent but instead of representing internal resources and requirements, it represents sum of resources and tasks of external partners.

To prove extra-enterprise abilities of the developed technology Modelarna Liaz and ACR Czech are asked to fulfill tasks that cannot perform by their own workshops in this scenario. To carry these tasks out they ask the each other for collaboration and the asked one tries to incorporate received tasks to internal plan. The tasks obtained from the cooperator cannot cause delay of the internal tasks, because their priority is always set to be lower then the priority of any locally initiated task. It is a responsibility of the partner that initiated the cooperation, whether it will accept plans, proposed by the partner, or whether it will search for another possibility.

We have tested the realistic management scenario in the extra-enterprise planning level. Following example contains outsourcing of one sub-task scenario to clearly present the capability of the ExtraPlanT based planning on the extra-enterprise level. The Figure 3 is a screenshot of the communication on the extra-enterprise level recorded by the extra-enterprise Meta-Agent. This is snap of negotiation of the advertising free capacities of ACR Czech to Modelarna Liaz.

Following Figure 4 displays the successful plan, where a part of the order vfB-A-02 is covered by the ACR Czech capacities (ACR Czech executes the subtasks requiring Manual Design workshop). On the side of Modelarna Liaz, the E2E Agent represents ACR Czech capacities (see plan of E2E Agent on the Figure 4). On the side of ACR Czech, the cooperation request is represented by the two virtual orders. Modelarna Liaz is still responsible for coordination of the virtual orders; ACR Czech only provides the free capacities of their resources. Even though Modelarna Liaz itself is not able to satisfy customer needs (basically fulfill the order), using the successful cooperation with ACR Czech, the order is fully covered.

This scenario presents usability of the technology in the real industrial case. In the daily use it can improve business relationship and brig significant economic benefits. Automatic support of the whole supply chain can accelerate cooperation of the industrial partners and increase efficiency of production processes.

4. EXPLANTECH AND EXTRAPLANT USE CASES

ExPlanTech technology based system is daily used in industrial cases, but ExtraPlanT technology is designed to fulfill future needs. There is no running industrial implementation of ExtraPlanT but it is successfully evaluated on the real cases. Presented experimental scenario (see section 3.4) is based on real data and shows the possible profits in the future. However, many ExtraPlanT features are adapted in the implemented ExPlanTech based systems and others are in the stage of industrial testing.

There is a set of the most usual ways, how to utilize ExPlanTech and ExtraPlanT multi-agent technologies:

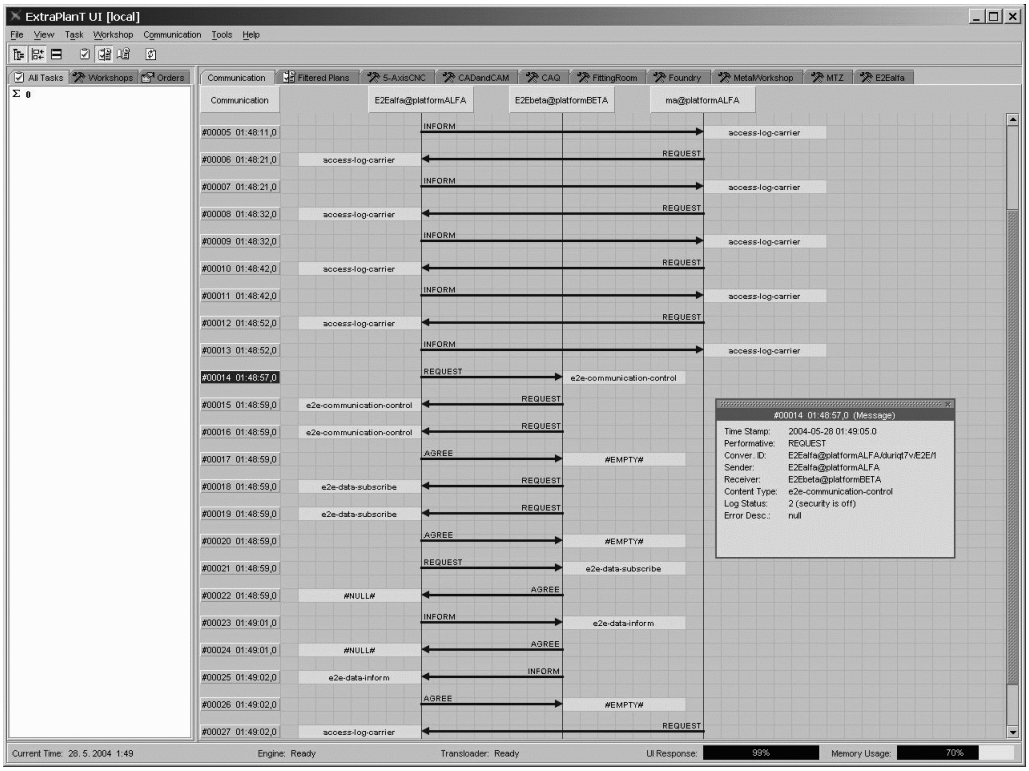

Figure 3 Modelarna Liaz Supply Chain scenario – Communication record of E2E agents concluding the providing of free capacity of ACR Czech to cover needs of Modelarna Liaz

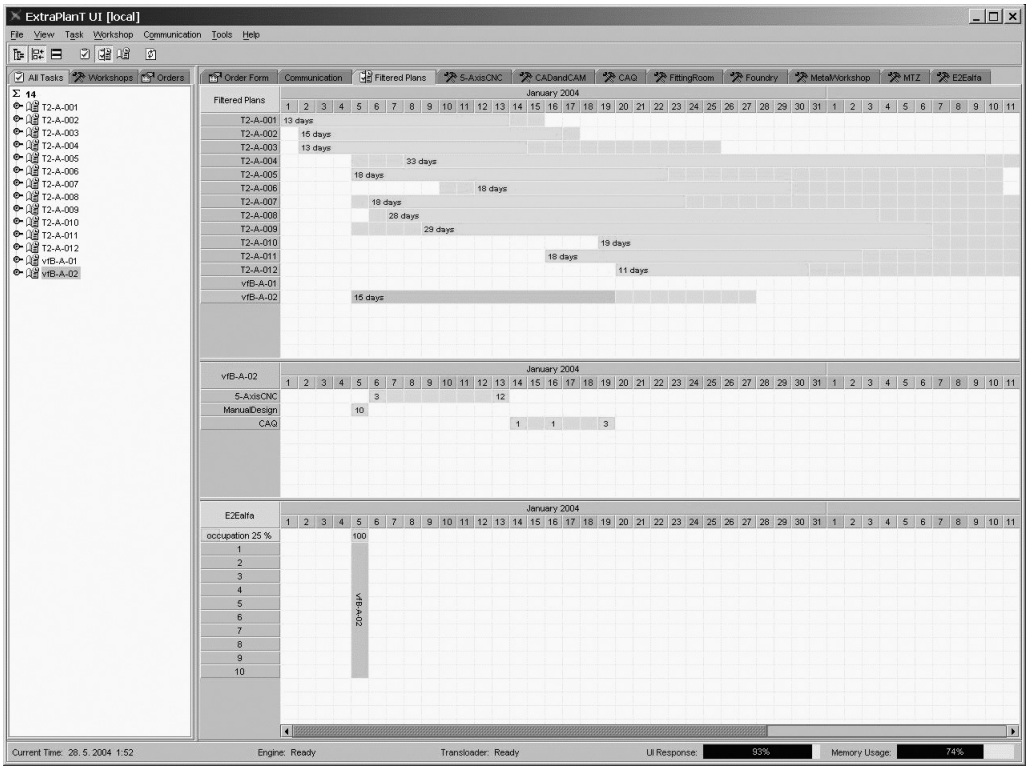

Figure 4 Modelarna Liaz Supply Chain scenario – Subtasks of T04-ALFA-001 are planed to a workshop (Manual Design) provided by another enterprise

- **Production planning, dynamic re-planning:** The most obvious use case is intra-enterprise production planning. The ExPlanTech provides sets of linear and non-linear plans and schedules of in-house manufacturing activities that are to be carried out so that the requested orders and tasks are achieved while utilization of the enterprise resources is optimized.
- **Supply Chain Management:** In order to solve a complicated task of an automated supply chain management, many technical and commercial difficulties have to be overcome. Unlike in the case of the intra-enterprise planning, ExPlanTech has not a complete knowledge about supplier's parameters and capacities. This is why the simplest "master-slave" interaction approach is not sufficient and classical negotiating techniques (e.g. contract-net-protocols) are provided by ExtraPlanT. In addition ExtraPlanT handles secure and authenticated communication, and it uses the concept of acquaintance models in order to handle temporal suppliers' inaccessibility.
- **Simulation:** Simulation can support decision-making process in two wais. First of them is a simulation of a new enterprise or of an overhauled or upgraded existing enterprise. The simulation capability of the ExPlanTech supports a high-fidelity analysis of what the performance of the investment alternative will be. The second way to use a simulation tool is a decision support in enterprise control to test how changes in performance of key machines would affect the manufacturing process as a whole. ExPlanTech provides an integrated simulation environment that allows simulation of different manufacturing scenarios in order to make technology changes and control safer.
- **EE Access:** It is possible to access the planning system remotely using the thin client (based on extra-enterprise agents) or the thick client (based on enterprise-to-enterprise agents) technology. The former approach requires merely an appropriate WEB or WAP browser on client's side whilst the latter one assumes installation of software based on Java and JADE technology on a user's computer and provides user with more comfortable way to handle the planning system.

There are several industrial partners whom we have deployed with the ExPlanTech technology. They did not use the identical collection of software system, while the solution for each of them has been custom tailored.

Modelarna Liaz spol. s r.o is middle enterprise in the Czech Republic. The customers of the enterprise are mainly from automotive industry. The used criterion of the plan was the load of the strategic workshops (machines) and delivery times. The multi-agent decomposition based planning within the ExPlanTech was implemented to support human expert decision-making. Upon the order specification in the company ERP system the ExPlanTech prototype provides production plans. The ExPlanTech prototype (enriched by ExtraPlanT technology) also provides the extra-enterprise access to the plans. After several months the system proved its potential and helps the company to extend production capacities. The overall machine utilization increased by 30% and average due time was reduced by 5.3%.

In collaboration of GEDAS, s.r.o and CertiCon, a.s. the concept of the ExPlanTech technology has been successfully applied in design of the robust planning system for car engines manufacturing [33] in the new SkodaAUTO motor. High volume production (thousands of engines manufactured daily) and a high variability in types of motors to be

manufactured the planning problem is not a trivial task. The planning system was required to provide hourly plans for the period of six weeks. Like in Modelarna Liaz, the plan had been prepared by human experts manually using basic office tools and the planning strategy was oriented mainly to big stock reserves. The designed solution helps to decrease the stock reserves to the minimal level with guaranteeing of maximal utilization of assembly lines. The design was successfully adapted by GEDAS and system implemented is in daily use.

Within the IST EC take-up action technology transfer project the ExPlanTech technology has been evaluated at the Chatzopoulos S.A. (the large packaging company) production site (in close collaboration with CertiCon and ALTEC Information and Communication Systems S.A. (former UniSoft S.A.). The production planning capacity of ExPlanTech has been exploited primarily for optimization of the production load at two different factory sites. For any new incoming order ExPlanTech provides the user with an estimate of the promised delivery date, taking into account the production place.

The developed technology has been also verified in the BEHR GmbH & Co. (automotive supplier of Cooling and Air Conditioning systems.) environment. Simulation part of the ExPlanTech, supported by simplified planning, special Cockpit Agents and Meta Agents was employed to compare long-term effectiveness of several shop floor layouts.

5. CONCLUSION

Covering all the needs of modern industrial enterprise is not easy problem. We propose two technologies for manufacturing support on two different levels: ExPlanTech for intra-enterprise and ExtraPlanT for extra-enterprise level. ExPlanTech and ExtraPlanT technologies can be used simultaneously or together. ExtraPlanT system is extension of ExPlanTech, but it was designed to be able run standalone. The standard configuration consists of several independent ExPlanTech systems linked to the virtual organization by ExtraPlanT E2E Agents together with proprietary non ExPlanTech systems (using also E2E Agents).

Presented technologies illustrate the potential of the agent-based decision support technology in various fields of manufacturing – planning, supply chain management, simulation, extra-enterprise access, etc. The integration exercise that we have carried out at different industries validated that the agent-based technology is viable in situations where the planning problem is dynamically changing (e.g. project driven production), and needs frequent and continuous re-planning. In these situations the collective aspects of the agent technology have been exploited. At the same time we have identified a great potential of the technology in situations where the planning problem is inherently complex but it features some of the internal logic. This has been case of the high volume production, where not only collective aspects of agent technology have been used but also the integrative capabilities of agents have been exploited (e.g. integration of the linear programming heavy-duty solver). Obviously in situations where the planning data are widely distributed and not fully available the agent technologies provide an elegant integrative and distributed planning framework. This is the case of the supply chain management and virtual organizations formation. It has been shown that the multi-agent approach provides a specific modeling and simulation alternative to the known mathematical and system science modeling technologies for simulating the manufacturing process.

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