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# Intelligent automation systems for predictive maintenance: A case study

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**Abstract**

A case study is presented, where a predictive maintenance solution for non-critical machinery (such as elevators and machine tools) was sought. Both cases are different. There is no experience in elevator monitoring and diagnosis, and modeling has been performed using Neural Networks. On the other hand, machine tools were monitored through vibration systems where some experience exists. In this case, Bayesian Networks are the paradigm of choice as it was also recommended to include some 'adaptation' mechanism for the knowledge modeled in the network. The final system also includes a sensor processing unit and a remote maintenance module system that provides an automated remote condition monitoring system, for both applications. Results indicate the feasibility of partial solutions in monitoring and diagnosis, though future enhancements are needed to compose a complete solution. This paper explains the characteristics of the Bayesian Network solution finally developed for high-speed machine tools, evaluate their strengths and weaknesses, and indicate the future enhancements.


*Keywords:* Bayesian networks; Knowledge modeling; Monitoring; Diagnosis; Uncertainty; Adaptation

## 1. Introduction

Predictive maintenance strategies are very efficient in mechanical-failure modes, when failure probability increases with time, and one or more condition-monitoring techniques (vibrations, oil, thermography, sound,…) can predict the failure before breakage. However, use of these techniques have been always linked to a very limited kind of assets, where unavailability can lead to safety loss (Aerospace), or big economical losses (Energy).

One of the greatest problems in predictive maintenance is the need to handle great amounts of data and the cost in personnel training. To overcome this problem, several decision support systems are in development and research. However, the ill-structure of predictive data makes it difficult to automate the tasks, as there is normally uncertainty in the diagnosis process. Moreover, some diagnosis and monitoring models must be built straight from data as there is no experience available. Finally, there are cases where continuous adaptation of diagnostic and monitoring solutions is required, as knowledge in maintenance increases.

In order to cope with these problems, several algorithm paradigms coming from machine-learning field can be applied to a variety of situations, and with diverse requirements and problem characteristics (supervised, unsupervised, reinforcement learning, expert knowledge, data mining). Among these, there are some that have developed into robust tools that can be used for the modeling of several kind of classification problems, such as monitoring and diagnosis. Examples of successful paradigms are CBR systems, neural networks, induction trees & rules, and Bayesian networks.

A case study is presented, corresponding to EC partially supported MINICON project (minimum cost, minimum size, maximum benefit condition monitoring system), where a predictive maintenance solution for non-critical machinery (such as elevators and machine tools) was sought.

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## 2. State of the art in monitoring and diagnosis

Maintenance actions are launched depending on the status of a parameter that is usually related to known equipment malfunctions. Typical indicators here are vibrations, temperatures, performance losses, etc. This maintenance is more commonly referred to as condition-based maintenance (CBM) or predictive maintenance (PdM) and the use of the above indicators is normally referred to as a condition-monitoring activity. It is important to point out that other techniques, such as statistical process control, can also be of help.

Predictive maintenance seeks for a much more cost-effective analysis than preventive maintenance, improving equipment reliability (avoiding unexpected machinery failures).

However, predictive maintenance methods require great quantities of information in order to provide adequate response to different fault detection sub-problems: identification of abnormalities, diagnosis, assessment of fault severity, prognosis, etc. All these tasks are 'knowledge intensive', as there is an evident need of expertise to be able to handle them. Also, the answer of previous problems requires the inclusion of information from many different sources (vibrations, temperature, oil, wear debris,...), sources that not very long ago were isolated.

Uncertainty appears in diagnosis problems at different levels, that can be classified as information and/or model flaws [1]. In a problem space such as failure diagnosis by analysis of vibrations, we can see that, when talking about failure modes, the borderline between dissimilar problems is often fuzzy. For instance, it is difficult to determine if there is just misalignment or there is also unbalance. In many cases, though there is a crystal-clear difference, several issues complicate this:

- machinery symptoms are likely to be a mix of different problems (unbalance and misalignment appear very often, though one of them is at a minimal level),
- information (e.g. spectra) could be unclear. For instance, frequency resolution is limited and, depending on the number of the components in analysis, and the spectral range, some measurements can be bonded to more than one problem,
- in many cases, the range of the devices installed can limit information, such as the ability to measure the HFD and Spike energy measurements,
- models also have inexactitudes, due to high human dependency when assessing severity of spectral peaks. Concerning machine tools, for instance, there is hardly any information about peak limits surpassed.

As a result, a given spectral pattern can be related to several problems, with uncertainty linked to interpretation (in almost all cases) and, therefore, uncertainty should be treated in order to solve diagnostic problems adequately.

Another challenge relates to the need to keep automated systems adapted. In [2], it is indicated that once we have a knowledge-based system, no matter how has it been created, we can distinguish three basic motivations for learning and *knowledge change*:

- correction of system errors (knowledge acquired through experience and feedback)
- enhancement of knowledge base (new products, new analysis means)
- improvement of knowledge base in terms of efficiency (dynamic strategies for maintenance cost reduction)

## 3. MINICON project

This paper introduces the work carried out under a larger project (MINICON) that intends to develop a cost-effective integrated sensor processing units (SPUs) for inclusion of on-line condition monitoring systems on all range of industrial and civil machinery. This includes two objectives: the consecution of a cost-effective hardware monitoring unit (or sensor processing unit-SPU) and the availability of automated systems to perform decision support on fault diagnosis and troubleshooting.

### *3.1. MINICON overview and objectives*

MINICON [3] aims to apply cost-effective operation monitoring and maintenance to small elements of industrial facilities (i.e. machine tools) and civil infrastructure (i.e. elevators and escalators). By introducing flexibility, self-configuration capability, improved performance and knowledge-based modules to the monitoring sensors, it helps to optimize the overall production and life cycle of the relevant machinery.

Finally, by developing a new remote maintenance management Scheme for these installations, which makes use of actual service data and is based on continuously monitoring structural integrity and prognosis of relevant damage, MINICON intends to drastically reduce the relevant maintenance costs (Fig. 1).

### *3.2. Monitoring and diagnosis algorithms in MINICON*

The design of diagnostics models able to adapt to new conditions is of primary importance within the MINICON final framework system. The consecution of a cost-effective SPU depends in part on the incorporation of robust fault detection methods. For these methods to work, we used a knowledge-based modeling strategy. The main advantage over previous knowledge based approaches is the use of algorithms that facilitate the re-use of knowledge and the inclusion of examples in an adaptive, on-line, learning approach.

Given this, we may see that the different nature of machine tools and elevators not only relates to the different