NEXT GENERATION MAINTENANCE THROUGH THE ADOPTION OF E-MAINTENANCE

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SUMMARY

A remarkable step forward in maintenance has been taken through the adoption of e-maintenance techniques. The new methodology enables the efficient use of maintenance related information and services wherever and whenever they are needed. New monitoring techniques together with advanced use of mobile devices and RFID technology help the maintenance engineer to assimilate many different information sources, enhancing the quality and cost effectiveness of maintenance decisions. With the help of personal digital assistants (PDA) the maintenance engineer is offered not only highly efficient and practical monitoring and diagnosis tools, but also direct assistance on how to carry out the maintenance tasks effectively and reliably so that the possibility of introducing faults during the execution of maintenance tasks is also minimized. The introduction of maintenance e-training provides additional tools to achieve this aim. Key to the implementation of e-maintenance is the combined use of web services and interoperability standards, enabling data and intelligent processes service integration (monitoring, diagnosis, prognosis) in a distributed manner, with smart embedded services. Such devices, services and data integration duly takes into account local or remote information, as well as input from intelligent predictive planning systems, in order to optimize maintenance costs, operational reliability and availability. The decisions made by the engineer in the field are therefore well-informed, based upon up-to-date information and take a holistic view of the overall maintenance strategy. The paper summarizes the results of a highly successful EU IP project DYNAMITE (Dynamic Decisions in Maintenance), where a flexible e-maintenance framework was developed and demonstrated at different end users and application scenarios.

Key Words: Maintenance strategy, Maintenance economy, Condition Based Maintenance (CBM), e-maintenance, web services, Personal Digital Assistant (PDA), monitoring, diagnosis, prognosis

1 INTRODUCTION

The maintenance of industrial assets such as production machinery forms a large part of the overall operating costs. However, effective application of maintenance processes and techniques can guarantee high availability and efficiency of production machinery, together with high quality products, safe operation and minimal waste and environmental impacts. Modern and efficient maintenance practices involve, at least, the identification of the root–cause of component failures, reduction of production systems failures, elimination of costly unscheduled shutdown maintenances, and ultimately an improvement both in productivity as well as in product quality.

The perception of the maintenance function from within companies and from the public at large is slowly changing as higher levels of product quality, reliability of service and environmental responsibility is demanded by customers. It is also
widely understood that the efficient use of industrial assets is a key factor in supporting current living standards and enabling sustainability.

The maintenance function plays a critical role in a company’s ability to compete on a broad range of factors and is therefore taken into account to a much greater extent in production requirements [1, 2, 3]. The increasing importance of maintenance activities has created a new role for the maintenance function, particularly for the manufacturing industry. Taking into account the life-cycle management oriented approach, where limits on resources and energy consumption require a sharp change in the objectives of manufacturing. This change will cause a shift in emphasis from the need to produce more efficiently to ensure customer satisfaction and profitability. Hence maintenance activities will become of equal importance to production activities [4].

To respond to the new challenges, the maintenance concept must undergo several major developments and move towards more proactive approached. This will require changes in transforming traditional ‘fail–and–fix’ maintenance practices to ‘predict–and–prevent’ e–Mainte nance strategies. Such an approach takes into account the potential impact on service to customer, product quality and cost reduction [5]. The key advantage is that maintenance is performed only when a certain level of equipment deterioration occurs rather than after a fixed period of calendar time or number of hours of operation. In other words, there is a shift away from the current mean time between failure (MTBF) practices to mean time between degradation (MTBD) technologies.

The DYNAMITE Project has adopted many e-maintenance techniques in order to most efficiently use maintenance related information and services. New sensor and monitoring techniques; intelligent use of mobile devices; RFID technology; wireless communications, web services; have all been integrated seamlessly to provide substantial benefits.

- Increasing the speed of gathering data.
- Improving the methods of processing information
- Assisting personnel to assimilate many different information sources
- Making more informed decisions based upon the scenario faced.
- Effective use of mobile communication technologies
- Enhancing the quality and cost effectiveness of automated maintenance decisions.
- Maintenance e-training facilities

The decisions made by the engineer in the field should therefore be well-informed, based upon up-to-date information and take a holistic view of the overall maintenance strategy. These key features have been implemented on several different industrial case studies of different sizes and machinery complexity. It is hoped that further research will be completed to more fully evaluate the system effectiveness over the long term and to demonstrate significant cost-efficiency for many types of organisations.

2 E-MAINTENANCE AND ENABLING TECHNOLOGIES

Maintenance engineering and decision making is benefiting from the rapid introduction of e-maintenance [2, 7]. E-maintenance is neither a strategy nor a single technology. It is the end result of the integration of different technologies that creates a highly innovative and efficient ICT framework for the integrated and efficient handling of maintenance. The key objective is to implement ubiquitous maintenance management. This implies that maintenance operations, planning and decisions as well as data and tools to process and act upon them are made available anytime, anywhere and to anyone authorized to access them at multiple levels of operation [8]. At the operations level, e-maintenance involves technologies and tools to integrate functions related to monitoring component degradation status and availability state, support personnel decisions with diagnostics & prognostics information, as well as support the estimation of performance indicators. Further up in the hierarchy, e-maintenance provides enabling tools and information mediation to facilitate the implementation of the maintenance policy selected at the strategic level, while providing interfaces to the CMMS and ERP systems. Finally, at the highest hierarchical level, e-maintenance makes available the necessary IT tools for supporting decisions about the maintenance policy to be adopted, as well as for defining this policy and assigning its execution to lower hierarchical maintenance layers.

- Among the key enabling technologies supporting e-maintenance are:
  - Web-based technologies and software
  - Wireless communications and protocols
  - Hardware and devices exploiting wireless networking
The synthesis of the above technologies enables the design and implementation of a new generation of maintenance services, including automated asset tagging and tracking, electronic documentation, remote condition monitoring, diagnostics & prognostics and maintenance e-training [9]. The combined use of such technologies, along with the usage of a unified maintenance-related data interchange model, such as MIMOSA (www.mimosa.org), can lead to the development and operation of Integrated e-maintenance at the organisation level, comprising: Maintenance – related data integration / Maintenance – related services integration.

It emerges that the pathway to success in implementing e-maintenance is the efficiency and the degree of integration at all levels of operations related to the maintenance function. The Dynamite project has achieved to design and implement an e-maintenance architecture that offers integrated maintenance-related data, decisions and services handling, with extensive use of wireless technologies. The architecture is described in the following sections.

3 THE COMPONENTS OF DYNAWEB

There are quite a number of challenges when maintenance is carried out as economically possible based on CBM strategy. Most importantly the maintenance organisation needs to define when maintenance should be carried out. The timing is based on the information given by condition monitoring sensors. In Dynamite project a number of solutions for condition monitoring were developed. New solutions were developed both for vibration monitoring and oil analysis. For vibration monitoring an online solution DWC28 together with an USB sensor DWC12 were developed. In addition wireless Mem’s sensors capable of measuring vibration, pressure and temperature were developed (DWC3 and DWC17). In order to enable the wireless communication of condition monitoring sensors a specific communication hardware solution DWC18 and a software module DWC15 to support it were developed, see Figure 1.

The continuous on-line monitoring of lubricating oils enables the following of the development of the lubricant and through that the condition of the machinery. Altogether 5 different solutions were developed for oil monitoring (DWC4-8) due to the importance of this technology. In the development the focus was in optical methods. All the methods were tested in industrial environment with good success [10, 11].

In addition to condition monitoring data also more simplified information is of importance in maintenance. The machinery has to be found and identified. For these purposes RFID tags were tested and supporting software developed [DWC1-2 and DWC10-11] [4]. The tags provide an easy means to indentify the machinery thus provide the necessary solution for avoiding...
mistakes and thus the maintenance personnel can become certain that operations are carried out with the machinery that needs maintenance actions. The tags also support condition monitoring with movable equipment because they enable the automatic identification of measuring locations together with related diagnosis information.

With the technology available today it became apparent that the localisation of movable machinery based on RFID technology is challenging. In Dynamite project reliability of localisation could be improved with sophisticated software that can be used compensate for the contradictory information from various sensors. However, these results were not good enough for commercial use of the technology and thus further research is encouraged.

Already in the beginning the main idea in Dynamite project was to enable the full use of necessary information in various industrial environments [8]. Since the beginning of the decade a new term e-maintenance has been introduced to describe how maintenance can be supported through Internet [6]. Clearly the term e-maintenance also emphasises proactive maintenance strategy instead of reactive approach i.e. the possible problems are taken care of before they appear and stop the production [13]. However it has to be admitted making prognosis of the need for maintenance actions really is the heel of Achilles in today’s maintenance or as Lee et al. [14] define it “We do not know how to measure the wear of components, we do not have the necessary models which would explain what the change in measured parameters is telling us”. The Dynamite project has tried to give more light to this issue DWC21.

As explained before the main idea in Dynamite was to enable the availability of necessary information wherever it is needed. The technical solution that makes this true in the field is the PDA. A PDA can give access to the process or the production machinery or to the sensors and at the same time to all of the supporting system such as comprised maintenance management systems (CMMS) [15]. In summary, we can conclude that the PDA is a key element in the DynaWeb structure and it is arguably the most essential element in making e-maintenance possible in practise [16]. The information flowing from each of these other project work packages is required to be collected, assimilated, analysed, processed and presented to the user at the PDA. In addition all of the above information sources should be made available – through the choice of an appropriate PDA and associated hardware, the development of suitable software and also the development of wireless communication systems. Thus PDA is expected to support:

1. The use of Smart Tags for storage and handling of component data, details of maintenance actions, and machine diagnosis results.
2. Communication with Intelligent Sensors and performing local signal analysis and diagnosis.
3. Communication with the CMMS system for handling asset information, spare part information, work orders, asset identification and location issues, etc.
5. Performing cost effect analysis.
6. Logical and efficient display of raw data, processed data and summary information based on the above features.

When Dynamite project had been ongoing for more than a year it was realised how difficult it would be to integrate the results of various partners. Within the project there was a so called software team who tried to lead the way of using the same tools for software development etc. This had been successful i.e. all partners followed the same principles but this could not solve the issue of integration in an acceptable way. After a long debate the decision was made to use a common database. In practice there existed only one solution i.e. Mimosa [www.mimosa.org] which has been developed in order to serve this kind of purpose. Mimosa follows the ISO 13374: Machine Condition Assessment Data Processing & Information Flow Blocks standard. As such Mimosa is rather huge consisting of about 400 tables and it cannot considered easy to take into use. In Dynamite project a special user interface for the communication with Mimosa was developed (DWC25 & 26). At the same time also an interface for communication through the PDA was developed (DWC9). In the end the decision to rely on Mimosa proved to be very beneficial for the whole project. In fact it can be claimed that without this decision it would not have been possible to reach the high level of integration of modules created by various partners.

In Dynamite project also a translator for communication with Mimosa database was developed (DWC16). This module can listen to TCP/IP and Virtual Communication ports. In addition a module for SQL communication has been developed. Naturally these two modules have been linked together (DWC16).

Condition monitoring is as such very challenging and it takes real experts to be able to make the diagnosis and prognosis of the condition of the machinery. In order to automate this process a lot of effort was given in Dynamite project to create Web Services that could help in carrying out this demanding task (DWC19-22). The Web Services that were developed are available anywhere through the Internet and this really makes the solutions extremely flexible [17].

Quite often companies have to consider how efficient they are. Especially the organisation of maintenance raises questions. It seems to be a high cost and naturally one can ask could something be done in order to reduce the costs. This is very typical and even more pronounced attitude the further the people are from direct maintenance activities i.e. the benefits are not seen only the costs. In Dynamite a lot of emphasis was given to economical studies. How can the economical benefits of
maintenance be compared with the cost, what is optimal way of organising maintenance. For this kind of studies a specific toolbox was developed which enables the decision making based on real options (DWC24).

The integration of e-maintenance technologies poses some challenges to maintenance personnel, as they are not used to employing such technologies. Furthermore, e-maintenance is not covered by standard maintenance educational programs. To win industry acceptance, e-maintenance technologies need to be incorporated into dedicated maintenance training curricula. The Dynamite system therefore incorporated an e-training solution to enable users to get fast acquaintance with the developed tools and associated technology. The Dynamite e-learning platform, DynaTrain has been designed and implemented using the Moodle Learning Management System, offering web-based e-learning. DynaTrain has the prime aim to offer users the basic knowledge for developing skills to efficiently plan and execute the Dynamite – implemented e-maintenance functions. The developed content involves theoretical knowledge as well as guidelines and tips on how to perform certain e-maintenance tasks. The training is divided in different courses, based on original content offered by the Dynamite project partners and include vibration sensing (Diagnostic Solutions Ltd), data acquisition, (Wyselec Oy), PDA and RFID inventory tracking (University of Sunderland), prognosis web services and MIMOSA translator (University Henri Poincaré). An example is described by Emmanouilidis [18].

4 MODEL IMPLEMENTATION AND RESULTS

The components introduced in the previous section include a variety of functionalities that may allow the upgrade of any exiting maintenance systems to flexible, dynamic and condition based strategies. However, the migration from any existing system is always painful, as many existing technologies and legacy tools already exists, starting from SMMS and SCADA systems, firewall restrictions, etc. Therefore it is not always necessary, nor convenient, to implement all the technologies deployed in Dynamite, as demonstrated in the analysis of the likely end-user scenarios included in [15]. Certainly their integration was not straight forward and required a major effort.

Having this in mind, the adoption of Mimosa and the use of layered web services according to OSA-CBM distribution of information flow [17] is essential for the distributed modelling of the DynaWeb solution. Here a ‘plug & play’ approach is associated to every component (hardware or software), allowing the focus to be made firmly on the integration of those DynaWeb component modules that will leverage the existing scenario. As a result, the implementation of DynaWeb at different use cases has been very different. For instance, implementation in Goratu is directed toward an OEM supplier, interested in remote control and of machinery, especially at guarantee periods, see Error! Reference source not found.. In this sense, the solution relies on a limited set of sensors, specific for every type of machinery, plus wireless remote connection and limited monitoring processes. On the other hand, shop floor machinery installed on Fiat plant included almost all ranges of components developed, see Error! Reference source not found.. Concerning component results, these have demonstrated the advantages that such an extended range of new technologies may bring to different companies in order to perform cost-effective condition monitoring processes, enabling in this way the adoption of PdM and e-maintenance strategies. For instance, the use of novel optical technologies related to Visible and NIR spectral ranges have allowed a lubricant control that will extend machinery lifetime, because the existence of particle or water contamination, and the progress of lubricant oxidation, see Figure 4 and Figure 5 [19]. Hence lubrication performance may be tracked and timely actions made when required. It is important to note that real implementation of these sensors relies on several additional DynaWeb components. In this sense, the adoption of web services as the model to process

Figure 2. DynaWeb implementation at Goratu

Figure 3. DynaWeb implementation at Fiat
information is key to avoid real drawbacks (e.g. corporate firewalls) and yet provide on-line, global, and distributed access to the machinery status.

Another example is the inclusion of advanced algorithms, such as Bayesian Networks (BN) for mechanical fault diagnosis based on sensor fusion and showing adaptation and uncertainty handling abilities. Such a system has been customised for high spindle fault diagnosis [20] and conditioned to be accessed via the web according to MIMOSA protocols. The result is a diagnostic module that may be accessed wherever requested.

The Figure below shows some implementation details of the main processes corresponding to the OSA-CBM layers (feature extraction, monitoring, diagnosis, prognosis, work order scheduling) within the e-maintenance platform. Different detail levels, may appear depending on the characteristics of the interface (smart sensor, smart PDA, standard PCs)

At the end, the components related to the information processing and human interface (OSA-CBM web services, Smart PDA (Error! Reference source not found.), TESSNET (Figure 7) e-maintenance predictive management web site) allow a pervasive access to the information needed at any company level (machine, shop floor, management). This has allowed the DynaWeb e-maintenance concept to be demonstrated at three manufacturing industry sites. Overall results, in terms of technical application and satisfaction of test user groups were very positive. The quality of the separate components and their functionality, technical capabilities and economical feasibility was demonstrated.

5 CONCLUSIONS

During recent years a lot of technological development has taken place and this has made it possible to introduce complete new approaches to conservative areas such as maintenance which traditionally has relied on relatively old technology. The introduction of modern computer technology to maintenance enables the maintenance engineer to get whatever information he needs wherever he is located and also makes it possible for him to report the work he has done and any other findings there might be.

The commonly accepted term for describing this new approach is e-maintenance – where much of the information is passed through the internet either through wired or wireless communication. In the Dynamite project, within four years of creative and intensive research work, an e-maintenance solution called DynaWeb was developed. Some of the key findings in this development process were the following:

- Today the existing technological solutions for wireless communication and PDAs enable the introduction of e-maintenance technology to industrial environment. However, it is important to take into account the limitations that exist i.e. it is important that the developed system also supports the maintenance engineer even if no wireless communication is available.

- The introduction of e-maintenance technology in Dynamite project heavily relied on the development following technologies within the project: MEMS sensors with energy harvesting, online lubrication sensors, USB vibration sensors, smart RFID tags for identification and location of components, maintenance actions supported by PDAs (PDAs), wireless communication, diagnostic and prognostic Web Services, common (MIMOSA) database, work management scheduling support, cost-effectiveness and strategic decision support based on technical and economical considerations and all this
supported by an e-training solution.

- E-maintenance technology enables the practical introduction of CBM strategy as the maintenance strategy for very different types of industrial environments. Through the introduction of CBM strategy remarkable savings together with increased efficiency and improved quality can be gained.

- The DynaWeb e-maintenance system was integrated through a common database. This solution although at first very heavily and partially sceptically discussed proved to be one of most important decision within the project. With hindsight it can be said that the integration of the work of seventeen partners would otherwise have been absolutely impossible.

![Figure 7. An example of a diagnostic interface web site accessed through a PC](image)

The DynaWeb e-maintenance solution was tested at three industrial sites and the results were very good. The usability of the separate components and their functionality was high. In the final tests a lot of emphasis was given to the integration of the whole system and this really proved to work well through the common database. In a way this kind of result is self evident i.e. it is crucial that in an e-maintenance system the information can be easily passed between the various modules otherwise there would really be no point to develop such a system. In a way this also introduces a challenge for the future use of the developed system. Many companies have different kinds of software packages and hardware components that they use to support their maintenance actions. Unfortunately, these components usually do not communicate directly with each other very well and they do not follow the international standards. So the question to companies is what they should do with their old systems. Based on the findings in Dynamite project we can clearly recommend that the integration really is the key. Much of maintenance work really is related to information. What should be done? When should the actions take place? Who should do them and how can they be done? These really are the questions e-maintenance tries to answer in a very easily adoptable format. The final results of Dynamite project and the solutions built in the form of DynaWeb show that e-maintenance can be successfully implemented in real industrial environments, and that it offers improved availability, higher efficiency and quality in a cost effective way.
6 REFERENCES


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