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Management of Maintenance on an e-Maintenance Platform

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Abstract Maintenance of assets is an important part of the asset life cycle. Emergence of e-technologies has enabled faster and efficient maintenance activities with e-maintenance. This paper presents a maintenance management model on an e-maintenance platform, which uses Return on Investment (RoI) as the criteria for decision-making. The model assigns equal importance to both qualitative and quantitative factors in arriving at the decision. The novelty of the work lies in mixing multiple criteria for decision making while at the same time keeping profitability of the business as paramount

Key words E-Maintenance, RoI, Decision Making, Maintenance

1 Introduction

Maintenance is associated with production and operation phase of the asset. The word 'Maintenance' itself has often been regarded as a cost centre for industry. However, in the more recent times, it has graduated itself to being a great saver in terms of costs; thereby contributing positively to a company's bottom line [1]. The worldview is also shifting from a pure exploitative to a more sustainable society. This also means that maintenance must expand to cover the entire life cycle of an asset. From a global perspective of life cycle management, the role of e-Maintenance is now to enhance the eco-efficiency [2] of the product life cycle while preserving the product ‘‘characteristics’’ in terms of not only its availability, reliability, safety, etc. but also maintainability [3]. Therefore, maintenance has to be considered not only in production or operation phase but also in product design, product disassembly, and product recycling [4].

Maintenance can be defined as all activities necessary to keep a system in working order [5]. In the timeline of maintenance strategies, in the earlier times, repair was the only form of maintenance as the machines were allowed to run to failure (Corrective Maintenance, CM). This was owing to a lack of tools that could predict failures. Corrective maintenance had many drawbacks, which led to evolution of Preventive Maintenance or Time based Maintenance (TBM). However, TBM has its own problems. When the maintenance happens before it is required, it leads to avoidable loss of operation time and maintenance resources. This led to the advent of Condition Based Maintenance (CBM) in which the condition of the equipment was continuously monitored before deciding on the maintenance action. A CBM program, if properly established and effectively implemented, can significantly reduce maintenance cost by reducing the number of unnecessary scheduled preventive maintenance operations [6].

Since the start of this century, the term e-Maintenance has emerged in the literature. The emergence of e-technologies has enabled maintenance to become proactive and quick. Developments in the World Wide Web, wireless technologies and mobile devices have revolutionized the maintenance field. E-Maintenance is now a philosophy supporting the move from ‘‘fail and fix’’ maintenance practices to ‘‘predict and prevent’’ strategies.

In this paper, an e-maintenance management model is presented. The model is based on a decision making process that emanates from the concept of Return on Investment (RoI). The model considers both qualitative and quantitative factors to determine the maintenance action.

2 Proposed Maintenance Management Model based on e-Maintenance Systems

Maintenance, like all other activities of our lives, has been affected by the power of internet. It can be described as the integration of information and communication technologies (ICT) within the maintenance strategy. Muller et al. [7] define e-maintenance as Maintenance support which includes the resources, services and management necessary to enable proactive decision process execution. This support includes e-technologies (i.e. ICT, Web-based, tether-free, wireless, infotronics technologies) but also, e-maintenance activities (operations or processes) such as e-monitoring, e-diagnosis, e-prognosis, etc. More simply, e-maintenance is defined as a “maintenance management concept whereby assets are monitored and managed over the Internet" [8]. Through the "e" of e- Maintenance, the pertinent Data–Information–Knowledge–Intelligence (D/I/K/I acronym) becomes available and usable at the right place, at the right time for taking the best (anticipated) maintenance decision [9]. This type of maintenance results in a variety of benefits, which are described:

a) e-Maintenance provides a major advantage of keeping the pool of experts centrally at a location, and they are able to provide diagnostic advice to all outstation plant locations.
b) provides an opportunity for a large number of experts, located at different geographical locations to address problems of a single asset simultaneously. Collective/Collaborative knowledge of many experts can eventually help reduce downtime.
c) The experts provide a real time immediate advice on the diagnosis of the fault.
d) Recording of maintenance activities becomes much easier. The power of e-technologies results in a seamless exchange of information and data related to machines, irrespective of the manufacturer or the end user.
e) Use of e-technologies such as remote data transmission, has helped in achieving a more flexible facility layout.
f) Diverse historical data from multiple sources, of multiple types can be accessed on the web to aid in decision making to help provide accurate diagnosis and prognosis of machine faults.
g) Predictive maintenance tools help in preventing the failure to occur in the machine before the fault can occur. These tools can be made available on the web.
h) Equipment can be monitored through various tools thereby focussing on the degradation monitoring and predictive maintenance.

Figure 1 below is a typical e-maintenance setup which uses the power of e-technology, computing power of the processors, remote monitoring and communication through the web.

Data is collected from a range of sensors either attached to the particular asset or attached to a data collection rig. The need for Wi-Fi or data transfer cables depends upon the sensor configuration. The data is fed wirelessly or otherwise to the central server where the pre-processing and data monitoring/analysis are carried out. The incoming data is monitored against set alarms/thresholds and is also analysed to reveal if there are any trends. Knowledge repositories are consulted in order to carry out diagnostic or prognostic actions. The maintenance action is finally conveyed to the maintenance department.

Once the maintenance actions are conveyed to the maintenance department, there is a need to analyse whether that action needs to be completed or not. This can be achieved using a ROI criterion. Each maintenance action will require investment and/or the maintenance action will result in cost/production savings. An aim of industry is to earn profit, however there are other factors that need to be considered while calculating ROI. These factors are enumerated below:

- Loss due to Production downtime
- Plant damage
- Product damage
- Safety
- Environmental damage
- Damage to Brand name

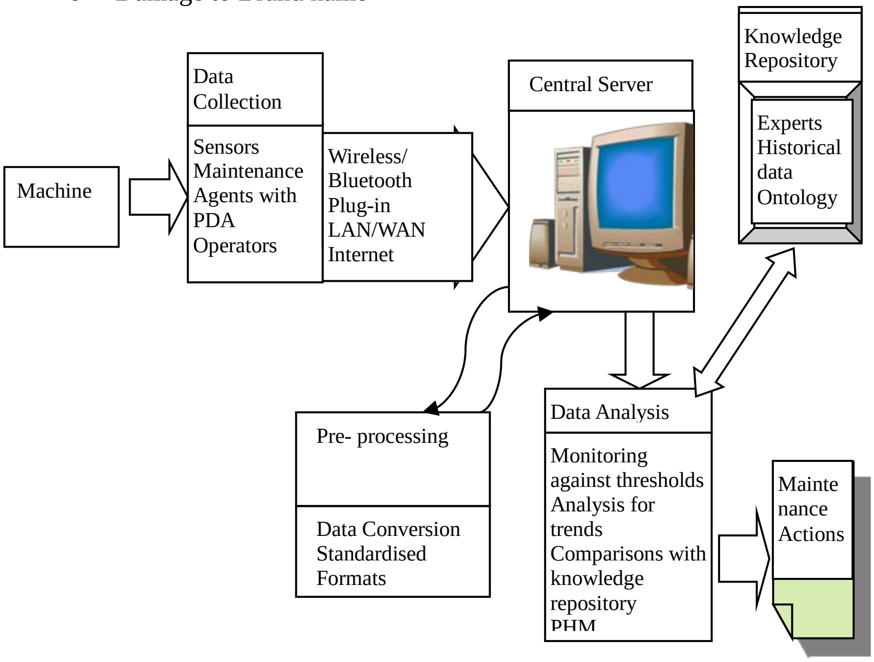

Figure 1: e-Maintenance setup

First three factors in the list carry a clear monetary implication while the last three are more subjective in nature. The calculation of ROI on the last three factors can be done using AHP, ANP, Fuzzy logic, TOPSIS, etc. A combined evaluation system to incorporate both types of factors should be developed that brings out the ROI of choosing/not choosing an option. Thresholds on the values of ROI can be pre-fed into the system to grade the decision either [Good] or [Bad].

The actions suggested by the central server will fall into certain categories of maintenance. These are enumerated in figure 2. It must however be noted that the categorisation of the maintenance action has absolutely no bearing on whether it will be carried out or not. The implementation of the suggested action will be done only on the basis of the ROI.

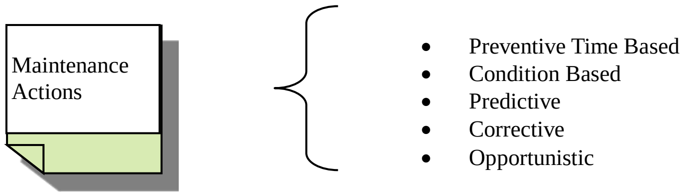

Figure 2: Classification of Maintenance Actions

To illustrate with an example, consider a case where the e-maintenance setup recommends an action to change the air compressor. The ROI calculation module will come up with a decision whether to change the part or not (Figure 3). In case the maintenance action has been suggested based on the condition of the part, the ROI may be limited and therefore it may be cost effective to allow the part run to fail rather than replacing it early.

The ROI module may return a poor or limited decision based upon the following factors

- Cost of the part is high.
- Its failure does not damage the plant/product/environment.
- Its failure does not affect the safety of the operator.
- The impending corrective action of replacing it after failure does not have a large downtime.

The model can easily be automated in order to implement to assist an effective maintenance management strategy

3 Practical Scenario

In this chapter, a simplified scenario of the measurement part shown in Figure 1 is presented. A smart data acquisition unit is connected to the cloud via internet and the state of the machine can be represented so that the maintenance team can monitor the assets remotely. This solution has been designed for the Condition-Based Maintenance (CBM) of rolling element bearings (REB) and it uses the MIMOSA standard for the information flow between the data centre and the cloud, in means of achieving interoperability among various components/systems of the e-maintenance solution [10].

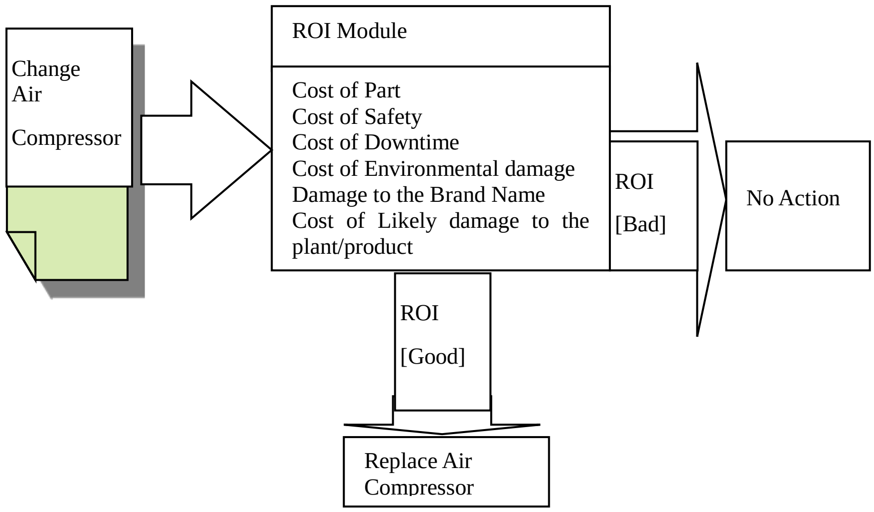

Figure 3: ROI analysis of suggested maintenance action

3.1 Cyber Physical Solution

The example can be described as a simple Cyber Physical System (CPS) solution that in this limited case consists of such components as:

- An accelerometer to detect the vibrations on the REB.
- An analogue low-pass filter to reduce the noise from the sensor.
- A programmable amplifier to amplify or attenuate the signal if needed.
- An analogue to digital converter.
- A Raspberry Pi 3 as a processing unit with internet connection to the cloud.

The accelerometer is placed on top of the bearing of the machine and it detects the vibrations that the bearing produces. The signal is cleaned from electrical noise and after converting it to a digital signal it is sent to the processing unit using SPI (Serial Peripheral Interface) communication interface.

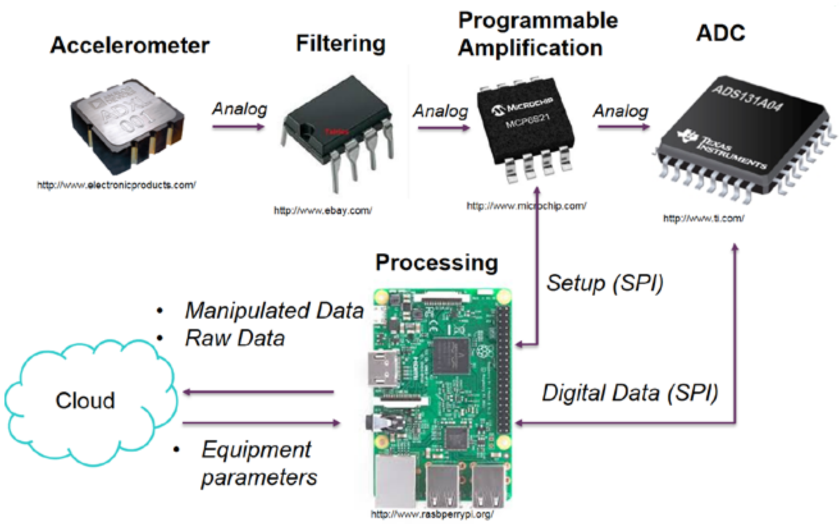

Figure 4: Main outline of the system

The first task the processing unit takes care of is to save the data in a file, saving the timestamp of the readings and the received values. Afterwards, the data is manipulated and an analysis is carried out to gather meaningful information. In this simplified laboratory example these calculations include statistical features such as kurtosis, skewness, root mean square, standard deviation, etc., and also a transformation to the frequency domain is performed using the Fast Fourier Transform (FFT), to later, apply the envelope analysis. Then, when all the calculations are complete, they are sent to the external database via internet, usually wirelessly.

One of the main objectives of this system is to be able to set it up in the least possible time and with the less possible cost. The hardware is inexpensive, it costs around 100€ and it can take readings up to 8k samples per second in 4 channels simultaneously while maintaining a resolution higher than 16 bits. Naturally, it should be kept in mind that a system with such low cost components cannot in the quality of signals compete with more sophisticated and expensive measuring equipment. In principle this means that more expensive equipment could be expected to detect the developing faults earlier than this system. However, there might be a number of cases where this kind of low cost solution might be economically justified i.e. the equipment that are monitored are not expensive and the consequences of a failure are not dramatic.

Each of the bearings that are being monitored might be different, so the equations and limits for each of them need to be modified as well. This is done automatically by having some of the parameters of each of the bearings (rolling element diameter, contact angle, shaft frequency, pitch diameter, etc.) stored in the MIMOSA database so that it is easy to get them and, therefore, modify the necessary equations automatically.

3.2 *Mantis Platform*

In this example case once the pertinent meaningful information is calculated, it is sent via the internet to an external MIMOSA database through a REST API. MIMOSA, as it has been mentioned before, is a standard architecture for moving information in a CBM system. The OSA-CBM process is divided in various functional blocks: Data Acquisition (DA), Data Manipulation (DM), State Detection (SD), Health Assessment (HA), Prognostics Assessment (PA) and Advisory Generation (AG). The DA and DM are carried out in the aforementioned CPS, and the following blocks are implemented in the cloud. Having some data processed in the CPS enables faster data-processing, less data transfer, and storage needed because only the necessary information is uploaded to the database. The database can be accessed through a Web Service and can be accessed remotely. In the Figure 5 the main page of this Web Service is shown.

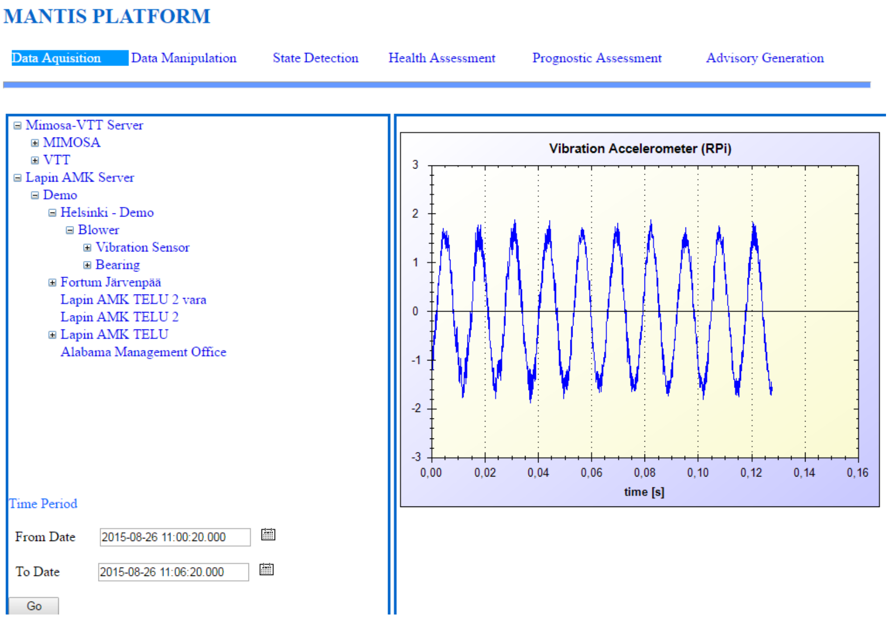

Figure 5: Mantis platform based on MIMOSA database

In the database, the limits for each of the statistical features, that have been previously calculated, are stored. As an example, in the following picture two different simulated waveform readings are shown: the one on the left displays a normal waveform that has no fault in the bearing, while the one on the right presents a waveform with a fault.

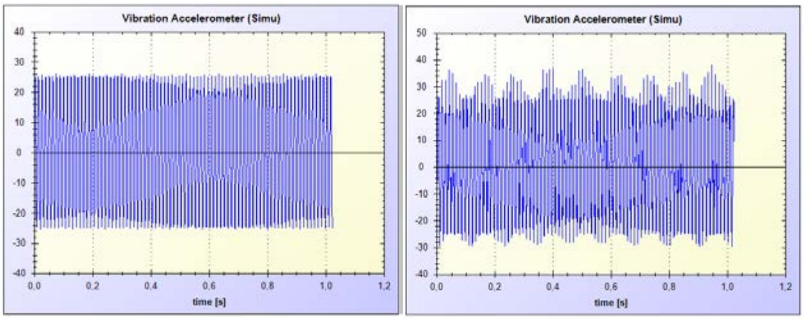

Figure 6: Normal waveform vs Faulty waveform

These waveforms are raw data that have been gathered straight from the sensor, without performing any analysis. However, the meaningful information is also sent to the database and in the State Detection tab from the Web Service the various statistical features can be read and compared to the previously defined limits. Two of these statistical parameters are the standard deviation and the kurtosis value. When the fault in the bearing progresses, both of the parameters have surpassed the previously stablished limits as shown in Figure 7. When the thresholds are exceeded, the system should send alerts to the maintenance technicians depending on the actions that need to be taken.

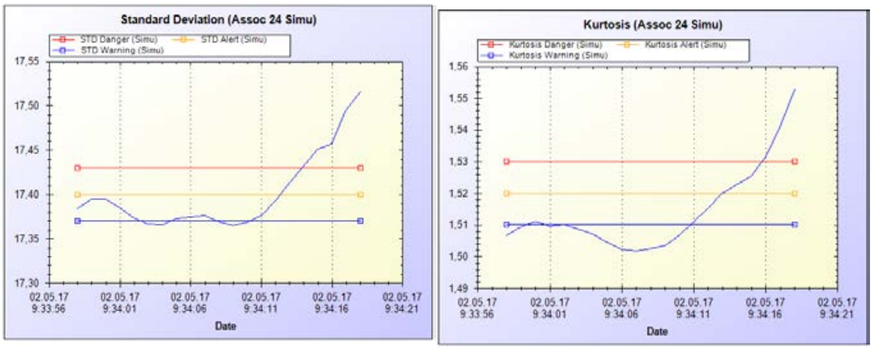

Figure 7: Standard Deviation and Kurtosis: From normal behaviour to faulty behaviour

4 Conclusion

E-Maintenance is an emergent field that can result in large amounts of savings in the operations phase of the assets. A maintenance management model based on e-maintenance has been presented in this paper. In addition, a simple case example of the measurement and analysis side of e-maintenance is given based on the use of low cost equipment. The shown example is built on Mantis platform.

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References

[1] Dixon, D., Baglee, D., Robson, K., Ylä-Kujala, A. and Sharma, P., (2016), "An Identification of the enabling factors for the development of a unified approach to Maintenance Strategy Development within the Automotive Supply Chain", *Journal of Maintenance Engineering*, Vol. 1, pp. 16-26.

[2] DeSimone, L. D., Popoff, F., & with The WBCSD, (1997), Eco-Efficiency, MIT Press.

[3] Cunha, P. F. and Caldeira Duarte, J. A., (2004), Development of a productive servicemodule based on a life cycle perspective of maintenance issues, Annals of the CIRP,53(1), 13–16.

[4] Erbe, H., Iung, B., & Morel, G., (2007), Maintenance models and services—A surveyregarding cost aspect, In Proceedings of the 8th IFAC COA, February 13–15.

[5] Pandey, M., Zuo, M., Moghaddass, R. and Tiwari, M.K., (2013), Selective maintenance for binary systems under imperfect repair, Reliability Engineering and System Safety , Vol. 113, pp. 42–51.

[6] Jardine, A., Lin, D., and Banjevic, D., (2006), A review on machinery diagnostics andprognostics implementing condition-based maintenance, Mechanical Systems andSignal Processing, 20(7), 1483–1510.

[7] Muller, A., Crespo Marquez, A., and Iung, B., (2008), On the concept of e-Maintenance, Review and current research, Reliability Engineering and System Safety, 93(8),1165–1187.

[8]Levrat, E. and Iung, B., (2006),TELMA: A full e-maintenance platform, WCEAM CM 2007 second world congress on engineering asset management.

[9] Iung, B.,Levrat, E., Marquez, A.C. and Erbe, H., (2009), Conceptual framework for e-Maintenance: Illustration by e-Maintenance technologies and platforms, Annual Reviews in Control, Vol. 33, pp. 220–229.

[10] MIMOSA. 2017. Open System Architecture for Condition-Based Maintenance. [ONLINE] Available at: http://www.mimosa.org/mimosa-osa-cbm. [Accessed 30 May 2017].

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