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## MAN-MACHINE INTERFACE FOR PREDEX, AN EXPERT SYSTEM SHELL FOR PROCESS CONTROL AND SUPERVISION

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**Abstract.** This paper aims at describing our research work related to Man-Machine interface for an expert system shell for process control and supervision, called PREDEX. The first part of the paper presents the PREDEX framework. This expert system shell integrates a qualitative model of the process. The second part of the paper describes the Man-Machine cooperation model and the main displays constituting the interface.

### 1. INTRODUCTION

When computerizing the control rooms of continuous industrial processes, Man-Machine interfaces were first based on classic representation modes such as synopsis displays, curves, bargraphs, etc. Lind's work [12; 13] has led to implementing a new mode of representation: flow models, which give a comprehensive functional description of the process. This process is described in terms of "mass" and "energy" and in terms of "transfer" and "storage". This symbolism has already been used in industrial applications such as those by Siebert, Sicart, Thebault [17] or Praetorius, Duncan [14].

Progress made in the field of qualitative reasoning has led to creating decision aid tools based on a qualitative model of the industrial process which needs to be controlled. Using such as model has, in the short run, helped take into focus and even improve potential "aid-devices" for the operator; for instance, predicting the future state of the process; focussing on a sub-system in case of problem; making the diagnosis process much easier; simulating the evolution of a variable in response to a change in another. It has thus become necessary to develop a new kind of interface meeting these new standards. These interfaces do also have to fit into the operator's decision-making process.

Our research work on Man-Machine Communication is based on these concepts, and this, mainly for decision aid systems which integrate a qualitative model of the process. This paper presents our work on man-machine interface design for PREDEX, an expert system shell for process control and supervision.

This paper is composed of two main parts: (i) the first one describes the different modules constituting the expert system shell PREDEX, which integrates a qualitative model of the process; (ii) the second part first describes the Man-Machine cooperation model. This model is used as a conceptual basis for our works related to PREDEX Man-Machine interface design. Then the different types of graphical displays constituting the interface are specified.

## 2. PRESENTATION OF PREDEX

PREDEX is an expert system shell for process control and supervision of industrial processes [22]. It is composed of a set of modules which interchange control information, and data. There are four modules: "Perception", "Prediction", "Diagnosis", and "User interface management", Figure 1. These four modules may run on different calculators connected together by an Ethernet network. Their information interchanges are monitored by a communication controller. These modules are autonomous, each of them realizing specific functions and operating on their own data and knowledge. In this context, the controller role consists in (i) initializing each module, then in (ii) assigning the data communication channels and finally in (iii) synchronizing in real time the different processes. The cooperation between the different modules allows to insure the complex task of assistance to the operator. These modules are briefly presented below.

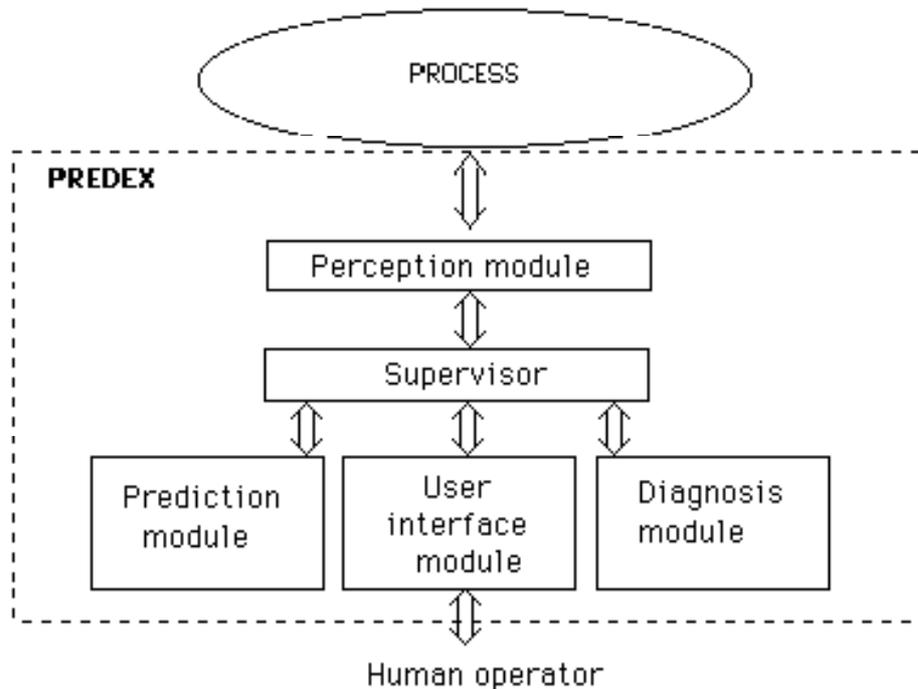


Figure 1: The modules constituting a PREDEX application

The perception module constitutes the physical interface between the aid system and the underlying process. Its purpose consists in acquiring data from the real world, in processing them and in providing the different modules with these data. This module is also able (i) to compute unmeasurable data, (ii) to realize specific treatments with the object of filtering noise, (iii) to validate data, (iv) to generate alarms which are stored in order to be used by the operator. This set of acquired or generated data is transmitted to the diagnosis process, which is described below.

The diagnosis is realized according to two different approaches which are implemented in two different modules: (i) the shallow diagnosis, using effective knowledge issued from a human expertise, (ii) the deep diagnosis, using descriptive knowledge on the process to be controlled.

So, first, the shallow diagnosis module - developed according to the Kramer approach [11] - detects and identifies the failing system which is at the origin of the dysfunctioning. This module has been implemented in PREDEX with NEMO, which is a first order inference engine. NEMO uses production rules and temporal primitives for knowledge representation. This first diagnosis phase provides a list of

failures which are likely to be at the origin of this dysfunctioning. This list is transmitted, through the supervisor to the deep diagnosis module.

So the deep diagnosis module is activated when the shallow diagnosis module has identified the failing system(s). The shallow diagnosis module provides the deep diagnosis module with a list of suspected failures which could have affected the process. So the deep diagnosis module must discriminate between these hypothesis in a way to make the diagnosis better, and to propose to the Human operator a reduced classified list of elementary failures. The implemented diagnosis method combines three different methods: (i) the structural reasoning method issued from Davis [3], (ii) the causal reasoning method issued from Console [2], and (iii) the qualitative reasoning method issued from Kramer [11]. The deep knowledge is based on several types of deep knowledge: a network of functional causality, a structural model, a fault model, a description of failure modes. When a failing system is identified, an action plan is then defined. This plan has to guide the operator in the creation of a procedure related to the abnormal state of the process.

In order to predict the behavior of the process to be controled, the system PREDEX also uses a qualitative modelling of it. The modelling corresponds to the one proposed by Tang [21]. This approach is based on "event propagation". Concepts of automation are introduced in this modelling [4, 6]: that is to say that interaction links between variables are defined by information such as 'gain', 'delay', and 'response time'. In this case, a dynamic process is modelled by an interaction network: the nodes represent process variables and links correspond to the relations between these variables. Temporal interactions between the variables are done by events exchange. They are the only sources of changes in the nodes and variables. The technique used in PREDEX consists in modelling a dynamical system by a propagation network of temporal events, and in optimizing the response time by using a qualitative hierarchical model of the process. So, a rule-based system - built on this technique - can optimize its treatment according to the real needs of the current task, for instance a diagnosis or prediction task, by identifying the smaller sub-model satisfying the task's objectives. For that purpose, it is able to focus its reasoning by using a minimal set of necessary data, and by avoiding useless treatments and reasonings.

The activation of the prediction module comes into effect after a failure has been identified. The prediction of the process behavior serves several purposes: fault hypothesis verification, fault anticipation and detection, proposed advice justification, possibility for the operator to evaluate the future state of the process with applying or not a proposed action plan. This module may provide, with an operator request, three types of predictions: (i) value and tendency to a fixed horizon, (ii) threshold over or underflow with maximum and minimum values, (iii) evolution curves in a fixed time-period. This information and also the data gathered from the interface-dedicated prediction module are at the disposition of the user interface management system. It aims at supplying interface displays through data files. Man-Machine interface is described in the following part.

### **3. MAN-MACHINE INTERFACE FOR PREDEX**

A decision support system realized with the expert system shell PREDEX provides the Human operator with diversified helps: diagnosis, supervision, prediction for instance. In a way to optimize Human-Machine Interaction, it is therefore necessary to base the design works on a model of cooperation between the operator and the decision support system. This model is now described.

#### **3.1. "Man-decision support system" cooperation model [10]**

The theoretical basis of the Man-Machine cooperation is the General Problem Solving Model proposed by Rasmussen [15; 16]. This model is henceforth commonly used in Human Engineering. In this

context, we suppose that during the normal functioning of the process, the human task consists in supervising it and in improving the production parameters. During the abnormal functioning of the process, the operator aims at (i) detecting dysfunctionings, (ii) making diagnosis, (iii) deciding action plans, and finally (iv) performing the adequate actions on the process.

So, it is necessary to specify the organization of the displays which ensure the presentation of the set of useful information to the operator. This phase is crucial because the specified organization sets the future cooperation between the decision aid system and the human operator. The solving of the possible conflicts, which can happen if the operator does not agree with the advices provided by the computer, depends on this cooperation. Indeed the Human-Machine interface must lead the operator to check the results corresponding to the different steps of his reasoning process, in order to find the origin of the conflict. For that purpose a solution consists in analysing in parallel the human's and the system's problem solving process, in order to provide the operator with relevant information according to different justification levels, with a view to finding a consensus as quickly as possible (see the works by Taborin and Millot [9; 18; 19; 20]). In order to specify the chaining between the different displays of the interface, a man-machine cooperation model is necessary.

Our model is summarized in figure 2. It gives a global overview on the communication between the operator and the interface, when a dysfunctioning appears. It is decomposed into three interconnected phases: (i) first, the decision support tool considers the situation and generates a set of hierarchical alarms; (ii) secondly, there is a phase of communication between the decision support system and the operator. So, facing the situation gravity, some complementary information may be displayed on the interface, such as advice action plans, justifications, and so on; (iii) finally, the third phase consists in problem solving, in which the operator and the system have to cooperate. In this phase, the three different behaviour levels quoted by Rasmussen [16] may happen: Skill-based behaviour, Rule-based behaviour and Knowledge-based behaviour (see figure 2).

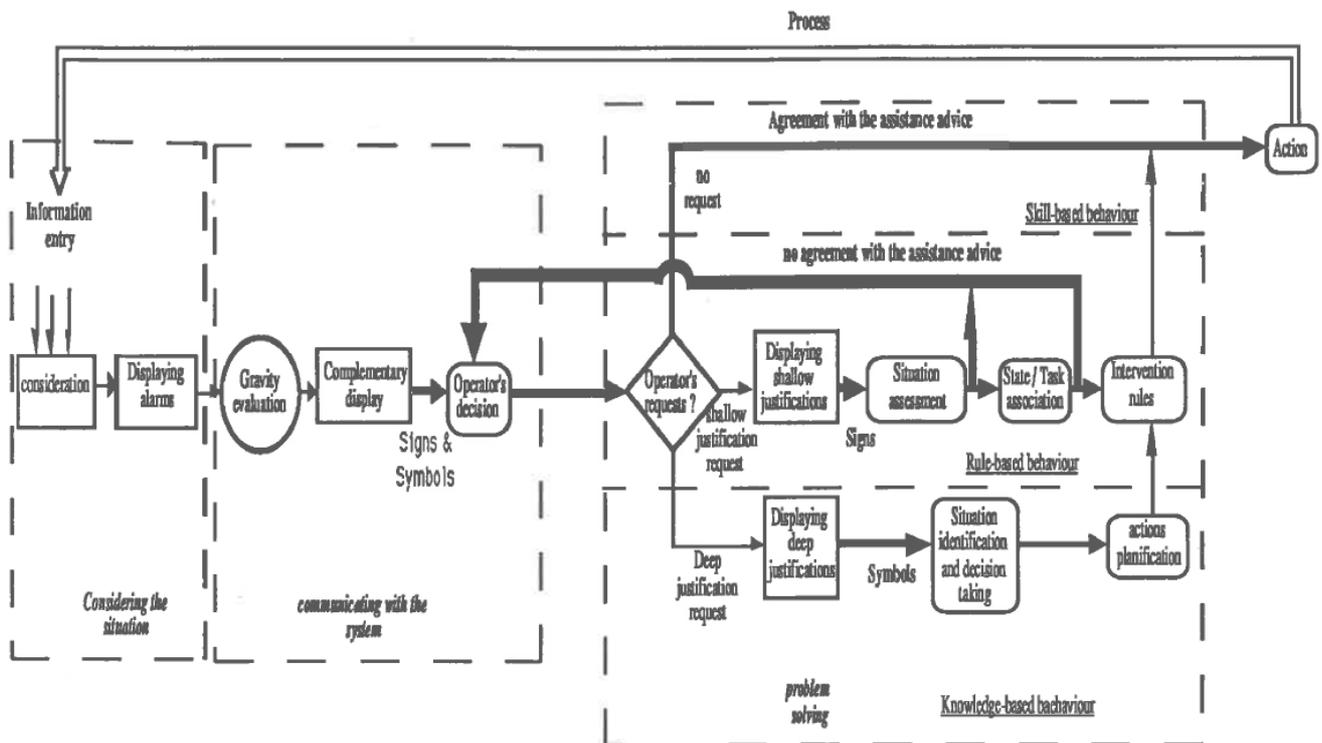


Figure 2 : "Man-decision support system" cooperation model [10]

Thus, for each of these three levels, the interface has to propose different graphical helps. The final

aim is to obtain a consensus between the operator and the decision support tool, when a dysfunctioning appears and when the operator has to make a decision. Thus, if the operator does not agree with the action advice issued from the decision tool, the interface must be able to explain them under many justification levels using supplementary graphical displays [18; 19]. The three different behaviour levels are presented below:

- The operator can agree with the decision support system and then, acts on the process. This behaviour can be identified to a Skill-based behaviour.
- However, he can be undecided and try to evaluate the situation in a better way, in order to make a diagnosis and to take a decision. He can base his reasoning on complementary information. If "shallow" justifications allow him to identify the process situation, he can admit them and adopt the (proposed or not) intervention rules. This behaviour can be identified to a Rule-based behaviour.
- To a third behaviour level (Knowledge-based behaviour), the operator uses "deep" justifications, helping him to make his own diagnosis. This one leads him to make a decision and to planify actions to be performed on the process.

After having globally presented the cooperation model, we describe in the following part ergonomical specifications for the different displays which have to ensure this cooperation.

## 3.2. Interface Description

Several types of displays have been or are being realized [5]. They are described below.

### 3.2.1. "Monitoring" display

The first type of display aims at synthesizing the process current state. Indeed, during a normal operation, the operator supervizes the variables in order to predict a failure. An alert state is generally not activated by an alarm generated on the process or by the aid system but by prediction activities which are proper to the operator. In accordance with (i) the type of sub-process to be controlled - constituted with independant or interconnected variables -, and (ii) the training level of the operator (it is more or less important), the operator is induced to scan either the set of variables or a subset of characteristic variables in order to compare them with the objectives of operations which are assigned to him. In this case, his cognitive approach deals essentially with the situation assessment. If the observed state or the prediction made by the operator are different from the fixed objectives, then the process is considered as being in an abnormal state. The "Star display", presented at figure 3, synthesizes in a particular way the more important variables of the process. Accessible through the command "Supervision" (see figure 3), the star display include the more significant variables of the process. This display consists in eight radii (in the presented case study) of a same circle. The characteristics of each variable are displayed on each radius: the set value, and five thresholds (normal, high, very high, low and very low alarm). These characteristics are normalised for each variable so that they are linked together by concentric circles. The temporal evolution of each variable is represented by a point on its radius. The eight points are linked with straight lines to form a regular polygon when the process operation mode is normal . When a defect appears, the polygon gets out of shape: the operator is alerted according to the expert system's prediction. Moreover, the star display pattern changes according to the prediction made on the variables presented on it. This prediction polygon is presented to the operator in order to help him in his anticipation of a defect. This representation, which principle is not new (see [1]), has been studied by many authors. So Jacob et al. [8] show that the interpretation time of a situation is lower than the one which is necessary when using a numerical value display. Other authors like Goodstein [7] advise to use the star display for the supervision of a process. Furthermore, an experimentation has shown the superiority of the star display over displays

containing bar-graphs and dials, according to the criterion of the time which is necessary to detect a disturbance [18].

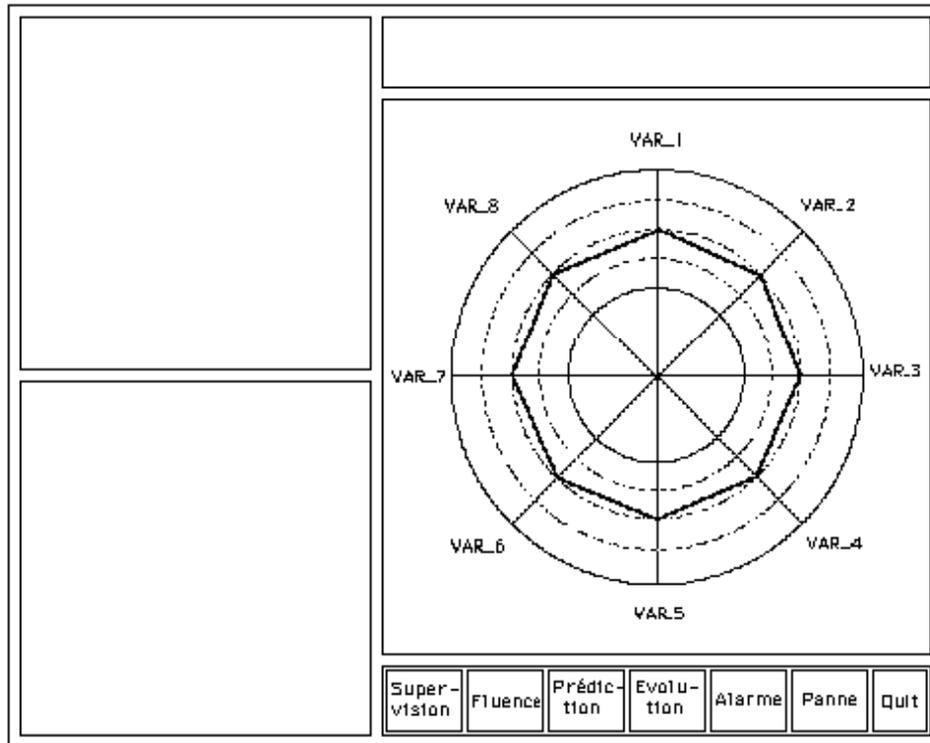


Figure 3: "Monitoring" display

In order to help the operator in his failure predictive detection task, essentially during the transient phases of state changes, it is recommended to display only the more significant information according to the considered functioning mode. Nevertheless let us note that in order to anticipate an abnormal event and to facilitate the decision making, it is necessary to display a prediction of these "supervision" variables (If these data can be provided by the decision support system). In order to represent the predicted tendency of these variables, the interface has to present their speeded-up evolution - for instance a second corresponding to a minute in the reality -. Concerning this point, it is interesting to note that a study by Van der veldt and Van den boomgaard [23] explains that the operators' performances are improved when using a predictive display, even if this one is not perfect. The star display is first and foremost a view of the smooth running of the process: if the variables presented in this view are all in their interval of normality, the process is in a normal functioning mode. In this context, each abnormal operation must affect these variables of control at a more or less long term. The prediction module provides the future values of these variables, on a time interval which has to be fixed a priori. It is therefore necessary to know when the disturbance will be propagated towards these variables of control. We can notice that the variables research or validation can be automated from the knowledge of the qualitative model of the process. It is therefore possible at this level to advise the interface designer about the choice of the variables of control. This option is under consideration for the next interface version.

### 3.2.2. The "action advice" display

When a failure has been detected, PREDEX deduces a recovery procedure and suggests a task to the operator, in the form of an action plan which contains the following information (see figure 4 in the upper zone, on the left):

- (i) The main objective of the plan: this objective is defined when the origin of the disturbance has

been identified by the diagnosis module. It aims at offsetting this one.

- (ii) A decomposition of the main task in sub-tasks consisting in a set of organised and dated orders able to reach the main objective. Action plan are organised into a hierarchy according to the delay of intervention.

At present time, only the two more important action plans are continuously presented to the operator, both for problems of lisibility and for the limitation of the operator's workload. Indeed two action plans can correspond to eight action advice. As seen on figure 4, action plans are displayed in the more scanned area of the screen (upper left area). These action plans include: (i) the disturbance to be corrected, corresponding to the action plan aim; (ii) the action maximum delay to correct the disturbance; (iii) one or more action means to succeed the correction; (iv) the amplitude of the correction to be realized; (v) the correction mode - automatic or manual -, according to the variable to be regulated or not. It is very important to know the level of description of the commands which have to be presented to the operator according to his knowledge level: indeed, for a skilled operator, the main objective should probably be sufficient, whereas for an unskilled operator, action to be executed should have to be more detailed. Moreover, if the number of action plans is greater than two, the operator must have the possibility to visualize them in a secondary drawport. This opportunity is accessible with the "Suite" button, figure 4.

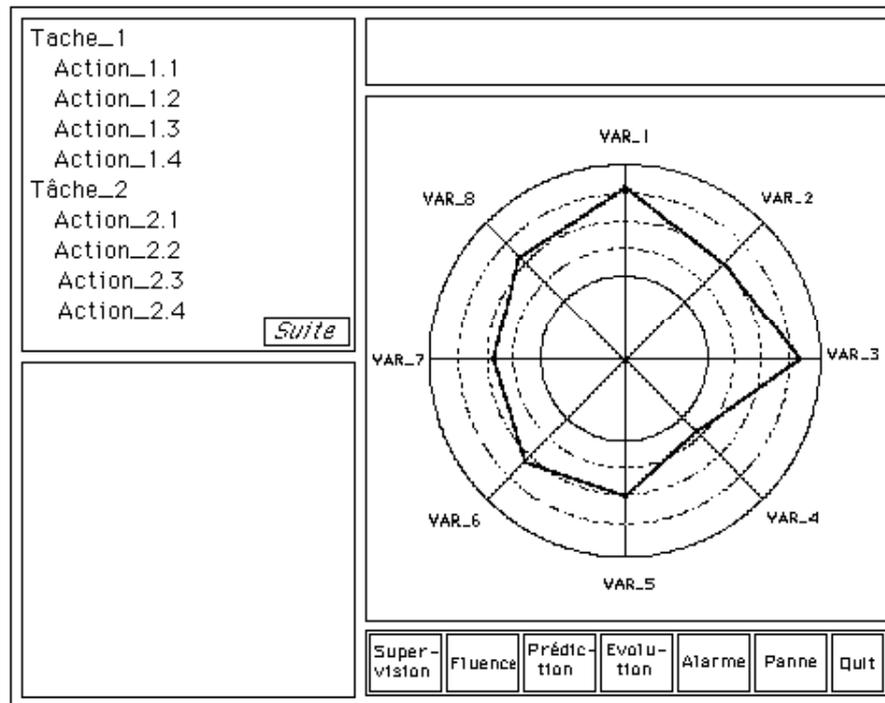


Figure 4: Action plan displayed in the upper zone, on the left

### 3.2.3. Accessibilty to the different justification levels of the diagnosis module.

Parallel to the expert system diagnosis module which process reasoning will lead to give advise to the operator, this latter may have processed his own reasoning and may have found his own diagnosis and recovery procedure. In accordance with the cooperation model described on figure 2, many situations may appear: (i) the operator agrees with the advised action plan proposed by the expert system, then he just has to act in accordance with the proposed action. In this case, the expert system reinforces his decision; (ii) the operator does not agree with the expert system deductions, or he may have not yet succeeded in an action plan definition: as a consequence, he wants some explanations. For this purpose, different levels of justification are at the disposal of the operator: the first one consists in

presenting to the operator a flow model of the action plan propagation; the second one proposes variables implied by the action plan and presents them in form of curves. These two levels are more precisely described below.

### 3.2.3.1. The first justification level: flow model

If the operator wants explanation on the advised action, he may access to a display called "Fluence". An example may be seen on figure 5. In this case, the star display is automatically shown in the left lower area of the screen. The operator is shown by this 'Fluence' display the failure diagnosis. On a simplified process synopsis are displayed the important process variables implied with the action plan linked together. These links represent the propagated correction due to the proposed action. To be created, this display uses the qualitative model of the process: the variables to be presented to the operator are deduced according to the knowledge of the action plan entry and issue point. This explanation level is accessible through the 'Fluence' button. If the operator wants more detailed explanations on the predicted propagation or if he wants to dispose of more information on the amplitude of the propagation, he may then access to a second level of justification: the "Prediction" display.

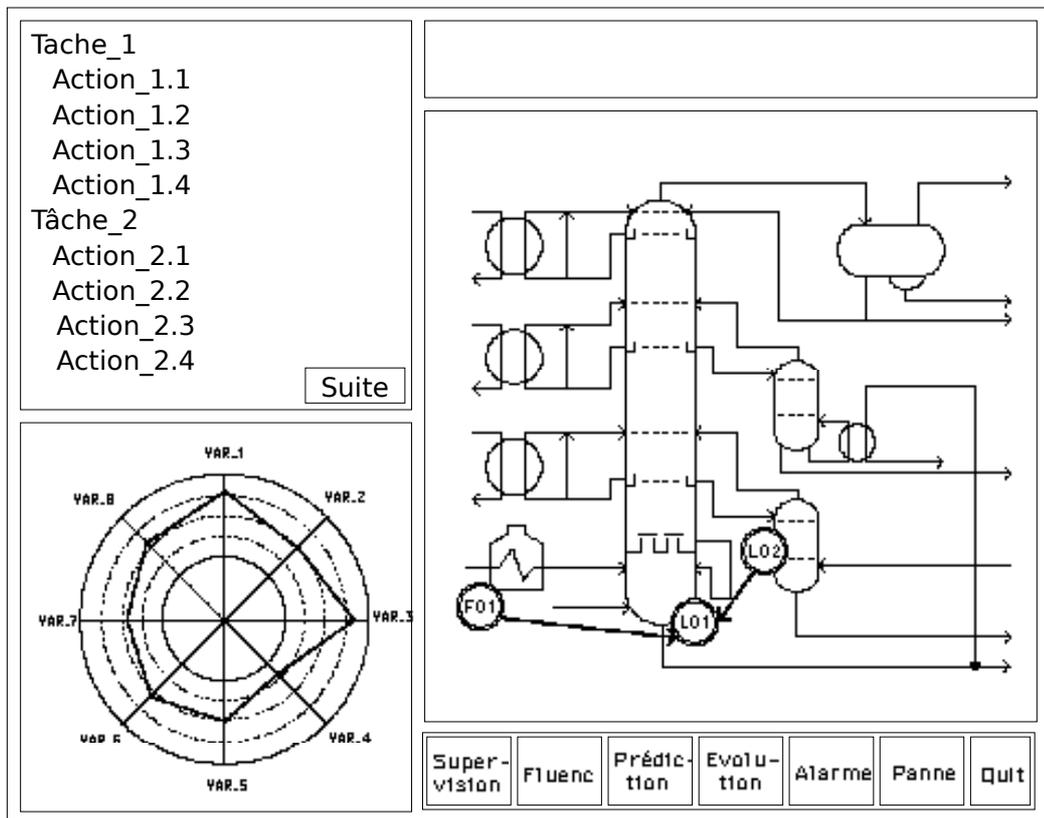


Figure 5: first justification level by displaying the action plan propagation

### 3.2.3.2. The second justification level: the "Prediction" display

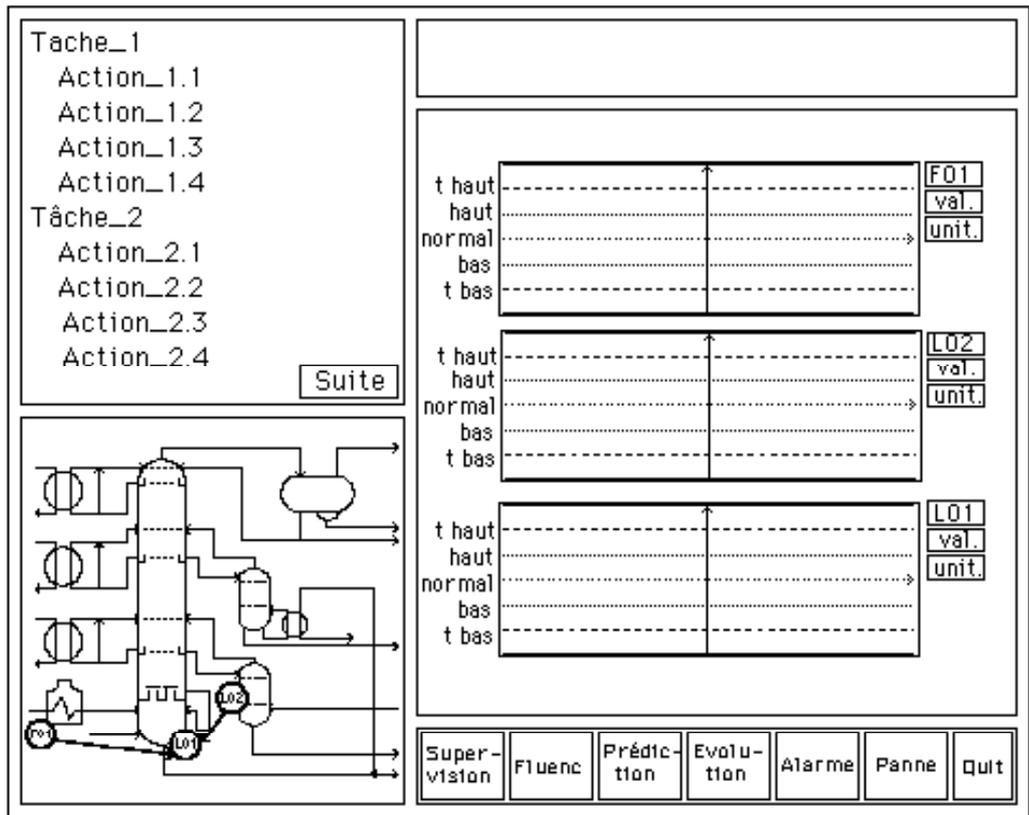


Figure 6: Second justification level by displaying the prediction of a disturbed variable

The "Prediction" display presents the tendency prediction of a disturbed variable, figure 6. This prediction is given by a module integrating a qualitative model of the process. The number of variables to be presented must be determined according to the operator informational needs. This display has to be generated according to the specific knowledge of the characteristics of the variables to be presented, that is: number of variables, references, change interval, threshold, historics and prediction time. This second level is accessible through the "Prediction" button. On figure 6, the automatical move of the "propagation" display in the lower left hand area can also be set into evidence.

### 3.2.4. Failure identification and explanation

The diagnosis module purpose is to recognize the failure which is at the origin of the disturbance. A failure may be either an equipment failure or a disturbance on a system entry variable. If a disturbance may be explained by a curve, this is not the case for an equipment failure. So, this disturbance has to be localised on the process synopsis with variables and their tendency which proof the failure. The same case appears when the system has to prove the disturbance on an unmeasurable variable. An example concerning Failure identification and explanation for an equipment failure is given on figure 7. The purpose of this "failure" display (on figure 7, the french term "panne" is employed) is to justify the detected failure. So, on this display, the failure is located. Furthermore, the variables and their tendency, which have permitted the detection of this one, are presented. As several failures may be identified at one time, the operator has to select the failure he wants to be explained. In this case, the operator selects "failure" display by clicking the "Panne" button. Then, he selects the action plan on which he wants a justification about the diagnosis.

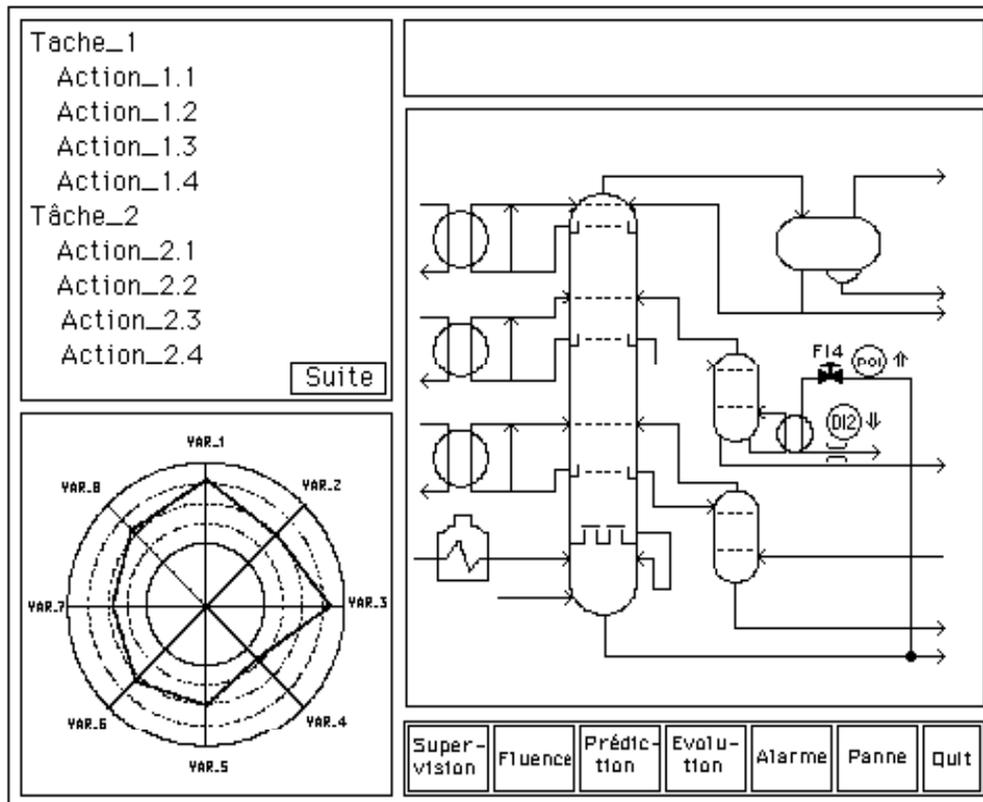


Figure 7: Example of Failure identification and explanation for an equipment failure

### 3.2.5. "Evolution" display

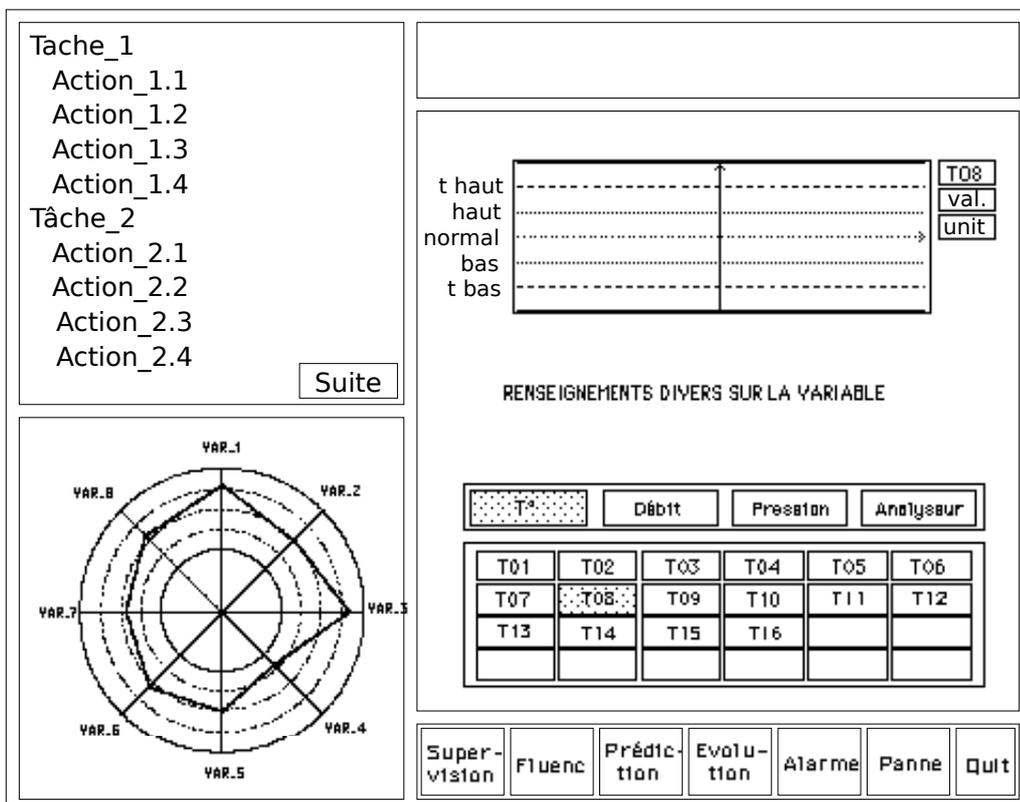


Figure 8: "Evolution" display

The operator may need to visualize the tendency of a variable which has not been planned by the decision support system. In that case, such a variable must be easily accessible by the operator. For this purpose, a display called "Evolution" has been developed.

As the process to be controlled may have many variables, these one have been grouped by type. For instance, in the case study presented on figure 8, four types have been distinguished: temperature, flow, pressure and analyzer. So the operator has to select a type. Then the name of each variable of this type is displayed on a panel. So the operator has to select the variable he wants to know the tendency. This functionality is accessible through the "Evolution" button.

#### **4. CONCLUSION**

This paper has mainly detailed the interface of PREDEX, an expert system shell for process control and supervision. The integration in PREDEX of a qualitative model of the process offers interesting prospects concerning the Man-Machine Interaction. Indeed it is possible to assist the Human operator by (i) predicting him the future state of the process, (ii) providing him different types of diagnosis: deep and shallow, (iii) displaying him different justification scales of the presented information, and so on.

The interface which is being realized has now to be dynamically validated on industrial sites, with the operators. Subjective and Objective evaluation methods will be used in order to evaluate the workload and the performances of the operators using a decision support system realized with PREDEX. According to the real needs of the operators, the displays will be ergonomically improved. In the same way, other types of displays could be developed.

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