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Challenges in the Development of an E-Maintenance System

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Abstract: e-Maintenance is generally understood to be the technology that makes the required information available for the maintenance engineer enabling communication with the supporting system irrespective of where the machine under inspection or maintenance actions is located. Increasing interest in improving overall production efficiency of manufacturing operations, together with technical developments in sensor and analysis equipment and wireless technology has led to accelerated research into e-Maintenance. Findings from a large European research project - Dynamite (Dynamic Decisions in Maintenance) are used to discuss the roles of various actors and roles in the proposed e-Maintenance scheme. The paper also highlights the main challenges faced in developing fully functional and economically optimised e-Maintenance support systems for modern production environments.

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Keywords: e-Maintenance, machine maintenance, software tools, computerised maintenance management.

1. INTRODUCTION

Maintenance is frequently identified as a potential solution to ineffective industrial production systems which suffer from poor efficiency and sudden production stops. Companies are under considerable pressure to deliver increasingly high levels of machinery reliability, efficiency, safety and environmental performance in order to sustain their competitive positions (Al–Najjar & Alsyouf, 2003). The costs associated with maintaining machinery and assets in European industrial production systems has been shown to account for a significant proportion of total operating expenditure. Many researchers have demonstrated that substantial savings are certainly possible through the use of more technologically advanced approaches to maintenance activities (Sharma et al, 2006). Maintenance system technology has progressed to some extent over the past decade or so but complete solutions with the flexibility to satisfy the demands of a wide range of users are still not widely available. A currently running, EU funded research project, DYNAMITE (Dynamic Decisions in Maintenance), is attempting to address these problems by developing and applying a blend of leading–edge communications and sensor technology, combined with state–of–the–art diagnostic and prognostic techniques. The objective of the project is to deliver a prototype maintenance system to enable the monitoring of machines and processes for predictive maintenance and control (Jantunen et al., 2008). An infrastructure for mobile monitoring technology is to be developed along with devices incorporating sensors and algorithms to support enhanced capability for decision support. Some key features include wireless sensors and communications, intelligent data analysis, smart tags, and semantic web technology.

One key aspect of this project involves the extensive use of electronic data for the efficient storage, transmission, processing and display of information (Jantunen et al., 2008). This strategy provides great advantages for both human and machine–based decision making capability. For instance the system aims to assist in the inspection and maintenance process by identifying priority cases, collating and delivering detailed documentation on maintenance procedures and also to plan and schedule these activities. This paper will identify several key aspects of the project and discuss together with the methods and technologies used to develop the maintenance infrastructure. In addition scenarios highlighting the rapid, efficient, and cost–effective decision making process will be discussed. The approach taken in this paper is somewhat different from the general point of view. In stead of looking at the matter from top to bottom view i.e. strategic view focussed on the needs of a maintenance engineer. Naturally, maintenance strategy and planning is the driving force to most of the actions taken by the maintenance engineer and thus in the background. However, in this paper the emphasis is given to the practical point of view i.e. how information is sent to the maintenance engineer.

2. DEVELOPMENT TRENDS IN MAINTENANCE

Growing interest in improving overall production efficiency and rapid technical development of sensors, analysis equipment and wireless technology has led to increased interest in e–Maintenance (Jantunen et al., 2008). E–Maintenance is generally understood as the technology used to make required information available for maintenance engineers, enabling communication with the supporting system irrespective of the location. The term has been in use since early 2000 as a component of the e–Manufacturing concept (Crespo Marquez, 2007). Life–cycle management
approaches for production and operations activities are commonly found in companies today. Limitations placed on resources and energy consumption by this type of approach impinges directly on manufacturing objectives, requiring efficient and timely production, ensuring customer satisfaction is achieved and profitability is maintained. Many researchers in the field predict a new culture in which maintenance activities become of equal importance to production activities (Takata et al., 2004). Maintenance strategies have undergone several major developments, from the traditional “fail–and–fix” practices to “predict–and–prevent” strategies. In addition, e–Maintenance systems have attracted greater attention because of their potential benefits, such as accounting for potential impacts on customer service, product quality and cost reduction (Lee, 2004). The key advantage is that maintenance is performed only when a certain level of equipment deterioration occurs, rather than after a specified period of time or usage. Mobile devices using e–maintenance systems offer the flexibility to initiate applications at many locations in unstructured networked environments. Relevant information may be quickly and efficiently retrieved from data sources. Personal Digital Assistant (PDA) devices play a key role in bringing Mobile Maintenance Management closer to daily practice on the shop floor. The use of PDAs enable maintenance personnel to directly gain information from monitored machinery e.g. current machine state, maintenance actions carried out, spare parts availability, maintenance procedure details, etc. New technologies (e.g. internet, mobile devices, MEMS–technology) are ready to be adopted in the redesign of maintenance systems to enable cost–effective e–Maintenance systems and hence rapid, effective and informed decision making (Adgar et al., 2008). This is the objective of the DYNAMITE Project.

3. MAINTENANCE ENGINEER

Considering the requirements of maintenance engineer, the essential information is basically “What to do?” On examining this question in more detail, it is apparent that there are many related issues such as (Jantunen et al., 2008):

1. Which machine should be worked on?
2. How can that machine be located?
3. What tasks should be done on the machine?
4. How are the maintenance tasks carried out?
5. How to report what has been done?

This list is far from complete but it illustrates the complexity of the work. Common attitudes towards maintenance are that it is costly and unpleasant work has led to low efficiency of maintenance and consequently operations. As mentioned in the introduction e–Maintenance tries to tackle this question and improve the overall efficiency of production plants and machinery. In the following sections some of technical tools and systems that support modern and effective maintenance are discussed.

4. TAGS AND SENSORS

Industry today faces the challenge of managing maintenance resources as efficiently and cost effectively as possible (Jantunen et al., 2008). The Dynamite project attempts to assist the maintenance engineer to more effectively perform the complex tasks that are involved in typical day–to–day activities. It is worthwhile to note that one of the key aspects of the project is that maintenance decisions can be made dynamically. That is to say that the maintenance engineer or technician will have all of the relevant information at his disposal (at any time, and anywhere on the plant) on which to make these decisions. Two of the key components of this maintenance strategy are the use of micro sensors and smart tags. These developing technologies have shown potential to be cost–effective solutions to many industrial maintenance problems. The use of these technical components is discussed in the following sections, in each case linking the technology use to the proposed solution and potential benefits.

4.1 Which machine should be worked on?

This apparently simple issue can cause many problems in real situations (Jantunen et al., 2008). In a manufacturing unit or processing plant with hundreds or thousands of machines, it is not a simple task to ensure that the correct machine has been identified for maintenance action. It is the role of the smart tags to ensure that the correct machine/asset is identified for maintenance action and the same machine is subsequently maintained. Smart tags have the benefit of reducing human error in asset identification and the electronic ID can be used to confirm machine details via query to a web database.

4.2 How can that machine be located?

The location of an asset, especially mobile assets (e.g. fork–lift truck), can be a problem in practice but the location may be determined using smart tag technology (Jantunen et al., 2008). The project is examining the use of active tags (powered devices with greater read ranges) to track mobile assets in the workplace. The objective is to provide real–time display of critical mobile asset location for rapid maintenance action and decision making purposes. For stationary assets this is not such an important issue as the location is unlikely to change often and location information can be provided directly to the user from the web database.

4.3 What tasks should be done on the machine?

Work orders for particular assets may be issued either manually or automatically (Jantunen et al., 2008). The use of micro–sensors is a key issue here as the machines can be quickly checked for health status based upon the sensor measurements (e.g. temperature, pressure, vibration, etc.) This can be done either by manual check with the PDA displaying the sensor measurements and locations on the machine or by an automatic software agent processing sensor data stored on the web server.
4.4 How are the maintenance tasks carried out?

The directions and instructions given to the maintenance technician for maintenance or repair action is heavily reliant on the delivery of appropriate static database information (e.g. repair instructions, engineering drawings, etc.) (Jantunen et al., 2008). However additional dynamic data is also available from processing smart tag data. Since many objects are proposed to be monitored with smart tags (for example: spare parts, diagnostic tools, personnel, etc.) it is possible for the user to determine when is the appropriate time for repair of a machine. Since repairs and other maintenance actions often require a diverse number of separate resources to complete (man–power, specific skill level, spare parts, tools, etc.) then it is sensible to check that all these are available at the time that the repair is planned. Tracking assets using smart tags allows the user to tap into this valuable source of information allowing rapid and simplified decision making.

4.5 How to report what has been done

The reporting of work carried out is another key aspect of the maintenance process (Jantunen et al., 2008). In many real–world scenarios such information is not kept up–to–date because time consuming processes or paperwork requirements. Simplified reporting of such activity is possible since most of the information required has been already utilised in completing the activity. This information can then be easily utilised to automatically generate a report on the work carried out. For example, information regarding the personnel who completed the work, the spare parts utilised, the time takes to do the work, the asset condition (sensor measurements) before, during and after the repair are all available.

4.6 Read-write tags

Another exciting aspect of the DYNAMITE project is the use of is read–write smart tags, enabling storage of information at a point local to the machine (Jantunen et al., 2008). For example, simple records of maintenance actions and repair work may be stored on the machine tag. This effectively forms an electronic service history for that machine. Obviously this has great potential for certain types of assets, for example remote assets (electricity sub–stations, water pumping stations, telephone cables, etc.) and mobile assets (e.g. cars, vans, trucks, earth moving equipment, generators, etc.). The data storage capability of tags is currently not large, but it is steadily improving. For example the information could easily indicate the date and nature of the last maintenance actions, (e.g. oil change, filter replacement, cleaning, electrical test, etc.)

5. DYNAWEB INTELLIGENT DISTRIBUTED WEB SERVICES

The use of components such as sensors and smart tags for data collection implies an increasing quantity of information to be processed and analysed automatically (Jantunen et al., 2008). The analysis of trends, spectra, etc. can become very time-consuming, repetitive and boring for experienced maintenance staff. On the other hand, linking different information sources (i.e. vibration, temperature, ultrasonic, etc.) indicates a need for high levels of knowledge in maintenance decision support and execution that is scarcely available. The DYNAMITE project focuses on the dynamic re-assessment and of novel technologies (i.e. online oil sensors) to improve the cost-effectiveness of the maintenance strategies (Ferreiro et al. 2008). This also indicates a need of continuous re-training on diagnosis and decision support knowledge to make effective use of the information available.

This can only be achieved with the support of software technologies that provide a distributed, automated and collaborative maintenance process. These technologies are referred here as DYNAWEB e-Maintenance services which form the supporting tool package for the maintenance engineer

5.1 System architecture

The DYNAWEB concept is best described as the information and communication platform that provides operational interaction between ‘plug-in’ technologies in the framework of a distributed information scenario, where technologies of interest may vary from a maintenance use case to another (Jantunen et al., 2008). Figure 1 provides a schematic overview of the complete system concept depicted for information and communication technologies that are considered within DYNAMITE project.

![Fig 1: DYNAWeb Platform](http://example.com/fig1.png)

5.2 Database

The information part of DYNAWeb is based on the existence of intelligent web services that provide appropriate processing capabilities for a series of maintenance actors that may require these processing options, such as intelligent sensors, smart PDAs, SCADA data collection systems or CMMS (Jantunen et al., 2008). Each one of these actors may find an added value in web services that offers knowledge-based answers to maintenance requests. It is important to indicate that DYNAWeb web services are planned from a plug-in approach, where existing legacy systems can upgrade...
their potential through the use of the services. In order to facilitate interoperability, services are designed according to two basic standards:

- **OSA-CBM** (Open System Architecture for Condition Based Maintenance) (Bengtsson, 2003) is used as a CBM layered architecture to provide a functional platform flexible enough to suit a broad range of applications. Standard-ization of networking protocol within the CBM developers’ community and users will drive suppliers to produce interchangeable hardware and software components. The architecture is described according to 7 functional layers (data acquisition, decision support, data presentation..)

- **MIMOSA** (Machinery Information Management Open System Alliance) is a database platform indicating standardised ways to store and interchange maintenance data (OSA-CBM architecture is fully embedded). DYNAWeb supports this standard in two different ways, for the sake of end user convenience:
  - Non-MIMOSA legacy systems: possible to use XML queries (defined data formats) on appropriate web services.
  - Also possible for web services to interact directly with MIMOSA database if such a database is one of the existing storage formats of the maintenance information.

**5.3 Intelligent web services**

Several web service packages are being offered to the maintenance engineer as part of DYNAWeb protocol (Jantunen et al., 2008). These correspond to several layers of OSA-CBM functional architecture.

**5.3.1 Layer 3 – Condition monitoring- State detection**

Receives data from sensor modules, compares data with expected values or operations limits and generates alerts based on these limits (Jantunen et al., 2008). In DYNAWeb, the state detection services investigates vibration (e.g. 1st harmonic of fundamental frequency), lubricant (e.g. Acid Number) and wear debris (i.e. Fe content) parameters, taking into account static (e.g. % of variation over base values) and dynamic (e.g. rate of change) limits. This provides an automatic uniform assessment of machinery status, also allowing customization and fast adaptation to new rules. In this way DYNAWeb defines for the maintenance engineer where his attention is needed and what the actual problem is.

**5.3.2 Layer 4 – Health assessment**

Receives data from condition monitoring and prescribes if the health in the monitoring component, sub-system or system is degraded (Jantunen et al., 2008). It is also able to generate diagnostic (based upon trends in the health history, operational status and loading and maintenance history) and propose fault possibilities too. In DYNAWeb, a first service will provide a method for fault diagnosis based on standard Failure Tree Analysis models. Additionally, a Bayesian Network system provides a default method for combined diagnosis based on vibration and oil related information to deal with uncertainty and allow adaptation.

**5.3.3 Layer 5 – Prognosis**

Plans the health state of equipment into the future or estimates the remaining useful life (RUL), taking into account estimates of future usage profiles (Jantunen et al., 2008). In DYNAWeb, two services provide basic prognosis based on two kinds of information sources (trends/condition and reliability/failure). This service is aimed at helping automatic maintenance planning by providing information on upcoming tasks and defining service date and required resources.

**5.3.4 Layer 6 – Decision support**

Generates recommended actions (maintenance or operational) until the current mission is completed without occurrence of breakdown (Jantunen et al., 2008). It accounts for operational history, current and future mission profile, high-level unit objectives and resource constraints. In DYNAWeb, an advanced work order planner / scheduler is made available and it gives the maintenance engineer the work orders in economically and technically optimised order.

**5.3.5 General Remarks Concerning Web Services**

First of all, it is important to indicate that technologies behind every web service associated to each layer are very different. For instance, a simple rule based system has been incorporated to provide decision support condition monitoring, whereas one of the web services for prognosis is based on the use of Weibull parameters. These are just some technologies implemented and it is expected that many additional web services can be incorporated - working at the same layer, with slightly different information (i.e. lubricant data available or not, specific component type known - indicates a specific web service can be used, etc).

Finally, it is important to notice that both the lower layers (Data acquisition and data manipulation) and the higher layer (Data presentation) are out of the scope of DYNAWeb web services (Jantunen et al., 2008). The first two layers indicate low level operations that should be performed locally at the device itself, or at an associated processing module, see section 3. The use of web communication for this type of tasks does not seem to be cost-effective. Data presentation is left to the actor requesting the service, mainly because presentation abilities may vary enormously based on who are the service requesters (from a web interface to a MAC-OS legacy system, from a PDA to a LCD sensor interface).

6. PDA - MOBILE USER INTERFACE

The maintenance engineers can use Personal Digital Assistants (PDA) as a means to communicate with the surrounding world (Jantunen et al., 2008). PDAs are mobile user interfaces giving access to the Computerised Maintenance Management System (CMMS). The CMMS is used to manage maintenance efforts as well as materials
needed and is termed DYNAWeb, i.e. the Semantic Web containing many tools for the maintenance engineer (Campos et al., 2008). As already described in section 3 the PDA provides the identification of the machine and access to condition monitoring data and diagnosis of the machine condition. Usually the PDA is a thin client i.e. most of the data is located and processing takes place in the central computers providing e-Maintenance services (Arnaiz et al., 2007) although in DYNAWeb the PDA can carry a copy of the most important tables of the database in order to guarantee the smooth use of the system even in places where wireless communication with the central database is not available, see Figure 1. Since it is not always easy to automatically diagnose what is the condition of a machine it is natural to include the condition monitoring and signal analysis capability in the PDA. However, this is something which should be used only when necessary, i.e. to gain further information in order to make the accurate diagnosis of the machine condition.

6.1 Wireless communication

It is necessary for the PDA to be capable of wireless communication to the maintenance centre and to the machine, tags and sensors. Different technologies are used for wireless communication for various distances and tasks. Wireless local area networks are available in many surroundings, providing access to the Internet and also Web Services described earlier (Jantunen et al., 2008). However, WLAN might not always be available as explained in the previous chapter and it might also be impractical to download high volumes of data (e.g. partial copies of maintenance related databases) and therefore it is natural to also have a wired link to the PCs that support the maintenance personnel. Usually the wired link today is based on USB connection. The same USB connection can also provide access to sensors and data acquisition components that support it. For the communication with smart tags an RFID communication link is needed. In some cases the sensors and data acquisition equipment might support Bluetooth connections which are common on other supporting hardware (e.g. printers, phones, etc.) In order to be able to take advantage of the electronic definition of location, GPS capability is needed. In case the maintenance engineer is expected to be able to carry out all tasks with the same device, mobile phone connections will be required for communication with phone, fax and email. The phone link can also provide access to Internet if a local area network is not available. For the case of maintaining mobile machinery it is not probable that WLAN could be found in practice.

6.2 Technical requirements

From the maintenance engineer’s point of view, the optimal PDA would have all the communication features described above and would also be small and easy to carry around (Jantunen et al., 2008). Unfortunately small size and lightweight devices are generally of lower processing powers. The screen size and resolution is of great importance if the device is used for e.g. showing a video of how to dismantle a machine, or when a report is prepared. The market would seem to suggest that small physical size is appreciated more than the screen size i.e. it seems that devices capable of VGA resolution (640×480) are typically used for making condition monitoring measurements and communication with the CMMS. A full-size keyboard is ideal for entering information in reports and messages, unfortunately keyboards do not fit nicely into small devices. Small keyboards are becoming more popular in such communication devices, however, it should also be remembered that the main task of a maintenance engineer is to keep the machines running and not to communicate with other people or systems. Usually maintenance engineers do not like writing reports (considered a necessary evil) and that is to be avoided if possible. Maintenance reports prepared in a verbal style are not ideal for collecting valuable historical data. All reports should be structured so that the CMMS can easily utilise the data, e.g. check lists.

6.3 Practical limitations today

Rapid developments of both PDA hardware and software mean that devices are getting faster, with more memory and features (Jantunen et al., 2008). Software programming tools are also rapidly developing to take advantage of the improved hardware. Consequently, there seem to be quite a number of challenges in practice. In many places the supporting environment does not provide wireless communication networks or the connection is lost from time to time. If all the PDA features are used simultaneously, battery life is less than one working day i.e. the device must be connected to a power source or turned off for some periods.

6.4 Trends

Today PDA devices are getting closer to smart phones i.e. devices used for calendar and office applications (Jantunen et al., 2008). Latest versions often have mobile communication capability. Luckily from the developer point of view the same is partially true with the development of programming tools i.e. the same programming package can be used for programming hardware based on different technologies and especially the web technology supports this kind of development. However, neither hardware nor software can be considered very mature due to rapid developments and the many technical challenges need to be solved in order to be able to achieve real system reliability.

7. RESULTS

The web services system depicted has been fully developed an it is now being tested on different real use cases that were specifically derived to offer varied analysis scenarios, as indicated in Arnaiz et al (2008). In particular, there are now three main test scenarios (an OEM manufacturer and two manufacturing and assembly plants) that are testing the 25 different modules developed under DYNAMITE project. Also quite a number of Web Services are available to the project consortium accessible from a typical web site that implements a maintenance management prototype (see http://tessnet.tekniker.es) for PDA direct access.
Technical developments in smart tags, sensors, data acquisition, signal analysis equipment and wireless communication has enabled the rapid development of new techniques in maintenance. When technological developments have been linked with new business development ideas and the ever present surge for higher overall efficiency in production, e-Maintenance has raised great interest. Based on the findings of a large European research project, the paper has discussed the roles of various actors in an e-Maintenance scheme. Contrary to many other presentations which start from the maintenance strategy point of view, the paper outlined the practical needs of a maintenance engineer both from the worker point of view and the company point of view. The paper also highlighted some of the practical problem areas, i.e. challenges in developing fully functional, economically optimised e-Maintenance support for modern production environments based on new hardware and software technology – much of which is not fully mature in all respect today. However, the final conclusion is that the potential of the new e-Maintenance approach really gives opportunities to gain remarkable economical benefits.

ACKNOWLEDGEMENTS
The authors gratefully acknowledge the support of the European Commission 6th Framework programme for Research and Technological Development. This paper summarises work performed under FP6 Integrated Project IP017498 DYNAMITE “Dynamic Decisions in Maintenance.”

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