Towards the Industrial Application of PHM: Challenges and Methodological Approach

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ABSTRACT

The diagnosis and prognosis capabilities are the key points of PHM (Prognosis Health Management) research. Most of the endeavor and investment are being oriented to get and improve these capabilities: new sensors, measurement techniques, communication/data solutions, detection algorithms, decision algorithms and reliability calculate tools. Nowadays it is actually possible take advantage of these capabilities to improve systems operation and maintenance. In spite of this, massive industrial application is still far away. Many of industrial sectors barely have heard about of PHM and its potential, or only have introduced classical CBM (Condition Based Maintenance) tools -vibration analysis, ultrasound, thermography- to specific and local maintenance applications.

In this paper a comprehensive understanding of the problem of transferring PHM into industrial environments and its relevance is introduced. It's also argued the need of develop a methodological approach as a key point for getting a broad applying of PHM-based solutions. To do this, the main challenges to be addressed are listed and analyzed..

1. INTRODUCTION

Nowadays it is actually possible to take advantage of the capabilities of ICT (Information and Communications Technology) to improve systems operation and maintenance. Among others, a most accurate description of the degradation processes is now available. How deep can we characterize the system states? Is it possible to take maintenance decision based on objective knowledge about these current and future states? PHM goes lot further than other maintenance management tools to answering these questions.

A PHM solution (PHM-based solution), in a first approach, can be defined as the process of determining the current state of a system in terms of reliability and prediction of its future state. Generally it combines sensing and interpretation of environmental, operational, and performance parameters to assess the health of a product and predict RUL (Remaining Useful life) (Zio *et. al*, 2010). But owing to its relevance and development, PHM has become a new engineering discipline. This is strongly defended by different authors and institution, especially the PHM Society. Attending to this approach, PHM is a discipline that relies on the use of in-situ monitoring and advance methods of analysis (include fault detection, diagnostics, prognostics, and health management) to assess system degradation trends, and determine remaining useful life, allowing system to be evaluated in its actual life cycle conditions and mitigate the system-level risk (Sun et al 2012).

PHM is considered by the different authors as the key factor to definitely promote a qualitative jump toward intelligent maintenance. Lee *et. al* (2006), give to PHM and e-maintenance a fundamental role in maintenance development, where maintenance actions are synchronized with the overall operation of the system as well as the necessary maintenance resources and spare parts. Ly *et. al.* (2009), explain how to develop solutions for PHM effectively and efficiently will take a tremendous effort to coordinate all levels of managements from engineers to the top corporate level (maintenance managers, project officers, program managers,…). The entire enterprise must be coordinated in order to make PHM effective over the lifecycle operation of any system from the design, manufacturing, operational and logistical domains.

So, why these powerful improvements are not being applied extensively? Despite the great advances achieved in the last decade in the technologies included within the PHM topic, massive industrial application is still far away. In every CBM/PHM solution (as it is referenced by Vatchevanos el al. 2006), high technological fields have to be combined and adapted. A successful implementation required a deep knowledge of involved technology, methods and algorithms, besides great expertise in the particular application field. It possible to conclude that there are two general challenges in this development process: the coordination between corporate levels (alignment of technology uses with the business model and with profit generation) and the design of methodologies and frameworks to support its implementation efficiently (complex application scenarios by signals number, technologies, process dynamic or human interferences)

In parallel to this, the maintenance strategies evolution has to be considered. From "run to fail" or corrective maintenance to a new strategies with high level of proactiveness, that take advantage of technologies to prevent the failures and avoid their effects. In this shift, two aspects have to be considered: the improvement of the maintenance engineering and its tools and, on the other hand, the very development of the systems to maintain. Jardine et al. (2006) explain how preventive maintenance has become a major expense of many industrial companies. They argue how the rapid development of modern technology has made that products have become more and more complex while better quality and higher reliability are required. And this makes the cost of preventive maintenance higher and higher. Because of this, more efficient maintenance approaches such as CBM are being implemented to handle the situation. In this point, it is necessary to clarify that actually two different views about the CBM can be considered. One is the classical CBM, comprising the well-known use of techniques as vibration, thermography, ultra-sound, etc., which has a great implantation in the industry. On the other hand, new concepts have been introduced, as CBM+ (Ly et al 2009) or PdM (Predictive Maintenance) (Gupta et al. 2012), trying to introduce a more comprehensive view of condition and health system management, which includes the understanding and employ of prognosis technological capabilities. Condition based maintenance referred by Jardine is closer to the last one, and it also point out to the proactive maintenance approach introduce by other authors.

The concept of "proactiveness" or "proactive maintenance" is driving the evolution of maintenance (Lopez-Campos et al. 2013). PHM and "e-maintenance" are the levers of this development (Lee 2006). This approach is also included in the definition of e-maintenance introduced by Muller et al. (2009) when they talk about "Maintenance support includes the resources, services and management Necessary to enable proactive decision process execution".

Following this introduction, Section 2 outlines the main factors of industrial application of PHM-based solutions, making an introduction of the benefits that it can provide in contrast with the complexity of its implementation. In Section 3 it is argue the necessity of methodological approaches for optimize and assurance the results of this solution. A review of interested standards is included and principal aspects for building a practical methodology are listed. Finally, in Section 4 the conclusions of this paper are summarized.

2. CHALLENGES AND BENEFITS OF PHM INDUSTRIAL APPLICATIONS

Crucial questions when introducing these advances within an organization/system-for asset management, maintenance or equipment design tasks- are the follows: true benefits of the introduction of these tools are obtained? Is it worth it for the company drives their development in terms of competitiveness and profitability through these types of improvements?

Clearly, the application of any new maintenance development is based on the fact it provides a cost reduction and/or improved system reliability to, in last term, optimize the system life cycle cost (Crespo2006).Now, it is not sufficient to justify the industrial use of PHM. PHM-based solutions imply complex technological developments, so it is necessary to be more precise making it clear to the company how these improvements are achieved and where they will have to work (assets, human resources formation, technology investment, etc). In this sense, it is important the expected results of the implementation of these improvements are aligned with the strategic objectives and according with the capabilities and resources of the company. The concept of e-maintenance, when it is analyzed from the view of its contribution with the e-business management strategies, play an important role in connecting the capabilities provided by the PHM-based solutions with business strategies (Figure.1)

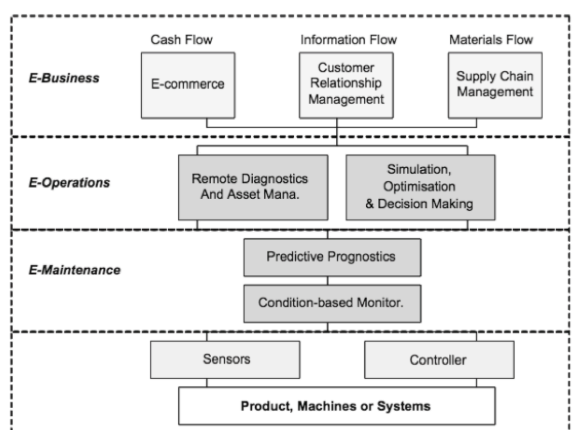

Figure 1. An enterprise view of e-maintenance (Lee 2004)

It seems then necessary, in order to promote a more extended use of PHM techniques, extract and show in a sorted way the positive results of the incorporation of these advancements in the industry. In order to do this, in this paper two different but complementary perspectives have been used: new capabilities/improvements for maintenance task execution and potential specific benefits that can be provided by PHM applications along system life cycle.

2.1. Improvement and Benefits of PHM Applications

2.1.1. New capabilities/improvements

PHM is related to the effective introduction of new capabilities at the service of maintenance management among others life cycle product stages. This approach helps us to understand the scope in maintenance evolution provided by these technologies. Muller et al. (2008), analyzing the potential improvements in the e-maintenance concept application context (we have exposed above, the close relation between PHM-solutions and e-maintenance), introduce the following references to the maintenance tasks evolution:

- Remote and on-line maintenance:
- Cooperative/collaborative maintenance:
- Maintenance documentation/record and knowledge capitalization and management
- Fault/failure analysis and predictive maintenance

<u>Remote and on-line maintenance:</u> here we introduce the capability to remotely link to a factory's equipment allowing remote maintenance actions as diagnosis, through data collection and analysis. This reduces the manpower cost and introduces tools to diagnose the faults and to improve the preventive maintenance thanks to the machine performance monitoring. The connection of field monitoring with decision centers adds value to the top line, trim expenses, and reduce waste (Crespo and Gupta, 2006).

<u>Cooperative/collaborative maintenance:</u> the opportunity to implement an information infrastructure connecting dispersed subsystems and actors. In many cases, very few technicians manage the key information of the system. As a result the company doesn't really control some critical aspect of their facilities. There is also a lack of information exchange between different actors. Implementing these strategies allows a strong cooperation between different human actors, different enterprise areas (production, maintenance, purchasing, etc.) and also external stakeholders (suppliers, customers, machine manufacturers, etc.).It provides maintenance management with a transparent, seamless, and automated information exchange process to access all the documentation in a unified way, independently of its origin (equipment manufacturer, integrator, and end-user) Information exchange process within the company is formalized, making the technical knowledge of the system is documented in the company (performance, maintenance, reliability) and not only in the hands of some good technicians. It also improve transparency and efficiency levels into the entire company and it can be an adequate support of business process integration (Hausladen and Bechheim, 2004), contributing to the acceleration of total processes, to an easier design, and to synchronize maintenance with production, maximizing process throughput, and minimizing downtime costs

<u>Maintenance documentation/record and knowledge capitalization and management</u>: One of the most urgent industrial problems is how to realize knowledge-based operation and maintenance of plants. It has to collect, record, and store information regarding degradation modes, degradation sections of the machine, degradation frequency, degradation time and place, time required preventing, cost required to prevent, suggested and/or applied maintenance practices, etc. This knowledge capitalization aims at creating a corporate memory (i.e. a structured set of knowledge related to the firm experience in a field domain) of enterprise (Rasovka et al 2005)PHM solutions give as a result accurate and wide information about systems condition and, at the same time, it implies a great knowledge of the system and its behavior..

<u>Fault/failure analysis and predictive maintenance</u>: This is the aspect more directly related to PHM. In order to properly analyze it, in the following paragraphs we are going to delve in the prognosis and PHM capabilities and its benefits.

2.1.2. Benefits of PHM

Gupta et a. (2012) argue that this techniques or solutions deepens the benefits of condition-based maintenance: (1) increasing the availability (avoid operational interruptions thanks to early detection capabilities reduce maintenance times by a better scheduling with less unscheduled maintenance); (2) reduction of direct maintenance cost (optimization of the use of each component, replacing it when it has reached almost all its full potential and better control on the maintenance scheduling: at the right place, at the right moment with associated resources to conduct the maintenance actions)

Ly et al. (2009) talking about differences between reactive, preventive and proactive maintenance, point out the main problems of schedule maintenance, which is the most extended practice in the industry: high cost, labor intensive; unnecessary maintenance operations performed when really not needed; does not prevent catastrophic failure. They also include high rates for false diagnostic indicators, and present some indicators such as: ReTest OK (RTOK), Could Not Duplicate (CND), No Evidence Of Failure (NEOF), No Fault Found (NFF). Finally argue that news approaches mitigate many of these problems and offer benefits including: decrease false alarms; increase operational availability and mission reliability; reduce logistics footprint; maximize return on capital invested, as measured by quantitative and non-quantitative benefits.

A more exhaustive analysis of the benefits of the prognosis is presented by Sun et al. (2012).They argue that prognosis can bring benefits in all stages of the system life-cycle process:(a) benefits for system design and development; (b) benefits in production; (c) benefits for system operations; (d) benefits in logistics support and maintenance; (e) benefits in phase-out and disposal (f); benefits in reducing Life-Cycle Costs (LCC). In general the approach given by Sun is very close to the principles of LCC analysis and it is in the line of other interesting work as Takata et al. (2004). In this sense is important remind the relevance of the first life cycle steps, since it is estimated that around 65% of improvement margins, the opportunities to create value, are decisions that can be taken during the early stages of the life cycle of the system (Crespo, 2006)

(a) In the system design, engineers can improve and optimize the design from the collected and stored useful historical information provide by an effective prognosis (system usage patterns, operating conditions, environmental conditions, known failure modes, and possible deficiencies). This information also could optimize test design and execution. These tasks consume a lot of resources (time and cost). In addition, prognostics can assist in constructing a logistics support system.

(b) In production phases, prognosis is a powerful tool for quality control process. The monitoring and prognostics of manufacturing equipment status can provide more information about equipment itself than traditional quality control, thus promoting the quality control process and quality assurance. In this phase is also analyzed the role of suppliers and OEMs (original equipment manufacturers) working with system manufacturers in the sense of "collaborative maintenance" explained above, provide component-level prognostics solutions.

(c) System operation: Getting an advance time of even a few minutes before failure could be very significant, and could enhance system safety, especially for systems whose failure might cause a disastrous accident. Prognosis also provides active control of system reliability. Actual operating conditions may be quite different from what the system was designed for, and will affect the life consumption and operational reliability of the system. The monitoring capability of PHM makes it possible to take active control actions regarding environmental and operational conditions. With PHM, operators can determine the remaining life and extended life, and develop replacement plans for systems and their sub-systems and reduce the occurrence of No Fault Found (NFF). Intermittent failures are impossible to assess using traditional prediction methods, resulting in the supply and maintenance chains suffering NFF problems, and prognosis is the most suitable approach to mitigate NFF risk. Finally warranty management and service is also a field where PHM and e-maintenance can have great influence, as is also discussed by Gonzalez-Prida et al. (2012)

(d) Regarding benefits in logistic support and maintenance, prognosis provides a foundation for PdM (predictive maintenance) or CBM, more powerful than traditional predictive plans (an interesting discussion can be consulted on Gupta et a. 2012). That results in minimized unscheduled maintenance, eliminated redundant inspections, reduced scheduled regular maintenance, extended maintenance cycles, improved maintenance effectiveness, decreased ground test equipment requirements, and reduced maintenance costs. Regarding to logistic issues, predictive logistics is expected to optimize the performance measures of a system, and improve the planning, scheduling, and control of activities in the supply chain. Others interesting benefits are: reduce maintenance and inspection and repair-induced failures, avoid costs in direct and indirect maintenance manpower and increase maintenance effectiveness. These benefits can be followed and assessed using graphical tools as presented by Barberá et al (2012)

(e) Phase Out and disposal: With PHM, a system’s full-life-cycle data, including installation, operation, and maintenance, can be managed and used to optimize end-of-life processing operations. Parts removed can be classified for treatment according to their life history and RUL. Here is included the consideration about that a system with prognostics capability can meet the requirements of modern society: energy saving, emission reduction, and a green environment.

(f) Reducing Life-Cycle Costs. As it is said above the approach used by Sun et al. (2012) is very close to LCC analysis. Here, in this point, it is specifically dedicated to the direct life-cycle cost reduction. Prognosis provide cost avoidance opportunities, especially for total ownership cost of critical system (reduce regular inspection costs, unnecessary replacement of components with remaining life)

(g) Replacement cost: The product/system useful life optimization has a great impact in replacement cost. This could be one of the most quantitative important benefits, with a best ROI (Return of Investment), depending on the company sectors. The cost benefit analysis indicates that investments in this area are likely to have large payoffs.

2.2. Introduction to PHM-application complexity

Industrial maintenance management has always been a complex activity that involves handling a large amount of information. Furthermore, in maintenance evolution new capabilities have been incorporated at the service of reliability and maintenance engineering. And manage more capabilities means more complexity. Tools like RCM and other significant efforts to develop frameworks, standards and methodologies (Lopez-Campos, 2011), have allowed enormous improvements through a better understanding of the maintenance task and the development of the maintenance management itself. However, better maintenance does not mean simpler maintenance. Actually, these techniques involve many resources and knowledge.

Likewise, the application of computerized tools and technologies of information and communication (ICT) - always present in the history of the maintenance function since the first personal computers in the 50s (Kans 2009) - has become in the essential support for modern maintenance, but it also introduces more level of complexity. And this is a great problem that companies have to deal.

The conclusion is that PHM-based solutions implementing is a very complex task. So, despite the benefits that can be achieved, this complexity imposes significant entry barriers, technical and economical. In Figure 2 main complexity factors that every PHM-based solution has to integrate are presented.

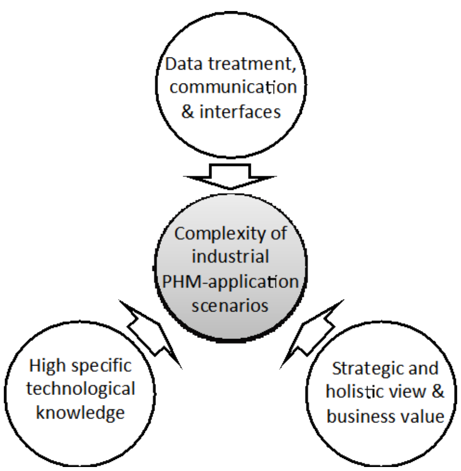

Figure 2. Complexity factors of industrial PHM-applications

Data treatment, communication and interfaces: An integral software / hardware solution has to be designed to bear the full cycle of information flow (Lopez-Campos et al, 2013): sensors, signal digitization, data capture and communications field level, processing basic detection algorithms, data storage, controls interfaces / alarm analysis interfaces. Furthermore, we must add the relation with others hardware/software present in the systems and the relation with information systems for the management process as CMMS (Computerized Maintenance Management System) or ERP (Enterprise Resource Planning).

High specific technological knowledge: it is necessary to combine and adapt different high-technology fields. We have just mentioned above the specific area of knowledge of software/hardware/communications. To this must be added the areas of technology equipment, measurement techniques, mathematical methods for fault detection, reliability engineering and finally the analysis of economic controls and ROI. A deep knowledge in every technology, method or algorithm is essential for a successful implementation, in addition of the knowledge in the application field (Cheng, Azarian, &Pecht, 2010). This is why it is required the effective implementation of a cooperative/collaborative open framework, in the sense it has been discussed in the previous section. This has to be support and interface for the necessary interrelation between different areas and technicians

Strategic and holistic view and business value: Finally, it is necessary to make the results of the investment in PHM-based solutions visible to the organization, assuring they responsive to management strategies. This is not a simple task. Especially if you consider that implementation times can be high and the design and development of these solutions combine multiple resources, implies high direct costs and interfere with the normal operation of the production process (Crespo 2006). All of this requires the management commitment and a deep knowledge of the process and its objectives by the involved staff. Although this is a well-known aspect to consider when an improvement process is implemented (as in the processes

All this requires the commitment of the management and the knowledge of the process and its objectives by the staff. This is a well known aspect in the implementation of improvement process as international quality standards.

3. JUSTIFICATION OF THE NEED OF METHODOLOGICAL APPROACH

The massive introduction of PHM techniques (within "e-maintenance" concept) in the industry, as mentioned above, implies the companies to know the utility of these tools and the benefits they provided, for the business, in last term. In addition the company has to incorporate the required knowledge by these new techniques and translate it into new skills of its staff. The other important aspect is the integration with business and production management, which includes the integration with other management tools and software.

PHM can be use in a specific solution for a particular case. It can provide great benefits in the short/medium term, especially when it deal with critical system or failure. But most ambitious approaches must include the design and implementation of a general strategy that combines different PHM-based solutions with more conventional maintenance options into a proactive maintenance plan (Lopez-Campos et al, 2013) It means that PHM applications have to be linked to the maintenance plan. In this sense Vachtsevanos *et. al* (2006) introduce a final module of its proposal of integrated system architecture for machine diagnosis and prognosis for CBM, a maintenance scheduler module. Other hand, different authors have proposed frameworks and methodologies to organize maintenance management in an industry, facility or system (Moubray 1997, Crespo 2006, Waeyenbergh & Pintelon 2009). These are practical approaches that try to help to engineers to schedule maintenance in real cases, giving a sequential process to use the different maintenance engineer tools and defined the set of various maintenance interventions (corrective, preventive, condition based, etc.) Other relevant aspect that is present in these methodological references is the role they give to the maintenance plan as main objective of the process and point where every decision is integrated within the overall maintenance strategy according to the company resources constrains. Taken these frameworks as reference of how industry treats the maintenance management process, we might conclude that it is necessary to link PHM result with the design and re-adaptation of maintenance plan and how integrate PHM with the rest of maintenance interventions within the overall maintenance strategy. It is also important point out the value of methodological approaches in the industry to develop an efficient and effective maintenance.

Standards are also references to consider that can be used to support PHM applications. Although few standards exist of direct relevance to prognostic systems and PHM system (Sheppard et al 2008) the close ties between PHM and traditional diagnostic and maintenance systems, several standards for the maintenance and diagnostic communities can be applied to PHM. Standards provide users with some guidelines to help them to accomplish their expected missions. In this sense, two main important approaches o standards groups could be distinguish:

- Information flow structure.
- Requirements and advices to assurance a good solution and the confidence of the results.

In relation with the first group, Ly et al. (2009) argue that CBM/PHM systems must have open systems architecture in order to maximizing the investment and remark the international institutions that are working to develop standards are key enablers to the architecture: Institute of Electronic and Electrical Engineers (IEEE), Society of Automotive Engineers (SAE), Machinery Information Management of Open Standards (MIMOSA), International Organization for Standardization (ISO). Here we can highlight the reference to ISO17334 and MIMOSA (CBM-OSA). An example of a practical interpretation and use of these standards is presented by Lopez-Campos et al. (2013). Other interesting references that we must also consider are specialized standards in hardware/software solutions as ISO 18435, IEC 62264 or some most specific ISO and IEEE standards.

In the second group it could be included standards as ISO 17359, ISO 13381 or even PAS 55 and ISO 14224. The ISO 17359 reference focuses on the general procedures and requirements to be considered when setting up a condition monitoring based program. It has to be highlight the fact this standard, like others standard referenced in it (ISO 17359 include an exhaustive list of condition monitoring standards), rely on traditional CBM approaches and they will must be adapted for support PHM based approaches in a most suitable way. The standard ISO 13381-1 defines failure prognostics, details the steps of the prognostics process, gives indications on the monitoring system and on how to estimate the confidence interval associated with the calculated RUL and proposes some mathematical tools which can be used to model the degradation (Tobon-Mejía et al, 2010).The rest of the mentioned standards in this paragraph introduce methodologies, aims and requirements to be included in a development of a overall solution, from the point of view of the general system performance and strategic or business approach.

Finally, there are a lot of references in the PHM specialized literature of frameworks to help PHM system developers and integrators for faster system development and deployment (Kunche et al. 2012). These frameworks address the problem of implementing a PHM solution from a technical point of view, but not the maintenance management issues.

We can conclude that there is a lot of background information and references. The problem is that it is difficult to access and manage this all these references in an orderly manner. This complicates in some way the industrial application of certain techniques, especially linked to the most advanced PHM. The problem is even bigger when working with complex systems with multiple signals and information systems. General methodological approaches have to be proposed to guide industry in the design process of new maintenance strategies where PHM potential has more relevance. In these proposals it is necessary to address how PHM is integrated with the maintenance strategies and the complete implementation process, from a need of a PHM solution is identified to maintenance plan execution.

What is presented below in this section is not the methodology itself, which will be subject to next research works. It is presented, preliminarily, the relevant aspects to be considered to implementing a PHM solution. They are presented providing an initial order to link these tasks in the following figure:

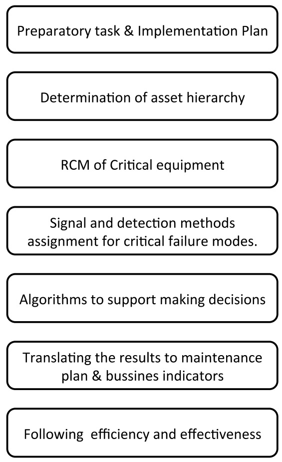

Figure 3.Relevant aspect include in a methodology construction

Preparatory task and implementation plan: It is necessary to request the relevant information over the facilities to be analyzed and the management systems that assist them. Also is necessary to create the work team. One of the most important constraints of this kind of approaches is related don't get an appropriated working team. This problem is well describing in references about RCM application (Crespo 2006). In fact much of the success of the process is precisely at this stage. Within these tasks may be included team formation.It is essential to establish a planning and allocation of resources to the project, including participation of required technical profiles. Also you have to make it very clear project phases, from design of the solution until the maturation phase after implantation.

Determination of asset hierarchy: The first point of this step is the analysis of operational context and the environment in which the system is integrated. You need to understand as clearly as possible the relation of the systems with the environment in which they are integrated. Issues such as the relation of the system with the overall productive process are valued. Describing the application environment it is also defined whether the PHM-based solution is used for product /system design (product/system design improvements) for the operation phases of the assets (process performance/control improvements) or both. After that, to establish the asset hierarchy, a criticality analysis is performed. It includes determination of criteria for evaluating the systems according to their severity. This approach introduces in the process of generate a PHM-based solution a link with strategic criteria. Finally, the analysis of CMMS systems is included, since they are necessary to obtain reliability data to evaluate the systems criticality.

RCM Analysis Critical equipment: In order to obtain all the benefits that PHM offers, it is necessary to implement it in an appropriated manner, selecting the most adequate items and the frontiers of the system to be maintained using this policy. Reliability Centered Maintenance (RCM) can be useful in this sense (Lopez-Campos et al 2013). The RCM approach contains a variety of methodologies such as: FMEA (Failure Mode and Effect Analysis), RBD (Reliability Block Diagram), RP (Reliability Prediction), FTA (Fault Tree Analysis) and ETA (Event Tree Analysis). As pointed out by several authors, the use of RCM technique is necessary for the proper selection of the CBM processes and technologies. This conclusion must be translated to PHM applications (Sun 2012, Cheng 2010, Gomez 2012, Vachtsevanos 2006) RCM analysis helps in selecting the optimal maintenance policy for every maintainable item: diagram Input-Process-Output determination of operating standards for each of the systems / functions, functional loss, failure modes and failure mode criticality

Signals and detection methods assignment for critical failure modes. From the information generated above, the possibilities to follow and detect each critical failure mode are analyzed. This includes the analysis of signals presents in the system, the analysis of the possible symptoms associated with each failure, the introduction of measurements technologies employed in classical CBM approaches and the use of advanced detection strategies, i.e, PHM detection tools. It is in this section where the contributions of the research on PHM detection methods will be discussed. From this point, with the support of information and advices from the standards, the platform software/hardware for running the PHM solution is designed (Lopez-Campos 2013). This platform can combine commercial solutions with ad hoc developments, both hardware and software.

Algorithms to support making-decision: This section includes the choice of models for calculating RUL, the economical estimation risk and comparison based on these data from different maintenance strategies. The calculation or estimation of the RUL is, jointly with detection algorithms, the main PHM solutions contribution. When PHM tools are used, is necessary to distinguish those that are used in each case. The methodology has to help to know what tools we have available, how they are used, when it is used and how the different results are related within the general system to be developed.

Transferring results to the maintenance plan and business indicators. A key module of the platform that will have the responsibility of PdM decisions, which will be integrated into the maintenance plans. Based on the results, the specific actions for being incorporated into the maintenance plan will be proposed and included in the CMMS. Finally a set of KPI's to control the process of improvements and its impact over the operation and business performance is also necessary.

Following the efficiency and effectiveness of maintenance. One of the key aspects of effective proactiveness is the ability to interpret the results of the actions and maintenance policies. So, in this section a practical performance control of the implemented actions is proposed. In this sense, one possibility is programming graphical tools supporting decision-making process. This achieves an accurate and efficient management of assets and resources in an organization, even when there is a large number of elements with functional configuration that is highly complex (Barbera et al 2012). To obtain actual applications of analytical models, practical, functional, innovative, and simple tools can be generated. Figure 4 present and example of GAMM method (Graphical Analysis for Maintenance Management) proposed by these authors, where they used two graphics to present jointly maintenance operation data and level of system reliability at the moment maintenance intervention. This will help to make tactical and operational decisions easier. New graphical tool on the basis of data related to the interventions sequence performed to a piece of equipment in during a time horizon. It must provides easy access to certain variables patterns showing useful information for maintenance management and decision making in the short, medium, and long term.

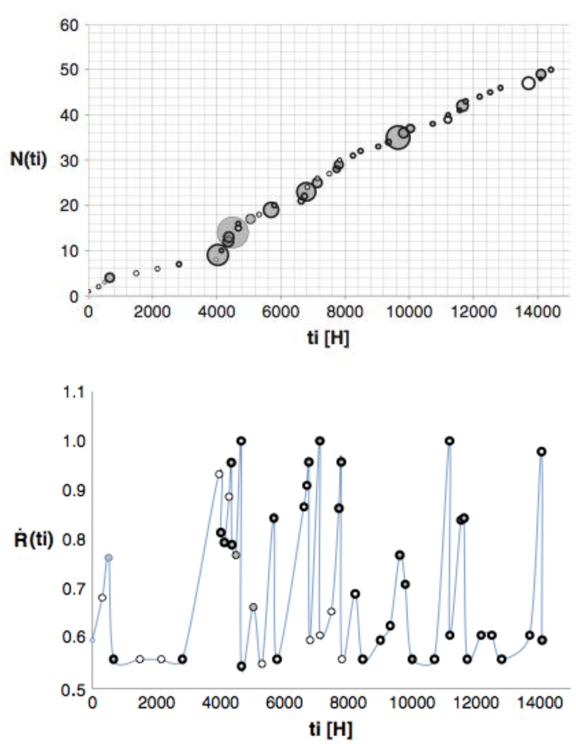

Figure 4.GAMM method. Example of programmable graphical method for following efficiency and effectiveness of maintenance plan execution (Barberá et al. 2012)

4. CONCLUSIONS

In this paper the general context of PHM industrial application has been presented, summarizing benefits and challenges. Finally the main factors that have to be considered for designing a practical methodology for implementing a PHM-based solution have proposed. The issues exposed in this paper are a first step in a much larger investigation, that will be focused, necessarily, on analyzes of PHM implementation in real cases. This will help to verify the practical utility of these solutions in different sectors and situations andit will let incorporate to the analysis the real constraints that these processes can incorporate.

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ACRONYMS

ALS Autonomic Logistic System
CBA Cost-benefit Analysis
CBM Condition-based Maintenance
CND Could Not Duplicate
ETA Event Tree Analysis
FMEA Failure Modes and Effects Analysis
FTA Fault Tree Analysis
GAMM Graphical Analysis for Maintenance Management
ICT Information and communications technology
KPI Key Point Indicator
LCC Life-cycle Costs
MTTR Mean Time to Repair
NEOF No Evidence Of Failure
NFF No Fault Found
PdM Predictive Maintenace
PHM Prognostics and Health Management
PM Preventive Maintenance
RBD Reliability Block Diagram
ROI Return on Investment
RP Reliability Prediction
RTOK Re-test Ok
RUL Remaining Useful Life

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