Expectations and Deployment of Agent Technology in Manufacturing and Defence: Case Studies

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ABSTRACT

Agent technology provides the manufacturing and defence with novel technological concept. This concept has been deployed in a number of different application throughout last few years. This contribution provides the readers with several case studies of agent deployment both in manufacturing and defence. Based on our experience the generalization of agents' applicability in these industry sectors is provided. We also discuss matching of the industry demands and expectations with agent technology promisees and real performance.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

General Terms

Management, Performance

Keywords

agents, multi-agent systems, production planning, manufacturing, defence applications

1. INTRODUCTION

The agent research community consolidated significantly in the last few years, especially by formalizing foundations of agent based computing, positioning of the domain with respect to adjacent fields of theoretical research such as formal logic, game theory, theorem proving and model checking, distributed and parallel computing, scalability and complexity theories. Within the community, there are also many research activities that are closer the potential business applications, such the closely related fields of semantic web, open systems and ubiquitous computing systems. All the achievement in these fields form a solid foundation for massive technology transfer from the university labs and research institutes towards the industry applications.

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While there is a reasonable amount of interaction between the research and industry, the main bottlenecks in fast and massive adoption of the agent-based solutions in industry are:

- limited awareness about the potentials of agent technology in industry - agents are used in few specialized disciplines, while they remain unused in the others where they fit
- limited publicity of the successful industrial projects with the agents
- misunderstandings about the technology capabilities [1], overexpectations of the early industrial adopters and subsequent frustration (Section 5)

On the other hand, agent-based technologies and designs have become very popular in the defense domain. Successful projects in the domain of the command & control, transmissions, environment sensing and battlefield communication are in the process of transformation from the prototype stage towards future applications. In this article, we will discuss both industrial and defense projects and show the differences and strengths of very different applications of the same technology. Historically, the R&D costs of many successful technologies were funded by defense projects and only subsequently used in the industry. In the multi-agent field, we expect to enrich the current industrial applications with both the experience and references from the defense domain.

This contribution is based on our longer term experience in deployment of the agent-based systems in industry and defense domains. It classifies the properties of the problems and domains where where the application of agent technology brings efficient solutions and we also present the counter-examples of technology misuse and overexpectations.

2. OPPORTUNITIES FOR AGENT DEPLOYMENT

Agents as a paradigm and the available agent techniques are considered to perform well in application domains with certain specific properties.

- **Competitive** and **non-cooperative** domains, where the restrictions on the information sharing prevent the use of the centralized decision-making architecture [2], e.g. E-commerce applications, supply-chain management and e-business. In this case, agent paradigm is used to design and describe the systems that are currently mainly web-based.

- Domains where the data required for automated decision making **are not available centrally** due to the geographical distribution of the knowledge (e.g. logistics, collaborative exploration, mobile and collective robotics, pervasive systems) or the environments with partial or temporary communication inaccessibility. Besides geographical distribution, it is also temporal distribution (eg, in satellite networks, where satellites have different views of the earth at different times of the day), and conceptual (eg, in layered hierarchies, where entities at one layer may have no knowledge of events or processes at other layers, as in the Internet or in supply chains)

- Domains where **survivable time-critical response** and high robustness in distributed scenarios are required: This is the field of time critical manufacturing or industrial systems control [3, 4], where replanning, or fast local reconfiguration is required to handle problems instantly.

- **Simulation and modelling** domains: Using agents for simulation purposes has been very common, while the right justification was often missing. Agents can be deployed in simulation exercises where we require easy migration from the simulation to real environment.

- Domains with **complex problems solving**: This has been the greatest overexpectation of the agent technology in industry. A simple use of agent techniques cannot solve the NP-complex problems and the potential of decreasing the computational requirements for problem solving is limited, but possible.

- **Open systems engineering** has been emphasized in the first projects, but the reality fails to deliver on expectations. While the ontologies and FIPA standards[1] have addressed many syntax issues, the semantics remains problematic. Web services and web technologies in general seem to take lead in the applications in this area.

It is interesting to note that most of the characteristics above fit the military domain, but fail to address the problem the industry has now. However, the "Power to the Edge" principle [5] that changes the mode of control of modern armies from rigid hierarchies towards more peer-to-peer approach with hands-off control seems to be gaining significant support in the enterprises who also seek to reduce the cost of management control.

The functionality requested by either manufacturing or defence can be classified into requirements for:

1. planning, scheduling, resource and strategic decision making,

2. diagnostics, control and real-time replanning,

3. software systems integration, interoprability,

4. integration of knowledge, ontologies and

5. simulation and modelling

[1] `http://www.fipa.org`

According to our experiences, specified in details within the paper, the predominant demand in manufacturing is on planning, scheduling and resource allocation. In rare cases agent based simulation and modelling of the production processes is also requested, while very often the classical modelling and simulation techniques are used (petri-nets, control theory).

In defence investigation of agent technology deployment is often requested for modelling and simulation. There has been also a great deal of attention paid to system and knowledge integration, real-time control, cooperative planning and resource allocation.

In the following we intend to present and comment on several applications that we have been engaged in previously. Based on our experience we provide a more unified view on applicability of agent technologies in manufacturing and defence. It needs to be noted this is not a review paper of the available technologies. The ambition of the paper is to provide a small collection of case studies illustrating our longer term engagement in agent applications. Besides suggesting in which application domain the agent technology fits the best, we also wanted to illustrate what are both the unspoken expectation and specific technological demands in manufacturing and defence.

3. CASE STUDY DOMAIN: MANUFACTURING

Aa mentioned previously, in manufacturing there is demand for applications addressing primarily planning, control, supply-chain and diagnostics. While there exist diagnostics and supply-chain agent-based application, in the following we will be mainly discussing planning and scheduling.

The typical problem of planning and scheduling in manufacturing is to allocate manufacturing activities to the available resources in the most optimal way so that manufacturing constrains are not violated. Manufacturing constrains are usually given by the manufacturing process specification and include a component list for a specific product, list of manufacturing activates, causal relation and list of possible manufacturing resources that can be allocated to an activity. Besides manufacturing process specification, an important input to the planning process is also current load and future commitment of the manufacturing resources.

We have experience in planning two different types of production: **mass production** and **project-oriented production**. In either of the domains we have used the ExPlanTech multi-agent system, that has been developed in part within the IST-1999-20171 European project.

3.1 ExPlanTech Architecture

The ExPlanTech framework [6]adopts the ProPlanT multiagent architecture [7]. It contains an approximately fixed number of nontrivial agents, each providing different system functionality for example, planning, simulation, and user access. We built ExPlanTech on top of the Java Agent Development Environment using JADE platform [2].

ExPlanTech system includes following types of agents:

- **planning agents** – responsible for configuration, planning, scheduling, decomposition and resource alloca-

[2] `http://jade.tilab.com`

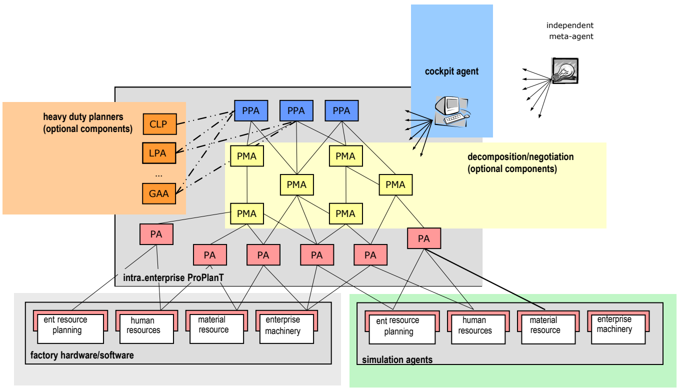

Figure 1: ExPlanTech Architecture

tion,

- **resource agents** – representing and modelling available manufacturing resources (CNC machinery, cad designers, workshops, etc.)
- **cockpit agents** – a graphical user interface allowing a multi-user access to the community of agents,
- **extra-enterprise agents** – allowing an access to the planning agents and planning data from outside of the factory.

3.2 Project-Driven Production

ExPlanTech has been firstly deployed in the pattern shop Modelarna Liaz who is manufacturing dies, casts and molds for the European car industry. Production is clearly project-driven, as a single (ore very limited number of) product has been always manufactured from one design. Given the high replaceability of production elements, variability of the manufacturing processes, high average occupancy of the manufacturing elements and short delivery times, the resource allocation process has not been trivial. Given the fact that a project consisted on average of 5 - 10 production processes, where almost each process can be further divided into high number of small subprocesses we are talking about a state-space well over 10^{10}.

In Modelarna Liaz there are 20 resource agents integrate three 5-axe CNC machines, one wood workshop (containing 5 people), one metal workshop (containing 10 people), twelve CAD designers and one finish workshop. The planning agent is supposed to decompose the production process into activities and task the resource agents. The difficulty is given by the fact that the optimal decomposition depends on the availability of the resource agents while their availability depends on the requested activity which is a result of the respective decomposition.

Resource allocation process has been implemented by means of a *iterative subscription-based-protocol* (ISBC)[8]. The planning agent subscribes the resource agents for meta-representation of their occupancy (as a function of the amount tasked). *Linear function* has been used as an estimate of the resource agents occupancy. The planning agent uses this estimate for suggesting the most optimal project decomposition. The planning agent requests resource agents for the resulting amounts.

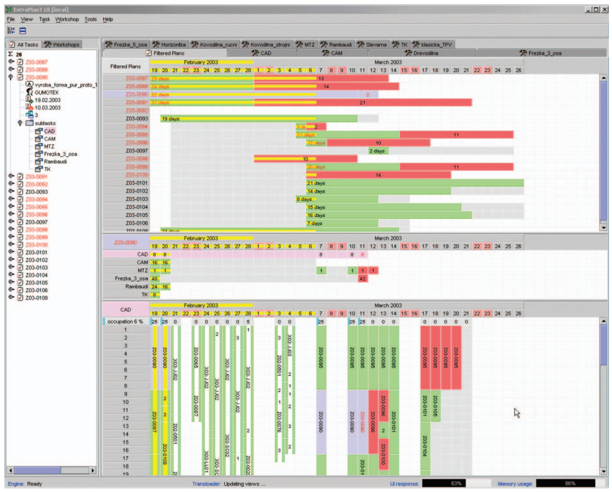

Figure 2: ExPlanTech GUI

It may happen that the estimate has not been accurate. If this is the case the resource agent reject to provide the resources as expected and sends the planning agent a counterproposal. This counterproposal is used for an update of the estimate and new decomposition proposed by the planning agent. Within a very small number of iterations the decomposition was very close to optimum.

3.3 Mass Production

Yet another application arena of the ExPlanTech multi-agent system was in planning mass-oriented production [9]. While deployment in Modelarna Liaz has been implemented jointly by the Gerstner Laboratry at the Czech Technical University and CertiCon, a.s., the mass-oriented deployment at SkodaAUTO has been coordinated by gedas, s.r.o. The SkodaAUTO has successfully applied the derivative of ExPlanTech technology to design a robust planning system for car engine manufacturing. This exemplifies high-volume production plant producing thousand of engines every day. A high variability exists in the types of motors to be manufactured. The planning system needed to provide us with detailed plans for a six weeks period, under following constraints:

- minimizing the volume of the store, while do not get over the store capacity and below the minimal required store volumes
- maximizing the production uniformity, in order to minimize the unnecessary handling of products between successive steps, and
- complying with the production requirements (amount and due date)and the production restriction (e.g. higher priority order, shortage of specific material, etc.).

While at the stage when we got involved in the project the primary development target has been a stand-alone planning system, the further requirements were directed towards an open, interoperable and highly flexible system. It has been planned to allow integration with production monitoring and control tools, allow real-time time re-planning in case of demand changes or production anomalies and allow easy and straightforward process reconfiguration of the planning tool at its run-time.

The planning solution has been implemented on two two independent levels:

- **longer-term planning** – On a higher level, planning module produces a rough plan. This plan specifies an approximate amount of engines to be produced each day so that all the requested constraints are met.
- **daily scheduling** – On a lower level the algorithm shall order the daily production in a sequence of lots so that uniformity of the production is maximized and all constraints are respected. Given the fact that the adjustment of the line for different type of motor takes some time and the production pace is not uniform, the daily load is always different than planned by longer-term planning. This causes conflicts and daily scheduling and automatic replanning shall also address this issue.

The planning task has been structured so that the higher level scheduling can be solved by iterative application of classical methods of linear programming. For the implementation a free third party LP solver was used, together with communication and data transformation wrapper. The whole scheduling takes less then 1 second on standard PC (with 28 days, 50 products and 3 lines).

Daily scheduling is conceptually distributed among the several agent's representing the manufacturing entities: production lines, store buffers and conveyor belts. Each agent carries out ordering of its daily load by a simple optimization mechanism based on a greedy algorithm, as the likelihood of replanning in the future nulls the advantages of more sophisticated methods. Each agent is also responsible for on-line production control, local or peer-to-peer replanning and escalation of severe problems to the centralized planner, so that they can be handled by the factory as a whole.

Unlike in the previous case, the functionality described here can be well achieved by a centralized algorithm without any needs for distributed computation. The main motivation for the agent based solution in this case was an explicit request from the customer for the multi-agent system deployment, so that the change in the plant configuration can be both simulated by the planning system to evaluate the rentability and realized without significant re-programming.

3.4 Supply-Chain Management

The customers at Modelarna Liaz were satisfied with the solution provided and they initiated a new project where the existing agent-based planning middleware would be expanded towards the external partners. As in project driven manufacturing some part of the project activities gets often outsourced (especially in the situations when the the factory gets overloaded) a technology for intelligent coordination with the suppliers and outsourcing partners has been requested.

The existing architecture of ExPlanTech has been extended by two classes of agents:

- **extra-enterprise agent** (EE) – handling the access to the planning system from outside of the company (via internet browser, via PDA devices and WAP enabled telephones)

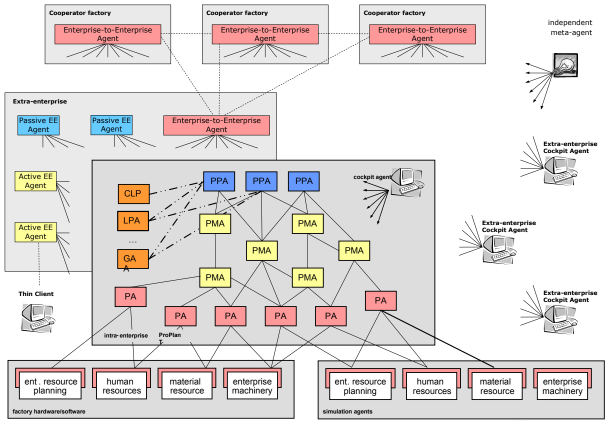

Figure 3: Extended ExPlanTech Architecture

- **enterprise-to-enterprise agent** (E2E) – allowing selective information sharing and cooperative planning with the resource allocation system used by the suppliers' and outsourcing partners' companies.

The E2E agent allow integration of (i) a yet another ExPlanTech system at the side of a supplier (ii) a third-party ERP system used by the supplier or (iii) a simple MySQL database with a servlet-based front-end where the suppliers can maintain their offers and commitments.

The system has been implemented and is currently in the site testing phase (unlike the previous two cases that are in routine use these days).

Besides integration capabilities (e.g. set of FIPA interoperability standards) the use of agent technologies is here clearly justified as the planning data cannot be stored locally at one place. The partners in the supply chain are not willing to reveal the full knowledge about their intentions, plans, commitments and resources. This is why it is not simply possible to collect the resource allocation related data at the servers managed by Modelarna Liaz. The subcontracting and delivery plans need to be elaborated by negotiation. In similar manners as previously, this information uses the planning agent at Modelarna Liaz for designing the right decomposition and subcontracting among the collaborative parties.

4. CASE STUDY DOMAIN: DEFENCE

Worldwide defence agencies are interested in deployment of agent technologies in a wide range of application domains ranging from low-level diagnostics and system control (e.g. warship chilling systems [3]), interoperability in coalition operations [10, 2], teamwork modelling and simulation, adversary modelling or networking in the disruptive environments [11, 12]. In the following we briefly summarize our experience with deployment of agent technologies in some of these areas.

We were involved in multiple research effort with the US defence agencies, where the most of them were engaged in modelling and simulation of complex activities with a subsequent algorithm transfer to real hardware or prototypes. Therefore the requirements for the multi-agent environment were (i) high scalability and operational efficiency, while maintaining (ii) readiness for migration towards distributed environment. The multi-agent environments available support either high level of openness, distributed operation and run-time reconfiguration or scalability and efficient operation of a high number of interacting autonomous agents. This is why we have developed a novel multi-agent environment $\mathcal{A}$-**globe** [3] [13] that besides the two listed requirements also supports autonomous agent migration, inaccessibility and environment simulation[4].

As an example of two defense oriented systems, we will present underwater mine exploration exercise and ad-hoc networking in disruptive environment.

4.1 Exploration

The NAIMT underwater exploration exercise[5] features a group of unmanned underwater robots whose task is to explore a wider underwater area and identify suspicious objects that may be mines. Robots communicate by means of acoustic modems. The trouble of the acoustic modem is that its bandwidth decreases with the distance between two robots. Therefore once an agent finds a mine it needs to interact with other robots so that they may form a feed that would relay a high resolution picture or a video sequence to the marine base where the human operator can evaluate the object.

We have made few simplifying assumptions. The variable bandwidth has been approximated by two communication reaches – the short for high volume data and a longer for coordination messages. Furthermore, flat surface with no obstacles has been assumed and the physical mode of robot movements have been simplified.

Each robot consists of several components, implemented as $\mathcal{A}$-**globe** agents running within one agent container: (i) **Robot Pod** simulator, managing robot moves, (ii) **Mine Detector** simulator, (iii) **Video** data acquisition and transmission element and (iv) **Robot Coordinator** implementing search algorithm, transmission coalition establishment and negotiation.

As the system is a military one, central coordination element would provide an adversary with a target of choice. Therefore, the group coordination is completely decentralized and managed by robots themselves, using three different algorithms for feed establishment.

- **level-1** Each robot can become a coordinator for a single feed planning process if it founds a mine. It plans the path and request other robots to move into the assigned positions.

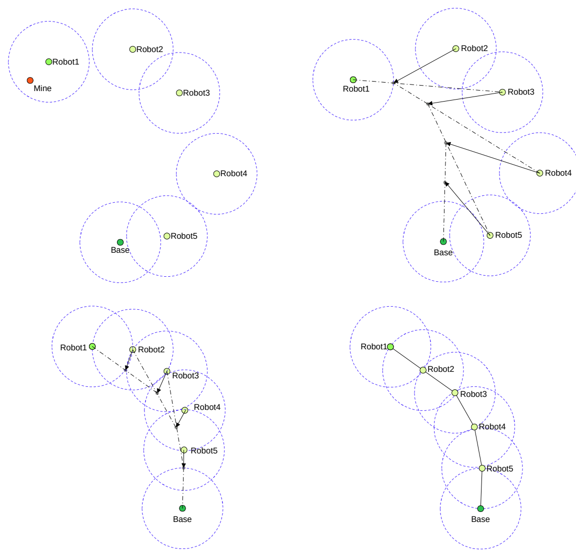

Figure 4: Feed formation process

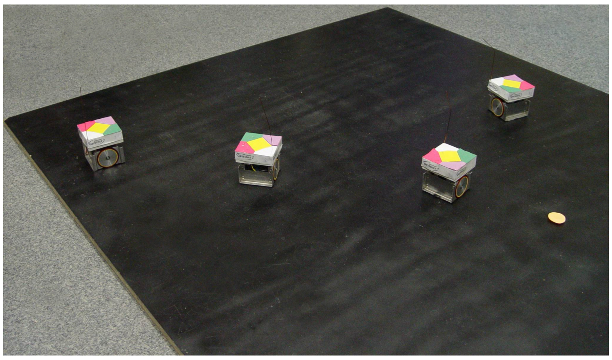

Figure 5: RoboCup Soccer deployment

- **level-2** The robots that are supposed to form the feed are also selected by the coordinator and each selected robot locates its desired position autonomously so that the feed is established.

- **level-3** Each robot in the transmission feed recruits the next collaborator and the feed building process propagates along the path.

The level-1 and level-2 distribution is desired to increase efficiency, flexibility and survivability of the coordination process. The level-3 distribution of the coordination can be justified only in the situations when it is impossible to bring all the planning information to the coordinator. This is very often the case of semi-trusted environment (not our case) or in the situations with very large area and small number of agents.

Besides the forthcoming integration of the coordination agents with the FlexFeed [12] platform used in the military prototypes, we have validated the technology in the simulated environment using the RoboCup soccer robots. In this case, simulation agents have been replaced with hardware inputs from the robots.

[3] `http://agents.felk.cvut.cz/aglobe`

[4] $\mathcal{A}$-**globe** has been awarded an Innovation Award at Cooperative Information Agents Workshop, 2004 in Erfurt. Similar to JADE $\mathcal{A}$-**globe** provides platform, containers, service and agent template. In addition there is a simulation agent that models the real environment and is replaced in the process of migrating the technology from a model to the real environment. After series of tests (memory consumption, avgRTT - message average round trip) implemented by Rockwell Automation Research Center it has been identified that $\mathcal{A}$-**globe** is substantially more efficient and lightweight in comparison to JACK, ZEUS, JADE and FIPA-OS [14].

[5] The underwater exploration exercise has been in parts funded by ONR within the NAIMT and N00014-03-1-0292 projects. We have closely collaborated in this exercise with researchers from IHMC, Florida.

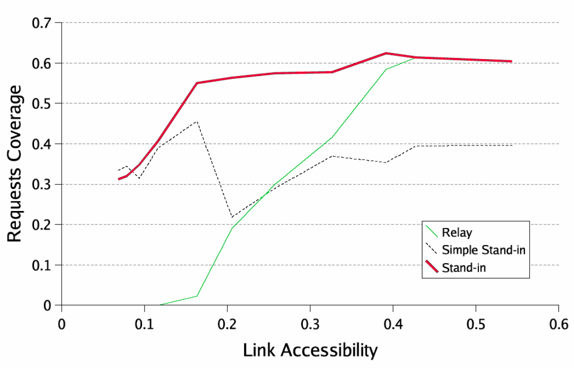

Figure 6: Operation of the stand-in agents

4.2 Ad-hoc Networking

In the other class of scenarios, we also address the problem of the communication inaccessibility in the community of mobile devices. However, in this case, we use agent technologies to ensure system synchronization – mutual awareness of distributed actors – with no or minimum interference with system operation – we don't ask system entities to change their positions to relay the information. Compared to the ad-hoc routing [15], we don't need to establish completely connected networks where the nodes route the information. Instead, we rely on the social knowledge [16] and stand-in agents [17].

Stand-in agent stands on the of the communication middleware and allows the agents to plan commitments even if they are temporarily inaccessible. The stand-in technology is (unlike classical network solutions) domain dependent. Stand-in agent is a reasoning and knowledge rich-copy of an agent who is inaccessible. The inaccessible agent may have wished to dispatch stand-in agents to regions of the network that has got a high potential of become inaccessible. When accessible the stand-in agents continually synchronize their knowledge with their owner.

Using the simulated humanitarian-aid logistics scenario to measure the cooperation quality in the system, defined as a percentage of satisfied requests for goods in the disaster area. This cooperation quality varies in function of system accessibility and used communication method (see Figure 6). The behavior of the simple relaying agents (the thin line), simple stand-in agents (dashed line) and stand-in agents who also synchronize the information one with another if their accessibility the owner is alike (thick line). We see that in highly inaccessible environment both versions of the stand-in agents outperform the relaying, while in the reasonably connected environment the simple stand in is rather inefficient. The sophisticated stand-in agent acts better then in either environment and profits from the scale-free characteristics of the network with intermediary accessibility, where it outperforms both the conservative stand-ins and relaying.

Note that the use of social knowledge gives the same results as the use of stand-ins- the system robustness and usability domain increases significantly. Currently, we are integrating the stand-ins and social knowledge into the FlexFeed [12] infrastructure to support opportunistic proactive networking between the military teams in the battlefield.

5. CONCLUSIONS

In this contribution we have illustrated that industry has got a wide range of demands and expectation on the agent technology and its practical deployment. Significant part of industrial and defense partners is aware of the potential of agent technology but is still looking for a ground-breaking successful deployment case that would clearly justify the extra cost of the multi-agent development.

Different application domains expect the agent technology to contribute to different classes of problems. According to our experience from working with industry for a longer time we have identified a list of the most common misunderstanding and overexpectations that the agent-technology enthusiasms may cause:

1. **Complexity**: It is often expected that agents technology can contribute to solving very complex (perhaps NP-hard) problems. By our experience, this is obviously incorrect.

2. **Black-Box**: Agent technology is often viewed as a black box technology (such as neural network, genetic algorithms) that can be fitted in for solving a particular complex problem. Agent technology provides primarily a system concepts and design paradigms that is useful in well defined classes of problems.

3. **Intelligence**: Agents problem solving, domain specific intelligence is not the issue studied (and being delivered) primarily by agent-based computing. The prime concern of agent researchers is their collective behavior and decision making, while the application of the technology to real-life problems is often overlooked.

4. **Agentification**: Process of agent integration and legacy systems encapsulation is considered to be fully automated. There is no sophisticated mechanism that would encapsulate any legacy system in fully automated way. Alternative technolgies (e.g. web services) are often used these days.

5. **Interoperability**: Standards and interoperability are computationally expensive. It is not wise to use full FIPA compliance in system where full openness is not necessary (e.g. in simulation and modelling).

6. **Learning**: The potential of learning in multi-agent systems is frequently overestimated. It is often thought that an agent shall be super-adaptable and able to accommodate to any requested behaviour (this comment is closely connected to comments 3 and 4).

7. **Mobility**: Agent mobility is often claimed as more inevitable and essential then actually required. Very often migration of data or simple communication is sufficient as opposed to migration of agent's code and state.

In this paper, we present the cases that show that the agent technology can be successfully used both in industrial and defense context. However, there are some significant differences between the two worlds. The most significant difference is the fact that defence agencies are ready to fund the prototype and demonstrator research that allows the careful evaluation of the real technology capabilities and therefore avoid unpleasant (and costly) surprises while working on the real projects. The experience acquired during the demonstration and field exercises have helped the clients to identify the real strengths of the agent technology – robustness, embeddability, opportunistic ad-hoc integration and reliable rapid response to local stimuli. Coincidentally, the new organizational doctrine adopted by armed forces [5] requires such capabilities and ensures that agents or derived technologies will be deployed on the battlefields in the near future.

In the industry, the situation is different. Enterprise budgets dedicated to new technology R&D or buying are more constrained than in the defense sector. Therefore, the industry adoption of the technology was driven not by the real capabilities, but by the needs of the clients who were promised a silver bullet solution for their problems. However, our experience have shown that the results are mixed. The agent technology can be generally deployed in industrial process control and diagnostics. According to our experience, the potentials and added-values of deployment of agents for planning, scheduling and resource allocation needs to be well analyzed and justified in order to meet the expectations. Agent technology can be used as an enabler of intelligent integration of different advanced AI planning solution. Agent technology also provides competitive advantage by its capability to integrate the hardware support for monitoring (and possibly control) of the manufacturing process. For planning in the self-interested distributed domains, the techniques of inter-agent negotiation are essential. Besides there is also a number of advanced agent techniques (from game theory, auctioning, negotiation, working with inexact and approximate information, nature inspired collective behavior) that provide an interesting alternative for suboptimal planning.

However, we shall avoid further overselling of the technology in the domains where it is not competitive and concentrate on the areas where the performances of the multi-agent systems justify the extra costs – ubiquitous computing, distributed process control, autonomous robots, sensor networks and other applications. We shall be careful enough not to provoke the hype and disillusion that would disqualify the agent systems from future applications. Many industries have recently started the business transformation processes similar to those in defense and careful application of agent technologies can help them in this process.

6. REFERENCES

[1] Wooldridge, M., Jennings, N.R.: Pitfalls of agent-oriented development. In: AGENTS '98: Proceedings of the second international conference on Autonomous agents, ACM Press (1998) 385–391

[2] Allsopp, D., Beautment, P., Kirton, M., Bradshaw, J.M., Suri, N., Knoblock, C.A., Tate, A., Thompson, C.W.: Coalition agents experiment: Multiagent cooperation in international coalitions. IEEE Intelligent Systems **17** (2002) 26–35

[3] Maturana, F.P., Tichý, P., Staron, R.J., Slechta, P.: Using dynamically created decision-making organizations (holarchies) to plan, commit, and execute control tasks in a chilled water system. In: DEXA Workshops. (2002) 613–622

[4] Bunch, L., Breedy, M., Bradshaw, J.M., Carvalho, M., Suri, N., Uszok, A., Hansen, J., Pechoucek, M., Marik, V.: Software agents for process monitoring and notification. In: SAC '04: Proceedings of the 2004 ACM symposium on Applied computing, ACM Press (2004) 94–100

[5] Alberts, D.S., Hayes, R.E.: Power to the edge: Command and control in the information age. Technical Report ISBN 1-893723-13-5, DoD Command and Control Research Program (2003)

[6] Pěchouček, M., Říha, A., Vokřínek, J., Mařík, V., Pražma, V.: Explantech: applying multi-agent systems in production planning. International Journal of Production Research **40** (2002) 3681–3692

[7] Mařík, V., Pěchouček, M., Štěpánková, O., Lažanský, J.: Proplant: Multi-agent system for production planning. Applied Artificial Intelligence **14** (2000) 727–762

[8] Pěchouček, M.: Role of subscription based contraction in agent based production planning. In: EUMAS. (2003)

[9] Rehák, M., Charvát, P., Pěchouček, M.: Agent system application in high-volume production management. In: Emerging Solutions for Future Manufacturing Systems, New York: Springer (2004) 193–200

[10] Allsopp, D., Beautement, P., Bradshaw, J.M., Carson, J., Kirton, M., Suri, N., Tate, A.: Software agents as facilitators of coherent coalition operations. In Shavlik, J.W., Dietterich, T.G., eds.: 6 th International Command and Control Research and Technology Symposium. US Naval Academy, Annapolis, MD, USA (2001)

[11] Estrin, D., Culler, D., Pister, K., Sukhatme, G.: Connecting the physical world with pervasive networks. IEEE Pervasive Computing **1** (2002) 59–69

[12] Suri, N., Carvalho, M.M., Bradshaw, J.M., Breedy, M.R., Cowin, T.B., Groth, P.T., Saavedra, R., Uszok, A.: Enforcement of communications policies in software agent systems through mobile code. In: POLICY. (2003) 247–250

[13] Šišlák, D., Pěchouček, M., Rollo, M., Rehák, M., Tožička, J.: Simulating agents' mobility and inaccessibility with A-globe multi-agent system. In: Multiagent System Technologies 2004. (2004)

[14] Vrba, P.: Java-based agent platform evaluation. In Mařík, McFarlane, Valckenaers, eds.: Holonic and Multi-Agent Systems for Manufacturing. Number 2744 in LNAI, Springer-Verlag, Heidelberg (2003) 47–58

[15] Woo, A., Tong, T., Culler, D.: Taming the underlying challenges of reliable multihop routing in sensor networks. In: Proceedings of the first international conference on Embedded networked sensor systems, ACM Press (2003) 14–27

[16] Pěchouček, M., Mařík, V., Štěpánková, O.: Role of acquaintance models in agent-based production planning systems. In Klusch, M., Kerschberg, L., eds.: Cooperative Infromation Agents IV - LNAI No. 1860, Heidelberg, Springer-Verlag, Heidelberg (2000) 179–190

[17] Rehák, M., Pěchouček, M., Tožička, J., Šišlák, D.: Using stand-in agents in partially accessible multi-agent environment. In: Proceedings of Engineering Societies in the Agents World V, Toulouse, October 2004. Number 3451 in LNAI, Springer-Verlag, Heidelberg (2005) 277–291