Multiagent Systems for Production Planning in Automation

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Abstract. The production planning represents a key activity in the performance of the industry, reason why the necessity of applications that offer support to this activity, that allow to reach the goals of production with the maximum benefit. The proposal of this work is to develop a Multiagent Systems (MAS) for the Production Planning in Industrial Automation (specifically, in continuous processes). In addition, we present an application of our proposal in a process of petroleum production based on the Artificial Gas Lift Method.

Keywords: Planning in Automation, Process of petroleum production, Multiagent Systems.

1 Introduction

The modern systems of automation must solve more and more complex requirements, in front of a greater degree of uncertainty and dynamic environment. This means that the automation platforms are highly complex and have a great amount of components that must interact. For that reason, new approaches oriented to the use of MAS in tasks of automation, such as control and planning, have been developed [1], [10]. Some works of MAS applied to automation are the following: in [6] is proposed a MAS for Planning and Management of the Production Factors. This work is based on SADIA model [1], a MAS for automation, and in a model of reference for distributed control systems intelligent based on agents (called SCDIA [3]). PABADIS [10] is a model designed for manufacturing processes, which focus in obtaining the flexibility and the decentralization of the automation. In this work, we propose a MAS for the problem of the Planning of the Production of Continuous processes, based on the model proposed in [6]. In addition, we are going to present an application of our work in a process of petroleum production based on the Artificial Gas Lift Method (AGL).

2 Multiagent Planning

Assuming that we know the initial state, a set of goals to reach, a set of agents, and each agent has its capacities clearly identified, the multiagent planning consists in finding a plan for each agent that allow it to reach their own goals, as well as the common goals. According to [8], the multiagent planning can be summarized as:

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1) Refine in an iterative way the global tasks in subtasks, until these subtasks can be made by the agents (refinement of the global tasks); 2) Assign these subtasks to the agents according to their capacities (tasks allocation); 3) Define rules or restrictions for the agents, with the purpose to avoid conflicts in the plans (coordination before the planning); 4) Formulate a plan for each agent, to allow it to reach its goals and the group goals (individual planning); 5) Coordinate the individual plans of the agents (coordination after the planning); 6) Execute the plans and synthesize the results of the subtasks (plans execution).

There are other approaches for the multiagent planning. Ferber [11] proposes the planning in three steps: think the plan; distribute and coordinate the different actions of the plan, and execute the actions. If the first step is made by an agent we call this approach centralized planning, if each agent constructs its own sub-plan then this approach is called distributed planning. If an agent coordinates the different sub-plans then this approach is called centralized coordination of partial plans. In [9] are proposed two tendencies in the multiagent planning: in one of them there is a central agent that coordinates the execution of the plan, and in the other all the agents participate, decide and coordinate their own actions. [7] establishes that the agents participate in the creation of a distributed plan, and act according to the distributed plan. According to the participation of the agents, [7] proposes the following techniques for the distributed planning: i) Planning Centralized for Distributed Plans, ii) Planning Distributed for Centralized Plans, iii) Planning Centralized for Distributed Plans.

3 Previous Works Bases of our Approach

This work is based on our SCDIA [3] and SADIA [1] models. The SCDIA is a multiagent reference model, which proposes a collection of agents that represent the elements of a process control loop, with the intention of establishing a generic frame for the management of control activities in industrial automation [3]. These agents are: i) *Observer Agent:* collects the necessary information to know the state of the process; ii) *Controller Agent*: takes actions based on the observations about the state of the process and the system; iii) *Coordinator Agent*: defines new objectives and services and coordinates other agents; iv) *Actuation Agent*: carries out the decisions taken by the controller, coordinator and /or specialized agents; v) *Specialized Agent*: carries out special tasks in the control community.

SADIA [1] is composed by three abstraction levels, where each one is a MAS. In the *first level* the trade objects are modeled as agents, this is, the different productive units are modeled as agents. The agents in this level negotiate between them so that they can get to an agreement that will help the accomplishment of the established production tasks. In a *second level*, each one of the first level agents is a MAS which is composed by other agents in charge of managing the activities necessary for accomplishing the goals of the trade objects: process control, engineering of maintenance, abnormal situations management, production factors management and production planning. The activities listed above are common for each one of the first level agents, and all the agents in that level will be basically constituted by agents that execute each one of these activities. Nevertheless, there are activities that exclusively belong to a trade object in particular, which are modeled through specialized agents. Finally, because the activities that second level agents carry out are complex, a *third abstraction level* is proposed, in which the agents of the second level are defined as MAS. The SCDIA model is used to define this MAS.

Some MAS approaches based SADIA and SCDIA models are: [5] proposes a model of MAS for fault management systems in industrial processes; in [2] is developed a generator of code for the community of agents of the SCDIA; in [4] is developed a MAS for the Management of Abnormal Situations. Finally, in [6] is proposed a MAS for Planning and Management of the Production Factors. Specifically, in [6] are proposed the next agents: i) *Observer Agent:* obtains the state of the internal and external variables of the process for obtaining the global state; ii) *Coordinator Agent:* obtains the general production plan and the detailed production plan, and when is necessary, generates a new general production plan (dynamic planning) and a new detailed production plan; iii) *Actuator Agent:* executes the detailed plan; iv) *Controller Agent:* continuously supervises the execution of the detailed plan, in order to detect any deviation and take the respective actions; v) *Predictor Specialized Agent:* Carries out functions of estimation of variables, validation of restrictions, etc.; vi) *Business Object Specialized Agent:* Based on the global state, predictions, and the negotiation mechanisms, it processes each request. This agent also receives and manages the requests made by the coordinator agent; vii) *Resources Manager Specialized Agent:* controls the resources inventory and the management of the purchasing order and the resources assignment within the process; viii) *Products Manager Specialized Agent:* manages, stores and distributes the final products; ix) *Waste Manager Specialized Agent:* manages the wastes generated during the productive process.

4 Proposed Planning Model

4.1 Production Planning Model

The planning of the oil business follows a hierarchic structure of several levels: the *superior level* defines the strategic plan, which considers planning horizons of long term (in the order of years) and the construction of general plans, and the *inferior levels* correspond to the construction of *tactical and operational plans*, where shorter horizons of planning are used and the programming of the activities are more specific and detailed.

The global plan in an organization with one hierarchic structure can be decomposed in several plans. A proposal for the decomposition of these plans was presented in [6], where the decomposition begins with the global plan of the company, and finalizes with the detailed plan of the business objects. That work also proposed to model the productive process like a MAS, where the diverse units of production are modeled like agents. Nevertheless, there is a problem for the implantation of the previous model since the production facilities are numerous, and to model them like agents adds much complexity to the system (for the case of the oil industry, if we have 300 wells then we would have 300 well agents). Additionally, in [6] is proposed that the agents of each level negotiated to each other to reach agreements that allow fulfilling the established goals of production. However, in the case of the oil industry, such negotiation does not happen in all the levels. For this reason, in this work we propose a new decomposition of the business plan beginning with the company global plan until arriving at the production plan (in the case of the oil industry, this production plan must consider its respective associated facilities: Station of Flow (SF), wells, Manifolds of Artificial Gas Lift (MLAG), etc., see Figure 1). In this work, we propose a functional model for the process of planning of the production conformed by two blocks (see Figure 2).

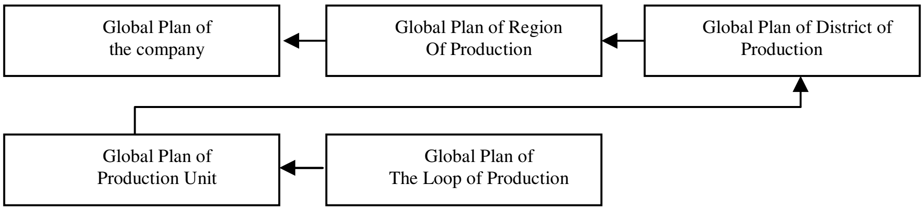

Fig. 1. Our Proposition for the Decomposition of the Business Global Plan

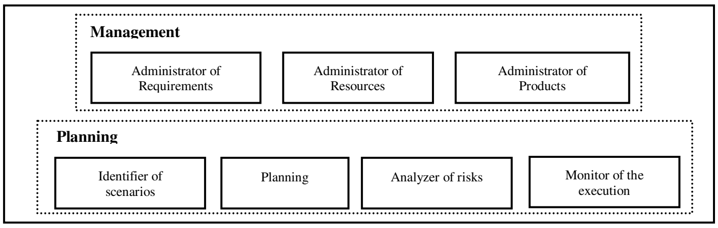

Fig. 2. Modules that Compose the Model Proposed for the Production Planning Process

Block of Management: It corresponds to the management of the requirements, resources and products of the planning process; and is composed by three modules: 1) *Administrator of requirements*: processes the orders received, in order to accept them or to reject them; 2) *Administrator of resources*: controls the inventories of the resources available and required for the execution of the plan, and assigns the resource within the productive process; 3) *Products administrator*: controls the finished products and the waste of the productive process.

Block of Planning: It carries out the planning process, and is composed by four modules: 1) *Scenario Identifier*: analyzes and processes all the information that corresponds to the current scenario of production. The state of the surroundings is defined for each area of the productive process, according to the internal and external variables of the process; 2) *Planner:* elaborates the production plan using the established production goals, the models of the productive process, the production mechanisms, the business rules, the optimization methods, the current scenario, and the market predictions. The plan will establish: The amount of product to produce and its lapses of delivery, the required resources, the planning of the maintenance activities, etc. Also, this module elaborates the programming of activities, which will establish: the sequence of activities of production by each unit of the productive process; the set point and the control strategies that must be applied to the different components of the productive process; the request, allocation, etc.; 3) *Risk Analyzer*: studies the probability that the results take place, and determines the expected values of the economic indicators from the current production. The sensitivity analysis is also included in this module, which consists of determining variations in the economic indicators when are modified some of the following variables: prices, investment, costs of operation, etc.; 4) *Execution Monitor*: During this time is necessary to monitor the performance of the plan, in order to detect possible deviations and to alert to the planner module.

4.2 Multiagent System for the Production Planning

We have identified the next agents, in order to carry out the production planning:

- *Administrator Agent of Requirements* (AAR^1): receives the requirements generated by the clients, analyzes them and determines if they can be taken care of. In addition, it defines the production goals to satisfy these requirements.
- *Administrator Agent of Products* (AAP): manages the products available generated by the productive process. For that, it controls the inventory, validates that the generated products fulfill the specifications of quality, etc.
- *Administrator Agent of resources* (AAR^2): manages the resources available and necessary to carry out the plans.
- *Agent of Planning* (AP): this agent, based on the goals defined by the AAR^1, constructs the plan, programs the activities identified in the plan, and details them more if it is necessary. AP requests from AAR^2 the allocation of the resources required in each task. In some cases, according to the level where this agent is working, it carries out only planning tasks (for example, in the levels of decision making) or of programming (for example, in the operational levels). This agent also must identify the strategy to mitigate the risks associated to the plan, identified by AAR^3, and make adjustments to the plan.
- *Identifier Agent of Scenario* (AIE): characterizes the current productive process scenario, based on its current state, the existing goals and restrictions, etc.
- *Analyzer Agent of Risks* (AAR^3): identifies the risks associated to the plan, analyzes its relationships and possible consequences. This agent will change key variables of the process with the purpose of identify if the plan is affected by these changes, and in this way to recognize the possible consequences in the plan (sensitivity analysis). Finally, it will inform to the AP.
- *Agent to Monitor the Execution* (AME): acts like observer of the execution of the plan. Its function is to observe the state of the process (defined from the information in real time and historical information), to validate that the resources are being assigned of opportune way, and that the tasks are being executed according to the planning.

With this architecture we provide a model of production planning based on agents, which can be used to support the planning tasks in each one of the levels within the company. Each level of the planning process will be differentiated by: the time horizon of planning, the level of detail of the used information, the requirements established, the premises and parameters of each level, the nature of the planned tasks, the type of risks and strategies used, among others.

4.3 Activity Diagram of the MAS for the Production Planning

We present the activity diagram that illustrates the basic flow of our MAS during the construction, execution and monitoring of the production plan (Figure 3). In the diagram we can observe that the flow begins with the reception of a new requirement (AAR^1). In this case we will suppose that the requirement corresponds to a request of certain amount of product with certain specifications. The AAR^1 analyzes the received requirement and determines if the production system can satisfy it. If the requirement can be satisfied, the AAP determines the amount of product available, if there are sufficient products then the AAP notifies the corresponding module so that it initiates the product forwarding. Else, AAR^2 determines the real capacity of production of the system, to determine if it can product the demand in the established time. If the demand cannot be supplied, this agent informs the real production capacity. Else, it informs to the AAR^1, that defines the new goals of production and notifies the IEA so that determines the current scenario based on the new goals, the existing conditions of operation and restrictions. This scenario is used by the AP to construct the plan (to define the macro-tasks), as well as to program its execution in the time and to assign the resources. As soon as the plan is constructed, the AAR^3 identifies the risks associated to the plan and their possible consequences. This information is used by the AP to define the strategies to mitigate the risks. Finally, the plan is executed and AME observes this execution. If there is a significant deviation, it notifies to AP in a way that it makes a replanning.

5 Case of Study: Process of Oil Production Using the Artificial Gas Lift Method

5.1 Description Case of Study

The process of oil production requires of installations which allow the extraction, treatment, distribution and transport of hydrocarbons. The oil production loop is based on the Unit of exploitation of Oilfield (UEO), and its main components are wells, stations of flow, tanks, gas compressing plants and manifolds. Diverse methods of hydrocarbon production exist, classified according to the used mechanisms to take hydrocarbons from the Oilfield to the surface. Our case of study is based on the AGL Method, which consists of injecting gas to a certain pressure in several points of the production pipe, to different depths, so that when mixing itself with the crude the pressure of the fluid rises, diminishes viscosity, and that helps the fluid to move to the surface. Our general multiagent model for this case is:

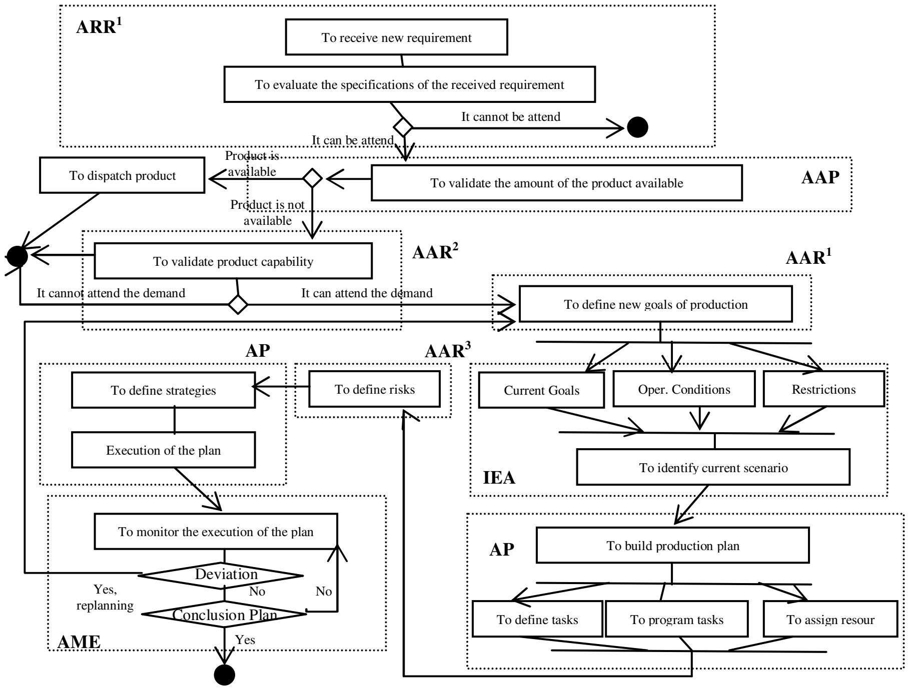

Fig. 3. Activity Diagram - Basic Flow of the Planning Process

- AAR[1]: receives the requirements. In this case, the goal of production established by the UEO for the loop of production in a horizon of time. These requirements are determined by the superior levels. For our case of study, this agent will validate that the specifications of the product required by the production goal corresponds with the characteristics of the product generated by the loop of production. If the requirement can be supplied, then it will inform to the AAP, on the contrary it will have to inform that the requirement could not be processed. Also, this agent defines the daily goals of production that allow fulfilling with the received requirement, and sends this information to the IEA.
- AAP: this agent, based on the information of the tanks about the amount of product available, determines if it can satisfy the requirement. If there is sufficient product in inventory, then it informs to the agent responsible to dispatch the product, on the contrary it sends the requirement to the AAR[2].
- AAR[2]: this agent, based on the potential of production and on the amount of resources available (active wells, gas for injection, among others), determines if it can fulfill the goal of production required in the horizon of time. If the request cannot supplied, then this agent will inform that a plan cannot be generated that fulfills the goal of production in the established horizon of time. In case that the request can be supplied, then it will reserve the resources for the elaboration and execution of the production plan.

- IEA: it identifies the current scenario of production, considering mainly the current goals, the conditions of operation, the planning horizon, the required energy, the available energy, etc. In general, some of the variables of interest for this agent are: current and estimated demand, potential of production, etc.
- AP: this agent defines the plan to execute based on the current scenario (it will establish the quota of gas injection per day for each well, during the considered horizon of planning, in order to fulfill the goal of production, as well as the date of exit of operation of wells by maintenance tasks). Its procedure is: 1) Create the model of each well (curves of affluence and effluence). 2) Determine the total amount of required energy based on the requirements of each well. 3) Determine the amount of available energy. The operation point will be determined by the conciliation between the supply (available energy) and the demand (required energy). 4) Distribute the available energy, using specialized systems of optimization, which calculate the optimal rate of gas injection for each ALG well.
- AAR^3: this agent will evaluate the behavior of the system due to change in variable keys of the process: due to the exit of operation of wells with high index of production, not consider maintenance tasks in the planning, among others.
- AME: in our case of study, the main task of this agent is to watch that the rates of daily gas injection for each well stay within the planned, that allows determining if the well is producing with the rate of planned gas injection. In the case that the rate of gas injection is outside this rank, this agent will inform to the IEA.

5.2 Simulation

To carry out the simulation, we have used JADE [12], and the following agents:

- User agent: carries out the request to the AAR^1. It sends the goal of production, the planning horizon, and the specifications of the required product. We assumes that the required product is "crude", with two characteristics: a) API Degree: it is a density that describes that so heavy or light is the petroleum with respect to the water: light (API > 31,1°), medium (22,3° < API < 31,1°), heavy (10°<API < 22,3°) and extra-heavy (10° <API). b) Factor of Characterization (Kuop): allows characterizing of the type of crude and its chemical composition.
- AAR^1: requests to AAP the specifications of the product given by the production loop, with the purpose to validate that the request can be supplied. In case the request can be supplied, then this agent will send a message to the AAP with the information of the requirement. On the contrary, it will send a message to the user agent to inform that the request cannot be supplied.
- AAP: For this simulation only one task was implemented, which corresponds with the search of the specifications of the product given its code. This agent has a product list with its respective specifications, when it receives a message with the code of the product, then this agent looks for in its list. If the product is found, then it sends a message to the AAR^1 with the information. On the contrary, it sends a message indicating that the product was not.

5.3 Tests

In the figure 3 we observe that the flow begins with the reception of a requirement (AAR[1]). In this case, we will suppose that the requirement corresponds to a request of certain amount of product with certain specifications. Two cases are tested:

- Case A: Horizon of planning 6 months, Goal of production: 60,000 barrels, Type of product: heavy crude, API degree: 12.5, Factor K: 11.0

In this case (see figure 4), the user agent creates the message with the information corresponding to the request, and looks for the AAR[1] actives to send it the message. The AAR[1] receives the message, and immediately it looks for the AAP; it sends a message to AAP where it sends the code of the type of product to consult. The AAP, when it receives the request, looks for the specifications of the product. With this information, it creates a message to send to the AAR[1]. The AAR[1] compares the specifications obtained with the request, and determines that the request can be supplied, because the specifications of the required product correspond with the specifications of the product given by the production loop. Finally, it sends a message with the information of the requirement to the AAP to reserve the product.

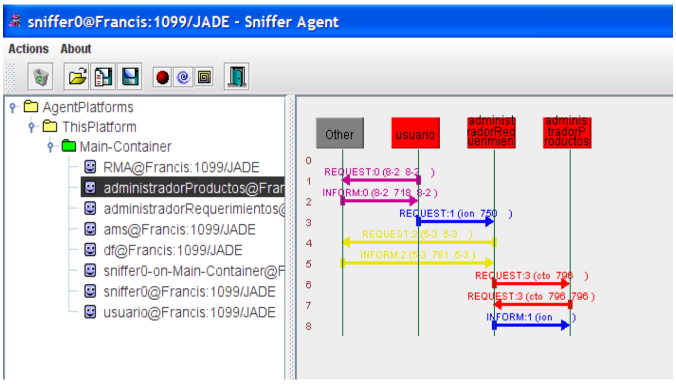

Fig. 4. Simulation of the Test A

- Case B: Horizon of planning 3 months; Goal of production: 40,000 barrels, Type of product: light crude, API degree: 25.0, Factor K: 12.0.

The user agent initiates the simulation creating a message with the information corresponding to the request, and looks for the AAR[1] to send it the message. The AAR[1] receives the message and immediately it looks for the AAP; and sends it a message with the code of the type of product to consult. The AAP, when it receives the request, looks for the specifications of the product. With this information, this agent creates a message and sends it to the AAR[1]. The AAR[1] compares the specifications obtained with the request and determines that the request cannot be supplied, because the required product for with API degree 25,0 does not correspond with the type of indicated product (crude light), reason why it sends a message with the information of rejected.

6 Conclusions

In this work is proposed a multiagent model for the planning of the production in the oil industry. In order to make this proposal the multiagent model of planning presented in [6] and the current process of planning in the oil industry was analyzed, which allowed to identify two weaknesses of the proposal presented in [6]: 1) the production installations are numerous and to model each one as an agent adds much complexity to the system and, 2) in the different stages from the business plan not always happens the negotiation between agents. For these reasons, a refinement of this proposal was carried out in this work, in which the planning of the production is made from a level superior of abstraction of the defined originally, which allows to diminish the complexity and to facilitate the implementation of the system. Finally, the simulation of a part of the model proposed was realized for the case of study the planning concerning the loop of petroleum production for ALG wells, specifically implementing AAR[1] and AAP with the aim of studying the behavior of the MAS on a real problem.

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