An Integrated Framework for Diagnosis and Maintenance of Machining Systems

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ABSTRACT.
Today's manufacturing equipment increases in complexity and size which makes more difficult the identification of potential break downs and generating maintenance procedures. In addition manufacturing companies, such as automotive manufacturers, use many different generations of machine tools that still make more difficult their maintenance. All these equipments represent an important, growing capital investment that makes important to quickly locate and solve problems. Many times solving problems require an expert engineer or technician with specific know-how and knowledge about the equipment. But such an expert is not always available or is simply busy with other tasks. This paper presents an integrated framework for semi-automating the diagnosis of failure but also to assist the generation of maintenance procedures. This framework is based on the integration of three applications: a Computer Aided Maintenance (CAMM) system, a Knowledge Base and a Supervisory Control And Data Acquisition system (SCADA). The knowledge base is the central system of the framework and was built using an ontology developed under Protégé. Finally, a study case from an automotive company plant is used to illustrate the framework.

Keywords
Maintenance, Diagnosis, Knowledge base, machining systems.

1. Introduction

The purpose of industrial maintenance is to insure that production systems are in working order and to maintain their functions throughout their life cycle. Lately, industrial maintenance is becoming one of the most important strategic functions in industry. It becomes a part of the continuous improvement policies. In addition, methods and practices of maintenance departments are in constant change due to the relentless technological development, the birth of new management methods and the increasing need for reducing production costs.

For a long time the only purpose of maintenance departments was to repair machines once they failed. In today's businesses, the maintenance function must allow the prediction of anomalies in the production system and prevent any downtime.

Because of such constraints new management tools are required to optimize maintenance operations. Optimizing the preventive maintenance is synonymous with the prediction of failures or the optimum moment to trigger maintenance operations.

Because all faults can not be solved by predictions and reliability analysis maintenance management, methods such as the TPM (Total Production Maintenance) are used in order to allow the production department to perform low level maintenance operations. TPM reduces the number of micro-failures due to simple adjustments (by machine's operators) and in consequence may help to detect defaults before they occur. In such policies, the maintenance department is able to better focus its expertise and time in order to optimally maintain the manufacturing system.

As a consequence of all these major changes, integration of maintenance tools into the Manufacturing Execution System (MES) becomes an increasing need for optimizing industrial maintenance. The objective of this paper is to propose an open architecture which will offer support for the optimization of preventive, predictive and corrective maintenance. The MES tools integrated by this architecture are SCADA (Supervisory Control and Data Acquisition) systems and Computer Aided Maintenance Management (CAMM) tools. Its open architecture enables future developments for integrating additional MES systems. Because the architecture must allow, beside the detection and diagnosis of failures the detection and analysis of micro-failures, a knowledge base is necessary and presented as the core of the system. A machining shop producing gear boxes is used to illustrate this architecture.

2. Maintenance's role in modern production systems

Today's consumer market is changing; product life cycle is shortening reducing strongly the delay to release a new product, As a direct consequence, workshops need to accommodate their manufacturing systems to manage an increasing number of references and decrease delays. This is amplified for machining shops. In order to adapt and to survive in this changing environment companies need to optimize their workshops by better controlling performances of the execution systems. Industrial maintenance plays a major part since its role is to maintain the execution system at constant specification. In many places, the role of industrial maintenance is changing from curative maintenance to preventive maintenance which makes necessary the use of computer aided tools like Computer-Aided Maintenance Management (CAMM) software.

A consequence of raising the importance of industrial maintenance is the need to communicate with the production and the equipment's designers in order to optimize the entire production system. Integrated manufacturing is not new to industry; it started with the CIM (Computer Integrated Manufacturing) concept. In today's applications, CIM must include more and more Manufacturing Execution Systems (MES). But as shown by many applications, management methods are needed to exchange information between entities. For maintenance, this exchange was reinforced in part by the TPM (Total Productive Maintenance) policy since the 80's by proposing a series of steps to ensure production and maintenance departments work together harmoniously.

Solving failures and reducing their frequency is the goal of maintenance departments. To exchange the right information, semantic analysis is necessary to detect ambiguous definitions. For instance, the term "failure" has different meanings given by either standards or by different publications. In this article the definition given by Iserman and Ballé in [3] is used. Their definition states that a failure is:"a permanent interruption of a system's ability to perform a required function under specified operating conditions". Generally, failures are well taken into account because their effects are long lasting. On the other side, micro-failures are not so well accounted for due to their short lifespan (often under a minute). But micro-failures may have a significant effect on production rates. The estimation of a micro failure duration is quite difficult without using a SCADA application and some knowledge rules, such as presented in section three.

Once a failure or a micro-failure has been detected, well defined procedures are needed to reestablish the failed function. A maintenance procedure includes two distinct parts: diagnostic and operative procedure. Diagnostics are not new to the industry, being integrated in expert systems since the 80's. One particular and interesting method is presented in [4] which uses a tree structure similar to the failure tree to diagnose mechanical systems. This method requires a good knowledge of the system and the probability of each node must be updated each time the component fails. Generating procedures adapted for each situation is rarely discussed.

As a consequence, even for reliability based maintenance, industrial maintenance needs a high level of expertise and knowledge of the system. These qualities do not come cheap for the enterprises, and it is simply not practical to hire an expert for every technological component. Keeping in mind all the elements presented so far and extrapolating from several state of the art papers ([5, 6]) we concluded that an integrated maintenance system must present the following characteristics:

- collect the knowledge and make it available to the enterprise
- combine expertise from different fields
- distribute the expertise inside the enterprise and its services
- working in a collaborative environment, thus allowing expertise from different domains to interact
- training less qualified technicians for the tasks at hand
- integrate essential quality policies
- add the machine operators in the role of industrial maintenance
- be ergonomic.

However and in order to maintain the expert system, the human component plays a crucial role and intervenes at many stages, from updating knowledge base data to performing the required tasks. Therefore it is included in the integrated architecture that is presented next.

3. Integrated maintenance system's architecture

The general view of the system's architecture is presented in Figure 1. SCADA's role is to supervise the production system and inform the user of changes, failures and the occurrence of predefined alarms. It has limited decision capabilities and focuses on the execution systems. CAMM stores in its data base the characteristics of every component found in the production systems as well as reliability data such as FMECA (Failure Modes, Effect and Criticality Analysis) and failure trees. Procedures, for components having a preventive plan, are triggered thanks to counters. CAMM generally presents few diagnosis capabilities.

A knowledge base is used to store procedures, SCADA and operator knowledge about failures including the tools necessary for TPM and quality control. The connections made from the SCADA (to CAMM and Knowledge base) are unidirectional: the supervisor sends at predetermined intervals the counters towards CAMM and each time a failure or a micro-failure occurs it notifies the knowledge base. The knowledge base requests procedures and part lists from the CAMM data base, it creates work orders, when necessary updates reliability data.

3.1 Micro-failures

From the point of view of the SCADA system, micro-failures can be placed in two categories: 1) detectable, and 2) non-detectable. It must be stated that for the SCADA application there is no difference between a failure and a detectable micro failure, they are treated the same way. As soon as they are detected the knowledge base is notified and data concerning its duration and number of occurrences so far are recorded and transmitted.

Detectable micro-failures are either directly detectable because there is a sensor dedicated or determined by combining values from different sensors. SCADA applications were not designed to detect micro-failures; however they were designed to detect failures. So in order to get data about micro-failures they are defined as failures. This is the role of the knowledge base to identify the micro-failure and its duration based on expert's rules.

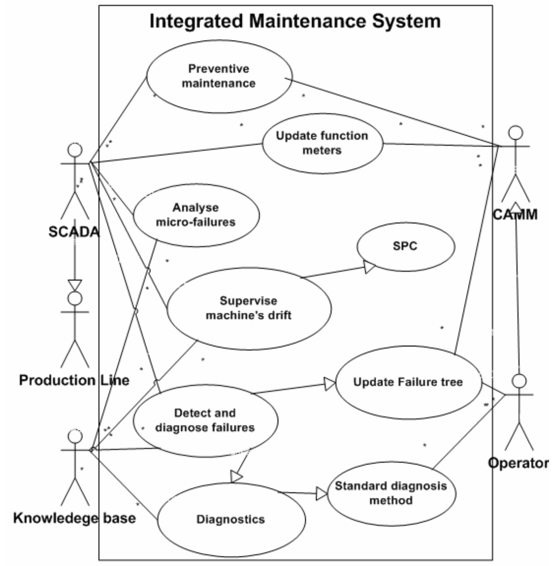


Figure1: Integrated Maintenance System architecture

Figure 2 presents a scenario for the treatment of micro-failures. When a detectable micro-failure occurs on the production system, SCADA increments its counter for that particular micro-failure and records its duration. Once the alarm is acquitted the information collected previously is sent to the knowledge base for determining the micro-failure's frequency. If the frequency is above a certain limit value then the machine needs to be retuned otherwise nothing is done. If there is a need for an intervention then a work order is generated for the maintenance operator trough the CAMM system.

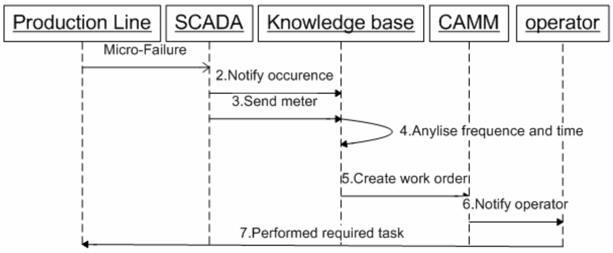


Figure 2: Sequence diagram for detectable micro-failures

Non-detectable micro-failures cannot be detected by the SCADA, so the system must rely on information from the operator. TPM tools are very useful to manually count the frequency of each micro failure. By combining average micro-failure duration, the total unproductive time due to the micro failure may be deduced. The frequency is also used to determine the necessary corrective actions on the equipment.

The actions to treat non detectable micro-failures are similar to the ones previously presented in Figure 2. Instead of a SCADA system, an operator is used to determine the fault and to take the decision. The knowledge base communicates the number of occurrences when an intervention is needed; in order to do so, data on occurrences must be introduced regularly.

3.2. Diagnostics

Diagnostic is more and more used to determine the cause of failures. Its importance depends mainly upon the machine position in its life cycle. During the beginning and the end of the life cycle, many failures are new to the operators so a diagnosis tool is needed to help them. During the maturity of the machine, failures are better known and may be better predicted. As a consequence diagnosis is needed occasionally during this period and new failures are rare. For the failures already treated in the past, "if … then" rules are used to determine the cause of the failure and their associated maintenance procedure.

Failure trees are often used to make a list of the components most probable to have failed. The advantage of using failure trees is that it is generally easily found in the machine's documentation or can be built based on technical documentation. In order to determine the probability of a component to fail, each node of the tree has a probability of occurrence which is the component failure rate λ given by the following equations:

$$\lambda = \frac{1}{MTBF}(failures / hour) \qquad [1]$$

$$MTBF = \int_{0}^{\infty} R(t)dt(hours) \qquad [2]$$

where the MTBF (Mean Time Before Failures) is calculated using the reliability function R(t)in (2).R(t) is estimated using the machine's failure history. By assuming that the reliability is a distribution function of a random variable, the probability that a certain component has failed after T_f hours is given by.

$$\lambda = \frac{1}{\int_{0}^{T_f} R(T)dt} \quad , \qquad [3]$$

The diagnostics program uses the failure tree to make a list with the components that have the highest probability to have failed, above 50%. This list is then feed to the theoretical model part, if the component has one, or presented to the operator. As presented in Figure3 the theoretical model program uses the sensor readings to compare the theoretical response of the component to the same input as the real component is subjected, if the experimental response is not in a certain interval of the theoretical response, then the component is faulty and must be replaced. If after this step no cause for the failure is found, then a standard diagnosis method is initiated which will guide the technician to determine the failed component(s). Once the repairs are made the operator creates an intervention report which contains the procedure he used or created to eliminate the failure, from this report a "if … then" rule is created and stored in the knowledge base for future usage.

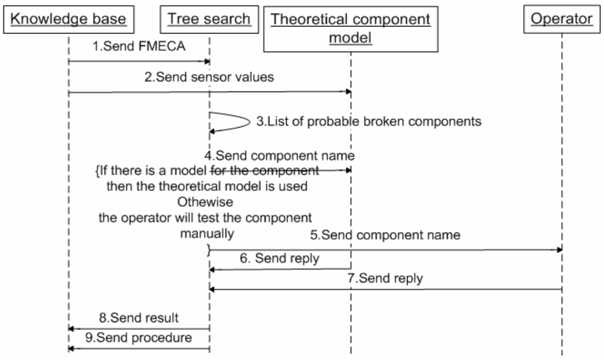


Figure 3: Sequence for diagnosis

3.3. Reliability function update

The diagnostics function uses reliability data in order to make a correct diagnostic so it is vital to keep the information up to date. This is done either by hand or using CAMM systems. Updating the reliability data is made automatically each time the diagnostics function is used or a failure occurs on the production system. Figure 4 shows the sequence of operations: once a failure occurs on the production system the diagnosis program is run and once the faulty component is identified the diagnosis program ads the new data to the machine's history and recalculates the reliability function.

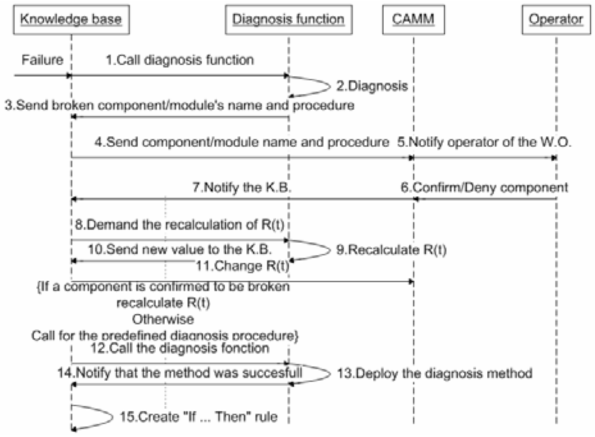


Figure 4: Sequence for reliability data update

3.4. Learning tool

All the procedures, failure types and their diagnosis are stored in the knowledge base. Some procedures are well known by the experienced technician; their storage and update ensure the reuse of the corporate knowledge by other operators. In Figure 5, two examples present the use of the system as a learning tool: one for displaying past data, i.e. the equipment history, the second one to display maintenance procedures.

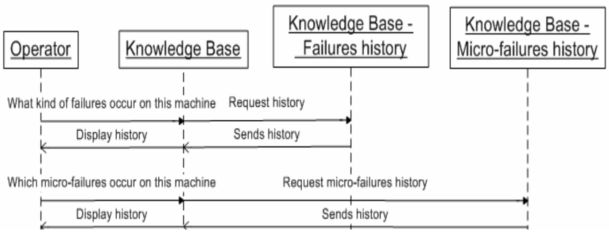


Figure 5: Example of using the system as a learning tool

3.5. Supervising machine's drift

Nowadays, most workshops use Synthetic Efficiency Rates (SER) to picture workshop's performance in terms of quality, availability and machine performance. As discussed previously SCADA Systems present very interesting functions for maintenance but also to more precisely evaluate SER. Many imprecision on SER comes from the lack of precise measures of micro-failures times. In order to correctly calculate failure times, SCADA system need the use of rules to effectively select the right micro-failure type and then produce the adequate process parameter or maintenance procedures to apply. Figure 6 illustrates such scenario. At regular intervals SCADA sends to the knowledge base files containing the quality parameters logged since the last update. The knowledge base analyses the new data and provides actions to perform on the system. In the case where actions on the system are required, the information is forwarded to the CAMM to generate a Work Order (W.O.). The operator executes the required tasks and the knowledge base is updated

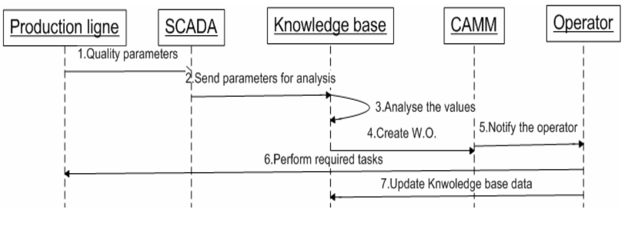


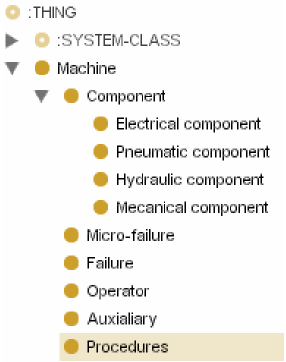
Figure 6: Sequence diagram for machine's drift supervision

4. Knowledge base architecture

As stated in the previous sections, the proposed integrated maintenance system must respond to every change on the equipments of the production system. An ontology, created using the method presented in [7], is used in the knowledge base. Since most components are common for all types of industries the ontology is useful for multitude of applications and it can be tailored to the particular needs of a workshop.

The ontology used in the knowledge base must reflect the equipment structure and their functions in the production system. The taxonomic structure presented in Figure 7 is used. At the top level the concept "machine" is the most abstract term used in the taxonomy. On the next level "component(s)" describing the sub-equipments of the machine are them-selves divided into subcategories corresponding to the technological components such as electrical, hydraulic, pneumatic, and mechanical equipments. On the same level with "component" the concepts of failure, micro-failure and operator are used. They obviously are not machines but the notions and the properties defined for them are needed for the functions mentioned in the previous section. A procedure class contains all the procedures not related to a failure (startup and shutdown procedures for instance). Procedures for failures are pointed into the CAMM system avoiding a double copy of the information. They are also used by the expert system to automatically update the knowledge base. The next concept, which is also on the same level with "component", is the "auxiliary" class for consumables like filters, cooling liquid, oil, and so on, for which there is a programmed maintenance and no reliability variable are related to them. This knowledge is still required and could have been placed in one of the categories mentioned before but in order to simplify data processing, they are kept separately.

Concerning failures, the concept "failure" is associated to symptoms, faulty component(s) and procedure. "Micro-failures" have a frequency and type (detectable and non-detectable). The "operator" has a name and he is authorized to perform certain types of interventions. "Procedure" has a title and the last time it was updated and "auxiliary" components have a CAMM reference number and a name.



- :THING
- :SYSTEM-CLASS
- Machine
  - Component
    - Electrical component
    - Pneumatic component
    - Hydraulic component
    - Mecanical component
  - Micro-failure
  - Failure
  - Operator
  - Auxiliary
  - Procedures

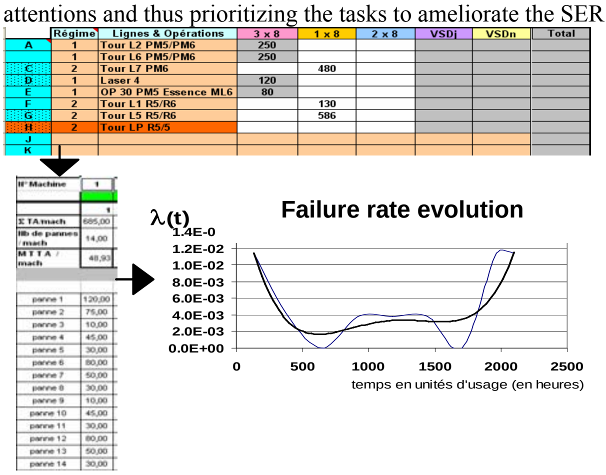
Figure 7: taxonomic structure of the Ontology

5. Study case

The architecture was implemented in the PSA Metz gearbox factory. The plant has over 3000 machines including machine tools and transfer machine of various ages and configurations. PSA is in an advance stage of implementing the TPM method in its plants. The production line used for this study case is close to the final stages of implementation: micro-failures have been reduced to a minimum and are clearly identified on a board where their frequency of appearance is noted on a daily basis.

The knowledge base was developed under Protégé [8] which is an ontology development tool that supports the creation, visualization, and manipulation of ontologies in various representation formats. The knowledge base is fully functioning; it allows the diagnostic of previously treated failures and to record the different types of micro-failures by using their occurrence frequency.

Data regarding micro-failures were analyzed by the system. For exemple, it allows the calculus of failure rate λ from the different failures and micro-failures which appear on the machine. A production reporting and status control file was used to retrieve data concerning failures. Figure 9 shows how relevant parameters are presented for one machine or for all of them using information collected by the production department. Data are presented in such a way to assist the maintenance department to identify primary micro-failure needing particular attentions and thus prioritizing the tasks to ameliorate the SER.



	Régime	Lignes & Opérations	3 x 8	1 x 8	2 x 8	VSDj	VSDn	Total
A	1	Tour L2 PM5/PM6	250					
	1	Tour L6 PM5/PM6	250					
C	2	Tour L7 PM6		480				
D	1	Laser 4	120					
E	1	OP 30 PM5 Essence ML6	80					
F	2	Tour L1 R5/R6		130				
G	2	Tour L5 R5/R6		586				
H	2	Tour LP R5/5						
J								
K								

N° Machine	1
	1
Σ TA/mach	685,00
Nb de pannes / mach	14,00
MTTA / mach	48,93
panne 1	120,00
panne 2	75,00
panne 3	10,00
panne 4	45,00
panne 5	30,00
panne 6	80,00
panne 7	50,00
panne 8	30,00
panne 9	10,00
panne 10	45,00
panne 11	30,00
panne 12	80,00
panne 13	50,00
panne 14	30,00

Figure 8 Machines daily production quota and failure rates

6. Conclusions

The integrated framework presented in this paper is designed to address all kind of maintenance procedures and policies using MES applications. The knowledge base ensures the integration of different MES systems using standard protocols. In this study a SCADA and a CAMM system were implemented since they are directly connected to maintenance. An initial implementation in an automotive manufacturing plant plant validated the architecture. Nevertheless, the system needs more implementation to extend its functionalities to additional MES systems (such as MRPs, ERPs …) but also to be able to use different kind of expert systems in order: 1) to improve automatic maintenance procedures editing using fault trees, and, 2) to ensure reliability based analysis for optimizing predictive maintenance.

7. References

[1] Subrahmanian E., Rachuri S., FouFou S., Sriram R.D.,2005,'Product Lifecycle Management Support: A challenge in supporting Product Design and Manufacturing in a Networked Economy,NISTIR 7211,NIST,USA

[2] Zwingelstein G.,1996,Reliability based maintenance: A practical guide for applying RCM" (La Maintenance basée sur la fiabilité: Guide pratique d'application de la RCM),Hermes Sciences Publication,Reading,FR

[3] Isermann R., Balle P., 1997,Trends in the application of model-based fault detection and diagnosis of technical processes,Control Engineering Practice,5/5:709-719

[4] Guan J.,Graham ,1997,An Integrated Approach for Fault Diagnosis with Learning,Computers in Industry,32: 33-51

[5] Patel S.A.,Kammrani A.K.,1996,Intelligent Decision Support System for Diagnosis and Maintenance of Automated Systems,Computers ind. Engng,30/2:297-319

[6] Liao S.-H.,2005, Expert system methodologies and applications – a decade review from 1995 to 2004,Expert Systems with Applications,28:93-103

[7] Noy N.F.,McGuinness D.L., 2001, Ontology development 101: A guide to creating your first ontology, available http://ksl.stanford.edu/people/dlm/papers/ontology-tutorial-noy-mcguinness.pdf (December 2006)

[8] Protégé available at http://protege.stanford.edu/ (december 2006)