A review of e-maintenance capabilities and challenges.

Adolfo Crespo-Marquez [a] and Benoît Iung [b]

[a] Department of Industrial Management, School of Engineering, University of Seville, Camino de los Descubrimientos s/n. 41092 Sevilla, Spain

[b] Nancy Research Centre for Automatic Control (CRAN), UMR 7039 CNRS - UHP – INPL
2, rue Jean Lamour, 54519 VANDOEUVRE-LES-NANCY Cedex – Fra*nce*

Abstract

Within the era of e-manufacturing and e-business, e-maintenance provides the opportunity for a new maintenance generation. E-maintenance integrates existing telemaintenance principles, with web-services and modern e-collaboration principles. Collaboration allows not only to share and exchange information but also knowledge and (e)-intelligence.

This paper outlines the basic capabilities provided by e-maintenance to companies as well as describes emerging challenges to benefit from these new operational improvement opportunities

- *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].

We have proposed an e-maintenance definition **[Muller el al., 2008]** 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]. 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 new capabilities provided by e-maintenance technologies according to their impact on the concerned maintenance types and strategies, maintenance support and tools, and finally maintenance activities. We will describe how, although the e-technologies provide certain capabilities, maximising the e-maintenance benefits for the overall maintenance efficiency requires more than technology. As depicted in section 3, it needs models, methods or methodology in order to make e-maintenance a key element to satisfy operational requirements and to improve the global production system performance. Finally, a review and conclusions are developed in section 4.

2. The e-maintenance capabilities

What are the advantages that e-maintenance offers? We have classified them as follows:

- Offering opportunities for the development of new maintenance types and strategies;
- Improving maintenance support and tools;
- Defining new maintenance afctivities.

2.1 New maintenance types and strategies provided by e-maintenance

We can summarize these potential improvements as follows:

- **Remote maintenance operations and decision making.** 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. This allowa them to take remote actions, such as setup, control, configuration, diagnosis, de-bugging/fixing, performance monitoring, and data collection and analysis [Hung *et al.*, 2003]. Consequently the manpower "on customers site" of many machine builders can be reduced and preventive maintenance can be improved thanks to the machine performance monitoring [Ong *et al.*, 2004].
  E-maintenance also offers the opportunity to connect field systems with expertise centres located at distant geographical sites [Hamel, 2000], allowing the `possibility of a remote

maintenance decision-making [Crespo Marquez et al., 2006].

At the same time, 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.

- **Business processes integration and cooperative /collaborative maintenance.** An e-maintenance platform may introduce unprecedented levels of transparency and efficiency into the entire industry producing an integration of business processes that 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 [Hausladen et al., 2004]. Data and information flows into the decision-making and planning process at all levels can be improved [Ucar et al., 2005] and by doing so the retrieval of a more accurate information to maintenance decision makers easily optimized ROI in new maintenance technologies[Moore et al., 2006].
  At the same time, E-maintenance connects geographically dispersed subsystems and actors (e.g. suppliers with clients and machinery with engineers) on the basis of existing Internet networks. The resultant platform allows a strong cooperation between different human actors, different enterprise areas (production, maintenance, purchasing…) and different companies (suppliers, customers, machine manufacturers…).
- **Fast "on line" maintenance.** Real time remote monitoring of equipment status besides programmable alerts and "management by exception" 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].
- **Predictive maintenance.** A holistic approach to combine the tools of predictive maintenance techniques is one of the e-maintenance major issues [Lee, 2003].
  Applications in this area include equipment failure prognosis based on current condition and projected usage, or remaining life prediction of machinery components.

  Prognostic and health management systems can effectively implement the capabilities presented herein also 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].

2.2 Examples of potential improvements of maintenance support and tools provided by E-maintenance

Some examples of these potential improvements are as follows:

- **Fault / Failure analysis**. Development in sensor technology, signal processing, ICT and other technologies related to condition monitoring and diagnostics 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.** For instance, Information like task completion form can now be filled once by user and then dispatched to several listeners (software or humans) that registered for such events [Bangemann et al., 2006]. Other example is the massive data bottle-necks between the plant floor and business systems, that can now 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].

2.3 Improvements of maintenance activities provided by E-maintenance

Some examples of these potential improvements are as follows:

- **Fault diagnosis / Localization**. A clear example is "E-diagnosis" which 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]. 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]. All these factors contribute to increase the availability of production and facilities equipment, reduce mean time to repair (MTTR).

- **Repair / Rebuilding.** For instance, 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.

3. Challenges for e-maintenance

We now offer examples of the technological, informational or organisational needs for e-maintenance according to their link with the Maintenance type and strategies, Maintenance support and tools and Maintenance activities.

3.1 Challenges for E-maintenance related to maintenance type and strategies

Some examples of these needs are as follows:

- **Remote maintenance.** Some business and human related issues that have to be resolved before the actual application of remote maintenance. For instance, security and reliability concern arising from transactions over the Internet [Hamel, 2000]. Also, it is necessary to concentrate efforts on the human resource restructuring, maintenance agreement and training [Ong et al., 2004]. Each maintenance actor (technician, engineer or leader) has to become capable of pacing with the speed of information flow and understanding the overall structure.

- **Business processes integration and cooperative /collaborative maintenance.** The construction of an e-Maintenance system involves a variety of cross-platform information integration issues, that have to be resolved, such as the development of data transformation mechanisms, the design of communication messages, the selection of data transmission protocols, and the construction of a safe network connection [Hung et al., 2003]. These requirements are parts of the enterprise integration, which bas been identified by [Zhang et al. 2003] as the first challenge to relieve for building a platform for e-maintenance. A successful process integration in the e-maintenance context requires also that the maintenance (logistical) processes must be stable and capable (ontology-based), i.e. the structure does not change on short term perspective and the processes are of high quality [Hausladen et al., 2004].

  Besides, there is a lack of cooperative systems formal models. This is why the efficiency of cooperation within a complex computerized remote system (with several different tools, with a particular cooperation algorithm...) is still a preoccupation for industrials who are users of these systems [Saint-Voirin et al., 2006].

- **Predictive maintenance**. An effective and efficient predictive-based machine condition prognosis is necessary for modern plants [Yam et al., 2001], but it is not yet existent due to the inconsistent set of heterogeneous models used by the different designers of partial maintenance processes [Léger et al., 2001]. In addition it is necessary to find holistic approaches and methodologies to integrate the different techniques involved [Holmberg et al., 2005]. To support these objectives, predictive intelligence (algorithms, software and agents) and mapping of relationship between product quality variation and machine and process degradation are required [Koç et al., 2003].

3.2 Challenges for E-maintenance related to maintenance support and tools

- **Maintenance documentation.** The maintenance platform need to support inventory and operation guidance (e.g. by using bar code reader, handhelds, laptops, scanners…) besides providing access possibilities to external catalogs is important [Bangemann et al., 2006]. There is also an important chanllenge related to the need to collect, record and store information regarding degradation modes, degradation sections of the machine, degradation frequency, etc. [Lee, 2003]. The success of this collaborative maintenance platform depends on having a multi-tasking and multi-user operating environment, and a fast and easy-to-manage database for international experts to use to retrieve or store their aggregated knowledge and experiences [Wang et al., 2004].

3.3 Challenges for E-maintenance related to maintenance activities

Examples of these challenges are as follws as follows:

- **Inspection / Monitoring.** There is still a clear need for generic systems, which can offer integrated monitoring solutions by enabling information processing at different abstraction and representation levels and be customisable to diverse applications [Emmanouilidis et al., 2006]. Distributed, autonomous monitoring is fundamental to the penetration of e-maintenance to the cutting edge of high capital and highly productive plant. A highly advanced sensor network should previously be presented [Tao et al., 2003], and the development of intelligent agents for continuous, real time, remote and distributed monitoring and analyses of devices, machinery and systems can be necessary.

- **Modification / Improvement - Knowledge capitalization and management.** One of the most urgent industrial problems is how to realise knowledge-based operation and maintenance of plants [Zhang et al., 2003]. The information flow collected by the e-maintenance platform has to be used for behaviour learning and rule extraction purposes. Hence, a knowledge base system can be achieved through intelligent conversion of data into information, and information into knowledge [Lee, 2003]. 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 [Rasovska et al., 2005].

4. Conclusions

This paper presents an overview of new e-maintenance capabilities and challenges. We have firstly offered a definition for the e-maintenance concept, that aligned with the recent European standards for maintenance terminology, considers e-maintenance as a maintenance support. A state of the art showing current research of both industrial and academic communities has been proposed.

According to our findings, e-maintenance supposes a maintenance revolutionary change rather than a maintenance evolutionary advance [Iung, et al., 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.

5. References

- Bangemann, T., D. Reboul, J. Scymanski, J-P. Thomesse and N. Zerhouni (2006). PROTEUS - An Integration Platform for Distributed Maintenance Systems. Computers in Industry, Special issue on e-maintenance, **57**(6), pp. 539-551
- Batanov, D. and E. Eloranta (2003). Advanced Web technologies for industrial applications. Computers in Industry, **50**(2), pp. 123-125.
- Crespo-Marquez, A. and J. Gupta (2006). Contemporary maintenance management: process, framework and supporting pillars. Omega, **34**(3), pp. 313-326.
- Emmanouilidis, C., Jantunen E. and J. MacIntyre (2006). Flexible Software for Condition Monitoring, Incorporating Novelty Detection and Diagnostics. Computers in Industry, Special issue on e-maintenance, **57**(6),pp. 516-527.
- Garcia, E., Guyennet, H., Lapayre, J-C. and N. Zerhouni (2004). A new industrial cooperative tele-maintenance platform. Computers & Industrial Engineering, **46**(4), pp. 851-864.
- Goncharenko, I. and F. Kimura (1999). Remote maintenance for IM [inverse manufacturing]. In: Proceedings of the first International Symposium on Environmentally Conscious Design and Inverse Manufacturing, pp. 862-867, Tokyo, Japan.
- Hamel, W. (2000). E-Maintenance Robotics in Hazardous Environments. In: Proceedings of the 2000 IEEE/RSJ International Conference on Intelligent Robots and Systems, Takamatsu, Japan.
- Hausladen, I. and C. Bechheim (2004). E-maintenance platform as a basis for business process integration. In: Proceedings of INDIN04, 2nd IEEE International Conference on Industrial Informatics, pp. 46-51, Berlin, Germany.
- Holmberg, K., Helle, A. and J. Halme (2005). Prognostics for Industrial Machinery Availability. In: POHTO 2005 International Seminar on Maintenance, Condition Monitoring and Diagnostics, Oulu, Finland.
- Hung, M., Chen, K., Ho R. and F. Cheng (2003). Development of an e-Diagnostics/Maintenance framework for semiconductor factories with security considerations. Advanced Engineering Informatics, **17**(3-4), pp. 165-178.
- Iung B. and Crespo Marquez A. (2006), Special issue on e-maintenance, Computers in Industry, **57**(6), pp. 473-606
- Koç, M., J. Ni, J. Lee and P. Bandyopadhyay (2003). Introduction of e-Manufacturing. In: 31st North American Manufacturing Research Conference (NAMRC), Hamilton, Canada.
- Lee, J. (2003). E-manufacturing: fundamental, tools, and transformation. Robotics and Computer-Integrated Manufacturing, **19**(6), pp. 501-507.
- Léger, J.-B and G. Morel (2001). Integration of maintenance in the enterprise: towards an enterprise modelling-based framework compliant with proactive maintenance strategy. Production Planning and Control, **12**(2), pp. 176-187.
- Li, Y., Chun L., Nee A. and Y. Ching (2005). An Agent-based Platform for Web-enabled Equipment Predictive Maintenance. In: Proceedings of IAT'05 IEEE/WIC/ACM International Conference on Intelligent Agent Technology, Compiègne, France.
- Moore, W.J. and A.G. Starr (2006). An Intelligent Maintenance System for Continuous Cost-Based Prioritisation of Maintenance Activities. Computers in Industry, Special issue on e-maintenance, **57**(6),pp 595-606
- Ong, M.H., Lee, S.M., West, A.A. and R. Harrison (2004). Evaluating the use of multimedia tool in remote maintenance of production machinery in the automotive sector. In: IEEE Conference on Robotics, Automation and Mechatronics, **Vol. 2**, pp. 724-728, Singapour.
- Ramus, W. and J. Neroda (2003). E-Diagnostics: The Value Proposition Story. Semiconductor International, 7/1/2003.
- Rasovska, I., Chebel-Morello B. and N. Zerhouni (2005). Process of s-maintenance: decision support system for maintenance intervention. In: Proceedings of the 10th IEEE Conference on Emerging Technologies and Factory Automation, **Vol. 2**, pp. 679-686, Catania, Italy.
- Roemer, M., Dzakowic, J., Orsagh, R., Byington, C. and G. Vachtsevanos (2005). An Overview of Selected Prognostic Technologies with Reference

to an Integrated PHM Architecture. In: Proceedings of the IEEE Aerospace Conference 2005, Big Sky, United States.

– Saint-Voirin, D., Lang, C., Zerhouni, N. and H. Guyennet (2005). Cooperative systems modelling, example of a cooperative e-maintenance system. In: Proceedings of CIRA 2005 - Computational Intelligence in Robotics and Automation, pp. 439-444, Espoo, Finland.
– Tao, B., Ding, H. and Y.L Xion (2003). IP Sensor and Its Distributed Networking Application in E-maintenance. In: Proceedings of the 2003 IEEE International Conference on Systems, Man and Cybernetics, Vol. 4, pp. 3858-3863, Washington, D.C., USA.
– Tsang, A. (2002). Strategic dimensions of maintenance management. Journal of Quality in Maintenance Engineering. **8**(1), pp. 7-39.
– Ucar, M. and R.G. Qiu (2005). E-maintenance in support of E-automated Manufacturing Systems. Journal of the Chinese Institute of Industrial Engineers, **22**(1), pp. 1-10.
– Wang, J., Tse, P., He, L.S. and R. Yeung (2004). Remote sensing, diagnosis and collaborative maintenance with Web-enabled virtual instruments and mini-servers. International Journal of Advanced Manufacturing Technology, **24**(9-10), pp. 764 – 772.
– Wohlwend, H. et al. (2005). E-Diagnostics Guidebook: Revision 2.1. Technology Transfer #01084153D-ENG, SEMATECH Manufacturing Initiative, http://www.sematech.org.
– Yam, R., Tse, P., Li L. and P. Tu (2001). Intelligent Predictive Decision Support System for Condition-Based Maintenance. International Journal of Advanced Manufacturing Technologies, **17**, pp. 383-391.
– Yoshikawa, H. (1995). Manufacturing and the 21th Century – Intelligent Manufacturing Systems and the Renaissance of the Manufacturing Industry. Technological Forecasting and Social Change, **49**(2), pp. 165-213.
– Zhang, W., Halang, W. and C. Diedrich (2003). An Agent-based Platform for Service Integration in E-Maintenance. In: Proceedings of ICIT 2003, IEEE International Conference on Industrial Technology, Vol. 1, pp. 426- 433, Maribor, Slovenia.