On the concept of E-maintenance. Information and Communication technologies applied to maintenance. Review and current research.

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ABSTRACT

The importance of the maintenance[1] function has increased because of its role in keeping and improving system availability and safety, as well as product quality. To support this role, the development of the communication and information technologies has allowed the emergence of the concept of e-maintenance.

This paper outlines the basic ideas within the e-maintenance concept and then, provides an overview[2] of the current research in this emerging field. An underlying objective is to identify the industrial/academic actors involved in the technological, organisational or management issues related to the development of e-maintenance.

- *Keywords:* Maintenance, E-maintenance, Monitoring, Diagnostic, Prognostic, Decision support

1. INTRODUCTION

The concept of e-maintenance that is today widespread in the industry refers to the integration of the ICT (Information and communication technologies) within the maintenance strategy and/or plan [Li *et al.*, 2005] to face with new needs emerging from innovate ways for supporting production (e-manufacturing), business (e-business) … expected by the Manufacturing Renaissance [Yoshikawa, 1995].

But let us first discuss this point: May we consider e-maintenance a maintenance strategy (*i.e.* a management method), a maintenance plan (*i.e.* a structured set of tasks), a maintenance type (such as CBM, corrective…) or a maintenance support (*i.e.* resources, services to carry out maintenance)? We can find some clues to answer this question in the following paragraphs:

- E-maintenance as a maintenance strategy. E-maintenance can be merely defined as a maintenance strategy where the tasks are managed electronically using real time equipment data obtained thanks to digital technologies (i.e. mobile devices, remote sensing, condition monitoring, knowledge engineering, telecommunications and Internet technologies) [Tsang, 2002]. From this point of view, E-Maintenance is interpreted as a maintenance management process [Hausladen et al., 2004], which deals with the expansion of the volume of data available. This definition is refined by Baldwin [Baldwin, 2004];

- E-maintenance as a maintenance plan. E-maintenance can also be seen as a maintenance plan, which meets the needs of the future e-automation manufacturing world in the exploration of the approaches of condition-based maintenance (CBM), proactive maintenance, collaborative maintenance, remote maintenance and service support, provision for real-time information access, and integration of production with maintenance [Ucar et al., 2005].;

- E-maintenance as a maintenance type. Generally speaking, e-maintenance is the symbol of the gradual replacement of traditional maintenance types [Han et al., 2006] by more predictive/proactive one. Regular periodic maintenance should be advanced and shifted to the intelligent maintenance philosophy to satisfy manufacturer's high reliability requirements [Tao et al., 2003]. Hence, Koç et al. referred e-maintenance (system) as predictive maintenance (system) [Koç et al., 2001], which provides only monitoring and predictive prognostics functions [Lee, 2001].

- E-maintenance as a maintenance support. Last but not least, e-maintenance can be referred as a maintenance support. For example, Zhang et al. consider that e-maintenance is a combination of

[1] The maintenance terminology used in this paper is extracted from the European standard *EN 13306:2001 de/fr/en European Standard on Maintenance Terminology*.

[2] Last year, within a current research project called: "Modelling policies for the improvement of production systems dependability" (Project number DPI 2004-01843) and sponsored by the Spanish government, we have launched a call for paper on e-maintenance to better understand the nature and the impact of the e-maintenance phenomenon. The results were presented in different conferences and some of them are published within a special issue on e-maintenance for Computers in Industry , Guest Editors B. Iung - A.Crespo Marquez [Iung and Crespo, 2006]

web service technology and agent technology, which provides a way to realise intelligent and cooperative features for the systems in an industrial automation system [Zhang et al., 2003]. [Crespo Marquez et al., 2006] define e-maintenance as a distributed artificial intelligence environment which includes information processing capability, decision support and communication tools, as well as the collaboration between maintenance processes and expert systems.

After all this conceptual review, our idea is to propose an e-maintenance definition that, on the one hand takes into consideration the European Standard (EN 13306:2001) for maintenance terminology, and on the other hand understands e-maintenance as a component of the e-manufacturing concept [Lee, 2003], which benefits from the emerging information and communication technologies to implement cooperative and distributed multi-user environment [Muller et al., 2004]. According to this we proposed the following e-maintenance definition:

Maintenance support which includes the resources, services and management necessary to enable proactive decision process execution. This support includes e-technologies (i.e. ICT, Web-based, tether-free, wireless, infotronics technologies) but also, e-maintenance activities (operations or processes) such as e-monitoring, e-diagnosis, e-prognosis…

Following this introduction, section 2 outlines the reasons why the concept of e-maintenance has emerged recently. We will see later on how the main reasons for this are related to the new capabilities provided by e-maintenance technologies. Said capabilities are thus described in the section 3 according their impact on the concerned maintenance types and strategies, maintenance support and tools, and finally maintenance activities. However, although the e-technologies provide certain capabilities, maximising the e-maintenance benefits for the overall maintenance efficiency requires more than technology. Finally, a review and conclusions are developed in section 4.

2. E-MAINTENANCE FACTORS OF EMERGENCE

The e-maintenance emergence can be attributed to two main factors:

- The appearance of e-technologies allowing the increase of maintenance efficiency, velocity, proactivity, and so on to optimise maintenance related workflow;
- The need to integrate business performance, which imposes to the maintenance area the following requirements: openness, integration and collaboration with the others services of the e-enterprise.

2.1 E- Technologies for maintenance improvement

At present, e-technologies start to play a crucial role to support maintenance decision making. The combination of modern information processing and communication tools offers the technical support required to access remote information. Indeed it is easier to transfer information, system and environment knowledge to different maintenance specialists in order they could interoperate together through remote exchange [Iung, 2003]. Thus, it provides manufacturing companies with the ability to design new solution of distributed vs. intelligent maintenance system.

To begin with, the Web allows universal access by having independent connectivity for different kinds of platforms using open standards for publishing, messaging, and networking. Since the Web enables multi-media support, both interactivity and extensibility, it can seamlessly include new forms of content and media [Wang *et al.*, 2004]. The developments in database and object technologies enable users to connect to back-end databases and legacy applications via user-friendly Web interfaces. The future smart transducer will have a built-in Ethernet module and support direct plug-and-play on the Internet without the need for a connection to a PC or having a separate Ethernet card, as is the case with today's systems.

Next, Wireless technology in industry [Egea-Lopez et al., 2005] brings cost reduction (no wiring), flexibility in manufacturing floor layout and information availability [Ucar *et al.*, 2005]. Remote data transmitting, monitoring and controlling through the network are facilitated by tether-free technologies, computerized data processing, remote sensing, and wide-band communication. It enables the equipment in factory to share its data, files and even permit remote equipment operation from anywhere in the world [Ramus *et al.*, 2003].

The gate to new interconnected system abilities is open. New ways of communication means, mobile terminals and data access modes to improve cooperation possibilities. Mobility inside the cooperative system is for example a major contribution which allows users to work together in new places [Saint-Voirin *et al.*, 2005].

2.2 Maintenance, a key element of the e-Enterprise

After having optimized the different services of the enterprise, essentially thanks to the computer science and the different theories of automatic control and of optimization, it appeared that a global optimization needed other approaches, other theories and other tools. The key words are then integration, computer integrate manufacturing, openness and open systems, interoperability [Bangemann *et al.* 2006]. E-manufacturing, teleservice and virtual enterprise are some of the first resulting concepts that have already been developed and applied in the industry [Ong et al., 2004].

Now, these requirements become more and more pressing in the maintenance area [Zhang *et al.*, 2003], due to the fact that the maintenance decisions have characters of system integration, in the sense that they are not limited to the maintenance function scope but entail co-ordination with objectives of other functions wherein a co-ordinated decision is addressed between maintenance and production [Macchi et al., 2006].

3. THE E-MAINTENANCE CAPABILITIES

We have identified and classified the e-maintenance advantages within the three following categories:

- Maintenance type and strategies;
- Maintenance support and tools;
- Maintenance activities.

3.1 Potential improvements in maintenance types and strategies provided by e-maintenance

We can summarize these potential improvements as follows:

- **Remote maintenance.** By leveraging information, wireless (e.g. Bluetooth) and Internet technologies, users may log in from anywhere and with any kind of devices as soon as they get an Internet connection and a browser. [Hung *et al.*, 2003]. Consequently the manpower of the machine builder retained at customer's site is reduced and there are facilities for him to diagnose the problems when an error occurs and next, to improve the preventive maintenance thanks to the machine performance monitoring [Ong *et al.*, 2004].

  Actually, one of the greatest advantage of e-maintenance is the ability to connect field systems with expertise centres located at distant geographical sites [Hamel, 2000], allowing notably a remote maintenance decision-making [Crespo Marquez et al., 2006] that add value to the top line, trim expenses, and reduce waste. The contribution to the bottom line is significant, making development of an asset information management network a sound investment [Baldwin, 2004].

  Moreover, the Web enablement of computerized maintenance management systems (called as e-CMMS) and remote condition monitoring or diagnostic (called as e-CBM) avoid the expense and distraction of software maintenance, security and hardware upgrade [Tsang, 2002]. Computer science experts can add new features and/or migrations without the users even noticing it.

- **Cooperative / Collaborative maintenance.** An e-maintenance platform introduces an unprecedented level of transparency and efficiency into the entire industry and it can be an adequate support of business process integration [Hausladen et al., 2004]. As a result, there is the chance to radically reduce interfaces, may that be between personnel, departments or even different IT systems. The integration of business processes significantly contributes to the acceleration of total processes, to an easier design (lean processes) and to synchronize maintenance with production, maximizing process throughput and minimizing downtime costs. In general, this leads to less process errors, improved communication processes, shorter feedback cycles and hence improved quality.

  In short, e-maintenance facilitates the bi-directional flow of data and information into the decision-making and planning process at all levels [Ucar et al., 2005]. By so doing, it should automate the retrieval of the accurate information that decision makers require to determine which maintenance activities to focus resources on, so that return on investment is optimised [Moore et al., 2006].

- **Immediate / On line maintenance.** The real time remote monitoring of equipment status coupled with programmable alerts enable the maintenance operator to respond to any situation swiftly and then to prepare any intervention with optimality. In addition, high rate communications allow to quickly obtain several expertises [Garcia et al., 2004] and to accelerate the feedback reaction in the local loop connecting product, monitoring agent, and maintenance support system. It has almost unlimited potential to reduce the complexity of traditional maintenance guidance through online guidance based on the results of decision-making and analysis of product condition [Goncharenko et al., 1999]. For example, personal digital assistants (PDA) devices play a key role in bringing Mobile Maintenance Management closer to the daily practice at the shop floor. The PDAs enable the maintenance personnel to directly gain information from monitored machinery.

- **Predictive maintenance.** The E-maintenance platform allows any maintenance strategy, and the improvement of the utilization of plant floor assets using a holistic approach combining the tools of predictive maintenance techniques is for example one of the e-maintenance major issues [Lee, 2003].

  The potential applications in this area include equipment failure prognosis based on current condition and projected usage, or remaining life prediction of machinery components [Ray et al., 1999]. In addition, these systems can compare product's performance through globally networked monitoring systems to allow companies to focus on degradation monitoring and prognostics rather than fault detection and diagnostics [Iung et al, 2003].

  Prognostic and health management systems that can effectively implement the capabilities presented herein offer a great opportunity in

terms of reducing the overall Life Cycle Costs (LCC) of operating systems as well as decreasing the operations/maintenance logistics footprint [Roemer et al., 2005].

3.2 Potential improvements of maintenance support and tools provided by E-maintenance

We can summarize these potential improvements as follows:

- **Fault / Failure analysis.** The rapid development in sensor technology, signal processing, ICT and other technologies related to condition monitoring and diagnostics increases the possibilities to utilize data from multiple origin and sources, and of different type [Holmberg et al., 2005]. In addition, by networking remote manufacturing plants, e-maintenance provides a multi-source knowledge and data environment [Ucar et al., 2005].

  These new capabilities allow the maintenance area to improve the understanding of causes to failures and system disturbances, better monitoring and signal analysis methods, improved materials, design and production techniques [Holmberg et al., 2005]: to move from failures detection to degradation monitoring.

- **Maintenance documentation/record.** The e-maintenance platform provide a transparent, seamless and automated information exchange process to access all the documentation in a unified way, independently of its origin, equipment manufacturer, integrator, end-user. Information like task completion form is filled once by user and can be dispatch to several listeners (software or humans) that registered for such events [Bangemann et al., 2006].

  At the device level, goods are checked out from stores against a work order or a location and the transaction is recorded in real time. Then, the massive data bottle-necks between the plant floor and business systems can be eliminated by converting the raw machine health data, product quality data and process capability data into information and knowledge for dynamic decision-making [Lee, 2003]. In addition, these intelligent decisions can be harnessed through web-enabled agents and connect them to e-business tools (such as customer relation management systems, ERP) to achieve smart e-service solutions [Koç et al., 2001].

- **After sales services.** With the use of internet, web-enabled and wireless communication technology, e-maintenance is transforming manufacturing companies to a service business to support their customers anywhere and anytime [Lee, 2001].

3.3 Potential improvements of maintenance activities provided by E-maintenance

We can summarize these potential improvements as follows:

- **Fault diagnosis / Localization.** E-diagnosis offers to experts the ability to perform on-line fault diagnosis, share their valuable experiences with each other, and suggest remedies to the operators if an anomalous condition is occurring in the inspected machine [Wohlwend, 2005]. In addition, lock-outs and isolation can be performed and recorded on location thanks to the wireless technology and palm computing.

  Consequently, the amount of time it takes to communicate a production problem to the potential expert solution provider can be reduced, the quality of the information shared can be improved and thereby, the resolution time reduced [Ramus et al., 2003].

- **Repair / Rebuilding.** Downtimes could conceivably be reduced through direct interaction (trouble shooting) with source designers and specialists [Hamel, 2000]. For another, diagnosis, maintenance-work performed and parts replaced are documented on the spot through structured responses to work steps displayed on the palm top.

- **Modification / Improvement - Knowledge capitalization and management.** The multi-source knowledge and data environment provided by e-maintenance allows an efficient information sharing and therefore, important capabilities of knowledge capitalization and management. With the availability of tools for interacting, handling and analyzing information about product state, the development of maintenance engineering for Product Life Cycle (PLC) support including maintenance and retirement stages (disassembly, recycling, reuse, and disposal) is becoming feasible [Goncharenko et al., 1999].

4. CONCLUSIONS

This paper presents an overview of the current research and challenges in e-maintenance. We have firstly offered a definition for the e-maintenance concept, which aligned with the recent European standards for maintenance terminology, considers e-maintenance as a maintenance support. Then, the main factors allowing this new maintenance support to arise have been presented. The E-maintenance capabilities have been summarized. At last, a state of the art showing current research of both industrial and academic communities has been proposed.

According to our findings, e-maintenance is more than the implementation of a maintenance strategy, or a maintenance plan, or a maintenance type. It supposes a maintenance revolutionary change rather than a maintenance evolutionary advance [Iung, 2006]. As e-business few years ago [Batanov *et al.*, 2003], the

impact of e-maintenance is probably overestimated in the short run, but underestimated in the long run.

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