Distributed manufacturing system in a multi-agent approach – An application to oil fields management

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Abstract

Multi-agent systems have been successfully used to represent distributed manufacturing systems. Each part or characteristic of the system can be represented by an agent that acts independently and in a cooperative way. Information exchange between agents and combined individual rules for each agent can lead to the emergence of a better integrated operation. Better decisions from a holistic viewpoint can be achieved when manufacturing asset management is supported by a multi-agent approach. A model to manage distributed manufacturing is proposed and applied to on-shore oil fields. The distributed characteristics of oil field units - such as wells, collecting stations, compressing stations, supplies – suggest that they should cooperate to reach production targets. The integrated management model provides a cost analysis and helps to identify unprofitable areas in oil fields as well as to support decision making processes. Agents help to reduce the load of information for the operator, giving him/her more time to focus on situations that require his/her attention. Successful applications which multi-agent model proposed could help oil field surveillance and support decision-making process are presented.

Keywords: Multi-agent approach, Oil fields, Operations

Introduction

An agent is a computational system that is situated in some environment, and that is capable of acting independently in this environment in order to achieve their design goals. In multi-agent systems, the ability for interaction between agents indicates that they may be affected by other agents, or by humans, and perform tasks in pursuit of their goals (Wooldridge 1999). This is a typical situation of the supply chain, where agents representing different links in this chain as suppliers and customers in several instances.

Some authors present successful solutions for the application of multi-agent systems to problems in the supply chain integration (Álvarez and Díaz 2004; Ferreira 2009; Jin and Li 2008;). According to Jin and Li (2008), the approach of Multiagent Systems seems appropriate to study supply chains because the different business units involved can be modeled as autonomous agents, as well as their management rules. For Ferreira 2009, the potential benefits of this approach are: the establishment of an effective mechanism for trading; the adoption of a technology for multiattribute negotiation; the offer of an effective mechanism to improve performance across the supply chain, thus supporting decision making. To achieve the desired level of collaboration, Álvarez and Díaz 2004 presents a decentralized approach to the supply chain through three subsystems based agents. The first is the communication subsystems within the plants (which will manage unforeseen events that may cause the need for new production schedule of the plant or part of it). The second is the interplant communication subsystem, which will manage events produced in a plant that will affect other plants. And the third is the communication subsystem of the supply chain, which will manage events occurred in the plant that affect suppliers and /or external customers.

The oil field can be considered as a set of distributed systems consisting of surface facilities, wells, reservoirs, logistic systems, suppliers and other staff working in the system. The supply chain approach is useful to the study of oil fields by allowing a extended analysis of decision, similar to a network of integrated operations. The proposed model seeks to represent each of the production functions of the field as an agent, as well as their relationships with service providers and equipment and the maintenance staff.

The independence of the agents is also a desired characteristic for oil fields, since production systems may change over time, these can be amended without any model change. For example, a well may have changed their mode of production or even changed their role from producer to water injection well, or a new collection station can be incorporated into the model.

Internally, the operatives seek the best result through cooperation rules that lead to a better condition of profitability for the asset. The operatives are connected through a flow value where, as the raw material moves along the transformation process, there is an increase in value in each of the stages. The management involves the administration of manufacturing value stream (monitoring resources used in each stage of the process) as well as investments seeking a better outcome of the system.

Externally, suppliers of maintenance and provision services compete for the attention of services requested by the oil field. Therefore a natural progression of service improvement can be achieved through a careful selection of service providers in the oil field.

The independence and agents capacity of action and reaction also reflects the possibility of using them to monitor the facilities, minimizing some of the activities previously undertaken by operators. This condition can conduct the oil field to a condition of unassisted plant.

Challengers in oilfield management

According to Al Meshabi and Khazandar (2010), there is a huge complexity associated with managing an asset operating in the oil and gas industry. To the authors, the management of these assets is a complex activity due to several factors, among them: the need for physical control while physical and chemical rules of procedure are respected; frequent changes of operation according to economic, social and strategic needs and; equipment reliability and criteria of integrity, and security of staff working on assets. The authors consider that the management of operating assets is the joint effort of several disciplines and hierarchies. It requires coordination of people and their knowledge of procedures incorporated in the work and coordination of business processes. This effort is only successful if it is guided by a clear strategy with stakeholders mobilized and aligned to the strategic objectives.

Traditionally, according to Cabrera et al.(2007), efforts to increase the ultimate capacity of oil recovery have resulted in competition. These efforts have often resulted in incompatible plans and proposals from various disciplines of asset management team. Each discipline has focused on issues in their respective areas, but no ability to understand the ramifications for other disciplines or the asset as a whole.

In Boschee (2012), Neeraj Nandurdikar, manager of exploration and production of Independent Project Analysis (IPA), warns about lack discipline for understanding and managing the asset. According to him, the areas that compose assets, such as wells, reservoir and facilities are well developed, but in a separate way.

The complexity of the problem is further aggravated by restrictions arising from the current workforce to retire senior professionals, thus reducing the number of experienced workers in the area of oil exploration and production. A small team means that fewer people understand the complexity and implications of competing proposals, and few people are qualified to evaluate these proposals and make recommendations. The authors also point out that the ultimate goal of all team members of a group of assets to be decisions that benefit the entire business, not just their respective domains (Cabrera et al. 2007).

Yero and Moroney (2010) corroborate with Cabrera et al.(2007) in the aspect of the difficulty of forming a technical body. From the authors' experience at Shell Exploration and Production, it was found in the technical área the difficulty of transmiting knowledge and lack of methods for sharing information, which makes it imperative to implement systems that optimize people's time, standardize the work, knowledge capture and automate surveillance activities.

In the opinion of Boschee (2012), there is a need for engineers to understand the systems in an integrated manner and are able to perform cost estimates for the facility. This competence will enable better assessments at various stages that make up the development of active installations, reservoir and wells.

Rahmawati (2012), who have had positive results with optimization and integrated operation of oil fields - including the reservoir, the surface facilities and an economic model coupled - believe that the current industry still has a very segmented supply chain. A part of the chain is treated separately from the other. The authors attribute as a cause of the fact that, in different parts of the chain, people are recruited with specific knowledge and use different tools to support decision limiting the integration, even in situations where integration has clear potential.

Boschee (2012), Cabrera et al (2007), Al Meshabi and Khazandar (2010), Yero and Moroney (2010) alert to the possibilities, still existing in the oil and gas industry, to gain advantages with integrated asset management. Be the lack of communication between different areas, be the lack of integration between systems, either by the lack of standardized methods and procedures, or even the lack of trained professionals, there is much to be done.

There is a gap in the oil industry: the need for decision making taking into account not only the production systems, but also other elements that constitute the supply chain of this industry. This situation is even more critical in mature oil fields. In these, the yield is not very high, compared with young ones and not all fields in the operation investment is justified. Thus, the research was aimed to improve the decision in land and oil fields mature through an analysis of economic variables and techniques. As the oil field a set of wells, reservoirs and other surface facilities which act to release the oil in refinery processing conditions for the oil.

Methodology

The research theme was chosen through a gap identified in the oil industry: the need for decision making taking into account not only the systems directly linked to production, but also other elements that make up the supply chain of this industry, such as logistics oil field. Through experience exchange with professionals, it was noted that this situation is even more critical in mature oil fields. In these, the yield is not very high, compared with young ones. Moreover, not all investments in the operation of oil fields are justified. Thus, the research was aimed to improve the decision in land and mature oil fields through an analysis of economic variables and techniques.

Whereas the elements that compose the field are distributed in nature, similar to a supply chain, a multi-agent approach presents itself as a suitable solution for modeling the oil field. This can be observed by different authors (Álvarez and Díaz 2004; Ferreira 2009; Jin and Li 2008;) adopting that approach. The independence of the agents is also a desired characteristic for oil field, since production systems may change over time, these can be changed without that the whole model have to be modified. For example, a well may have changed their mode of production or even change their role from producer to water injection well, or a new collection station can be incorporated into the model.

The independence and capacity of action and reaction of the agents also reflects the possibility of using them to monitor the facilities, minimizing some of the activities previously undertaken by the operator. As previously mentioned, this condition can let the oil field to a condition of unassisted plant. Whereas agents are intelligent, in addition to monitoring, the best decisions are made with learning, resulting in a better condition for the entire field.

After creating a generic model where agents are described, rules are defined, and relationships are mapped, we conducted a case study for confirmation of expected benefits. For the case study, it was chosen a mature oil field located in the state of Bahia (Brazil) that has greater similarity between the existing systems proposed. The field has around 200 wells with an estimated production of 270,000 bbl / month. We used monthly data over a time horizon of 5 years. Some variables that had no historical record or measurement were estimated by professionals.

Another aspect to be considered in the construction of the model concerns the ontology. The ontology is the representation of abstract concepts like events, time, physical objects and beliefs. In multi-agent systems, it is the knowledge representation of the agent. All actors involved in the same environment and that relate to each other must have its basis in the same ontology. Obitko et al. (2011) wrote about the possibilities for status display of industrial control systems based on ontologies. According to the authors, the use of ontologies for explicit description of the world has many advantages, including ease of integration and extensibility.

The fact that the knowledge in the system is expressed in a standardized semantic form contributes to a uniform view of the system as a whole as well as individual agents. In the proposed model for the management of the oil field, the development of the ontology will contribute to a proper construction of the architecture of the model, and the rules that will lead to cooperation among the agents to achieve a better return on the field as a whole.

The multiagent framework to oil field

The proposed model considered three types of agents: operational agents, intervention agents and supply agentes. These agentes are classified according to its role in the supply chain. The operational agents are those directly related to production. They make the processing of the product from extraction of oil and gas from the reservoir to the refinery for final transfer. This category of agent includes: wells and other smaller stations; the collection station; the carrier; the compression unit; the transfer unit oil; the water handling unit; the injection unit and; the storage unit. Intervention agents are those who perform preventive or corrective maintenance in industrial facilities, as well as small repairs and even larger investments. There are two types of intervention agents: internal and external intervention agents. The latter are partner companies that perform services on the premises of the oil field and are managed by internal intervention agents. The supply agents procure inputs (spare parts, chemicals and other necessary items to conduct operational processes) to production o. This agent is also driven and coordinated by internal intervention agent.

It has been performed an analysis of inputs and outputs in each one of the agents. This assay was carried out in order to identify input and output variables in each set of agent and its dependency relationships between them. It is noteworthy that, with the advancement of oil and gas from the reservoir until the transfer to the refinery, there is an added value along the supply chain. The oil in the output of the well has a lower value than in the output of the collection station. This value difference is performed by the costs in collection station agent to perform its function. This flow can be seen in Figure 1 below.

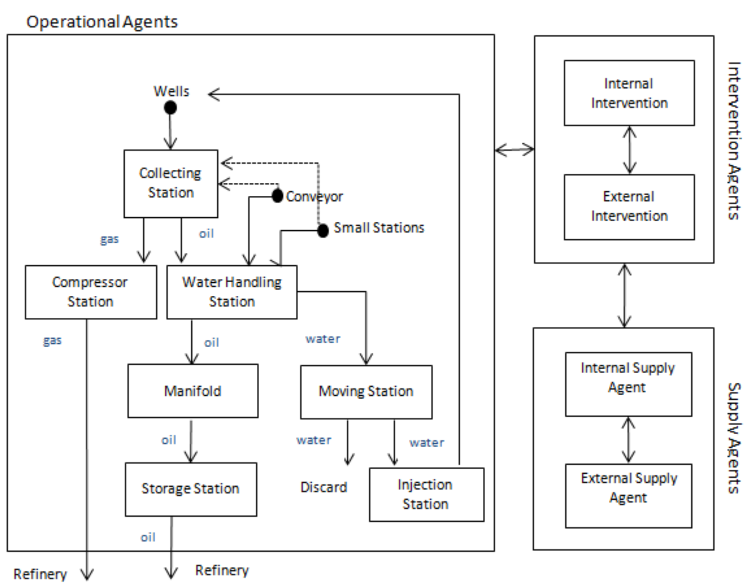

Figure 1 - Multi-agent framework for an oil field

The costs incurred by each operating agent are expenses made to perform their functions, such as spending on labor, electricity, supplies and maintenance service requests. The latter are made by the internal intervention agent who may need the supply agent for procurement of parts and equipments. The agent that performs the service will have an income, paid by the agent who requested the service. The operational agent that provides the product with an added value to other agent will also have a revenue, paid by the one who purchased it. Thus, revenues are amounts paid for services rendered to other agents or products purchased by other agents.

The profit function can be obtained from the difference between revenues and costs for the entire system as well as the agents individually. It is considered in the model (for simplicity) that no physical losses or accumulation occur in each of the agents and, the amount of product that arrives at the agent is equal to the amount that leaves it.

In each of the steps described in the framework, the product undergoes an added value. After passing by the agent, the oil or gas assumes a value that is at least equal to its value on arrival at the agent plus all costs that the agent performs in its operation. It is the intention of the agent to pass on the costs to the next agent in order to recognize the effort made by this.

The injection agent provides an important service to the oil field: pressurize it from the water injection with the goal of increasing oil production. The injection point of water in the reservoir or the location of this compared to other production wells, influences the production in each one of the wells. Thus, it was considered that the total cost with the water injection in the reservoir should be distributed among the wells. There will be a cost consideration to the distance between the production well and the injector well so that the greater the distance the lower the cost associated with the well.

This “gross simplification” only serves to remember that the effect of oil injection into a reservoir affect differently the production in each well. There are geological factors that exert influence on production and consequently the results of the actions of injection, but they are not considered in this model. It is assumed that the closer the well is from the injection point the greater the effect of that action on the production of this well, so the higher the cost to be borne by this well agent.

The agent can trigger alerts whenever the profit, or performance, is not compatible with its function. For example, if the cost of a well exceeds the value of revenue from the volume of oil transferred to the collection station, the agent can send a warning message to this condition. Alerts sent may sign the need for intervention, investments, changes in the settings of the wells (reservoir development), or even the abandonment of the operation, depending on the rule modeled for each agent within the context of the field.

Results

The framework was designed, initially, in a simplified manner, with an emphasis on building relationships between the agents in order to translate them to actual conditions in oil field teams. Only 2 types of possible intervention services were included, type 1 and type 2, for each intervention agent and; only 2 categories of materials procured by the supply agents: category A and category B. In actual condition of the oil field, there is a plethora of service types, materials and equipment that can be used.

For developing multi-agent systems, it is suggested the use of JAVA programming language. JAVA has been chosen for its simplicity of coding; for being an object-oriented language; for the existance of development of mature environments and; for being freely distributable. Furthermore, it is worth noting the portability that JAVA language provides. A system developed in JAVA is provided with an architecture for their own execution regardless of operating system. The JAVA language was used for the development of components (such as the Framework-JADE Java Agent Development Framework) which facilitates the implementation of multi-agent systems obeying its features and specifications such as autonomy, reasoning ability and knowledge-based messaging.

The modeled system in JAVA, in its current state, serves as a tool for monitoring production systems from established rules based on SPC, Statistical Process Control. The figures below show the two main screens of the system. They were designed to be the interface manager's field. Through the screens, in portuguese, it can be displayed an integrated view of all systems; the profitability in each of the production elements and; the profitability of the entire field (Figure 2). That figure gives an overview of the production system with its operational agents. It is possible to see the flow from wells (Poços) to refinery (Refinaria). The economic result for each agent and the whole field is shown on this screen (Valor de saída).

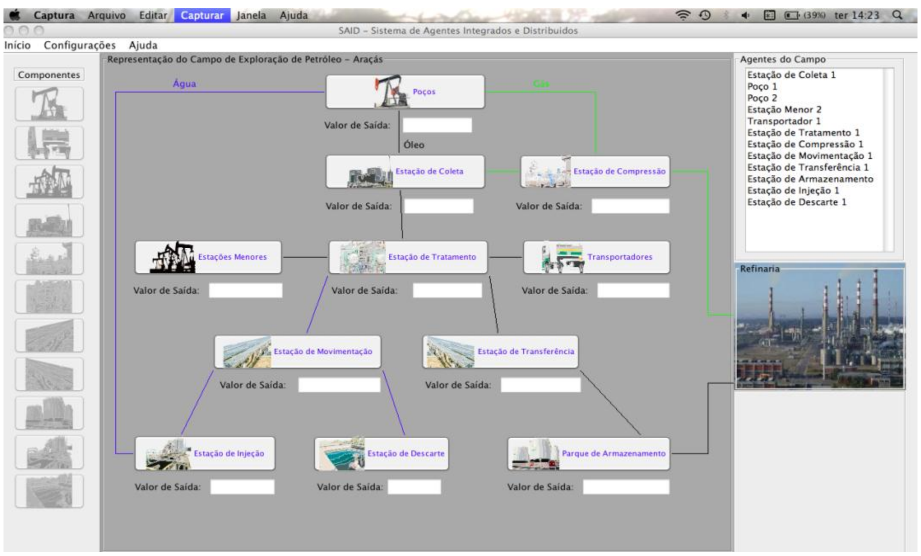

Figure 2 - The programe main screen

It is also possible to follow graphically the history of the variables of production and cost, making a comparison between the current state and prior periods, as well as view the messages exchanged between all agents in the system (Figure 3). The messages exchanged between agents that request services and agents that execute services can be viewed in detail.

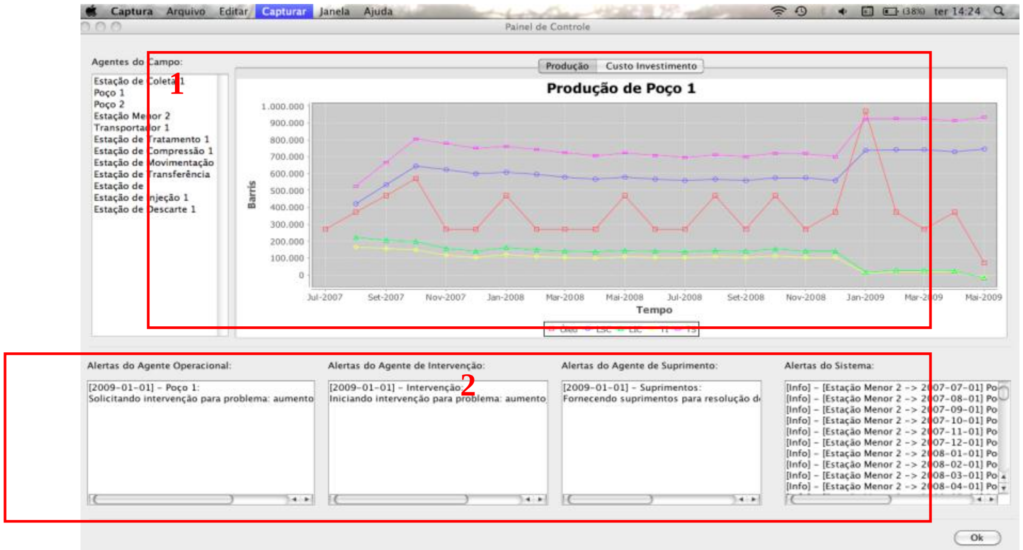

Figure 3 - The screen showing a production graph (1) and messages exchange among agents (2)

The system should evolve to a condition where the agents are intelligent and not simply react to rules. They need to be programmed in order to indicate the best operating condition, or service to be performed. To achieve it, the environment of the agent must reproduce the oil field and the agent must learn and develop his own knowledge. The learning process of the agent is based on the evaluation of actions and in the reinforcement of those that are better suited to the desired goal.

Finally, it can be said that the system has some motivations: oil field units, with distributed characteristics, should cooperate to reach production targets; oil field integrated cost analysis provides identification of unprofitable areas, which helps to make better decisions and investments; in mature oil fields profitability analysis is especially important, investment rises to keep production steady; agents help to reduce the load of information to the operator, giving him more time to focus on situations that requires his attention. It is desired a tool for simulation and real time situation diagnosis in a holistic approach.

Potential benefits and conclusions

The framework proposed to oil fields offers a systemic view to operators, supervisors and managers who are involved in decision-making process. The integrated view of the oil field in one main display screen gives to operator a view of all the impacts arising from the decision-making process and areas affected by this process. It alerts to the importance of criteria for prioritizing investments and services that maximize the overall result of the field.

The model helps in inefficiency identification process. The agents act as supervisors identifying potential problems and alerting an inefficient condition. The Alerts are generated from Statistical Process Control rules. When a production or cost variable reaches an upper or lower control limit an alert is issued for this condition. Through artificial intelligence techniques, rather than simply detect points of inefficiency, the model can still evolve into a solution detection and implementation. An intelligent agent can indicate a better production strategy, a reliable supplier, the right intervention and conduct the oil field to a profitable condition.

The operational performance analysis is reflected through the cost of oil at each stage of the process and the profit of the whole oil field shown on the main screen of the system. On it, there are graphs show trends with values of profit and investment costs for each stage of production. The manager has a better condition for asset management, investment prioritization and analysis of the flow value with cost information of extraction and oil processing at each point of the system.

It is possible too, to do some simulations and investment and disinvestment analysis. For example, it is possible to disable wells, to include new injector wells, to change services providers and supplies. These changes in network operations allow to test new operation conditions, even before the entry into operation. Always with the focus on maximizing the overall result of the field, the analysis should include wells, surface facilities and equipment and service providers.

Internal engineers focus on one of the stages in oil field, such as wells, surface facilities and suppliers. This may lead to the optimization of a number of subsystems; however, the sum of the optimized subsystem may present a problem to the optimization of the system as a whole. The system proposes an integrated view and applies the agent technology into the whole oil field from a systemic perspective.

The integrated analysis tool, with multi-agent approach, conducts to goals achievement in a collaborative way. An agent is a self-contained program capable of controlling its own decision making and acting based on its perception of its environment. In order to achieve one or more goals, an agent must possess any two of the following three behavioral attributes: autonomy, cooperation, and learning. The system comprises a number of intelligent agents, which represents the real world parties and cooperate to reach the desired objectives.

The proposed model was developed based on an oil field located on-shore in Brazil, but the proposed approach can be extended to off-shore oil field. Each operation on the platform, wells and other ground support systems can be represented by agents. These intelligent agents modeled with cost information and production data for each production system can lead managers to more rational decision-making.

Finally, it can be said that the proposed model integrates the various systems in oil field, as wells, treatment, collection, compression and injection station, as well as suppliers of equipment and services in a multi-agent system. Each production step is modeled as an intelligent agent. Each stage of production has individual goals and performance and interact with other agents in a collaboratively way to achieve the overall goal of the field. The model was translated in a software using JAVA, according to figures 2 and 3. It offer an effective mechanism to improve the oil field performance, improve the decision-making process, offers a systemic view to operators, supervisors and managers and provide new perspectives for oil filed management. We believe that the model proposed can be successfully applied to oil field management studies in practice and further evaluation will be carried out to validate its effectiveness.

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