Specification of a Multiagent System for Planning and Management of the Production Factors for Automation based on the SCDIA Framework and MASINA Methodology

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Abstract: - In this work, we propose a general reference model for planning and production factors management. Then, such a model is applied for proposing a system for the ERP problem for the automation applications. This multiagent system is specified in the framework of the SCDIA reference model by using the MASINA Methodology.

Key-Words: - Industrial Automation, Enterprise Resource Planning (ERP), Multiagent Systems (MAS)

1 Introduction

In previous works, we have proposed a reference model for the development of intelligent distributed control systems based on agents (SCDIA) [1], by using a set of agents for distributing supervision and control systems functions. With the SCDIA, it is not possible to integrate the enterprise, neither the execution of all industrial automation activities; nevertheless, as a continuity, work [1] has been enhanced in the work [2] by proposing an integration design using multiagent systems (defined as “Automatic Intelligent Distributed System based on Agents-SADIA”). This design proposes a model with three abstraction levels. The agents in the first abstraction level perform the business objects. In the second level, a set of agents capable of carrying out all activities related to industrial automation are defined. The third level includes the SCDIA agents modeling the processes control functions. Also, [2] proposes the model for the Abnormal Situations Management Agent in the second abstraction level, and [3] develops the agent model for the Failures Management Agent, also in the second abstraction level.

The main contribution of this paper is to develop the reference model of the Agent for Planning and Management of the Production Factors in the second abstraction level of the SADIA model, in order to offer a solution for the problem concerning to the Enterprise Resource Planning and Management. This agent is modeled and specified by using the SCDIA framework and the MASINA Methodology [4].

2 Theoretical Aspects

2.1 Planning and management of the production factors

Production planning refers to the making of the general plan as well as the detailed plan for the business object according to the requirements of the enterprise, the productive process models, production mechanisms and/or negotiation rules, optimization methods, global state, predictions and/or estimates, amongst others. With the general plan, the production goals are time-based determined (the period of time is usually called planning horizon), indicating what is going to be produced, which quantity, who requires the product and when it is being required. The detailed plan should show the activities sequence, which should be executed by the negotiating object throughout time, with the purpose of accomplishing the production goals, stated in the general plan.

The production factors management refers to the control of the required resources inventory for the plan execution, stock control of final products, and waste management. Using the functional data flow model proposed in [2, 7], the main functions and tasks of an ERP system were determined, shown below [7] :

- *Order Processing.* Its main tasks are: a) Manages, accepts and confirms the clients’ orders. b) Stores the products according to received orders.

- *Production Planning.* Its functions represent the interface between the functions of the control system and the enterprise, through production planning, the information about current production and the production capacity. Some of the general functions for production planning are: a) Indicates the production plan for each negotiation object. b) Identifies the long-term raw material requirements. c) Establishes the delivery program for the terminated products. d) Indicates the products availability for sale.
- *Production Cost Control.* Its main tasks are: a) Calculates and reports the production costs, b) Obtains the costs of prime material, manual labor, energy and other costs.
- *Material and energy control.* Its main functions are: a) Fulfills the material and energy requirements needed, according to the production plan. b) Assigning material and energy. c) Optimizes dynamically the inventory and materials management. d) Receives the material and entering energy supply and request the testing for assuring their quality.
- *Facilitating.* Its main tasks are: a) Providing purchasing orders to the prime material, parts, spare parts and other required materials suppliers. b) Monitoring the purchasing state and report to the requestor. c) Processing the entering receipts for their payment, right after the arrival and approval of the material.
- *Products inventory control.* It includes: a) Managing the inventory of the final products, b) Minimizing the quality gift (quality over the client requirements) and c) Managing the dispatch of finally products according to the delivery program.
- *Product dispatch.* a) Assignment of the final products, indicating about the client that will receive the product, the product cost, the delivery date, time of delivery, transport or delivery way, and all the information related to product sale. b) Generation of orders for waste management, indicating the product type, waste management normative, responsible person, date and time, etc. c) Report of shipment and transportations cost for accounting of production costs.

2.2 System of Intelligent Distributed Control Based on Agents (SCDIA)

The SCDIA is a multiagent platform specifically designed for control systems of distributed processes which proposes the use of a set of agents, representing the elements in a processes control loop (see figure 1) [1]. This way, the platform proposes five fundamental agents whose functions within the MAS are described below.

- *Observer Agent:* it gets the necessary information in order to determine the state of the process, executing the tasks of collection, consolidation and data processing. Combines data coming from different sources for offering information about the process.
-
- *Controller Agent:* it is the agent who evaluates the information of the process and takes decisions in order to follow a desirable sate and the ideal productivity, quality and security conditions.
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- *Actuator Agent:* converts the taken decisions by the controller, coordination or specialized agents, into actions that produce the changes necessary into the process for reaching the objectives.
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- *Coordinator Agent:* supervises the control loop, proposes the control schemes and decision making, changes the controller's parameters, including changes in the behavior of the control loop agents under its supervision.
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- *Specialized Agent:* it performs a specific function that supports the system, for example pattern recognition, statistic calculations, failures diagnosis, estimations, predictions, etc.

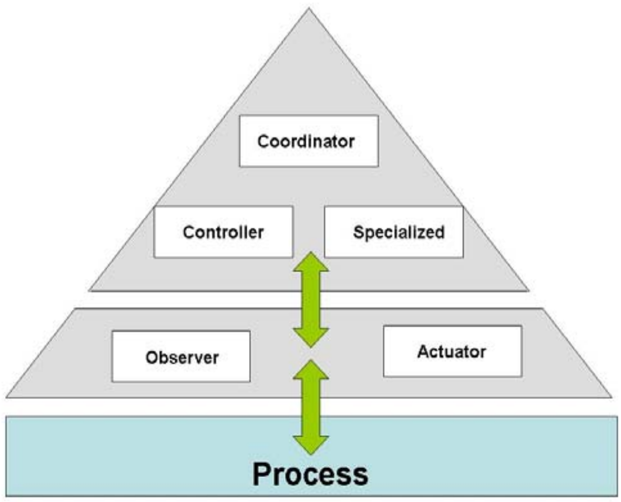

Fig. 1. Intelligent Distributed Control Based on Agents

Even though this architecture is easily identified with the activities in processes control system, it can be extrapolated for representing functions in other types of systems, as for example the model of the Failure Management Agent [3] and the Abnormal Situation Management Agent [2].

2.3 Methodology for the development of multiagents systems

For the design and analysis of the multiagent system we have applied the MASINA methodology [4]. In Figure 2, we can see the models defined by the methodology.

- *Agent Model:* shows the characteristics of all the agents involve in the problem resolution.
- *Task Model:* allows the description of the agent activities, through which the agent provides the services and accomplishes its objectives.
- *Intelligence Model:* describes the reasoning, learning and knowledge representing mechanisms, used by the agents to accomplish their tasks.
- *Coordination Model:* this model describes the coordination schemes between the agents, the direct and indirect communication mechanisms, the metalanguages, and the communication ontologies, among others. The coordination model is focused on services, where and agent can offer the realization of determined tasks to other agents, called services.
- *Communication Model:* this model describes the interactions (speech acts) between the agents.

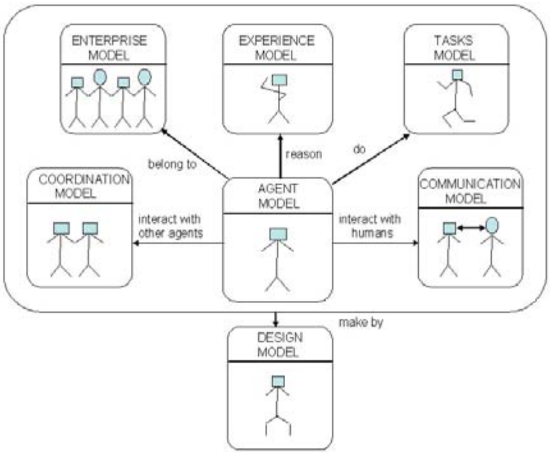

Fig. 2. MASINA Models.

3 MAS-Based Reference model for production planning and management of the production factors.

A support system for the production planning and management of production factors should generate and execute the necessary action sequences in order to satisfy the requirements of each one of the requested services. The sequence of actions (scheduling) involves the assignment of resources throughout time, until the full execution of the whole plan. This system should as well supervise the plan execution, and dynamically modify the executing plan in any case of deviation (re-planning). Figure 3 shows the proposal for a functional separation of three blocks.

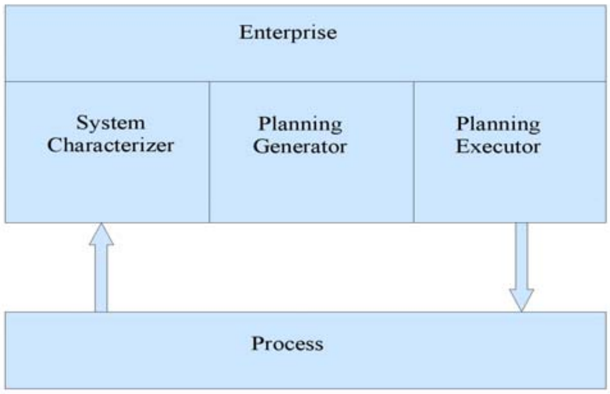

Fig. 3. Functional Diagram of the Planning and Production Factors Management System.

Each block in the system is composed by different modules interacting with each other, following a sequence determined by the negotiation rules, according to the reference model shown in Figure 4**.**

System Characterizer: It has two modules:

- Module determining the global state: It is in charge of obtaining and processing all the required information for the plan making. In general, the variables used are the following: Current request, Estimated request, State of production request, Production capacity, Compromised production capacity, Unattended production capacity, Available production capacity, Income indicator, Resources availability, Products availability for sale and/or usage of other negotiation objects.
- Module managing the negotiation requirements: In the productive process, the negotiation objects can assume the role of

requirement for generating objects, services offering object or both.

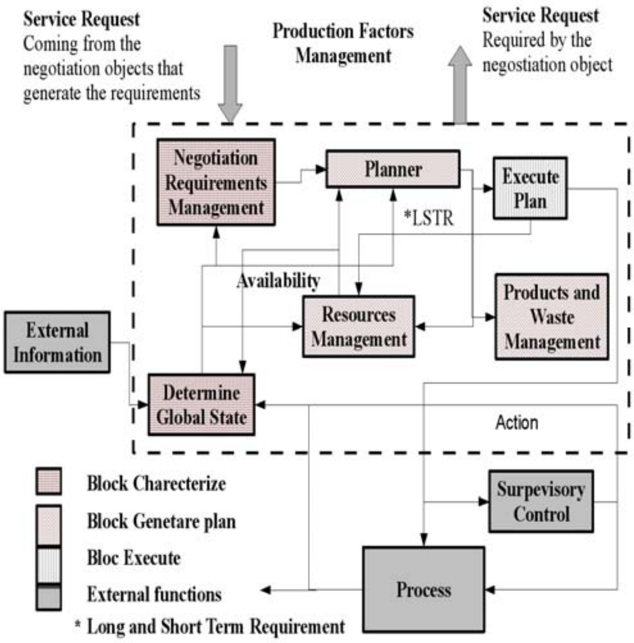

Fig. 4. Reference Model for Production Planning and Management.

Planning Generator: Three modules compose this block:

- Planning: It proposes the general plan and the detailed plan of the negotiation object according to the negotiation requirements, models of the productive process, production mechanisms and/or negotiation rules, optimization methods, global state, and/or estimations, and other aspects. The general plan refers to determining the production goals of the negotiation object in function of time, indicating: what is going to be produced, which quantity, who requires the product and when it is expected.
  The detailed plan (schedulling) should show the activities sequence that the negotiation object should execute throughout time, in order to accomplish the production goals, which have been established in the general plan. The detailed plan should at least establish: the adjustments (set point), the request, the assignment and mechanisms for resources delivery and reception, the detailed program for product delivery, the specification of the mechanism or strategy to be followed for realizing each one of the production tasks.
- Resources administrator: It is in charge of the inventory control of the resources required for the execution of the plan.
- Product and Waste administrator: It is in charge of controlling the final products stock. It should also manage the consequential wastes resulting out of the productive process.

Planning Executor: The module Execute Plan composes this block (the detailed plan).

4 Reference Model for production planning and production factors management based on SCDIA

The SMA for planning and management of the production factors should have the ability to mainly carry out the following activities:

- - Exchange of information between the different levels of the automation pyramid ISO/OSI.
- - Monitoring and analyzing the internal variables (coming from the different levels) and external to the process, with the aim of determining the global state in order to make the plan or re-planning of the existing plan.
- Make a general plan for the negotiation object.
- Execute the detailed plan for the negotiation object.
- Manage the resources associated to the plan.
- Manage the final products.
- Estimate and predict the variables and conditions which could have an impact on the plan and therefore on the performance of the business object.

4.1 Actors

Based on the functions that must be carried out, we identify and obtain the actors for planning and management of production factors (see table 1).

Table 1. Actors of the system for planning and management of the production factors.

Actor	Description
Characterizer	Receives the state of internal and external variables of the process and determines global state.
Negotiator	Sends, receives and processes the negotiation requirements.
Planner	Makes the general plan of the negotiation object taking in account the negotiation requirements, the global state, the estimations and/or predictions, etc.
Programmer	Makes the detailed program of the

	negotiation object based on the general plan, production mechanisms or negotiation rules, optimizing methods, etc.
Resources Administrator	It controls the inventory of the management resources and the management for their acquisition and assignment into the process.
Products Manager	It manages, stores and distributes the final products.
Wastes Manager	It manages the wastes according to the Hygiene, Environmental and Security rules
Predictor	Makes the estimation of variables required by the planner and the resources administrator
Executor	Executes production plan and notifies its execution state

The following sections describe the different models according to the methodology MASINA, for obtaining the specification of the MAS for planning and production factors management based on the SCDIA reference model.

4.2 Agent Model

Based on the actors identified on table 1, the agents supporting the management and production factors management are also identified, with their functionalities and activities. These functionalities could be distributed in the SCDIA general reference model. This way, the problem can be treated like a feedback control problem. The defined agents are:

- Observer Agent: This agent develops the functions of the characterizer agent; this way the MAS obtains the state of the internal and external variables to the process for processing and so obtaining the global state (state of the surroundings).
- Coordinator Agent: it carries the functions of the planning actor and the programmer actor. This agent can obtain the general production plan and the detailed production plan, and in case it is necessary it must get a new general production plan (dynamic planning) and a new detailed production plan. This agent should as well generate the requests of services by the specialized negotiation object.
- Actuator Agent: this agent processes the detailed plan, but if the actions are simples, the controller agent can directly execute them.
- Controller Agent: this agent should process the detailed plan and continuously supervise its execution in order to detect on time any deviation and take the respective actions. During the supervision of the plan, the agent evaluates the performance of the objects. In case the performance of the object is lower than expected, the controller agent must notify to the coordinator agent so it can obtain a new general production plan.
- Specialized Predictor Agent: Carries out the functions of the predictor actor. Supports the coordinator agent for making the general plan and to obtain the detailed plan of the negotiation object. This agent is able to predict and validate all the restrictions, so that the coordinator agent uses this information for elaborating or validating the plan, or even for compromising in the production goals.
- Specialized Negotiation Object: The agent receives the requests coming from the requirement generating objects. Based on the global state, information coming from the predicting actor, and the negotiation mechanism, it process each request. This agent also receives and manages the requests made by the associated coordinator agent, for this it determines the negotiation mechanism for contracting the required services to the offering objects.
- Specialized Resources Manager Agent: it is in charge of controlling the resources inventory and the management for the making of the purchasing order and the resources assignment within the process.
- Specialized Products Manager Agent: it is in charge of the management, storages and distribution of the final products.
- Specialized Waste Manager Agent: it is responsible for the management of the wastes generated during the productive process.

Table 2 shows the relationships beetwen each actor and the respective SCDIA agent.

Table 2. Relationship Actors – Agents.

Actor	Agent
Characterizer	Observer
Planning	Coordinator
Programming	Coordinator
Executor	Controller, Actuator
Negotiator	Specialized Negotiator
Resources Manager	Specialized Resources Manager
Products Manager	Specialized Products

	Manager
Waste Manager	Specialized Waste Manager
Predictor	Specialized Predictor

In this work, only Negotiation Agent is described on tables 3 and 4. The rest of the agents are described in [7].

Table 3. Specialized Negotiation Agent

Name	Specialized Negotiator
Type	Software Agent
Role	Management of negotiation requirements
Description	Receives and processes the negotiation requirements coming from the negotiation objects which generate the requirements from the associated negotiation object

Table 4. Objective

Name	Manage the service request requirements and/or intermediate products offered by the negotiation objects in the value chain
Type	Event-driven objective
Entrance parameter	Received requests from other agents (negotiation objects) or from the same agent
Exit Parameter	Requirement response
Activating Condition	Request
Ending Condition	Processed request
Success Condition	Request processed successfully
Failure Condition	Not possible to process request

The Negotiation Agent services are: Process negotiation requirement, Process negotiation requests and Select best offer. On table 5, we describe only the first of them, the remaining services are described in [4].

Table 5. Service

Name	Process negotiation requirement
Type	Free, Concurrent
Entrance	Negotiation requirement
Parameter	
Exit Parameter	Negotiation Offer
Representation Language	Natural Language

All of the agents possess common properties in all of the the services they offer: complexity and quality of the service. Table 6 presents one of them, the remaining can be found in [7]:

Table 6. Service-Property

Name	Quality
Value	Good
Description	The quality of the offered services depends on the reliability of the data and the rigorousness of the used methods

4.3 Tasks Model

Table 7 shows the tasks that must be carried out by each of the agents.

Table 7. Tasks of the MAS for Planning and Management of the Production Factors

Agent	Task	
Observer	T1.1	Obtaining state of internal variables
	T1.2	Obtaining state of external variables
	T1.3	Data Request AGD[1]
	T1.4	Determining current global state
	T1.5	Determining indicators for management of the general plan
Specialized Negotiator	T2.1	Making negotiation offer
	T2.2	Analyzing negotiation result
	T2.3	Making negotiation requirement
	T2.4	Selecting best offer
Coordinator	T3.1	Evaluating global state
	T3.2	Defining service request
	T3.3	Obtaining general production plan
	T3.4	Detecting deviations on the general plan
	T3.5	Modifying the general production plan
	T3.6	Evaluating state and resources availability

	T3.7	Evaluating state and products availability
	T3.8	Evaluating waste state
	T3.9	Evaluating production mechanisms
	T3.10	Obtaining detailed production plan
	T3.11	Determining deviation on detailed plan
	T3.12	Adjusting detailed production plan
Controller	T4.1	Determining state and results of detailed plan
Specialized Resources Manager	T5.1	Generating request for resource acquisition
	T5.2	Generating order for resource assignment
	T5.3	Determining resource entrance into the system
	T5.4	Controlling the level of resources inventory
Specialized Products Manager	T6.1	Generating order for the assignment and product dispatch
	T6.2	Controlling on products inventory
Specialized Waste Manager	T7.1	Determining mechanism for waste treatment
	T7.2	Generating order for waste treatment
Acting	T8.1	Executing action of the detailed plan
Specialized Predictor	T9.1	Estimating future production capacity
	T9.2	Estimating resources request (requirement to be received)
	T9.3	Estimating restrictions
	T9.4	Estimating date of resources income

The task T2.1 carried out by the specialized negotiation agent is described bellow, on table 8. The remaining tasks are described in [4].

Table 8. Task T2.1

Name	Make negotiation offer
Objective	Makes the offer for the service requested by any requirement generator agent
Description	The negotiation agent is the one responsible of analyzing the requirements received from the objects generating the requirements, and based on the production capacity the agent could accept the service offer or reject the request indicating the cause
Precondition	Existence of a negotiation requirement
Subtasks	Estimate production capacity

4.4 Intelligence Model

All of the proposed agents are susceptible to intelligence. The general structure of the intelligence model is presented as follow.

Experience

Representation	Rules
Type:	According to the case
Reliability degree:	Depends on the integrity of the information
Processing Scheme	Adjustment of the parameters of knowledge and incorporation of new models

Learning Mechanism

Type:	Adaptive
Representation	Artificial intelligence based techniques
Learning source	History, global state
Updating Mechanism	Feedback based on experience

Reasoning Mechanism

Information Source:	Previous results of the planning and management of production factors system
Activation Source	Intervention, events, programmed tasks
Type of influence	Based on rules
Reasoning strategy	Could be deductive or inductive, use of artificial intelligence classical techniques

4.5 Coordination Model

The coordination model describes the MAS communication scheme; that is, the conversation, protocols. In order to describe the conversation the sequence diagram UML is used. For the problem of planning and managing the production factors some of the conversations defined are: a) Design general production plan, b) Modify general production plan in case of low performance, c) Receive negotiation requirements, d) Make negotiation requirement, e) Design detailed plan, etc. The conversation *Design detailed plan* is presented below, on table 9, 10 and 11. The remaining conversations can be seen in [4].

Table 9. Conversation: *Design detailed plan*

Objective	Design the detailed plan (the strategy) which will assure the accomplishment of the goals of the general production plan
Agents	Coordinator,Observer, Actuator, Data Management[1]
Initiator	Coordinator
Acts of speech	New general production plan, Request global state, Data request, New detailed plan, Register detailed plan
Precondition	There is a new general production plan
Ending Condition	Detailed plan has been generated base on the general production plan
Description	Obtains the combination, sequences and times in which the activities should be executed in order to assure the achievement of the goal of the new general production plan

Table 10. Scheme for *coordination* conversation

Objective	Coordinate the interactions between the involved agents
Type:	Predefined
Default coordination	Centralized, using the messages delivery between agents

Table 11. Communication mechanism of the conversation

Type	Direct
Technique	Message Delivery
Metalanguage	KQML
Ontology	Related to the planning and management of the production factors

[1] Data Management Agent belong to the Middleware agents community

4.6 Communication Model

The MASINA communication model describes the interactions in the conversations. Each interaction between two agents is made through the delivery of messages and there is a speech act associated to it (see UML diagram on figure 5)

The model introduces the following concepts:

Message: Data structure exchanged by the agents for communication.

Speech act: intention of the message deliverer when sending it contents (see Table 12)

Table 12. Speech Act: Request for global state

Name	Request for global state
Type	Information requirement
Objective	Obtain global state
Agents	Coordinator – Observer
Initiator	Coordinator
Precondition	The coordinator agent should elaborate a new detailed plan
Ending Condition	Information received
Conversations	Design of the general production plan, Modify. General production plan out of low performance, Modify. Detailed plan
Description	The requesting agent requires the information of the environmental state in order to execute its functions

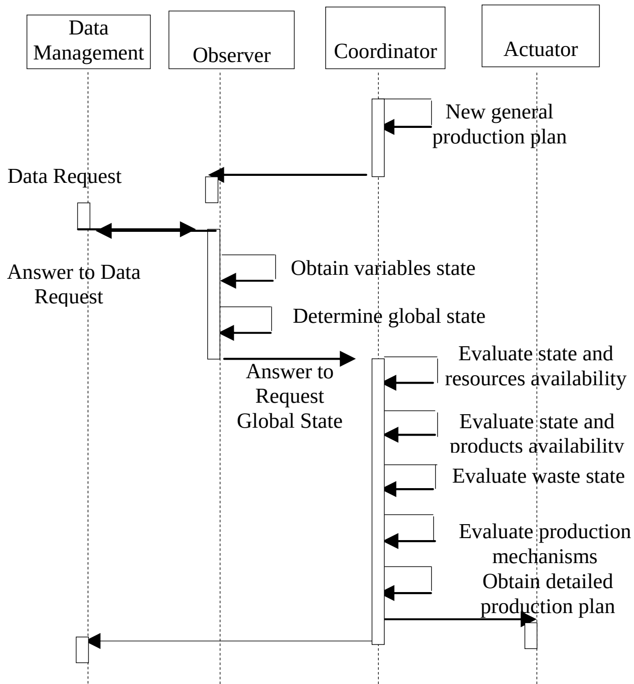

Fig. 5. UML Sequence Diagram of the Conversation "Design detailed plan"

5 Comparison with previous works

Many of the works are addressed to the ERP problem, an a good part of the planning works based on agents are focused to manufacturing systems, as is shown in [8], in which are used different architectures and approaches to which we propose for the case of continuous processes. In [9] it is defined an abstract model for the ERP that captures different alternatives and options. From this abstract model, it determines the most appropriate modeling language to represent this model. In this sense, the work proposes an extremely generic model that does not provide specific characteristics to take into account for the ERP modeling problem. In [10] it is designed an ERP information system with modular and flexible structure, developed on Web platform. The system has two basic parts: an engine managing the flow of tasks of the business process and, on the other hand, a module of resources management that uses a scheduling management subsystem. The proposal basically is centered on the benefits of the use of the Web technology, but there is not a clear approach for modeling the ERP systems. The work in [11] proposes a model called Web-based Object Oriented Model to implement an ERP system under a global perspective. The model is composed by four domains of objects characterized by a high degree of flexibility and integration derived from the use of the objects technology. Nevertheless, although this proposal details an architecture of the objects, it is centered in how developing to the Web application and the ERP problem is not modeled. In [12] it is presented a system to dynamically generate plans in virtual environments. The plan is generated according to the available resources, which dynamically changes in the manufacturing process. The dynamic planner generates a plan reliable that helps to create a reduced number of feasible scenarios. It is an interesting work that goes in the same direction of our work, but in our case we focuses on the model specification of the major functions of ERP problem.

The following works also propose the use of multiagent systems. In [13], the work presents a model based on agents to model the ERP problem in small and medium enterprises. The work proposes architecture of three levels: in the low level there are the execution agents, in a mean level the planning agents and in the high level the coordination agents, that from the knowledge of the plans of the agents it decides if some negotiation is necessary. The different enterprises resources are dispersed between the multiple agents and each agent must at least have an objective. The work describes in a general way what each agent does, but it does not present a specification detailed of them, neither specifies which the different resources are considered, nor does either formalize the required models of communication and/or coordination. The work in [14] presents an approach based on multiagent systems to obtain, dynamically and effective way in costs, the integration, optimization, configuration, simulation and control of the manufacturing systems and networks of resources. The system allows to generate alternative scenarios with respect to the planning, programming configuration and reconstruction, as much of the manufacturing systems how of the resource supply networks. Several agents are proposed, as the resource agent and the product agent, among others. In [15] it is proposed the use of intelligence agents in the process of automation based on the model of BDI agents. Its operation is based on 4 modules: router, planner, scheduler and executor. In this system is used a simple scheme for the planning process and tasks execution, but it does not incorporate the management of the production factors, as it is made in our work. In [16], the work presents a similar scheme to our proposal with three main components: the structure of data, the planning process and the execution process. Nevertheless, the production factors do not appear explicitly in the planning process.

6 Conclusions

In this work has been presented a reference model including the most general functions that must be performed for supporting the planning of the production and the management of the production factors in automation, mainly based on the ANSI/ISA-S.95.00.01-2000 Standard [17]. Based on the reference model, a new model is proposed for supporting the planning and management of production factors based on the SCDIA reference model. Such a new model has been specified by using the MASINA methodology.

The proposed SMA has the necessary tasks for the planning and management of the production factors in automation, and it inherits as well, the properties which characterize the agents, such as: autonomy, mobility, intelligence, communication, distribution, reactivity, among others. This system completes the design of the agents proposed in the second abstraction level of the SADIA reference model (Automatic Distributed Intelligent System based on Agents) [2].

The proposed model can be implemented for supporting the tasks of planning and management of production factors of the production processes which could be continuous, in batch and discrete, distributing the tasks and objectives in the different agents of the model. This way, the proposed MAS is a distributed model, the agents are autonomous and there is no centralized supervising system. On the other hand, the MAS could have emerging behaviors, derived from the requirements of the environment needed to adjust. The emerging behavior is a current investigation topic in the MAS area.

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