MODELLING FLEXIBLE MANUFACTURING SYSTEMS AS MULTIAGENT SYSTEMS

(MAS)

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ABSTRACT

Manufacturing processes, as a ‘chunk’ of any business organization, must be viewed as ‘social’ systems. Moreover, the new information economy ‘push’ companies toward a new conceptualisation of management activities. Autonomous and intelligent Flexible Manufacturing Systems (hereafter FMS) are claimed to face the challenge of satisfying new markets, where changes happen so fast that only the best companies will succeed.

Our proposal of intelligent and autonomous FMS is subsumed into a general architecture FAMSA (Flexible Autonomous Management System Architecture) we developed to face virtual economies to come. Indeed it is a promising research field from MultiAgent Systems technology. A similar purpose is faced by other groups. We will describe the common features between our approach and those.

The paradigm of autonomous cooperating agents will allow us to handle unforeseen changes and disturbances, like any other normal operation, along the management process. But here we focus on production tasks. Our agents have encoded their knowledge in production rules, and they will be able to learn from past events. The rulebases are firstly validated on a programming language that corresponds to a logical formalism to model organizations. The results are translated to a procedural object-oriented language for real time applications.

The machines and robots of a FMS interact in different modes, and communicate through a well established communication protocol. There is also communication with humans and/or at least with a Master Production Plan. We describe a model to build these entities as artificial agents, looking for cooperation, but this agents will never compete.

Keywords: Flexible Manufacturing Systems, MultiAgent Systems, Decision Support Systems

1. ARCHITECTURES FOR BUSINESS PROCESSES MANAGEMENT.
MultiAgent Systems (MAS) have become the key information technology for the next generation of manufacturing control. As Steiner (1998) states, one of the key advantages of MAS technology is the support it offers in integrating and coordinating heterogeneous systems in a distributed and open environment. This advantage is increasingly being put to use in industrial environments, in particular, where components are provided by different companies or groups (the new information economy we face up).

As we are engaged with the industrial application of this technology, we must enable the users to design and program successful MAS in real environments. We agree with Bussmann (1998) that MAS technology implies in particular that engineers should handle the design and programming of agent-oriented control systems, in a straight-forward and efficient manner. It raises an important challenge: apart from functionality, successful applications\(^1\), in an industrially used manufacturing system, must satisfy: reliability, fault-tolerance, maintainability and transparency.

Some agent-oriented architectures have been showed in the literature to handle the business and production processes before related. MASCADA (Brueckner, 1998) i.e. (manufacturing control systems capable of operating production change and disturbances) is aimed to tackle and resolve the upstream research issues for the development of manufacturing control systems, in the sense Bussmann claimed. ADEPT is also a general multiagent architecture for the management of business processes (Norman et al. 1998), although we find that it is mainly intended to high level communicative relationships. Both architectures are grounded in a multiagent basis, but they are not feasible to support the new organisative and productive functionality we are describing. The first one is well suited for control of current industrial applications. The second one is engaged with organization and communication processes.

Our work entails and is built up from a general model of knowledge. This feature is an important feature in other models: SHEL (Edwards, 1972), Human Problem Solving (Rouse, 1983), Step-Ladder/Skill, Rule, Knowledge (Rasmussen, 1986), or Contextual Control Model [COCOM] (Hollnagel, 1993).

We propose a general architecture for virtual companies, and within this framework, a more specific architecture for manufacturing systems, as subagents of those companies. This is named FAMSA, that stands for Flexible and Autonomous Management Systems Architecture (see figure 1). This architecture represents the framework for our systems. The final goal is to build the real global communicative system and the virtual entities that allow the autonomous functionality.

2. ‘FAMSA’ AND INTELLIGENT DECISION SUPPORT SYSTEMS

We have been engaged in the development of intelligent agents which may support the mental functions of decision-makers in an autonomous manner. This agents have been used to deal firstly with artificial scenarios we define to check the accuracy

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\(^1\) The FIPA (Foundation for Intelligent Physical Agents) has been founded in 1996 in order to promote the successful use of agent technology by establishing common frameworks and interfaces for the interaction between agents and their physical and software environments.
of that implementation. Three control modes are envisaged: Functional, Tactical and Strategic.

This modelling approach is a social one in the sense that it involves designing artificial agents that exhibit human skills, as communication, cooperation, etc. The cognitive architecture underlying the agent conceptualisation guarantee that the design and the purpose are not binded. So, our artificial agents could handle unexpected situations (such as emergency problems) as humans do, but reducing the probability of human managerial errors. From this view, we are building an intelligent decision support system (IDSS).

We join the group embracing the integration of two not so different perspectives on agents: psychologists and sociologists on one side, and engineers on the other. The cognitive scientific approach is based on identification and analysis of human behavioural features, while the engineering perspective applies knowledge to new useful artifacts. As Gadomski & Zytkow (1993) assert, a model of intelligent systems would be advantage for both, the cognitive and the engineering perspective, enabling us to organize the study of human rational behaviour, to formalize it, and to design artificial systems similar to humans capacities for real world problem solving.

As far as we are concerned, our work is not very different of the Intelligent Decision Support System people at ENEA are developing, as both means the designing agents that handle abnormal situations as humans perform. We can only find two differences:

a) The cognitive architecture we adopted is ACT-R theory (Anderson, 1993). This theory enables the definition of human skills as production rules systems, and declarative knowledge and procedural knowledge are well differentiated. A general functional theory of interactions between an abstract intelligent agent and its domain of activity is used in the ENEA’s projects to build IDSS: the TOGA personoid architecture² (http://www.casaccia.enea.it/ing/tispi/gadomski/gadpe01.htm).

b) Our current targets are somewhat different. They are involved in pure emergency management treatment. Notwithstanding, their idea of a Global Emergency Management Information Network is not far away from our view of forthcoming global companies. The management activities are similar in both networks.

3. THE MULTIAGENT SYSTEM: ‘FAMSA’.

This paper makes a first step towards an agent-oriented architecture to operate manufacturing control of FMS in global companies. Roughly speaking, a FMS is a set of robots and numerical controlled machines that work together to make some goods. When we extend the production capabilities to a global frame, the complexity to coordinate production and

² TOGA stands for Top-down Object-based Goal-oriented Approach. Personoid is an abstraction of certain functions of human mind which can be considered as a basic entity for any intelligent goal-oriented system. The construction of personoids is founded on elementary relations between the following basic concepts: information, knowledge, preferences and goals.
delivery to supply the market is highly increased.

In such a context, to deal appropriately with complexity, we should classify the agents, as Brassel et al. (1997) suggest:

*Reactive agents* react to messages from their surroundings by sending other messages to other agents and by actualizing the inner representation of their surroundings. All this happens according to fixed rules or plans which cannot be changed by these agents.

*Intentional agents* have the same capabilities as reactive agents. Applying metarules they are even capable of defining goals. They can detect conflict between goals, set priorities and design plans to achieve their goals, and they can also be informed about each other’s goals, assumptions and actions.

*Social agents*, as an additional feature, have explicit models of other agents. This is why they are capable of reasoning about other agent’s goals, expectations, motives and capabilities, and to include them into their action plans.

Modelling MAS involve three stages: analysis, design and implementation. The design process depends on the cognitive theory and the selected language for programming. We remark that we will build cognitive skills as production rules evolving in the time. Our agent modify mental models in the metalevel through a model of endorsement we adopted from Moss (1998).

The first step undertakes three main tasks: system specifications, description of embodied entities, and communicative channels relation. The main elements in our FMS system are:

The supervisor, a *Unique Master-Agent* that controls the agents (robots and CNC machines) in an efficient way. It is a social agent that communicate with other supervisor in the same level, with higher-level managers and with clients.

*Communication* flows between agents. Agents have private and public information, and they can communicate with each other. The Master-Agent registers every message within its database.
Reactive Agents can communicate to accomplish the tasks the supervisor order to them in a cooperative way (even with physically distributed similar units).

The design embraces a more detailed task: the agents’ skeleton, and the definition of communicative protocols. In figure 2 the functional communicative protocol is showed.

Agents are defined as subtypes arranged in a type of hierarchy which corresponds to a module. Our first target is programming rulebases to define agent’s behaviour. This rulebases will be consistent with the logical formalism FOSGAL\(^3\) of the programming language SDML\(^4\). The second one is related with encoding knowledge in an efficient manner. We distinguish between declarative knowlege in permanent memory of agents, and procedural knowledge, obtained firing rulebases and looking for the most successful models.

It should enable the transcription of knowledge based systems in a more real-time efficient language. Here starts the engineering work, mainly engaged with the definition of real decision support systems operated by artificial intelligent and autonomous agents.

4.- WHERE ARE WE?

We define the next agents as components of a general FMS multiagent system: robots, CNC machines, virtual agents (customer and other factories) and the central supervisor/manager. We report the current state of our work:

a) To define a real-time supervisor we need to combine the human creativity in resolving abnormal unforeseen situations (the cognitive model), and efficient algorithms to schedule operations according to goals (sometimes conflicts between goals appear). We are looking for any algorithms (Zilberstein and Russell, 1994) to solve scheduling in an efficient time-consuming way.

b) We are developing models for top-level managers who can deal emergency situations (financial crisis, climate catastrophes, etc.) and bargain in complex environments (López & Hernández, 1999).

c) We have modelled collision between mobile robots. If the robot is forced into a position where collision is sure, it tries to resolve this conflict communicating with its partner. If it cannot be solved, a message is sent to the supervisor looking for assistance (see figure 3).

\(^3\) FOSGAL stands for Fragment of Strongly Grounded Autoepistemic Logic.

\(^4\) SDML stand for Strictly Declarative Modelling Language.
d) The communicative process between nonstandard robots has been designed (figure 4). The Unique Master Agent controls the global system in a unique location. After optimal real time scheduling is finished, we will be able to substitute the managerial function of humans by another one more objective (perhaps more rational in the sense of computability and emotions).

The cooperative coordination and subgoals related to robots’ movement were translated into a procedural language like C. A real model of the robots was developed to simulate their behaviour. The code was proved and the accuracy of the results confirm that our methodology is well suited to accomplish the final goal. The figure 5 shows the knowledge codified into a subroutine.

5.- CONCLUSIONS AND FUTURE RESEARCH

We view the manufacturing process as a social one. A social system is defined where communication and behaviour emerge from physical and virtual agents. We illustrate it with a single example: two robots cooperate in coordinating their movements and avoiding collisions.

The challenge we are concerned with is obtainable from the advances in the Cognitive Science and Distributed Artificial Intelligence. Some architectures and other parallel studies acknowledge this is a promising field, and applications are a strong motivation for further research. The integrative work of psychologists and sociologists with engineers is a new conceptualisation for scientific and technologic advances.

Our proposal benefits from the social cognitive approach to model agents as real individuals. After the social science treatment of agents, a normative and procedural approach is intended to model real physical systems. In this way, we establish an intelligent (in the social sense of the word) flexible management system which must operate in an autonomous way (under the supervision of a Master Agent). An architecture for a more general framework is showed as FAMSA.

Advances in real-time solutions of complex tasks are being developed. We hope to extend easily the first autonomous and intelligent FMS to services management: hospital management, transport networks, etc.

We hope to look for synergies with other approaches, like the IDDS work in the ENEA group. The communication between close works is a sure source of enrichment for the whole community in this field.
REFERENCES


Figure 1: FAMSA: Flexible and Autonomous Management Systems Architecture
COMMUNICATIVE CAPABILITIES DESIGN

Communications
1. Environmental information
2. Execution order
3. Availability request
4. Confirmation of availability
5. Planning to start
6. Tasks distribution report
7. Task execution
8. Finished execution report

Some relationships

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Figure 2

Figure 3
PUDE COMPROBAR LAS MAQUINAS.

Figure 4

Figure 5