1st International Conference on Experiments/Process/System Modelling/Simulation/Optimization
1st IC-EpsMsO
Athens, 6-9 July, 2005

ON-LINE PLANT DIAGNOSIS SYSTEM COMBINING FMEA TECNIQUES AND DATA-MODELS

M. Murri[1], M. Tavassi[1] and A. Di Marzo*

[1] Centro Sviluppo Materiali S.p.a. (CSM)
Via di Castel Romano,100 - 00128 Roma, Italy
e-mail:m.murri@c-s-m.it, web page: http://www.c-s-m.it

[*] Consorzio SESM
via Gianturco, 31/C - 80146 Napoli, Italy
e-mail: adimarzo@sesm.it, web page: http://www.sesm.it

Keywords: Plant diagnosis, FMEA, Data-Models, Virtual sensors.

Abstract.
Productivity increase and production cost reduction are mandatory in complex processes like steel industry; hence quality management, mostly granted by plant technicians experience, assumes more and more importance.
Technologies that combine human experience with objective data analysis provide software tools, that, applied to plants, can support the operators in plant/process management and, at the same time, improve the human plant/process knowledge.
The paper describes a prototype diagnosis system, dedicated to a pilot line for cold treatments, where Failure Mode Effect Analysis (FMEA) techniques and data-models are integrated in a unique software tool; the rules and predicates, defined for each plant component according to the FMEA methodology, are verified and integrated through the relationships between process/product parameters and plant faults/anomalies coming from multivariate statistical analysis on historical data. Outputs in form of graphics, alert messages, warning lights, etc.. advice operators on the plant events, suggesting countermeasures.

1 INTRODUCTION

For improving the product quality and increasing the productivity it is necessary to have a good management of the knowledge related to the plant component failure mode and its effect on the process, but the operations of knowledge acquisition and formalisation are typically very critical.

One of the best working method for the knowledge engineering activity is the FMEA (Failure Mode and Effect Analysis); this is an inductive method to analyse failure modes, using down-top methodology.

The analysis starts from the basic structure of the system and particularly from those system elements for which accurate information about failure mode and its causes are available. By analysing the functional relationships among these elements, it is possible to identify the possibility of propagation of each type of failure and to predict its effects on the production performance of the entire system.

A best performance of the FMEA can be obtained by developing a new technology that uses the results of FMEA techniques in combination with the evaluation of process/product data. The new method can be realised as a software system that, applied to a plant, is able on one hand to perform the plant diagnosis and, on the other hand, to find better process parameters relationships aiming to help the operator and avoid quality problems. In such way it is also possible to increase and to verify the FMEA knowledge reducing the risk of the "human error".

To reach this goal the proposed work presents a prototype diagnosis system realised combining FMEA techniques and data-models able to evaluate the risk of a failure occurrence. This approach is based on the concept of "virtual sensors": data-models are introduced into the system among the elementary plant components and monitored at each field data acquisition.

The prototype performs an on-line data-models testing by a feedback on their behaviour aiming to assure their reliability in forecasting a plant fault.

2 TECHNIQUES AND METHODOLOGY

The work carried out for the prototype realisation can be resumed in two main steps: the performance of a preliminary FMEA techniques to extract the knowledge about cause and effect relationships of failures and the use of the database to enhance and exploit the knowledge acquired trough it.

Plant diagnosis has been implemented by means of fuzzy logic applied to FMEA knowledge in order to identify faults or anomalies. Data-models have been defined using process/product data, from plant database, for verifying and improving fuzzy-logic and FMEA knowledge.

2.1 FMEA analysis and fuzzy-logic

The prototype diagnosis system has been developed and tested on a pilot line that CSM has realised at Terni Section closed to Krupp-Acciai Speciali Terni works. The pilot line exactly reproduces the main processes of the industrial cold treatments line for magnetic steel, like cleaning, decarburisation and oxidation annealing.

The pilot line is provided with instruments that make available a great number of field data and with a line database where process/product data are stored.

The plant is composed of four main sections corresponding to: Pre-treatment section for coils cleaning, Treatment section for thermic treatments and an exit Services and Thermic Separator.

Plant FMEA decomposition is shown below:

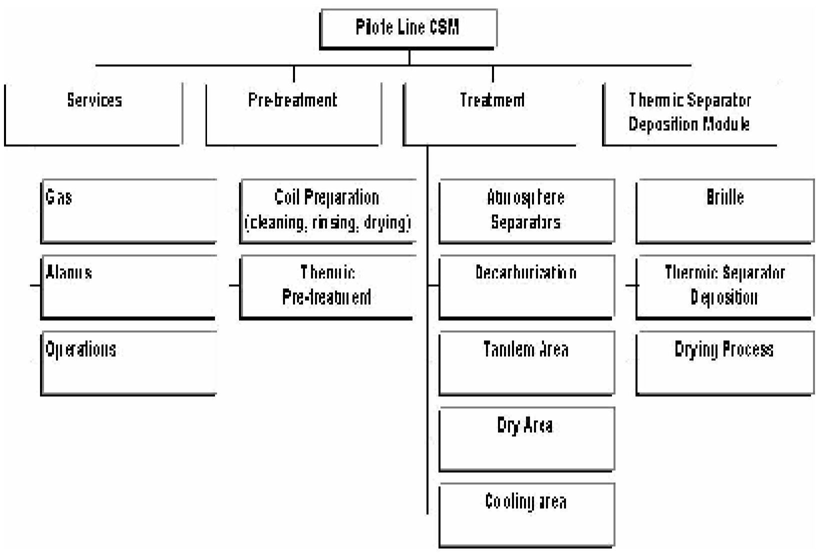

Figure 1. Components of the line

The acquired FMEA knowledge, causes-effects and failures, has been stored into a dedicated relational database (FMEA database). The database also contains other information about the plant, like field data, equipment nominal data and a set of linguistic rules which describes the operator's inspective strategy.

By means of a special Fuzzy Inferential Engine (FIE) and the information of the FMEA database, it is possible to analyse and identify the faults. A schema of the communication between FMEA database and FIE is shown below:

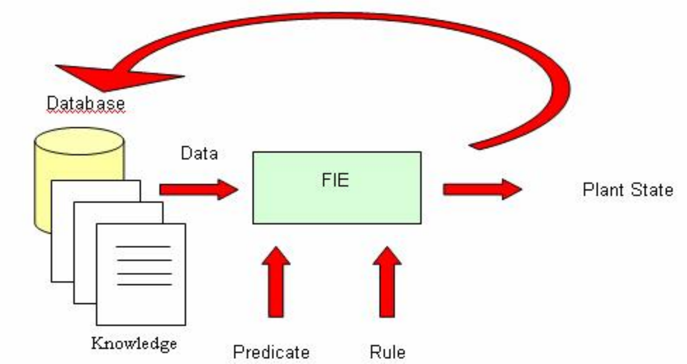

Figure 2. Schema of communication FMEA database and Fuzzy Inferential Engine

2.2 Data-models definition

Data-models have been defined using historical process/product data opportunely extracted from the line database. Data samples construction is based on process/product parameters applied to the rules/predicates coming from the FMEA knowledge.

By means of logistic regression, the event ‘occurrence/no occurrence’ of a specific failure, or anomaly, has been correlated with the process variables properly chosen, among the many process parameters, using the selection procedures usually provided in regression analysis. This leads to a relationship, expressed according to the link function of the logistic model (1) and (2), that represents the probability (p) that a failure can happen.

$$\mathrm{Logit}(p) = \log(p/(1-p)) = a_0 + a_1x_1 + a_2x_2 + \ldots\ldots + a_nx_n \qquad (1)$$

$$p = \frac{e^{a_0+a_1x_1+a_2x_2+\ldots\ldots+a_nx_n}}{1+e^{a_0+a_1x_1+a_2x_2+\ldots\ldots+a_nx_n}} \qquad (2)$$

where a_0 , a_1, a_2 … a_n are the coefficients estimated by the regression and x_1, x_2 , … , x_n are the selected process parameters.

The function (1) defines a probabilistic model whose statistical significance has to be verified through the main statistical tests required in this type of analysis, with particular reference to significance tests on the model coefficients estimates. In a valid model, the coefficients estimates are, both singly and simultaneously, significantly different from zero, with a significance level typically equal to 0.05 (95% confidence level).

Once defined, the model capacity in forecasting the failure occurrence has been verified using specific test data samples. When satisfactory results have been obtained, the relative data-models, after discussion with plant experts, have been introduced into the system in order to verify and to integrate the plant knowledge acquired during the FMEA analysis.

During system working, the probability function is calculated using the field data properly synthesized and the correspondent value is used as condition for an alert message display, i.e. a green light for low probability that the failure can occur or red light for high probability.

In this work models definition has been focused on the faults or anomalies due to the pressure differences measured in various zones of the line treatment section, as this is the most critical section plant for quality products. By means of statistical analysis valid models have been defined and implemented in order to alert the operator on wrong set-up of the pressures.

2.3 A method for combining FMEA and Data-models

A method for combining FMEA and data-models has been found implementing data-models directly into the system as part of the plant. The adopted solution considers data-models as a sort of “virtual sensors”, that is like elementary plant components to be inserted into the plant structure according to the FMEA technique.

Likewise to the other plant components, “virtual sensors” management also requires to define specific rules and predicates to be applied to them. Referring to probabilistic models, the associated rules can be defined according to the two characteristic indexes, model sensitivity (percentage of failures occurrences correctly forecasted) and model specificity (percentage of failures no occurrences correctly forecasted), resulting from models tests. Based on these results, the rules for “virtual sensors” have been defined setting the lower and upper threshold corresponding to those probability values for which the fault occurrence is high or low. The new rules integrate the other ones defined during the FMEA analysis phase.

By means of monitoring interfaces, where a special section is dedicated to “virtual sensors”, it is possible to check the sensor behavior at each data acquisition: a light signal is switched on green light for low probability that the correspondent anomaly can appear, and red for high probability.

The primary problem in integrating this type of data-models is to assure their robustness and reliability in forecasting a plant fault or anomaly. Besides the results of statistical indexes (sensitivity and specificity) and the system off-line tests aiming to check the correct models output, the developed system has been provided with a functionality for causes acknowledgment that can be successfully used for monitoring the models behavior. By means of apposite user interface, the operator can acknowledge both the correct causes related to the occurred fault and the associated model output. The second acknowledgement provides information about the coherence between FMEA predicates values and probability value; the information, opportunely stored into an historical faults archives, are available for a deep analysis of the model behavior.

3 PROTOTYPE DIAGNOSYS SYSTEM REALISATION

The prototype has been developed with WEB Technology and Relational Database (SQL Server 2000). The realisation is based on a multilevel architecture described below.

3.1 System Architecture

In Figure 3 shows the software architecture.

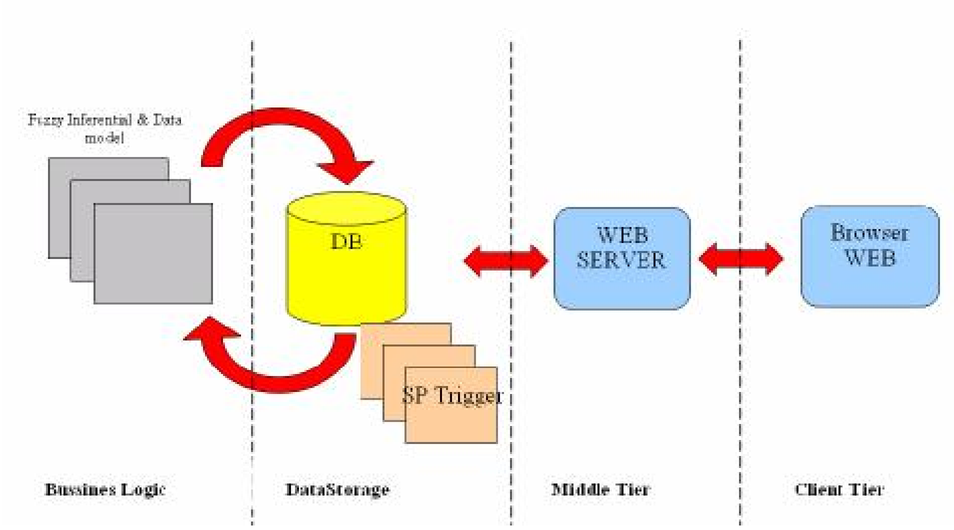

Figure 3. Software system architecture

It is a multilevel architecture composed by four tiers: Bussines Logic Tier, Data Storage Tier, Midle Tier and a Client Tier. The business tier implements business logic and it contains the Fuzzy Inferential Engine (FIE) and the Data Model Engine (DME). The FIE analyze the state of plant using the information of the FMEA database. The FIE elaboration provides the operator with a message in case of fault occurrence. The Data Storage tier contains, besides the FMEA database, system rules, process data and any other information necessary for plant diagnosis. A dedicate SQL Server database implements this tier. Middle Tier and Client Tier are dedicated to data presentation by receiving user events and controlling the user interface.

At scheduled time, the system collects and analyses the equipment status and the instrumentation measurements by applying validation and reconciliation procedures, rule-based (Fuzzy inferencial system FIE) and data-models reasoning in order to detect inconsistencies, anomalies and faults. In case of faults o anomaly detection, these ones are submitted to the operator in order to identify the relative causes.

The prototype verifies the reliability of the process measurements in order to identify instrumentation malfunctions (first level fault identification). At the second step, FIE analyses validated data to individuate faults due to the process and/or the plant components (second level fault identification). If at the second level a fault is detected, the associated diagnosis rules are activated to identify the possible causes. The operator may also ask for diagnosis explanation. Emergency operating practices could be requested through alarms displayed on the operator interfaces.

3.2 Implementation of the combination method

The prototype is provided with a Data Model Engine (DME) package properly developed for the implementation of data-models. At each field data acquisition, the DME performs the data-models evaluation and the results set the state of the associated virtual sensor with the correspondent value.

If a type of fault has associated a virtual sensor, when the fault is detected by the FIE, the virtual sensor state is checked. FIE and DME results are available to the operator for their comparison. In case of discordant results, he verifies the involved process parameters before the acknowledgment of the data-models output.

In this sense the operator performs a feedback of the prototype allowing a better tuning of the two packages FIE and DME.

The above is schematised in Figure 4 where the different elaboration steps of the two engines are highlighted.

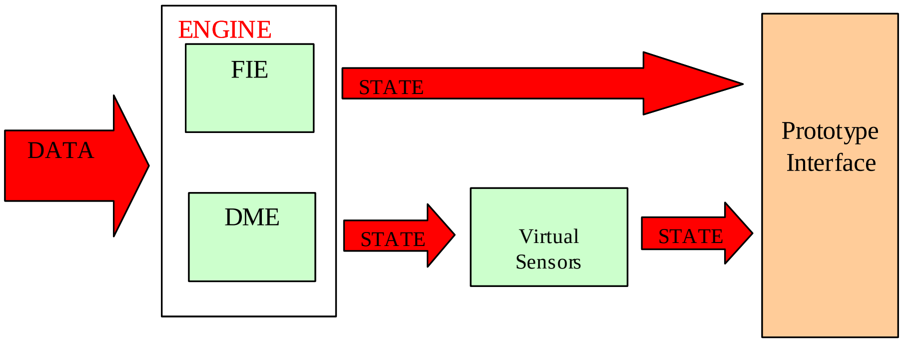

Figure 4. FIE and DME outputs

The acquired field data are elaborated by the two engines: FIE output is the state of the plant component defined according to the relative FMEA rules and predicates, while DME produces, as first output, the data-model value, that is a probability value to be elaborated according to the virtual sensor rules.

The prototype is provided with an additional functionality, called Fault Analysis System (FAS), that supports operator in analysing faults, causes and data-models behaviour by means of an historical fault database.

.

5 CONCLUSIONS

This work, still running, has produced a diagnosys system prototype combining FMEA techniques and data-models in a unique software tool to be applied to a plant.

The adopted solution for combing FMEA techniques and data-models is based on the concept of "virtual sensor": data-models are treated as elementary plant components to be monitored. The relative outputs, displayed on the prototype monitoring section in form of light signal, help the line operator alerting him before the fault occurs.

The integration of data-models into the system provides a continuous monitoring of them, like the other plant components, monitoring which is also an easy way for testing the models output. By means a prototype functionality, models output are stored in the faults database for further historical analysis on data-models behavior.

Therefore, this approach has the double advantage, on one hand, to help the operator in preventive diagnosis and in verifying his knowledge, on the other hand it provides an immediate check of the robustness and reliability of data-models, in special way when they include many parameters, in disagreement with the parsimony principle.

The testing phase, at present in progress, is focused on data-models tests in order to verify their robustness, that is their adaptability to different process conditions. The tuning of data-models could lead to a better definition of the associated rules and predicates and/or to an integration of the FMEA knowledge.

ACKNOWLEDGEMENTS

Work carried out with a financial grant from the European Coal and Steel Community under the contract N°7210-PR-342.

REFERENCES

[1] Hand D., H. Mannila, P. Smith (2001), *Principles of Data Mining,* MIT Presse, Cambridge: MA.
[2] Rizzi, A. (1997), *Inferenza statistica,* UTET, Torino
[3] Peters H., Heckenthaler T, De Abajo N., Murri M., Hilliges F., Boesler R. P., Le Goc M. (2002), *Implementation of an assessment and analyzing system for the utilization of a factory-wide product quality database,* EUR 20927