HYBRID KNOWLEDGE BASED SYSTEM: A DECISION-SUPPORT PROPOSAL FOR NATURAL GAS COMPRESSOR STATION MAINTENANCE AND OPERATION

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Abstract: *Knowledge Management (KM) associated with Artificial Intelligence (AI), specially Knowledge Based Systems (KBS), is consolidating itself as a fundamental tool for maintenance and operation of complex automatized systems, increasing the reliabilty and agility of the interventions and preserving, at the same time, the intelectual capital, resulting in competitive advantages for the companies.*
This article proposes and emphasizes the advantages of the application of hybrid systems based in knowledge and numerical simulation in order to guide the decision-making during maintenance and operation interventions of Natural Gas Compressor Stations (ECOMP). In such systems, the accurate and assertive interventions are directly related to criterious procedures and to the level of expertise and knowledge of experts involved in maintenance and operation.
Besides the theoretical knowledge inherent to the content mentioned above, this article introduces practical examples of hybrid systems for maintenance and operation support that are already applied to the Natural Gas Pipeline Bolivia-Brazil, known as GASBOL.

Keywords: *Knowledge Based System, Natural Gas Compressor Station, Simulation, Maintenance.*

1. Introduction

A hybrid system is the result of an integration of two or more technologies to maximize the strengths and minimize the weaknesses of each technology. The hybrid model proposed in this paper combines a simulation model with a rule-based Expert System (ES) to assist natural gas pipeline operators and maintainers as a decision support system. From collected field-data, the simulator supplies operators and maintainers with the operational conditions of the system.

The information provided is basically a large amount of data that the new operator and maintainer often consider difficult to understand. This article aims to propose the development of an ES to provide the operator and maintainer with useful description about the process, as descriptive information is highly understandable. However, an ES is not able to handle a large amount of calculation as a simulation program does, hence the need for combining the two technologies. This combination characterizes a Knowledge Based System (KBS) and from this point on we intend to explicit this application, not only for maintenance but also for Natural Gas Compressor Station (ECOMP) operation, including aspects of Knowledge Management (KM), having as an example an ECOMP of GASBOL.

2. Knowledge Creation and Storage

For any organization, one of the most important assets must be its individual members and their accumulated knowledge. The overall knowledge of an organization however may be less than that sum up of individual parts of knowledge, so methods of accessing, utilizing, sharing and storing this knowledge are important factors to be addressed in organizational studies. Metes and Gundry (1997) define some operational characteristics of knowledge as follows:

- Knowledge is a human capability (i.e. a capability to do or judge something now or in the future). Knowledge is the transformation of some information by a person.
- Knowledge acquisition is a dynamic process. Knowledge Management tools do not have an inherent capacity to manage knowledge - instead they help to capture, organize, store and transmit source material, so that an individual may acquire some knowledge. Whether an individual does acquire knowledge from a source depends on a dynamic interaction in which two factors are important:
  - The similarity between the person's context (his situation, history and assumptions) and the context described;
  - The degree of congruence between how the material is structured and how the structure of the domain appears to the user.

- Knowledge is multi-dimensional. It means that it can be explored and have abstractions applied to it; having knowledge enables the possessor to generate new statements about a subject rather than merely reproduce the statements that were received. The multi-dimensional nature of knowledge is linked to a fourth aspect (i.e. that knowledge is elaborate). Knowledge is a complex body of organized information, delivered in large packets. The acquisition of knowledge by an individual then may be hindered by information overload without the aid of some filtering tool or map.

Knowledge Management (KM) creates routines and systems in order to increase and share acquired knowledge in a certain environment. The KM process (Fig. 1) includes the generation, codification, dissemination and the appropriation throughout the entire organization of knowledge that is usually restricted to an individual or group of people, thus, enabling the generation of new kinds of knowledge. This process, called Knowledge Spiral presumes the overcome of a competitive and egocentric environment by a cooperative one in harmony with the organization purposes.

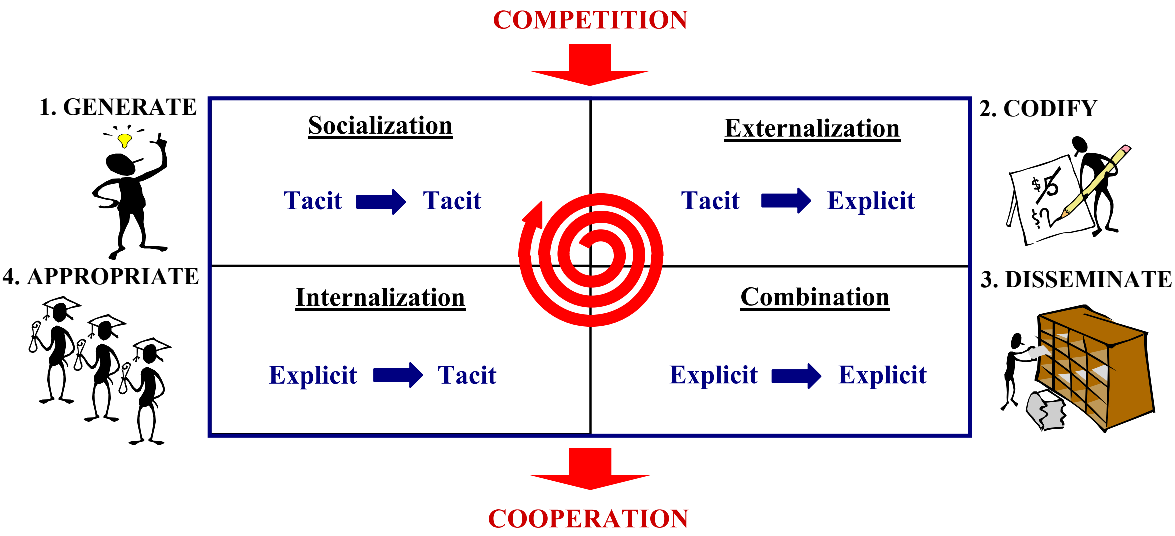


Figure 1 - Knowledge Spiral. Adapted from: (Nonaka and Takeuchi, 1997).

Within this proposal, KM will be used to avoid the loss of tacit knowledge of ECOMP operators and maintainers, socializing and making knowledge explicit in order to make it part of the strategic organization management process alleviating the problems created by the lack of information and also by the knowledge accumulated by the organization.

The current research addresses the question of how AI tools may facilitate the organization, dissemination, storage and interpretation of knowledge. In this context, two AI techniques stand out: Case-Based Reasoning (CBR) and Expert System (ES).

CBR is a problem-solving approach that takes advantage of the knowledge obtained from previous attempts to solve a particular problem. A record of each past attempt is stored as a case, and it is the collection of historical cases, which forms our model. When a CBR system solves a problem, rather than starting from scratch, it searches its case base for similar cases whose attributes are similar to the problem that it is being asked to solve. The CBR system then creates a solution by synthesizing the similar cases and adjusting the final answer for differences between the current situation and the ones described in the cases. As the case base grows, the accuracy of the system should improve (Watson, 1997).

ES, the focus of this article, is conceived to reproduce the behavior of human experts in the problem solving of the real world, even though the domain of these problems is restricted. On the other hand, within such a domain, stored knowledge must be kept within the limits of expertise and also organized in a way that facilitates the consultancy for solutions by non-expert users. With these features, not only does ES differ from conventional information systems (that facilitate exclusively the obtainment and storage of information), but also ES become useful for training new personnel. In modern knowledge engineering, ES was incorporated to the KBS whose function was to implement a process for problem solving, that was rationalized and standardized by an organization, instead of reproducing only the knowledge of an expert. The process of development and evolution of KBS (Fig. 2), includes the following phases (Russell and Norvig, 2004 and Rezende, 2003): KBS Planning; Knowledge Acquisition; KBS implementation; Validation and Refinement of the KBS.

In the context of this project, the KBS will help ECOMP operators and maintainers in their decision-making process. Besides being a decision-making support tool during operational and maintenance interventions, a KBS can be used as a knowledge manager when associated to these interventions, helping the creation of knowledge repositories and avoiding knowledge loss due to the absence of experts.

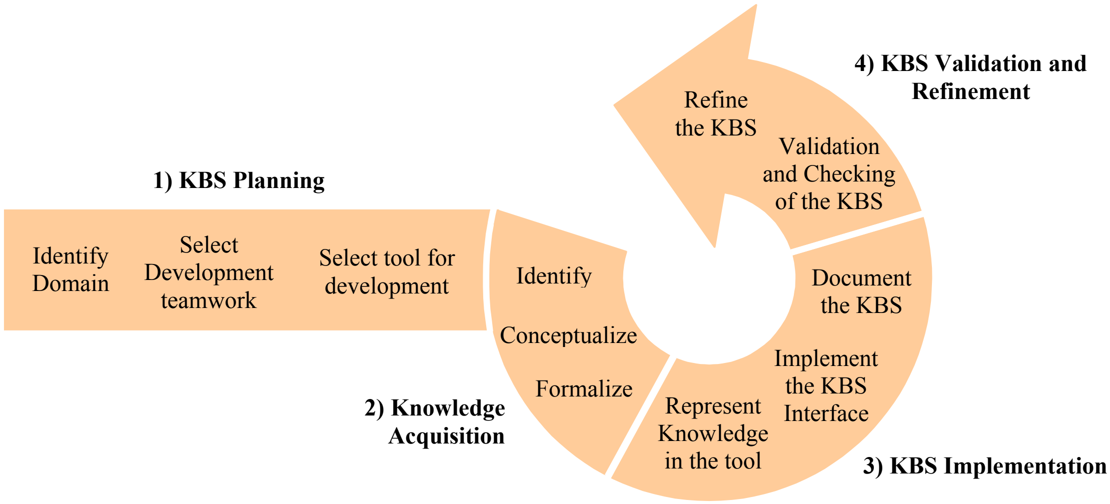


Figure 2 - KBS development process. Source: (Rezende, 2003).

3. KBS for Natural Gas Compressor Stations Maintenance and Operation

The conceptual framework of this proposal is based on RCM (Reliability Centered Maintenance). RCM establishes condition-action rules that enable KBS conception, through techniques of failure analysis and applying heuristic knowledge of maintainers and operators.

One of our partners in this research project is TBG - Transportadora Brasileira Gasoduto Bolívia-Brasil S.A.. The company initiated**,** in the year 2000, a study program based on the RCM methodology (Ribeiro and Alves, 2005). The program purpose was to analyze its main and more critical installations and systems, aiming to guarantee a high reliability through maintenance. These studies allowed the participants to know deeply the installations systems and devices; to map out all the principal failure modes of various systems and devices through FMEA (Failure Modes and Effects Analysis); to evaluate the consequences of failures and their impact on security, environment and operation; to determine the maintenance activities (preventive, predictive and detective or failure search) necessary to support of system reliability; to identify opportunities for the installation project upswing or changes, aiming the improvement of its reliability and to identify the needs for implementation of maintenance and operation procedures or modification of ones that already exist.

In 2001, a partnership involving TBG, SCGAS (Gas Company of Santa Catarina), UFSC (Federal University of Santa Catarina), PETROBRAS with the financial support from FINEP, started the development of a project called SEGRED (Expert System for Gas Network Management). The SEGRED project is a computational support tool for operation and maintenance of a typical natural gas distribution network, using techniques of ES for decision-making support. Thus, it aims to act directly in the reduction of the response time of the maintenance group for problems that can be identified or diagnosed by means of process variables. It operates with a system of data acquisition and uses data remotely obtained, in order to make inferences about the network operational state. It focuses on the identification and diagnosis of problems such as: excessive consumption of gas for the dimensions of the network and the failure in the pressure reduction station valves. Moreover, the system can incorporate information about equipments and clients that, added to available graphical resources, can help in tasks of maintenance and management of the network. Its development is based on the feasibility of the following functionalities (Caletti et al, 2004 and Silva et al, 2004):

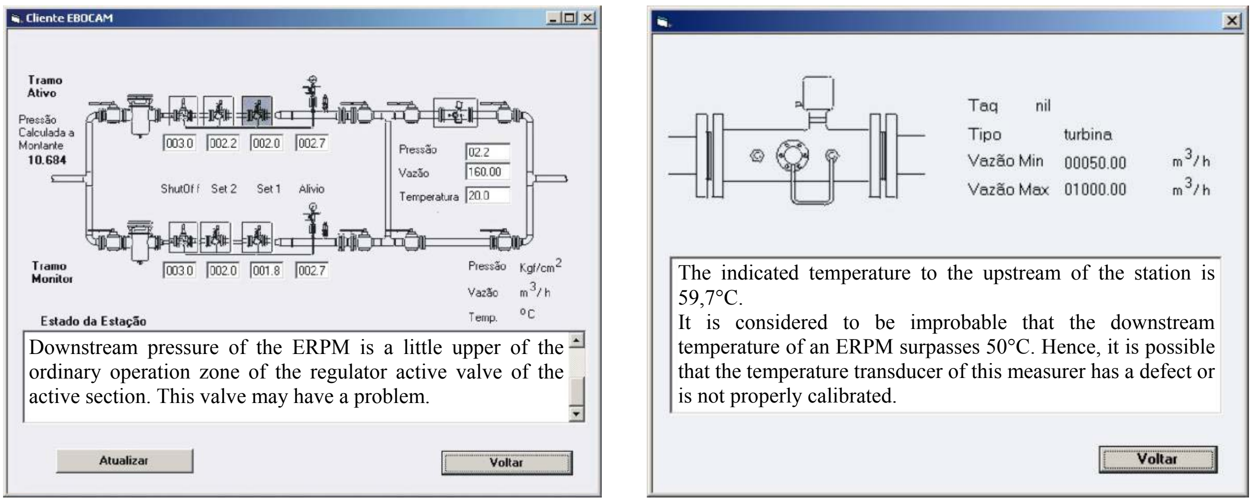
- Detection of failure and operational problems in the network.
- Indication of probable causes for the problems that are found.
- Suggestion of corrective procedures for the problem

The necessary information to make the inferences is codified in the knowledge base of the expert system in the form of rules. For the implementation of this knowledge base, CLIPS was used, which is a complete environment for the development of expert systems developed by NASA. The model of the network was developed in the AMESIM software, which is an advanced environment for modeling of engineering systems, (Lebrun, 1997). The integration of these two systems is carried out through an intelligent agent that works in the data structure of the expert system and in the parameters and results of the simulation (Silva J. and Silva, 2002).

One of the items not included in the SEGRED project and, for this reason, is proposed in this article, is a hybrid KBS specific to ECOMP. From field-data and numerical simulation, an expert system, will be able to guide the decision-making during the interventions of maintenance and operation of ECOMP. The proposed system can help operators and maintainers through the implementation of the following functionalities:

- Creation of a repository of the heuristic knowledge of the maintainers and operators of the ECOMP to accelerate the operation and maintenance process resulting in a loss time reduction of the system function.
- From numerical simulation and field data acquisition via SCADA, the KBS can, in a real time, anticipate insecure situations or those kinds of situations that can jeopardize the system function, launching preventive or corrective actions to reestablish the levels of reliability.
- Programming of predictive and preventive actions based on the real time monitoring of the system and on the heuristic knowledge of maintainers and operators.
- The KBS proposed here can serve as a support for the training of new operators and maintainers, simulating risk situations and the loss of the function of components or parts of the system, contributing for the reduction of human failures during the maintenance of the system.
- Preservation of the company's corporative memory regarding maintenance and operational activities to overcome problems related to the loss or inactivity of the human expertise.
- Assistance for decision-making to field operation and maintenance groups, where it is not possible to count on with a full-time human expert.
- Through the usage of information technology it is possible, from a distance, to execute technical assistance for maintainers and operators, by means of the help of non-expert personnel that have access to the system.
- From the monitoring, in real time, of the system and also based on maintainers and operator's heuristic knowledge, it is possible to assist on the detective maintenance of items that are not frequently requested or that have a doubtful functioning.
- The analysis of tendencies with heuristic knowledge can contribute to corrections or to the redesign of the system if future requests are necessary.

All these items can contribute to an increase of the system reliability, as it becomes less susceptible to human failures and inadequacies. An example of some of the items just mentioned is shown in Fig. 3, for an ERPM - Pressure Reduction and Measuring Station included in the SEGRED. Figure 3a shows an analysis of the operational situation of the ERPM through the process variables, derived from the dynamic simulation and knowledge about the functioning of the network. Figure 3b shows a failure diagnosis that was obtained based on the heuristic information of experts and in the study of failure modes of the component (Castelani, 2002; Silva, 2003).



(a) ERPM Situation (b) Diagnosis of failure in a component

Figure 3 - Example of a module of maintenance support. Source: (Castelani, 2003)

Besides being a support tool for decision-making in the issues that are referred to maintenance, the proposed system can count with a module to help ECOMP operators in decisions, increasing the reliability in the operational activities of the ECOMP and reducing the risks caused by human or functional failure. To exemplify this process, we discuss, from now on, how a KBS in real time can help the operator to adapt the supply curve of the ECOMP, according to customer demand.

In general, the main purpose of natural gas pipeline operation is to transport gas to customers in order to satisfy their demand at all time, while dispatchers or operators are responsible for the monitoring of the gas volume to determine whether it can satisfy such a demand. In addition, they need to decide when turn on/off compressors to control flow and pressure. Sometimes the dispatchers might make unnecessary start/stop decisions because they lack experience. As a result, some months are required to train new dispatchers to properly operate the system. However, it takes a number of years for them to gain extensive experience to operate the system smoothly and cost effectively.

The simulator program generates a compressor discharge pressure curve versus a customer station pressure curve as shown in Fig. 4. Both curves indicate the relationship between demand and supply. If the gap between them is wide the customer satisfaction is guaranteed, yet the cost is high. On the other hand, if the gap is too close, it becomes cost effective but future customer demand may not be satisfied. Ideally, the best performance of an operator is to close the gap but not to overlap the curves. In practice, each operator performs his/her task in a different manner and, usually, a more experienced dispatcher is better able to close the gap. In order to assist new operators, a hybrid KBS for operational decision support is proposed here.

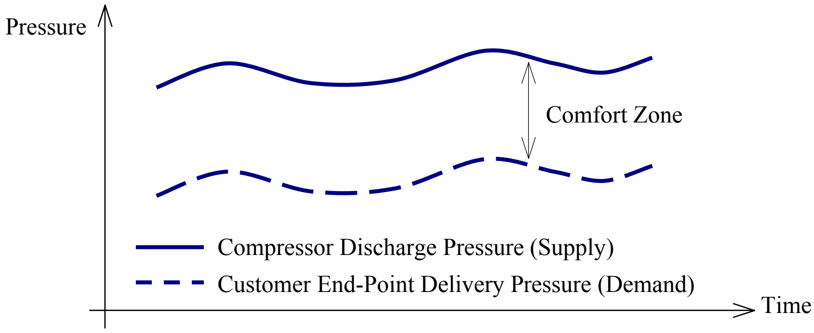


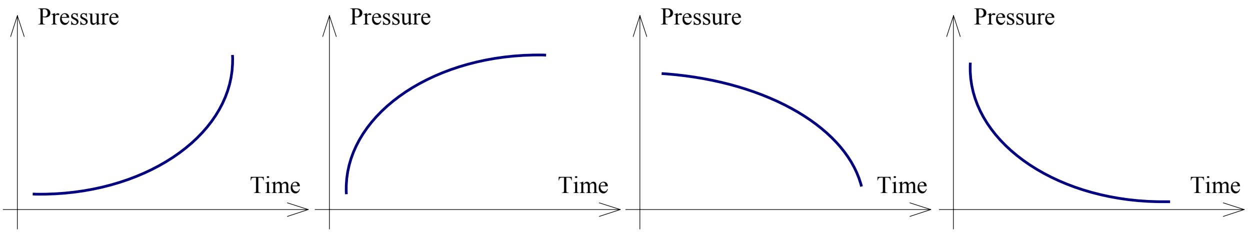
Figure 4 - Demand versus Supply graph. Source: (Uraikul, 2000).

In order to develop such ES, knowledge from an experienced dispatcher, who already has several years of experience and is familiar with the process of the control system, is acquired and represented in the knowledge base. Once the ES is built, it can be used to help inexperienced dispatchers operate the processes more effectively. There are four important parameters that the operators in the natural gas pipeline industry must consider:

- Current line pack level.
- Current point delivery pressure.
- Rate of change of pressure.
- Rate of change in line flow.

Among these parameters, the line pack level is the most important one for optimizing natural gas pipeline operations. It can be defined as the volume of natural gas between an ECOMP and the customer demand locations. When the line pack level is low, there is not enough natural gas supply to customers. On the other hand, when its level is high, too much gas is transported and the energy that is used may be unnecessary.

An operator is responsible for turning on and off the compressor unit several times during the day in order to adequate the system to customer demand fluctuation. A parameter, that indicates the demand for natural gas at the customer's location, is the end point delivery pressure. Once the simulator program inputs the transient data of pressure into the ES, the ES can use that data to plot the end point delivery pressure graph. The pressure graphs can be categorized into four types, divided into two classes, which are positive and negative pressure change rates, as shown in Fig. 5.



(a) - Positive Pressure Change Rate (b) - Negative Pressure Change Rate

Figure 5 - Rate of Change of Pressure. Source: (Uraikul, 2000)

A positive rate of pressure change indicates that the demand for natural gas at the customer's location is decreasing while a negative rate shows that the demand is increasing. The operator, thus, issues the appropriate action for different types of changes. For instance, if the pressure is falling or customer demand is increasing, the operator needs to quickly turn the compressor on; otherwise, the demand cannot be satisfied. On the other hand, if the pressure is rising or demand is decreasing, the operator needs to shutdown the compressor. Usually, a new operator tends to turn on/off a compressor too early or too late, since the demand of the natural gas always changes from time to time. In general, a senior operator has a good understanding of the relationship of the customer demand curves and other process of the system what makes this knowledge important for operating the natural gas pipeline. The ES can be used to capture this knowledge, which on its turn, can be used for standardizing the training of new operators. Such ES can also provide system recommendations regarding knowledge and, as a result, the system can help a new operator in making fast and reliable decisions to properly operate the system. In fact, the recommendation from the ES supports the operator's decision-making. Figure 6 shows an overview of the hybrid system proposed and the interaction of its components.

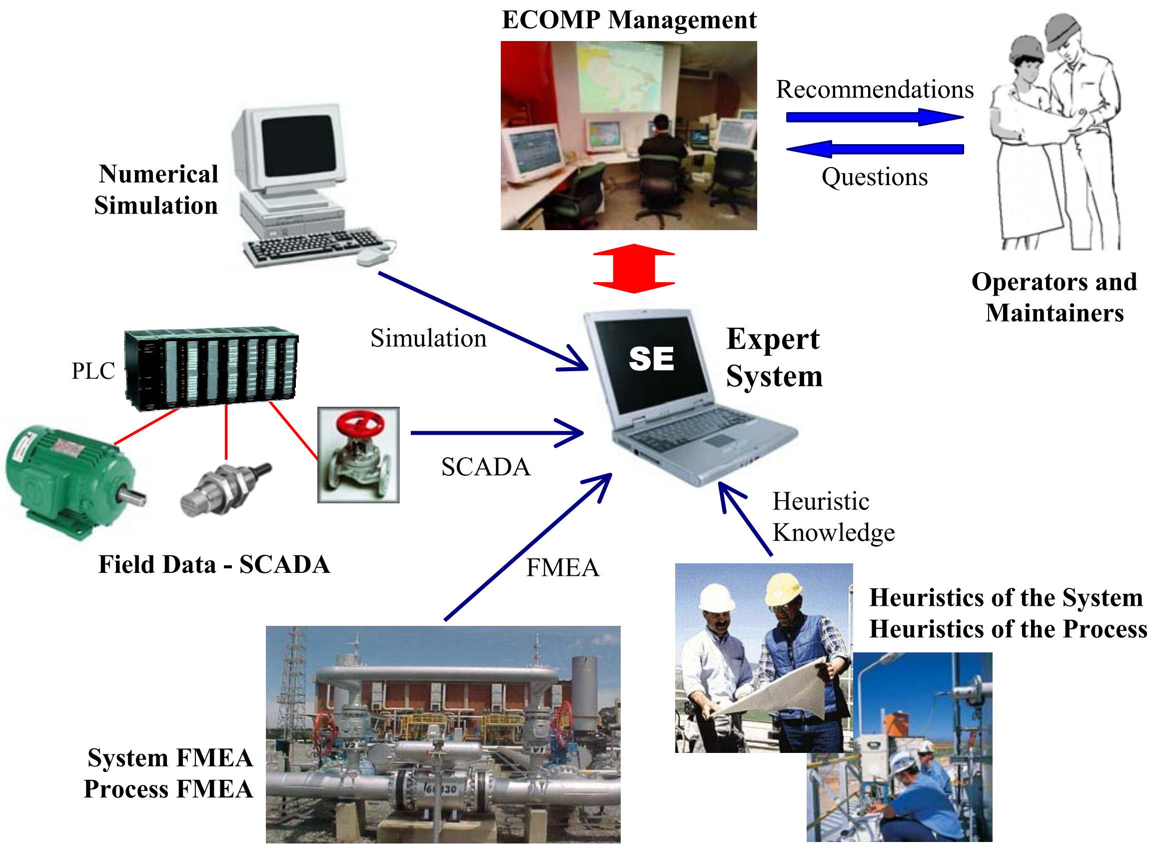


Figure 6 - Overview of the Hybrid KBS.

Firstly, the ES receives output data from the simulator. After the ES reads the field data, it performs calculations on the system line pack, break horsepower (BHP) requirement, change of pressure and rate of pressure. The first task of the ES is to calculate the system line pack level, while the second one is to determine what is the required horsepower to satisfy the customer's demand.

The third important ES task is to provide operators with the information regarding which compressor unit should be turned on/off, that is done by using heuristic knowledge obtained from senior pipeline operators. Based on the value of the three recommendations (line pack level, BHP requirements, and choice of compressor to turn on/off), an operator can choose whether to follow the system recommendation or not. In addition, the operator can also change or modify the recommendations.

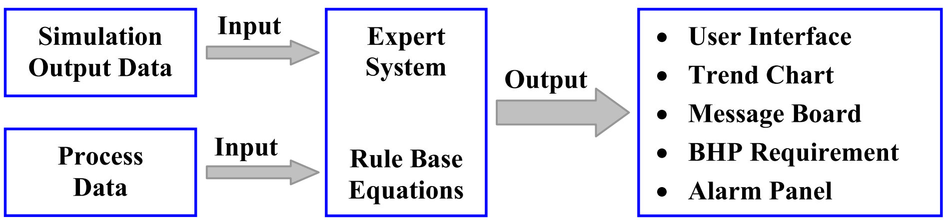


Figure 7 - Input and Output of the System.

Figure 7 shows the input and output of the proposed hybrid system. The input (Simulation and Process Data) to the ES is in a text file. The file contains pressure information about the ECOMP, and customer's demand locations, as well as the ECOMP flow. The outputs from the ES can include the following:

- User's Interface - it helps the operator to visualize the system conditions and make changes or modify them in an easier way for the user**.** So, the operator can have a better understanding of such conditions. From the user's interface windows, an operator is able to visualize a system pressure change over a period of time. The windows let the operator pause, reset or modify the system.
- Trend Chart - it helps the operator to monitor end-point delivery pressure over a time period.
- Message Board - it provides the operator with knowledge of the current condition of the system, for instance: low, high or enough line pack in the system. If the line pack level is not enough to satisfy customer's demand, the ES indicates low line pack level and suggests turning on compressor units. If the line pack level is high, the ES indicates high line pack level and suggests stopping or decreasing the compressor unit power. On the other hand, if the current line pack level is enough for future customer demand, the ES recommends no action.
- BHP Requirement - it is also given to show the amount of horsepower that should be supplied to the system if its line pack is low. In case it is high, the system shows how much BHP is needed to decrease.
- Alarm Panel - The simulator triggers an alarm when the system is in serious condition that is not adequate from an economical point of view. The ES will be developed to avoid this serious system condition by using high/low alarm panel that will inform the operator before the serious alarm panel in the simulator program is triggered. It will be, therefore, a measure to ensure safety as well as cost effectiveness.

The proposed system will also show pressure change, rate of pressure change, in-line flow, and current line pack (with calculation details). These parameters are provided to help the operator understand the system conditions. Moreover, the ES makes recommendations based on these parameters and, plans are being made to analyze G2 shell as platform for this project, this system has user-friendly editor features to help a developer who does not have any programming knowledge to set up rules. All rules are formatted in the basic IF-THEN formalism and have been validated by the senior operator (Gensym, 2005). An example of the IF-THEN rule that the ES can have is shown as follows (Uraikul, 2000):

IF the Current Line Pack is α to β m^3
AND Change of Pressure is γ to δ Pa/h
AND Rate of Change of Pressure is Positive
AND In Line Flow ε to η m^3/h
THEN the Current Line Pack is low

4. Conclusion

This article is part of a doctorate project that aims to integrate the concepts of ES, Knowledge Management and Numerical Simulation in order to create a hybrid KBS able to assist decision-making during the operational and maintenance interventions of ECOMP.

Some advantages of developing a hybrid KBS that assist this decision-making process during operational and maintenance interventions of ECOMP include the following:

- The usage of the KBS improves the reliability of the decision-making process. Human beings tend to forget relevant factors, especially if they are under stressful conditions or in a critical situation. Intelligent machines are immune to such factors.
- The KBS offer an increasing consistency in relation to the relative importance given to different decision factors, once it treats all the decision factors without the human limitations that are inherent to the process of decision. They can also present higher accessibility and better abilities to explain their outcomes.
- Hybrid KBS can bring innumerable economical advantages for companies regarding the ability and efficiency of their actions, minimizing wastes and maximizing profits.
- Knowledge management is an important ally in order to avoid re-works and interventions that were already proved to be inefficient in the past and that due to the lack of information are repeated, at the same time they preserve the intellectual capital of the organization.
- KBS can accelerate the maintenance process reducing the time loss of the function of the system.
- KBS can be used as a decision-support tool for inexperienced maintainers and operators for compressor operation at ECOMP.
- Simulation data can be used for validating the KBS.
- The operating heuristic knowledge of senior operators and maintainers can be documented and used to standardize the training of new dispatchers.
- The KBS helps to increase the system reliability by reducing unnecessary compressor start/stop at the ECOMP.

From a technological development point of view, we consider that the concepts mentioned in this article can contribute with useful solutions to the study of the knowledge engineering applied to the decision-making during the interventions of operation and maintenance of the ECOMP.

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