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## A Real Time Expert System For Decision Making in Rotary Railcar Dumpers

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### 1. Introduction

In a great deal of industrial production mechanisms approaches able to turn automatic a wide range of processes have being used. Such applications demand high control pattern, tolerance to faults, decision taking and many other important factor that make large scale systems reliable (Su et al., 2005), (Su et al., 2000) and.

In particular, Artificial Intelligence (AI) presents a wide applicability of those approaches implementing their concepts under the form of Expert Systems (Fonseca Neto et al., 2003). Applications with this architecture extend knowledge-based systems and allow the machine to be structured into a model apt to act and behave in the most similar way a human specialist uses its reasoning when facing a decision taken problem (Feigenbaum, 1992).

The VALE production system comprehends several mining complexes, among which is notorious the Ponta da Madeira Dock Terminal (PMDT). In this complex macro level processes of Unloading, Storing and Minerals Shipping are performed, supervised by a very reliable Operational Control Center (OCC).

This article discusses the development of an on-line expert system applied to decision taken when facing faults occurred in the VV311-K01 used to unload minerals at the VALE's PMDT. This project attends the handling of a large quantity of available operative data created at production time, and cares of the organization, interpretation and understanding of these data.

Besides automation technologies, in order to attend our proposal, we apply some information technologies such as: the JESS, the JAVA language and also XML (eXtensible Markup Language) aiming the real time running of the Expert System.

This article is organized as follows: Section 2 describes the Expert System proposal; in Section 3 are described the particularities and the operation of the rotary railcar dumper system, the real time hardware and the monitoring performed by the supervisor system. Faults occurrence is also described starting from the behaviour of the VV311-K01 rotary railcar dumper. In Section 4 are detailed the Expert System Development steps using techniques of Knowledge Engineering within the context of CommonKADS methodology. In addition, in this Section are also presented resources of the JESS environment used as

inference motor for the system's decision module, the system's application and implementation global architecture and the final remarks.

## 2. Expert System Proposal

The system's proposal is to reach the decision process considering as input the faults detected by the VV311-K01 rotary railcar dumper system components, aiming at furnishing enhancement and speed to the decisions to be taken when facing faults in the minerals unloading system.

The faults identification actually is obtained through Microsoft electronic spreadsheets and Access database analysis. This means a lot of operative data and potential information that have not integration with VALE's Plant Information Management System (PIMS). The decision process in order to achieve the possible solutions for a fault in VV311-K01 positioner car, the engineers and technician team need to deal with several relevant devices tracing it fault mode, effects and it related causes. Stated another way this is made according to follow model.

$$H_{fault} : x_{devices} \rightarrow y_{relevant}$$

Being  $x$  the set of VV311-K01 devices or subsystems. The Expert System propose consider the plant devices mapping dealing and inferring the functional relationship (i.e. fault-device) between the set of plant devices and faults mode. By example:

$$x = \{x_i | devices\}$$

Being  $x_i$ , **shaft, engine, sensors**, coupling, shock absorbers and furthermore VV311-K01 car positioner devices. Associated to this propose, these sets are inputs to begin the system modelling and discovery in which conditions the decision making procedure is sustained. In addition, the Expert System is built by using the AI symbolic reasoning paradigms (Luger and Stablefield, 2008) to be modelled for the industrial sector.

Notice that the Expert System considers the VV311-K01 significant characteristics based upon the knowledge of experts and the domain agents (i.e. engineers, operation analysts and operators), during positioner car operation **in order to improve the unloading system's productivity** along the execution of the involved tasks at the VALE industrial complex.

## 3. The Rotary Railcar Dumper System

The minerals unloading mechanism initiates at the rotary railcar dumper with the arrival of the locomotive pulling behind it 102 to 104 rail-wagons that will be positioned in the dumper, and from there on the goal of each rotary comes to be the unloading of 2 rail-wagons per iteration. That iteration is the time the positioner car needs to fix the rail-wagons in the dumping cycle.

To attain the rotation a positioner car fixes the rail-wagons in the rotary and this, consequently, unloads the material by performing a 160° rotation - it can eve be programmed to rotate up to 180° - in the carrier-belts (Fonseca Neto et al., 2003). Remember that while the rail-wagons material is been unloaded and at the same pass as the positioner car is already returning to fix the next rail-wagons, the railroad-cargo is kept immobilized by means of latches, until the rail-wagons that are in the rotation are freed.

### 3.1 Real Time Hardware

The physical components of the devices that command the dumper are typically compounded by peripherals such as inductive and photoelectric sensors, charge cells, presostates and thermostats, limit electromechanical switches and cam switches.

Really, dumper's peripherals play an important role in the behaviour of the following functions: displacement stop or interruption, position signalling, pressure and temperature monitoring, beside other aspects characterized in this context.

Thus, rail-wagons dumper's hardware are potentially something like an intermediate layer (i.e. a middleware) important for the communication between the Expert System and the VV311-K01 hydraulic and mechanical components at the operation time.

### 3.2 Supervision Control System

Supervision is conducted by means of the programmable logic controllers (PLCs) which receive all the information from the dumper hardware through input cards, commanding also the Motors Control Centre (MCC) through output cards. In the dumper, the programmable logic controllers command actuators and action drives (converters).

The programming, developed in LADDER, is structured in such a way that the first mesh are destined to the faults; to the command mesh and finally to the output mesh. The program is developed in subroutines by moves, with one subroutine for each component (e.g. positioner car, rotation, latches and etc.) present in the dumper. The command mesh was developed such that they depended only on the supervisory command to be closed.

The Operational Process is supervised by the Supervisory Control and Data Acquisition (SCADA), a system composed by two servers that run the InTouch software from Wonderware and by four clients that collect data for the SCADA system through the Dynamic Data Exchange (DDE) from Microsoft.

### 3.3 Faults occurrence

The faults that occur in the production process and in the system's stopping for a long period of time due to equipments overloading, sensors defaults and problems with other component sets of the rotary railcar dumper, have currently caused much financial damage to the VALE industrial pole, based on the monthly unloading average of the VV311-K01, which is around 16120 rail-wagon cycles (i.e. 155 trains, each with 208 rail-wagons).

Among the faults in the dumper, most of them occur at the positioner car once, according to the statistical VALE reports, this component can be responsible for the reduction in the monthly average in 1095 cycles of rail-wagons.

From this information, the VV311-K01 positioner car was selected as one of the critical points to be analyzed in already mentioned production sector.

## 4. The Expert System Development

Before initiating the Expert System developing stages, it is necessary to select some important characteristics that will be used to build the system, such as the JESS and the CommonKADS methodology.

#### 4.1 JESS

The JESS is a tool for constructing the Expert System developed by Friedman Hill at Sandia National Laboratories. The JESS is totally developed in JAVA, and is characterized as an API for creating the expert Systems based on production rules. Its architecture involves cognition components defined like: Inference Engine, Agenda and Execution Engine. All these structures catch assertions or domain facts and also create new assertions.

The inference JESS engine is constituted by the Pattern-Matching mechanism (i.e. patterns joining) that decides which rules will be activated. The Agenda programs the order in which the activated rules will be fired, and the Execution Engine is in charge of the triggering shot (Friedman-Hill, 2006). Besides that, such rules can contain function callings that care of code statements in JAVA.

In JESS the facts have attributes or fields called slots, which must be grouped in templates in order to keep common feature assertions, and have some of their properties grouped in classes like Object-Oriented.

The reasoning formalism used by the JESS presents rules composed by if...then patterns, represented by the LHS (Left-Hand Side) and RHS (Right-Hand Side), respectively. The inference process is given by the Rete algorithm (Forgy, 1982) that combines the facts according to the rules and selects the one that will be shot to execute their corresponding actions.

Having JESS as decision core, the Expert System will operate by matching the facts, which are the right statements on the attributes contained in the VV311-K01 knowledge base, with the rules that translate the domain of the agent's explicit knowledge of the VALE unloading system's.

#### 4.2 CommonKADS

The historical scope of the CommonKADS methodology was confirmed by the results of several projects of the ESPRIT program for building knowledge based systems. Even though it was conceived at the Amsterdam University, initially under the name KADS (Knowledge Acquisition Design System), it referred to a method for knowledge acquisition; later some contributions papers and European Science Societies developed various knowledge systems through it. As a consequence of the good results obtained with the KADS technique, they decided to expand it towards a set of techniques or methods applied to all development phases of systems based upon knowledge, creating the CommonKADS methodology, becoming acknowledged by several companies as a full pattern for knowledge engineering (Labidi,1997).

Products arisen from Expert Systems development that use this methodology are the result of the performed phases modelling activities, and characterize the input artifacts for the successive refinements undergone in the next steps of the CommonKADS life cycling.

Having in hands the particularities that will be used in the Expert System building, the steps of the system with actions such as Acquisition and Knowledge representation are organized- also including the analysis phase - Rules representation - ruling the Design phase - and the System's Settling- satisfying the settling phase.

**4.3 Acquisition and Knowledge representation**

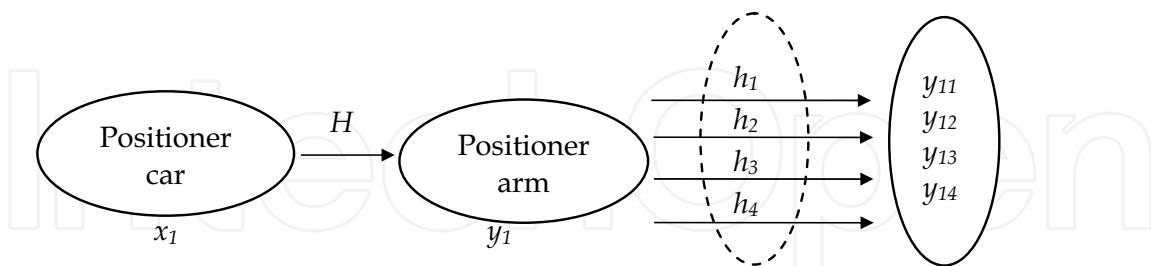
Knowledge acquisition is the most important step when developing Expert Systems, and aims at the detailed attainment of the knowledge used by the expert to relate problems. All the knowledge elicitation was done by means of interviews with the expert through information kept in the operational reports, spreadsheets and off-line database. The method used to the knowledge representation was built based upon production rules. These rules map the knowledge of the VV311-K01 operation expert onto computing artefacts take into consideration the set of relevant faults (i.e.  $y$ ) instance and its generator sources, modeling the conditions in which the faults deduction can points out the diagnosis or support the expert’s decision making. Highlighting the relevant faults, they establish a vector in which the positoiner car devices are relevant faults attributes according to following set.

$$y = [y_1 \ y_2 \ y_3]$$

In this set,  $y_1$  is the kind of generator source,  $y_2$  is the priority and the  $y_3$  is the historic, reminding that only generator source is treated in this chapter. In order to undestand the relevant faults model instance, was considered the car positioner in agreement with the following set.

$$y(x) = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix}$$

Being  $x$  the VV311-K01 positioner car and  $y$ , the set of faults belongs to it,  $y_1$  is the engines situation,  $y_2$  positioner arm situation,  $y_3$  latches situation and  $y_4$  coupling situation. These mathematical elucidation are early requirements to understand the amount of situations that enginers and technicians team have to deal during the productivity system. The following model represents the possibilites during a decision making scenario.



In fact, all this situations and conditions will be handled by JESS inference engine. The JESS handles the knowledge representation as production systems and rules them like condition-action pairs. A rule condition is treated as a pattern that decides when it can be applied, while the action will define the associated problem solution step (Friedman-Hill, 2003). In this way, there were defined the sort of problems presented by the positioner car, along the mineral unloading process, for the elaboration of production rules.

There were observed the main concepts related with the dumper’s positioner car along activities in the operational productive system, aiming at getting knowledge elements

description by elaborating the organizational model that complements the CommonKADS (Breuker et al., 1994) Analysis phase.

SLOT	OPPORTUNITIES	PROBLEMS
Situation	Engine	Vibration
		Broken Rollers
		locked
		Lack of voltage
	Positioner arm	Short-circuit
		Broken fixing screws
		Broken Counter-bolts
	Latches	Disruption
		Infiltration
		Internal Fugue
		Insufficient outflow
	Coupling	High oil level
		Low oil level

Table 1. Organization Model.

The domain facts and experiences deal with the equipment situation and the potential causes that promote the main system stopping or reduce its productivity. Therefore, in Table 1 is presented the organizational model, correlating problems and opportunities that can be solved or enhanced by the Expert System from which extracted the identified slots for building the VV311-K01 templates. The slot called 'Situation' is one of the units that comprise the templates for representing the knowledge in the JESS inference engine (Friedman-Hill, 2006).

SLOT	INFERENCE LEVEL	TASK LEVEL
Cause	Vibration	Motor basement snap
		Resonance
		Bend axle
	Short-circuit	Terminal out of order
		Low isolation
		Falling's wire material
	Insufficient outflow	Worn Pump
		Obstructed Tabulation
	Obstruction	Safety Valve with insufficiently fixed

Table 2. Knowledge Model.

It was observed that the causes that lead the dumper to reach certain circumstances are pointers for guiding what must be done as to specify derivations that constitute a method for the VV311-K01 positioner car problem resolution, and the strategies to attain this solution. The efforts spent in this stage are described through the knowledge model of the CommonKADS methodology, as shown in Table 2.

According with (Labidi, 1997), the inference and task levels are layers that describe the expert Knowledge; thus, the model in Table 2 constitutes a set of knowledge instances on the VV311-K01 positioner car component. Starting from the model in Table 2, in order to better characterize the system's knowledge mechanism in agreement with the CommonKADS methodology, the activities organized in the inference model presented in Figures 1, were decomposed.

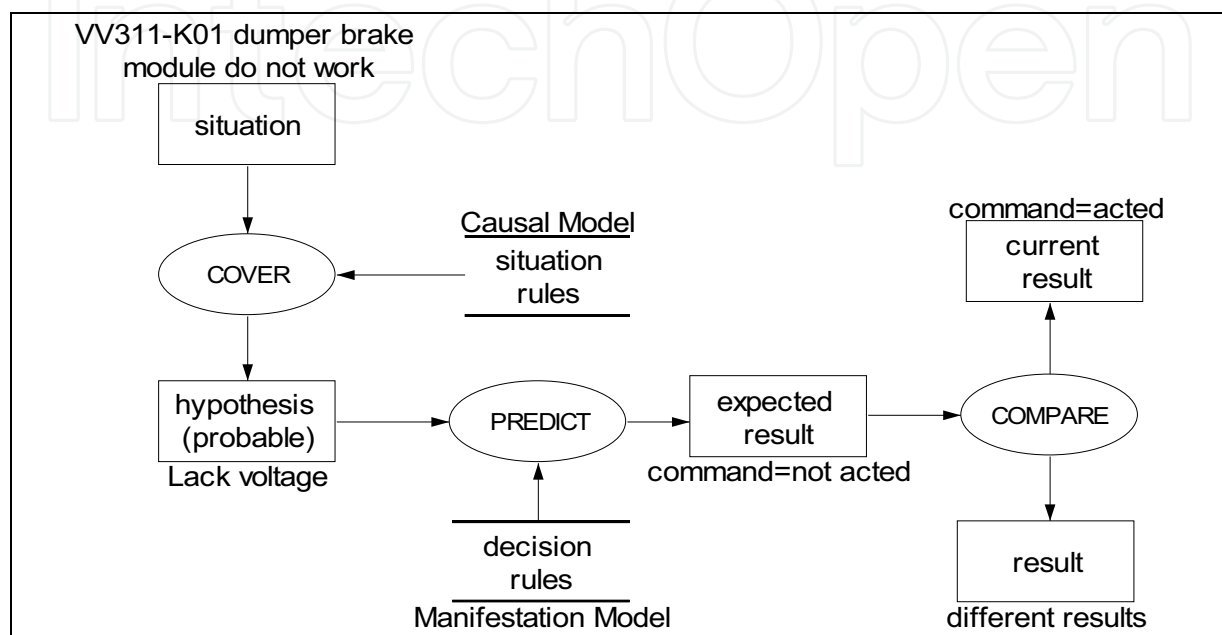


Fig. 1. Inference Model.

This model aims at elaborating a declarative specification of input and output properties, and the inference actions used in the Expert System reasoning. The Inference Model in Figure 1 describes a deduction example done for the VV311-K01 positioner car component, and can be explained as follows: the knowledge's roles are functional names that capture the elements participant in the reasoning process as diagnostic the positioner car state, and can present variable actual status (i.e. temporal stopping, overheating, etc). Inference actions assume as inputs static roles, represented by the manifestation and causal models.

Within the causal model, the rules relate the positioner car fault modes taking into account their attribute's values, while in the manifestation model are reunited the production rules that express their responsibilities through the attributes' values, which satisfy some given conditions (Labidi, 1997).

The COVER, PREDICT and COMPARE inference concepts, represent reasoning axioms that will be mapped by the JESS inference engine used in the Expert System. Basically, is done a transition from abstract concepts as input artefacts to synthesized concrete concepts in a set of assertions as output artefacts (Friedman-Hill, 2003).

Once we have in hands the analysis of the main elements that model the general goal of the knowledge specification stage, according to the CommonKADS and taking into account the granularity of the acquired information for the VV311-K01, significant levels of detail were obtained for representing the knowledge, under the form of production rules.



#### 4.4 Rules Representation

After establishing the knowledge sources, the effort used in this step are linked to the structuring of rules of the type if...then. Firstly, the selection of this type of representation was justified in function of the shell JESS inference engine promotes the building of rules in production systems, and also as a consequence of the attained results in a system built by (Fonseca Neto et al., 2003), which used production rules to detect faults in the mineral belts conveyors at the VALE PMDT in off-line mode.

The example below shows the 'dumper' template that will treat the attributes 'situation' and 'cause' at the Expert System knowledge base.

```
(deftemplate dumper
  (slot situation (default NF))
  (slot cause (default NF))
)
```

The 'dumper' template gathers the characteristics considered in the interviews for the possible situations (new status) that the VV311-K01 can generate and the pre-attributed values - NF: Not Found - in events within which there is no chance of pattern unification (i.e. pattern-matching).

In the 'decision' template are grouped the possible causes as particularities that can correspond to 'dumper' template situations (current status) expressed by means of the sensors. The next template was also defined with slots and predefined default valued.

```
(deftemplate decision
  (slot dec-sit (default NF))
  (slot dec-cause (default NF))
  (slot dec-decision (default NF))
)
```

After the templates specifications, the rules were built taking as basement their slots definition. These slots in the JESS rules structure are part of the so called LHS patterns (i.e. premises) and will be unified (pattern-matching) by the inference engine through the Rete algorithm. The templates and the rules were built with the 7.0p1 version of shell JESS, licensed for academic use.

#### 4.5 System Implementation

For the system's encoding it was built an executable little version of the Expert System as a means for finding functionalities omitted during the interviews looking for reminiscent knowledge. The tool selection was also done by means of the linguistic resources that the JESS makes available in terms of inter-operationability and portability that can be added to the VALE operational productive system.

In order to facilitate the systems operation handling, the Expert System decision module performs a scanning on the faults detected by the sensors present in the VV311-K01 instrumentation. Through the checking of these faults addresses, which are generated by the programmable logical controllers and mapped into faults tagnames stored in the relational database, the Expert System rules that active a given condition are activated in the working memory of the JESS inference engine. Tagnames (e.g. AFF\_CEP\_F01@VV311K01) are part of historical registry from PIMS. In the Expert System they plays input data for the rules that deduce the situation of the VV311-K01 components pass through, that is why they form the rules LHS pattern in the JESS language syntax, as can be seeing in the excerpt bellow:

```
(defrule rule198
```

```
(test
(eq TRUE(actedTag "AFF_CEP_F01@VV311K01")))
=>
(store RESULT198 "Loose-Wire-Connection")
(assert (decision(decCausa Loose-Wire-Connection)
(decPrint "Loose-Wire-Connection"))))
```

The above rule presents in its LHS pattern, a `actedTag` function, which returns true for 1 and false for 0, according to the result read in the XML file generated by stored procedure into the PIMS (Plant Information Management System) oracle database server (see Figure 2), location at which are stores the faults tagnames. The XML document is shown as following structure:

```
<?xml version="1.0" encoding="UTF-8" ?>
- <tags>
- <tagname id="ASC_B11@VV311K01">
  <value>0</value>
</tagname>
- <tagname id="AIN_ALI_001@VV311K01">
  <value>1</value>
</tagname>
- <tagname id="AFL_BEP_001@VV311K01">
  <value>0</value>
</tagname>
- <tagname id="ATA_BRT_M01@VV311K01">
  <value>0</value>
</tagname>
...
</tags>
```

The function 'actedTag' assumes as input the description of a tagname to check whether its value acted or not using set and get methods upon JAVA call functions. The 'actedTag' function can be seen in JESS language statement as following:

```
(deffunction actedTag (?tagName)
  (bind ?sb (new BeansTag))
  (definstance beans ?sb)
  (call ?sb setTgName ?tagName)
  (if (eq (call ?sb getTgValue)1)
    then return TRUE else
    (if (eq (call ?sb getTgValue)0) then return FALSE))
)
```

Starting from an acted tagname, the rule's LHS pattern is evaluated by the conditional function `test` (Friedman-Hill, 2006) - which is part of the own JESS language - responsible for determining that this pattern will only be unified if the result of the `actedTag` function returns true. Taking as example the following parcel of the system's decision rule, is possible to observe that the cause 'Loose-Wire-Connection' deduces that the ultrasound on VV311-K01 must be made. The RHS pattern of the rule's parcel stores the result through the command store, and next inserts in the 'decision' template, the action to be done.

```
(defrule rule204
(decision (decCause Loose-Wire-Connection))
=>
(store RESULT204 "Do ultrasound on VV311-K01"))
```

```

(assert (decision
      (decDecision Do-ultrasound-on-VV311-K01)
      (decPrint "Do ultrasound on VV311-K01")
    )))

```

The architecture components collaboration is achieved by integration of JESS inference engine and PIMS database server, which is supplied by historical database connected to VV311-01 throughout PLC device. The key point is the usage of the XML pattern aiming convert the SQL queries from PIMS database to knowledge base.

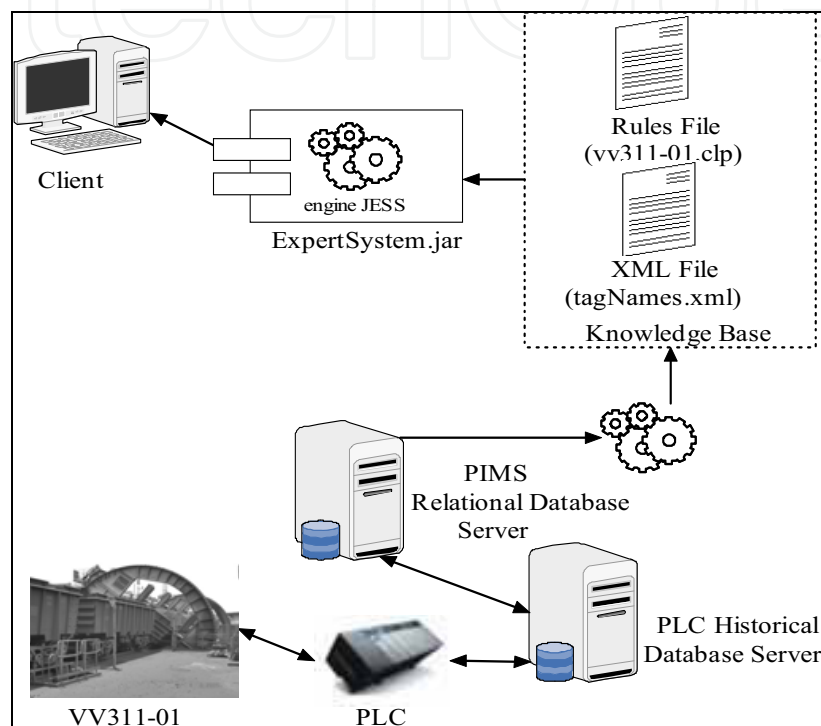


Fig. 2. Expert System Architecture.

Aiming to highlight the global and external view of the system, in Figure 2 was described the Expert System architecture and the nodes distribution that form its structure in order to summarize the Expert System solution and its knowledge base composition.

At the end of the performed deductions, in the shell JESS working memory is shown a window with the recommendations that were stored by the command store (Friedman-Hill, 2006), based in the causes that led to the inference process pointed out by the system, along the responses given by the user. Figure 3 shows the decision making delivered by the system.

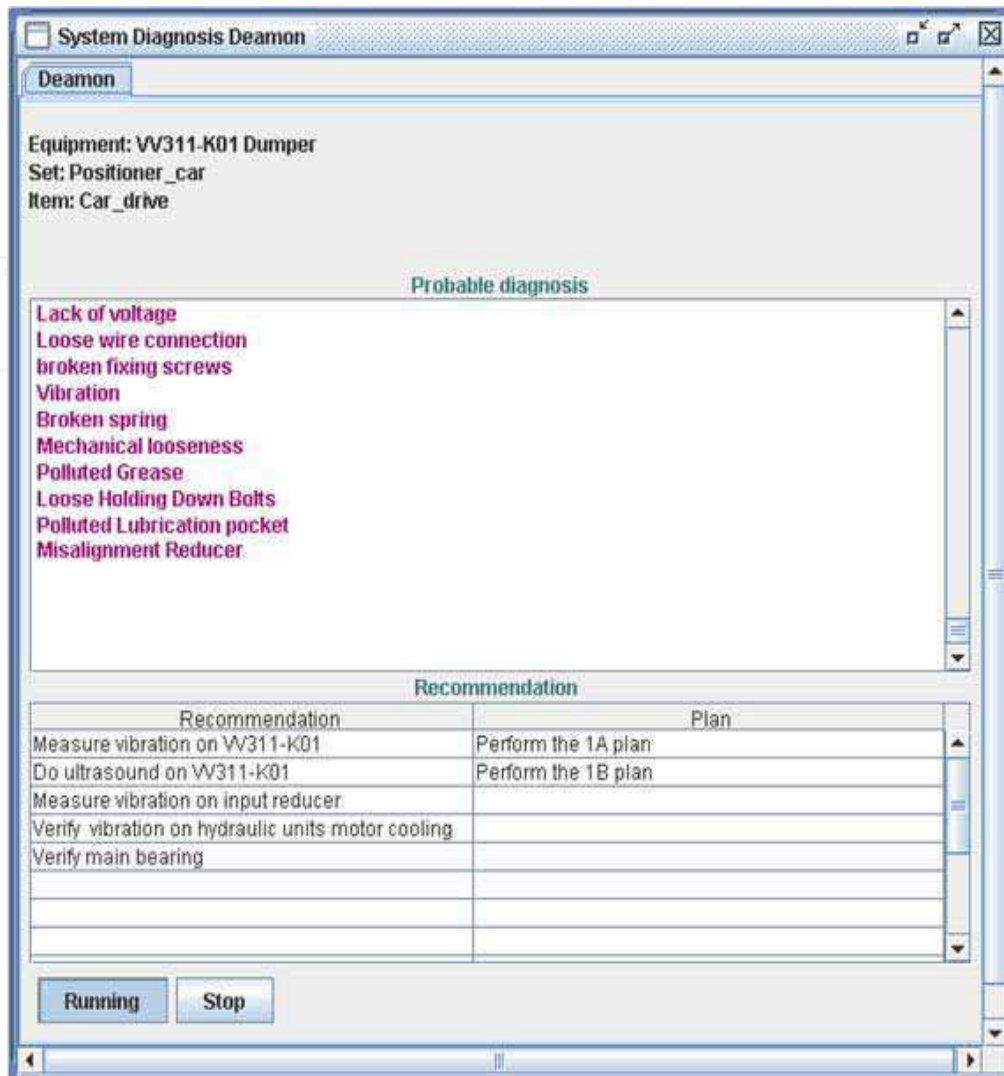


Fig. 3. Expert System Recommendations

For each plan recommended, the Expert System details the needed activities in order to its running. Besides, the amount of people that will perform the tasks related to the faults. By example, in Figure 3 the necessary information to measure vibration on VV311-K01 is listed by class of maintain plans.

Starting from recommendation, the user (technician or engineer) can access its details by double clicking over plans line, according to Figure 4. Through this screen is possible to perform the activities related with decisions and maintain plans launched by Expert System. Notice that these plans comprise maintain methods developed by VALE's specialists and include all background accumulated by themselves too. In fact, this feature can promote the activity decomposition by steps, the labor involved with each recommendation.

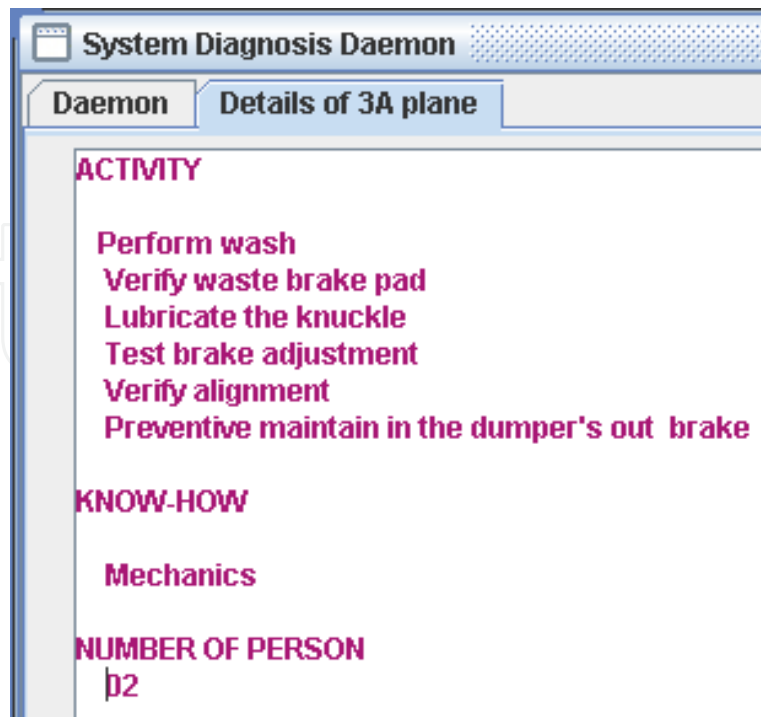


Fig. 4. Expert System Plans Details.

The recommendations viewed in Figure 5, represent the rules that were activated in the working memory of the JESS engine were triggered (shot) only because they got the unification of patterns present in its structure, deduced by the Rete algorithm. The control structure used for the Expert System rules chaining was based on backward chaining (Friedman-Hill, 2003).

## 5. Experiments and Results

The developed expert system approach is focused in the information and automation architecture and infrastructure. For the first results obtained through its putting into operation, the system was set on the corporative mineral unloading mesh of the VALE Company at the OCC installments.

The system's performance while processing operative data in the JESS inference engine was considered satisfactory once the search frequency of such data elements was tested at 5 s. interval for the deduction of 250 rules, although its standard configuration requires 5 minutes of response time, in order to update in the working memory of the expert system the events occurred at the PIMS server.

The speed and proper timing obtained in terms of the updating processes of the expert system rules base was due to the use of the XML technology as to feed the systems' knowledge base. In addition, the expert system is nor directly connected to the PIMS server, thus avoiding the expenditure of computational resources due to the flux of information between the application and the VALE's data manager, once all the programming necessary for generating the file XML was implemented in the own database.

The comparison of the results between the system and the human expert was characterized by the need of fast and reliable decision taking, fact that allowed operators and maintenance

teams to minimize the time spent from the fault's detection to its correction. These efforts are shown in Box 1.

Set	Fault	Is it correctly detected by technician?	Is it correctly detected by Expert System?
Arm command	Damaged contact block	Yes	Yes
Car command	Lack of Measuring	No	Yes
Drive command	Pulley out of place	Yes	No
Drive command	Defective switching	Yes	Yes
Drive command	Vibration	No	Yes
Drive command	Heat of rollers	Yes	Yes
Arm command	Misalignment	No	No
Drive command	Burn	No	Yes

Table 3. Comparison between Expert System and Technician.

As a critical point observed during the results comparison are highlighted atypical events such as a slight misalignment and pulley out of place which was noticed by the system, but did not work in the next cycle. These experiments are very important because the results can contribute to modify the knowledge base inference logic in order to improve these decisions which human expert still have some advantage over the system.

## 6. Conclusion

The system developed in this work presented the conception and automation of the strategic knowledge required by VALE's mineral unloading system activities. Considering that minerals exploitation is a task that requires a vast specialized knowledge, starting from the domain's understanding, knowledge representation based on production rules using the JESS inference engine was got.

The building of the Expert System in JESS, turned available the use of existing and well succeeded methods for the developing of systems based on knowledge, like the CommonKADS. The direct handling of JAVA technology objects and XML allowed better results when implementing the detailed system's architecture in real time, assuring that the operations to be executed will shown at the very instant they are occurring, as well as its easiness interoperability with any database.

Finally, this system furnished enhancement and relative readiness to the knowledge processing, as a guide for the decision making of the VALE's rail-wagon unloading system experts.

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## **Automation Control - Theory and Practice**

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The present edited book is a collection of 18 chapters written by internationally recognized experts and well-known professionals of the field. Chapters contribute to diverse facets of automation and control. The volume is organized in four parts according to the main subjects, regarding the recent advances in this field of engineering. The first thematic part of the book is devoted to automation. This includes solving of assembly line balancing problem and design of software architecture for cognitive assembling in production systems. The second part of the book concerns different aspects of modelling and control. This includes a study on modelling pollutant emission of diesel engine, development of a PLC program obtained from DEVS model, control networks for digital home, automatic control of temperature and flow in heat exchanger, and non-linear analysis and design of phase locked loops. The third part addresses issues of parameter estimation and filter design, including methods for parameters estimation, control and design of the wave digital filters. The fourth part presents new results in the intelligent control. This includes building a neural PDF strategy for hydroelectric saturation simulator, intelligent network system for process control, neural generalized predictive control for industrial processes, intelligent system for forecasting, diagnosis and decision making based on neural networks and self-organizing maps, development of a smart semantic middleware for the Internet, development of appropriate AI methods in fault-tolerant control, building expert system in rotary railcar dumpers, expert system for plant asset management, and building of a image retrieval system in heterogeneous database. The content of this thematic book admirably reflects the complementary aspects of theory and practice which have taken place in the last years. Certainly, the content of this book will serve as a valuable overview of theoretical and practical methods in control and automation to those who deal with engineering and research in this field of activities.

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