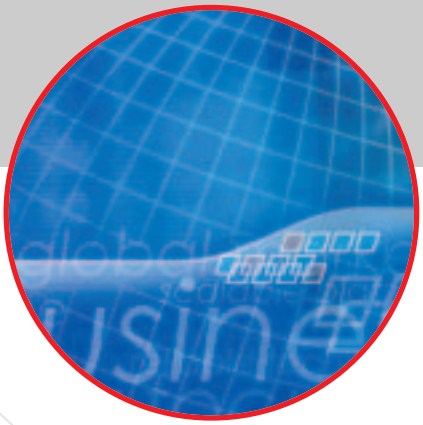


ExPlanTech/ExtraPLANT: Production Planning and Supply-Chain Management Multi-Agent Solution

P. Bečvář, P. Charvát, M. Pěchouček, J. Posíšil, A. Říha, J. Vokřínek

ABSTRACT - AN INTELLIGENT SUPPORT AND AUTOMATION OF PRODUCTION PLANNING IN BOTH SMALL AND MEDIUM ENTERPRISES AS MUCH AS BIG MANUFACTURERS IS A KEY FOR ACHIEVING FAST DUE-DATES, HIGH DEGREE OF MANUFACTURING FLEXIBILITY, MINIMIZATION OF STOCK RESOURCES, BALANCED LOAD OF THE MANUFACTURING MACHINERY, ETC. IN THIS CONTRIBUTION WE PRESENT A JADE-BASED MULTI-AGENT SOLUTION FOR INTRA-ENTERPRISE PRODUCTION PLANNING AND FOR EXTRA-ENTERPRISE ACTIVITIES SUCH AS SUPPLY CHAIN MANAGEMENT.

JADE:
Java Agent
Developmen
Framework

INTRODUCTION

An intelligent support (or even automation) for production planning in both small and medium enterprises as much as big manufacturers is a key for achieving fast due-dates, high degree of manufacturing flexibility, minimization of stock resources, balanced load of the manufacturing machinery, etc. By mistake, the concept of production planning and resource allocation has been viewed separately from the process of material supplies, components purchase and customers' relations. In this contribution we argue that multi-agent technology is an ideal mean for integrating the intra-enterprise and extra-enterprise production planning activities. Based on a solid, long-term research in the field of agent-based production planning systems, we have developed the ExPlanTech (7) system for planning the project-driven production in Liaz Pattern-Shop (Czech Republic), who produces jigs, forms and patterns for the European automobile industry. Implementation of ExPlanTech is based on the ProPlanT multi-agent architecture (will be presented later). Besides Liaz, the ExPlanTech system has been exploited in Hatzapoulos (Greece), a producer of packaging technology. Currently, implementation of the ExPlanTech based technology is being carried out jointly with the GEDAS software company for ŠkodaAUTO, the VW owned car-manufacturer. ExPlanTech is expected to plan production at their new engine assembly.

ExtraPlanT is an extension of ExPlanTech in order to support the extra-enterprise production planning activities such as access to production planning data from outside of the factory and supply chain management support. For the secure connection of the extra-enterprise agents, the X-security package developed at the Gerstner Laboratory was adapted.

Research and technology transfer of the ProPlanT technology to the industrial partners has been supported in parts by two European projects.

SYSTEM ARCHITECTURE

The ProPlanT architecture suggests three main classes of agents for intra-enterprise production planning (see figure 1):

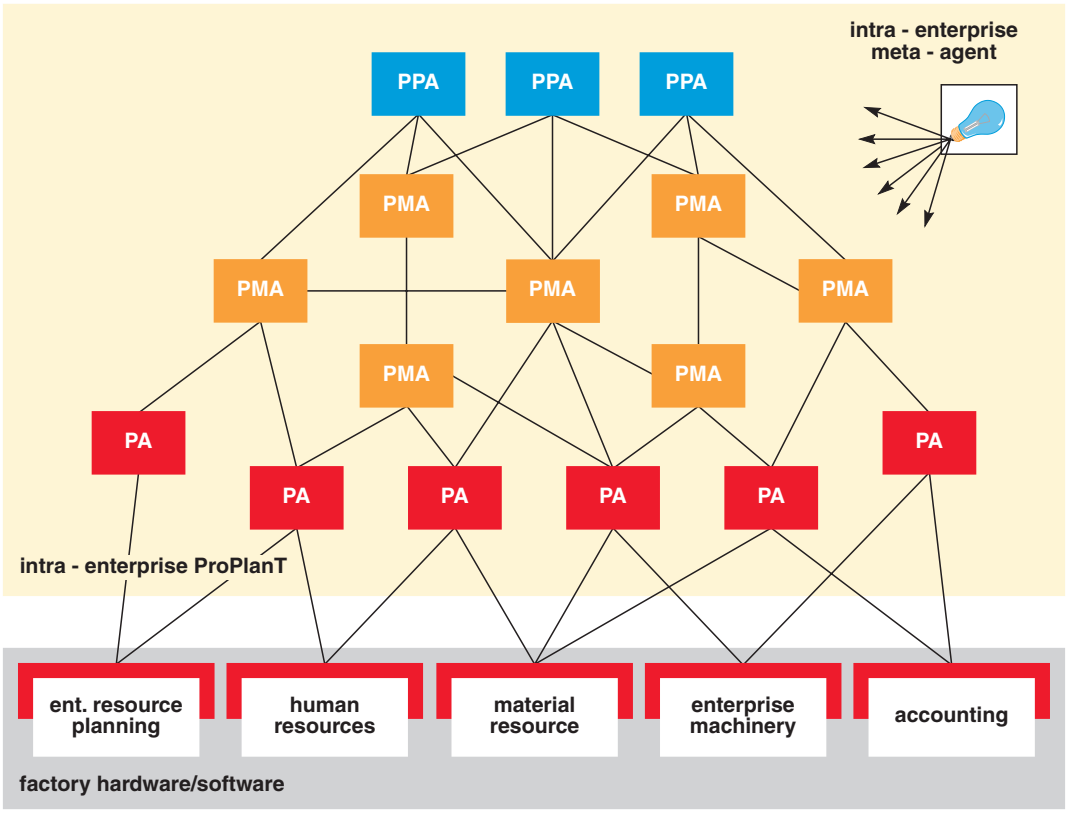
pechouc@labe.felk.cvut.cz

Michal Pěchouček

Michal Pěchouček works as an assistant professor in Artificial Intelligence at the Department of Cybernetics, Czech technical University. He graduated in Technical Cybernetics from CTU in 1995, got his M.Sc. degree in IT: Knowledge Based Systems from University of Edinburgh and completed his Ph.D. in Artificial intelligence and biocybernetics at CTU in Prague in 1998. He is the head of the Agent Technology Research Group at the Gerstner Laboratory. He is interested to social knowledge, acquaintance models, forming coalitions, monitoring, meta-reasoning and reflection in multi-agent systems while at the same time he is interested in industrial applications of agent technologies. Dr. Pěchouček participated in and coordinated several international projects (EC funded) and acted as a principal investigator of direct research contracts (Rockwell Automation, US Air Force, Office of Naval Research, NASA). He is an author or co-author of about 50 publications in proceedings of international conferences and journal papers. In addition, he is the co-chair of the HOLOMAS 2000, 2001, 2002 and CEEMAS2003. Besides, he is a PC member of several workshops and conferences related to multi-agent system research. Michal Pěchouček consults to Rockwell Research Center in Prague and is a senior research consultant in CertiCon, corp.

- Production Planning Agent (PPA) is in charge of project planning and its aim is to construct an exhaustive, partially ordered set of tasks that need to be carried out in order to accomplish the given project. It builds product configuration and contracts PMA agents.
- Production Management Agent (PMA) performs project management in terms of contracting the

Figure 1
ProPlanT System Architecture



best possible PA agents (in terms of operational costs, the delivery time and current capacity availability). PMA delegates its responsibility either to another PMA or it controls work of a group of PA agents contracted for the considered task.

- Production Agent (PA) represents the lowest level production units that simulates or encapsulates shop floor production processes on the IAE. PA carries out the parallel-machinery scheduling of given tasks and manages resources allocation. PA agents integrate (agentify) currently existing information systems.

Besides, we have also a Meta Agent (MA) who is a special monitoring agent which provides analysis of behavior of the agents' community as a whole and advises on optimal system efficiency (including material and work flow visualization). It should be note that the community of agents would survive well with no meta-agent.

ExPlanTech multi-agent system is an implementation of the ProPlanT architecture and is based upon interaction of the following instances and subclasses of agents:

- operator: an agent with properties of the PPA a PMA agents, responsible for project configuration and decomposition of the project down to activities in particular workshops and departments,
- workshop: a scheduling agent (with properties of an abstract agent PA), who plans activities and allocate resources of a given department or a machine,
- database agent: an integration agent (with properties of an abstract agent PA), whose duty is to integrate the ExPlanTech system with an ERP system for production resources administration – ISML,
- material agent: an agent (with properties of an abstract agent PA), that integrates a system of raw material administration and raw material purchase.

The ExPlanTech is fully FIPA-compliant and has been developed in JADE (Java Agent Development Environment) (1, 3, 4). Currently it is running in distributed manners on several computers (operating windows and linux). Each of the agents has been equipped with a specific graphical user interface (GUI). Obviously new agents can log into the community as much as the overall configuration of the system can be altered in the run-time of the system. As the distributed GUI is not very convenient from the users perspective, a specific agent – a cockpit agent (see figure 2) – has been implemented to allow easy and multi-user access to the planning system (visualization of plans, planning task specification, agents properties editing, etc.). ExPlanTech allows export to MS-Project system for alternative plan administration and visualization. Integration with SAP is under development currently.

Figure 2
Cockpit Agent GUI (The leftmost part of the UI shows either list of workshop agents in the system or list of all planned tasks. Each task has several attributes like possible start time, deadline, priority, customer, 4 production phases – milestones, precedence relations among subtasks. The rightmost part of the window represents plans. Describing from top, there is a list of tasks (their plans) spread out in time (x-coordinate). The middle part relates to the particular task selected in the previous section and shows the task distributed across the workshops. Finally the bottom part of the window represents the plan of the task (selected in the previous part of the window) in one particular workshop (y-coordinate represents capacity of a workshop in man*hours). These three parts relates to each other, so the top part is the most general view on tasks while the bottom part is the most detailed view on one particular task.)

INTERACTION

In ExPlanTech, the agents interact via several different protocols. The collective decision making and planning has been achieved in particular by two specific protocols - contract-net-protocol and subscribe-inform. Let us briefly discuss either of them.
In the contract net, an operator starts negotiation by sending a request for proposals to several suit-

able workshops. Each workshop carries out internal deliberation and replies with collaboration proposals. The operator selects the best proposals and contracts the appropriate workshop. See the following interaction for contract-net in ExPlanTech:

```
(cfp
  :sender operator@mas0:1099/JADE
  :receiver workshop@mas0:1099/JADE
  :language XML
  :ontology plan-task-ontology
  :protocol fipa-contract-net
  :content
    (<?xml version="1.0" encoding="UTF-8"?>
     <plan-task>
       <task-id>Z_211-0242</task-id>
       <time>10</time>
       <day-load>8</day-load>
       <priority>1</priority>
       <start-day>20011026T000000000</start-day>
       <dead-line>20011120T000000000</dead-line>
       <strategy>F</strategy>
     </plan-task >)
)
```

Here agent operator@mas0:1099/JADE sends to workshop@mas0:1099/JADE a request for suggesting a proposal for implementing a task <plan-task>. The Agent workshop@mas0:1099/JADE can either refuse the offer by sending a 'refuse' message, or suggest a proposal by the 'propose' message:

```
(propose
  :sender workshop@mas0:1099/JADE
  :receiver operator@mas0:1099/JADE
  :language XML
  :ontology plan-task-ontology
  :protocol fipa-contract-net
  :content
    (<?xml version="1.0" encoding="UTF-8"?>
     <plan-task>
       <task-id>Z_211-0242</task-id>
       <time>10</time>
       <day-load>8</day-load>
       <priority>1</priority>
       <start-day>20011026T000000000</start-day>
       <dead-line>20011120T000000000</dead-line>
       <strategy>F</strategy>
     </plan-task >)
)
```

Here workshop@mas0:1099/JADE proposes the operator@mas0:1099/JADE, to plan the task using the strategy <strategy>F</strategy> (forward planning) by deadline <dead-line>20011120T000000000</dead-line>.

An alternative interaction strategy, used in ExPlanTech is the subscribe-inform strategy, where the operator subscribes the workshop for the information about their availability. Workshop periodically updates this information and informs the operator. Upon a request for planning the operator selects the best possible workshop by consulting the subscriptions and makes a contract.
Another subscription is made between each workshop and database agent:

```
(subscribe
  :sender workshop@mas0:1099/JADE
  :receiver DBA@mas0:1099/JADE
  :language XML
  :ontology capacity-ontology
  :content
    (<?xml version="1.0" encoding="UTF-8"?>
       <change-capacity/>
       )
)
```

Here agent workshop@mas0:1099/JADE asks agent DBA@mas0:1099/JADE to make him aware about all new capacities and updates of the capacities (such as holiday) of the particular production units, that are inserted in the ERP system. As a reply with each update the agent DBA@mas0:1099/JADE sends an 'inform' message to workshop@mas0:1099/JADE:

```
(inform
  :sender DBA@mas0:1099/JADE
  :receiver workshop@mas0:1099/JADE
  :language XML
  :ontology capacity-ontology
  :content
    (<?xml version="1.0" encoding="UTF-8"?>
       <request-change-capacity-message>
```

```
<day-capacity-list>
 <day-capacity>
  <day>20011120T000000000</day>
  <capacity>10</capacity>
 </day-capacity>
   </day-capacity-list>
  </request-change-capacity-message>)
)
```

This communication protocol is particularly suitable for *dynamic replanning* – a planning process on top of the continually changing reality. Plans in the system are viewed as conditional, dependent on the precondition that is defined as state description of the respective agent in the instance of planning. In the case, that state of the agents' changes, the precondition is not valid anymore and replanning within the minimal sub-community needs to be triggered. Administration of these preconditions has been implemented by means of the subscribe-inform protocol.

Besides previously mentioned protocols we used also standard fipa-request protocol. As content language we decided to exploit XML language as it is easy to be manipulated and for integration reasons.

PLANNING ALGORITHMS

Planning in product-oriented manufacturing is complex problem. Each order is unique and arrives independently on the others. Finding optimal plan is NP-complete problem (8).

Task T is defined $T = \{ST, PT\}$, where set of sub-tasks $ST = \{t_i, 1 \le i \le n\}$, n is number of sub-tasks, and precedence tree $PT = \{P(t_i,t_j,lap(t_i,t_j)), 1 \le i \le n, 1 \le j \le n, i \ne j\}$, where P is precedence between subtasks t_i,t_j and $lap(t_i,t_j)$ is percentage overlap of the subtasks. Each task contains several numbers of sub-tasks, and each sub-task can be dedicated to several machines (departments). Each sub-task can be again decomposed into set of the sub-tasks, so the planning is provided hierarchically – the sub-task become the task on the next planning level (PMA).

The planning (and similarly replanning) problem is to add new incoming task into plan with given *start-time* ST_i, *deadline* DL_i and *priority* w_i. The chosen criterion for optimality is *average weighted lateness* $L = \frac{1}{m} \sum_{i \in \overline{T}} \frac{d_i}{w_i}$, where

$\overline{T}$ is set of planned tasks,

m is number of tasks,

w_i is priority of the task T_i, where lower value means higher priority

d_i is delay of the task T_i.

Implemented distributed planning uses heuristic minimizing this criterion. It is built on the ideas of well-known standard scheduling algorithms. Distributed algorithm works in two levels: i) decomposition and distribution, and ii) resources scheduling. PMA (ExPlanTech operator) decomposes the tasks into subtasks and computes the *critical path* of the tasks. The critical path defines the minimum time needed to fulfill the task. Then the agent specifies start-time $st(t_i)$ and deadline $dl(t_i)$ for each sub-task with respect to the start-time and deadline of the whole task, critical path and resources utilization (plans for preceding sub-tasks). Each sub-task is dedicated to the best cooperator (PMA, PA or ExPlanTech workshop). The best cooperator is chosen using contract-net-protocol or subscribe-inform protocol. The case-specific rule is applied for selection between the best intra-enterprise and extra-enterprise agent.

PA (ExtraPlanT workshop) provides scheduling resources for maintained department. When new sub-task arrives (or some sub-task has to be changed) scheduling/rescheduling is started. Scheduling algorithm respects given priority of the sub-tasks, thus no sub-task with lower priority can block the resource when higher priority sub-task can be scheduled at this time.

The *filling index* is evaluated for each sub-task: $fi(t_i) = \frac{md(t_i)}{ts(t_i)}$, where $md(t_i)$ is minimal duration of this sub-task (by sub-task definition and resource constraints) and $ts(t_i)=dl(t_i) - st(t_i)$ is *time-slot* for the sub-task. The scheduling algorithm puts the sub-tasks into resources with non-increasing filling indexes.

The outlined distributed planning heuristic has polynomial complexity with guarantee of minimal value of the chosen criterion. Agent-natural distribution of planning algorithm and hierarchical task

decomposition allows reducing of the state-space and speeds up the planning process (9).

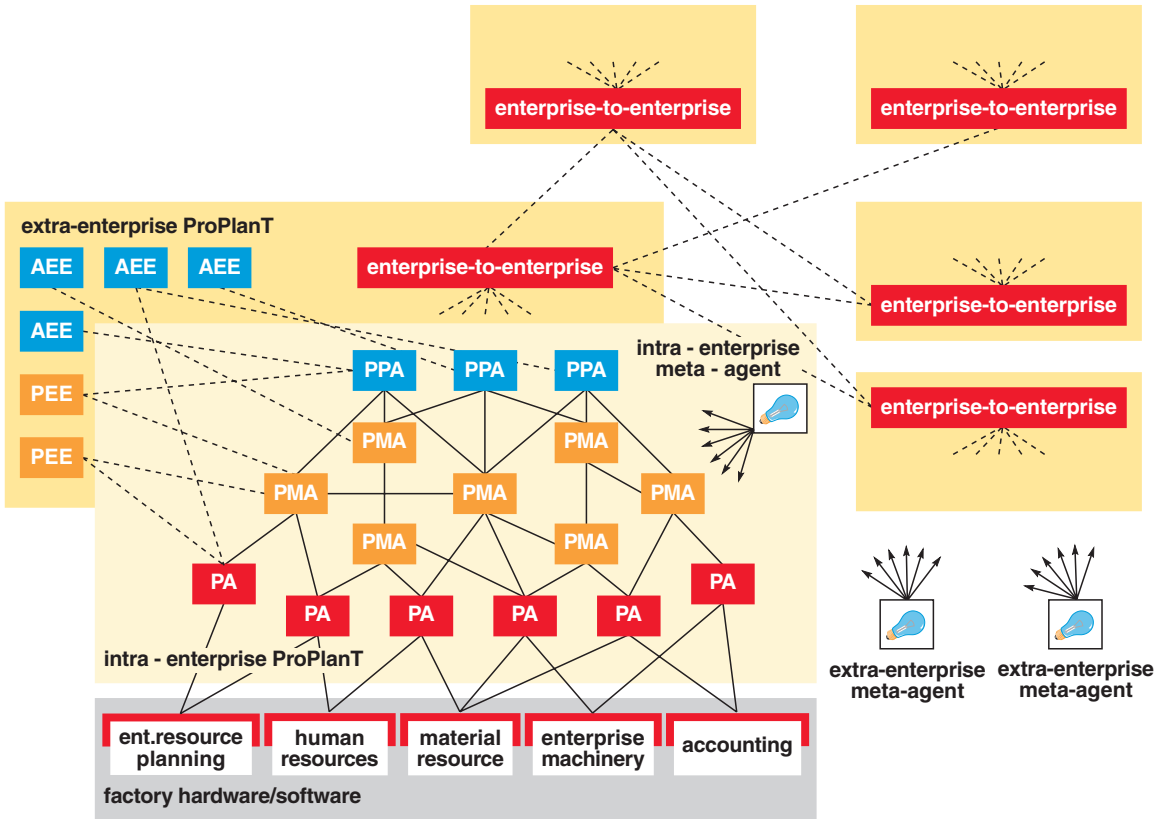
EXTENDED ENTERPRISE

The concept of production planning and resource allocation has been viewed separately from the process of material supplies, components purchase and customers' relations. The ExPlanTech system has been extended so that the same technology that has been used for integrating the manufacturing machinery has been used for allowing a remote access and integrating suppliers and customers in a dynamic supply chain (2, 5).

The original ProPlanT architecture has been extended with two additional classes of agents (see figure 3):

- Extra-Enterprise Agent (EEA) which may access the production planning data from outside of the company. A passive PEE agent may only obtain any important data from the intra-enterprise community and present it to a user outside the company. An active AEE agent may trigger the entire course of production planning from outside of the enterprise. The EEA agent negotiates with the PPA agent in order to specify the production requirements, the deadline and the budgetary constraints. It can also subcontract individual PMA or PA agents for only parts of the products.
- Enterprise-to-Enterprise Agent (E2E) which extends the ProPlanT technology for managing outsourcing and capacity sharing across various enterprises. E2E agent can also work as a data proxy accessible by remote EEA only on a secure communication channel.

Figure 3
ProPlanT Architecture for an Extended Enterprise



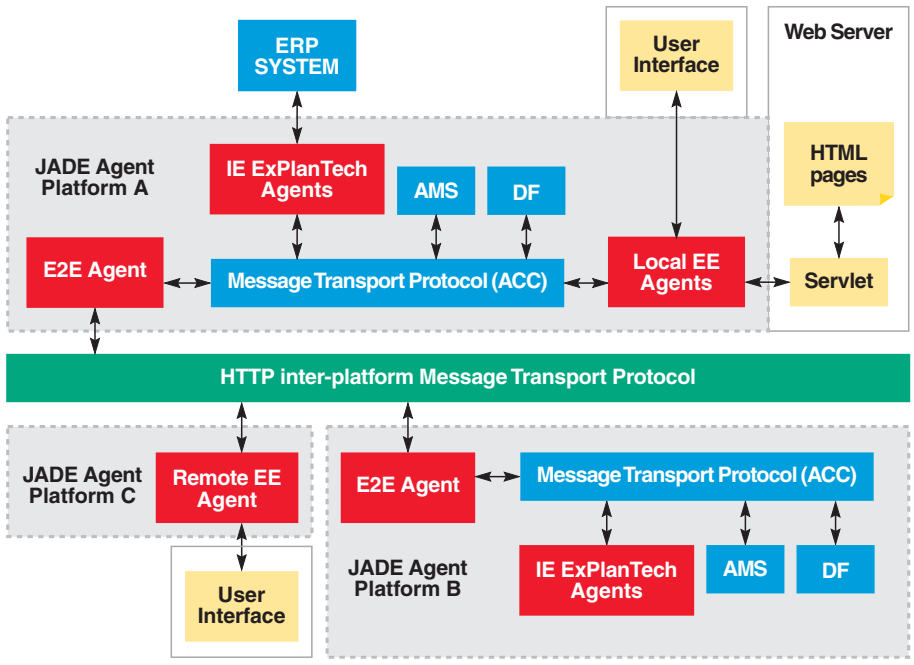
Either a user or the EEA agent usually communicates with the PPA agent. The PPA agent constructs a component list and delegates further responsibilities to the PMA agents who contract either the best possible PA agents or via the E2E agent the best possible supplier or a collaborating entity. Costs and due times, that represent the distributed production plan, are then back propagated to either the EEA agent or the user.

The extra-enterprise agents can be appreciated either by production managers when traveling (monitoring of the production, competitive planning etc.) or by customers (observing production progress of their orders). The extra-enterprise (EE) technology provides accessibility of the production planning data to the management of the enterprise while they are out of the enterprise using modern information/communication standards (see figure 4). This technology is primarily designed for accessing the production data (occupancy of workshops, list of orders, material etc.) via the Internet by an ordinary web browser. Apart from the portable or the desktop PC, the extra-enterprise agents can be installed on the mobile PDA devices that are based on the Windows CE platform. The extra-enterprise agents' wrappers can be adapted for communication using the Wireless Application Protocol (WAP) for running in the cell-phone devices. Only authenticated agents/human users can access and manage the intra-enterprise production planning data.

The E2E agent extends the ExPlanTech technology for managing outsourcing and capacity sharing across various enterprises (see figure 4). E2E agent plays several roles in the enterprise-to-enterprise interaction:

- E2E agent can search the community of known remote E2E agents for services they provide. In the intra-enterprise community the E2E agent itself behaves as a PA agent – provider of the services, provided by the remote partners. The planning system is able to contract E2E agent as a PA agent and consequently E2E tries to outsource the task to a remote service provider. If there are several providers of the same service, E2E agent uses the contract-net-protocol to choose the best supplier for each task.
- E2E agent can be contacted by remote Extra Enterprise agents and offer them data about the

Figure 4
Integration of ExPlanTech/ExtraPlanT system using EE agents



local intra-enterprise community. E2E agent can (if the user of the remote EE agent is permitted to provide such operation) execute commands requested by the remote EEA.

- E2E agent usually behaves as a service provider in the community of E2E agents. It periodically checks with its intra-enterprise agents for their available resources and advertises these to the other E2E agents. When any remote E2E agent tries to allocate some local resources, E2E agent forwards the request to the local PPA agent, which process the request.
- E2E agent can contact remote suppliers of material supplies or components in order to purchase supplies not available in the local material agent. If there are several providers of the same material supply, E2E agent uses the contract-net-protocol to choose the best supplier for each purchase.

Not all these features must be implemented in each E2E Agent. E2E agent registers all features that provides in the local DF Agent. Other intra-enterprise agents can use information stored in the DF Agent to decide, whether a requested feature of E2E agent is available in the local community.
From the enterprise-to-enterprise point of view, each E2E agent agentifies the whole enterprise. Each E2E agent advertises services and material supplies provided by its enterprise to other E2E agents. The shared (public) knowledge about currently available resources is prepared in a standardized form with respect to the agreed and shared knowledge ontology. E2E agent responds only to queries and requests dealing with the advertised services. That is why E2E agents that do not implement all the features can safely cooperate in the community of E2E agents.
E2E agents can be implemented using several approaches of various complexity and abilities:

- In the simple case, a supplier/collaborator can be represented as a virtual workshop by a simple E2E agent that advertises (and administers) only the services and capacities it is able to provide. The agent could, for example, read the data from the partner's enterprise database or could be provided with this data by the ERP system. If there are not enough resources locally available, the planning system is able to contract such an agent and avoid failing to meet the deadline.
- The second, more sophisticated option is to use the E2E concept for interconnecting several enterprises that use the ExPlanTech technology on the intra-enterprise level. In such a case, the E2E agent does not simply represent services, the collaborator offers to the community, but serves as proxy to its own multi-agent community. Each intra-enterprise ExPlanTech system maintains one E2E agent that periodically checks with its intra-enterprise agents for their available resources and advertises these to the other E2E agents. Once the production planning agents within one enterprise are threatened by a possibility of failing to meet the deadline, they immediately contact their E2E agent which initiates negotiations with the other E2E agents representing the outsourcing resources and finds the most suitable subcontractor.

Security

Assuring a safe and secure communication for inter-agent communication is a must when designing and implementing industrial or e-business applications.

Within the ExPlanTech/ExtraPlanT community, it is necessary to pay attention to the two possible security issues. One is secure communication among agents on the intra-enterprise level and the other one is secure communication on the extra-enterprise level (among E2E agents). While on the intra-enterprise level it is sufficient to hide the platform behind the company firewall this will not work on the extra-enterprise level because whole communication among E2E Agents is based on HTTP inter-platform message transfer protocol supported by JADE. It causes the fact that any agent from outside of the company can directly communicate with any agent on the platform while we would like all extra-enterprise agents to access the platform via E2E proxy agent.
To ensure a protection of the private intra-enterprise data, each message is encrypted and digi-

tally signed. A Secure Socket Layer (SSL) feature of JADE-S package included in JADE 2.61 is used for a message encryption. JADE-S (authorization, permissions and policies) is also used to prohibit agents from external platforms to directly communicate with other agents than E2E agent. For a digital signing of the messages, an X-security package is used (6).

X-security package offers these two basic functions:

- Security Certification Authority (SCA) - stand-alone agent, application independent, which allows certificate registration/deregistration and provides other agents in community with these certificates. It isn't a part of the platform (like AMS or DF).
- Security module - this module has to b1e included into an agent that wants to use a communication security.

Security package currently uses these algorithms for communication security:

- Message signing - SHA with DSA algorithm
- Message encrypting - RSA algorithm (using BouncyCastle security package)

This package also allows maintaining data about system users, their usernames, passwords and access rights to different system features.

Conclusion

This contribution presents a unified ExtraPlanT/ExtraPlanT technology for intra-enterprise and extra-enterprise production planning. Using JADE development framework, we have managed to generalize the production planning and scheduling components in order to be equally exploitable on the level of virtual enterprises and supply chain management.
The end users have positively accepted the technology. System stability and especially user friendliness, given by the separate cockpit agent, has been highly appreciated.

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Glossary

ACL	*Agent Communication Language*
AEE	*Active Extra Enterprise*
AMS	*Agent Management System*
DF	*Directory Facilitator*
EEA	*Extra Enterprise Agent*
E2E	*Enterprise to Enterprise*
ERP	*Enterprise Resource Planning*
FIPA	*Foundation for Inteligent Physical Agents*
GUI	*Graphical User Interface*
HTTP	*Hypertext Transfer Protocol*
JADE-S	*JADE Secure Agent Platform*
MA	*Meta Agent*
PA	*Production Agent*
PDA	*Personal Digital Assistent*
PEE	*Passive Extra Enterprise*
PMA	*Production Management Agent*
PPA	*Production Planning Agent*
SCA	*Security Certification Authority*
SSL	*Secure Socket Layer*
WAP	*Wireless Application Protocol*
XML	*Extensible Markup Language*

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CONTACTS

Petr Bečvář
CertiCon, a.s., Applied Research Department
Václavská 12, 120 00 Praha 2, Czech Republic

Petr Charvát
CertiCon, a.s., Applied Research Department
Václavská 12, 120 00 Praha 2, Czech Republic

Michal Pěchouček
Gerstner Laboratory, Agent Technology Group
Department of Cybernetics, Czech Technical University in Prague, Technická 2, 166 27, Prague 6, Czech Republic
pechouc@labe.felk.cvut.cz

Jiří Posíšil
CertiCon, a.s., Applied Research Department
Václavská 12, 120 00 Praha 2, Czech Republic

Aleš Říha
Gerstner Laboratory, Agent Technology Group
Department of Cybernetics, Czech Technical University in Prague, Technická 2, 166 27, Prague 6, Czech Republic

Jiří Vokřínek
Gerstner Laboratory, Agent Technology Group
Department of Cybernetics, Czech Technical University in Prague, Technická 2, 166 27, Prague 6, Czech Republic