E-maintenance: Opportunities and Challenges

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Abstract. E-maintenance offers various opportunities as well as challenges in contemporary business undergoing transformation. This paper provides an overview of opportunities and challenges in different areas related to e-maintenance. Literature review and empirical findings through action oriented research give way to identify and present these opportunities and challenges. One contribution of the paper is, it finds the opportunities and challenges with e-maintenance in different industries which creates a pathway for future direction in further studies regarding e-maintenance. The findings indicate that there is much potential to study these with respect to technology and business.

Keywords: E-maintenance, condition monitoring, remote diagnostics, action oriented research

1 Introduction

The term 'E-maintenance' has been discussed in several times in the past few years in many maintenance related literature. It has been discussed with different perspectives. E-maintenance basically refers to the integration of the information and communication technologies (ICT) within the maintenance strategy or plan [1]. E-maintenance has been discussed one of the four ways: 1) a maintenance strategy (i.e. a management method), 2) a maintenance plan, 3) a maintenance type or 4) a maintenance support [2]. E-maintenance as maintenance type describes replacing traditional maintenance with technological maintenance where predictive maintenance is done with the help of artificially intelligent systems that provide only condition monitoring and predictive prognostic functions [2]. In this paper, e-maintenance is also considered as a maintenance type because our focus is to discuss involvement of ICT in the previously non-ICT based maintenance system to monitor condition, fault detection and diagnosis.

One of the reasons behind the use of e-maintenance in different companies is the competition factor. Smart companies must focus on service innovation and asset optimization for customer intimacy [3]. E-maintenance emerges with globalization and fast growth of the information and communication technologies [4]. Proper implementation of e-maintenance will benefit the manufacturers and users to have process reliability with optimal asset performance and seamless integration with

suppliers and customers [4]. Moreover, e-maintenance enables manufacturing operations to achieve nearly zero downtime performance [4].

Rapid developments in information and communication technologies are providing novel opportunities to the existing cultures of maintenance. Since 2000, e-maintenance has been into considerations and gaining more attention in contemporary maintenance related literature. The competitive environment in manufacturing firms compels most of them to think in advance about the opportunities and associated challenges regarding their future products and services. E-maintenance based on remote diagnostics opens new areas of research [5]. One example is the transformation of the vehicle industry where new opportunities for e-maintenance based on remote diagnostics systems are emerging [6]. Others examples of its applications include power industry [7]; manufacturing and mineral processing industry [8]; chemical process industry [9]; computer Printer [10]; aero planes [11]; jet engines [12]; and warehouse, semi-conductor industry, Ford and Toyota Motor companies [13].

The purpose of this paper is to show the use of e-maintenance in different industries and also discuss the opportunities and challenges that different industries are facing or expect to face with e-maintenance.

At first, a review has been done on different e-maintenance types that are proposed or employed in various industries. This is followed by the research approach to conduct the research. On the basis of collected data and literature, opportunities and challenges regarding e-maintenance have been presented. Concluding remarks with future work end the paper.

2 E-maintenance in different industries: a review about the technology

Various types of e-maintenance have been applied or proposed in different industries. After reviewing the literature that describe different e-maintenance types and also searching the web regarding the use of e-maintenance, we have made an overview of those technologies that are either applied in different industries or proposed for implementation in different industries.

Condition Monitoring Multi Agent System (COMMAS) is a system that addresses a new area in intelligent electrical plant monitoring as it supports the use of more than one computational intelligence technique through agent technology, in order to interpret the plant data and derive meaningful conclusions [7]. Mangina et al. [7] describe how the theoretical framework of Condition Monitoring Multi Agent System (COMMAS) for intelligent data interpretation has been applied and implemented in the identification of partial discharge signal defects of Gas Insulated Substations (GIS). There are lower levels of intelligent functions in COMMAS. Attribute Reasoning Agents (ARA), Cross Sensor Corroboration Agents (CSCA) and Meta-Knowledge Reasoning Agents (MKRA). The data is fed initially to a set of Attribute Reasoning Agents (ARA) which determine if there are any anomalies which must be considered. After performing their intelligent data interpretation, the result is sent to next layer of agents known as Cross Sensor Corroboration Agents (CSCA). These

agents attempt to identify sensor problems as opposed to plant problems. Finally, the conclusions of the CSCA agents are communicated to the Meta-Knowledge Reasoning Agent (MKRA) which provides the final interpretation to offer the end user improved condition monitoring information [7]. This agent based approach offers a flexible condition monitoring architecture which can be applied for any plant item. The distribution of the intelligence allows for scalability and ease of integration of new intelligent reasoning modules. Additionally, it allows the reasoning to be performed across a number of processors at a number of locations [7].

For chemical processing industry, a multi-agent based condition monitoring system has been proposed by Sun et al.[9]. The proposed architecture has been designed according to the principles of use of the mechanisms of encapsulation, isolation and local control. Each agent is composed of a control modular, a database, a communication block, a knowledge base, an information processor and a data acquisition and network listening block [14]. The knowledge interchange between the agents is made through the automatic translation languages of messages programmed in Common Knowledge Representative Language, which is based on the C++ programming language. This monitoring technology alarms are triggered whenever fixed thresholds are exceeded [14].

For manufacturing and mineral processing industry, Ebersbach and Pegg [8] have developed an expert system for condition monitoring. It provides a different way of working for the maintenance personnel, since the tradition is to apply the analysis methods manually. It is believed that the use of an expert system could allow comprehensive analyses as well as enabling the maintenance engineer to perform routine analyses. The vibration analysis expert system (VES) uses a knowledge base for fault identification. It has a peak detection algorithm whose objective is to search for the vibration data file of a particular frequency, or the frequency or time domain pattern. Microsoft Visual Basic was selected for implementation due to the requirements of the user interface, allowing ease of use including on-line help screens. The system has 75 rules and is implemented in ‘if’ loop type statements, in order to diagnose 54 different machine component faults. It was modeled using a pseudo code to implement the flow chart. The VES was successfully tested using vibration data obtained from a laboratory providing the detection of various faults [14]. It is a tool that may potentially be used for both the laboratory and on-site maintenance departments of large manufacturing and mineral processing plants [14].

For pumps, Hardig [15] describes a predictive maintenance system. It is a web-enabled system. This makes it possible for any facility with internet access to establish a world-class predictive maintenance program for less than what it would cost to run an in-house program. We-enabled monitoring systems enable predictive maintenance data collected by a company’s designated technician to be uploaded easily and accurately to a remote web server for trending and analysis by experienced third party professionals. An e-maintenance program provides a standardized approach to managing a predictive maintenance program and integrates all the participants into a team with clearly defined roles, responsibilities [15].

Angeles [13] shows the use of RFID (Radio Frequency Identification) technology as the control and monitoring technology in the logistical operations of several different industries such as cosmetics, biscuits, semi-conductor and cars. RFID is a type of auto-identification technology that uses radio waves to identify individual

physical objects [13]. RFID technology uses tags that have both a microchip and an antenna. The microchip is used to store object information such as a unique serial number, which transforms the information on the RFID tag to a format understandable by computers. RFID technology also uses the tag reader. Through the method of inductive coupling, RFID readers communicate with tags. The coiled antenna of the reader creates a magnetic field with the tag's antenna, which subsequently drawn energy from this field and uses this to send back waves to the reader. These waves are transformed into digital information representing the Electronic Product Code (EPC) [13]. In Unilever, the RFID technology is used in the following way for logistical operation: transponders (RFID tags) have been installed at the bay doors of the warehouse to track pallets that pass through them. Thereafter, another transponder transmits that information about the passing transport vehicle to the computer system. This information on the individual pallet weights stored in the computer database is used in comparing the weight of the total load of a truck [13]. As a result of the RFID system, the number of daily pallets handling has increased and the information on the movements of the physical loads has become more reliable [13].

For mining industry, Lewis and Steinberg [16] describe condition monitoring system INTELLIMINE. It facilitates the implementation of a proactive maintenance program. This maintenance management program has seven modules: real-time, reporting, remote condition monitoring, data acquisition and filtering, field interfaces, third party interface and configuration. These modules will provide the maintenance supervisors, planners, reliability engineers, technicians and managers with the information necessary to make educated decisions regarding maintenance activities [16].

Another industry where e-maintenance and e-diagnostic have been proposed is semi-conductor industry and is proposed by Min-Hsiung et al.[17]. A prototype is tested through various operational scenarios. The development process, i.e. the analysis, design, functional requirements and system implementation of the prototype system, is presented [14]. UML is used in the design of the development process. The authors mention that the proposed framework achieves the automation of diagnostic processes and integration of diagnostic and maintenance information under a secure communication infrastructure. Web technologies and web applications based on web services and XML are proposed as baseline technologies [14].

The computer manufacturing company Canon employs e-maintenance for their printers [10]. The functions that the e-maintenance system provides are : instant email notification of faults or performance issues often before the user would even know there's a problems, automatic monitoring of maintenance requirements and performance, the e-maintenance is suitable for most Canon multifunction devices, Easy consumables management (for example, receive a notification when toner is low), Automated fleet management [10].

In the aero plane industry we can also see the deployment of e-maintenance [11]. Aircraft manufacturer Dassault Falcon recently completed successful testing with Falcon operators based in Europe and the United States on a new maintenance program called 'Falcon E-Maintenance' [11]. The program enables the Falcon Technical Center or a Falcon service center to remotely access an airplane Central Maintenance Computer, or any other aircraft maintenance application, to troubleshoot

and diagnose issues. This connection is made through a laptop provided by Dassault with WiFi or satellite capabilities [11].

The maintenance laptop makes it possible for the aircraft technicians, service center and the Falcon Technical Center to work in real time on one common communication platform that is capable of both audio and video. From there, they can share technical documents, transfer files and organize multimedia conference meetings. If needed, it will be possible for an Authorized Service Center or the Falcon Technical Center to remotely access the aircraft's central maintenance computer [11].

3 Research Method

This research is a part of an ongoing project together with a firm in the vehicle industry. This is collaboration between research community and practitioners from the industry as such that it can be characterized as action oriented research ([18], [19], [20]). On the basis of remote diagnostics, an expansion from traditional manufacturing oriented to the manufacturing plus service oriented business has been visioned by top management. The project is aimed at the followings (i) to explore and develop new remote diagnostics technologies, (ii) to develop new digital services, identify the related conceptual business models and its implementation in their business models. The purpose in this paper is to address exploration part of the first aim.

In line with action oriented research approaches, the project is organized as a collaborative process in four steps: exploration, conceptualization, development, and implementation and verification. At this point of project, the exploratory study has been done with the purpose to understand and explore the existing technologies and business situation. This will lead to further probe what they can offer to each other. Several activities have been performed in order to gather information by involving important stakeholders. Data was gathered from the workshops, service development and monthly meetings and documents including weekly project reports, meeting minutes, mail correspondences.

In order to ensure that different aspects of value networks were captured in the exploration, several data sources were used to generate a comprehensive understanding. Even thought interviews are rich sources of interpretations, they should be supplemented with other sources [21]. In this study we have used a number of different data collection methods including interviews, workshops, and documents.

The exploratory study was organized as follows: It started with the service development meeting with the purpose to create refined scope document. Each of the meeting lasted between 1-2 hours. These meetings were more concerned with the planning activities, understanding and discussion about potential areas of study of the project in addition to preparing ground for workshops. Meeting notes provided the firm's perspective expectations and coupled with other documents. .

Monthly meetings were 3 hours each, generic in nature and discussed project issues which occurred across the disciplines such as technical, business, service development. Also the cross-disciplinary inputs about opportunities and challenges were collected using notes and meeting minutes.

Workshops were conducted as full-day activities and included interviewing business area representatives and drawing value networks to understand the existing structure and character of the value networks for each business area. The main focal point about exploring opportunities and challenges were considered during these activities. The interviews were recorded and transcribed to interpret data. These were one of the major sources of information for where value networks were drawn with the particular business areas representatives to find out existing status of value networks. The service development meetings and documentation provided the basis to run these workshops.

Different kinds of documents such as weekly reports about project status, field notes, and company documents were collected and analyzed for the common purpose during exploration. A follow-up study was conducted using mail correspondence and additional on demand meetings and the information from those meetings was added to the analysis.

Following table summarizes the data collection activities, the numbers and participants involved in each of the activity.

Activities		No.	Informants or Participants
Service Development Meetings	Biweekly On demand	21	• Service Developers (2) • Project Manager (1) • Technical Researcher (1) • Informatics Researchers (3)
Workshops		2	• Service Developers (2) • Business Area Representative (1) • Informatics Researchers (2)
Monthly Project Meetings		3	• Service Developers (2) • Project Manager (1) • Informatics Researchers (3) • Technical Developers (2) • Technical Researchers (3)
Documents	Meeting notes, weekly Project reports, mail correspondence		• Service Developers (2) • Project Manager (1) • Technical Researcher (1) • Informatics Researchers (3)

Table 1: Summary of data collection activities

4 Findings: Opportunities and Challenges with E-maintenance

In this section, the opportunities of e-maintenance and its challenges/limitations are highlighted. The information are found from the literature review, two workshops, three monthly meetings and many service development meetings with the company staffs and also from various documents such as meeting notes and weekly project reports.

Talking about the opportunities of e-maintenance, with the help of a multi-agent e-maintenance system for power industry the condition monitoring will be more powerful [7]. However, as a limitation it can be pointed out that the e-maintenance system provides results for an application where there are decentralized resources [7]. And also the toolkit is not a commercial toolkit [7].

In chemical processing industry, there is opportunity of e-maintenance with the use of multi-agent systems and web technologies [9]. Diagnostic agents communicate by exchanging messages and both local and global knowledge to solve process abnormal situations [9]. But there are many problems in multi-agent system such as sensor validation, providing explanations for the propagation of faults, possible multiple fault situation handling are the challenging problems in this study [9]. Because of these problems getting the full advantage might be difficult.

There is opportunity of e-maintenance in manufacturing and mineral processing industry where a high throughput vibration analysis condition monitoring is possible with vibration analysis expert system (VES) to be performed by non-expert technical staff [8]. However, as a future requirement, the completion of the system need to facilitate the design of a comprehensive machine condition monitoring expert system utilizing oil, wear debris and vibration analysis techniques [8].

There are several positives of deploying e-maintenance in the pumps [15]. The good points of e-maintenance are: 24-hour surveillance of the pumps, centralized data, i.e., past data from all locations is easily accessed by authorized personnel. Another positive thing is field support, i.e., the ability to share data among sites and between specialized analysts and field staff equips in-field personnel with access to more complete and accurate data on which to base timely decisions that may impact operation. And the final positive about the e-maintenance is minimized investment. But as a future challenge, a maintenance strategy and risk analysis should be in place before making an investment [15].

There are several opportunities of RFID (Radio frequency identification) as e-maintenance in several industries such as cosmetics, biscuits, cars etc. RFID technology promises process freedom and near-perfect information visibility throughout the supply chain across different industries [13]. However, as a future challenge it needs to be pointed out that more detailed understanding of effective implementation strategies and best practices need to be undertaken [13].

In mining industry, with the use of remote condition monitoring system, the maintenance process can be optimized as in mining industry maintenance related cost is really big [16]. But a limitation is that most of the remote condition monitoring programs have not achieved the return on investment [16].

In semiconductor industry, there exists the following opportunities of e-maintenance : automatically integrating diagnostics, fixing, monitoring of equipment and fault prediction which are necessary to support the e-diagnostics/maintenance

tasks in semi-conductor factories [14]. But meeting all the requirements of maintenance/diagnostics systems for the semiconductor industry is the future challenge [14].

From one of the workshops with the staffs from a vehicle company, we have found out the following opportunities of e-maintenance: small scale implementation of remote diagnostic systems in construction equipment at the initial stage to find out fatal errors, deploying remote diagnostic systems in the sub-components where troubles occur regularly, the remote diagnostic system will bring goodwill to the company which will provide this service, it might save good amount of money in maintenance. But the discussants also point out some future challenges: correct information about the errors is required without any chance of misinterpretation, time is a big issue in maintenance; providing the service in time is a big challenge, the information should be tied with instruction for the next step, the business model needs to be reshaped, shifting the thinking from just manufacturing construction equipment to providing additional services to those equipment is the real challenge.

During another workshop, the discussants state that the e-maintenance has the following opportunities: increasing up-time of the vehicles, creating new commercial offerings through the remote diagnostic system. But they were also unanimous that attracting all types of customer groups will be tough and lowering the operating costs will be a challenge.

Table 2 below shows various opportunities and challenges in two major areas i.e. in the technology and in the business and business models. Each of the opportunity is associated with some challenges or limitations that lessen its advantages.

The major opportunities in the area of technology are condition-based monitoring as well as predictive maintenance and diagnostics. Condition-based monitoring as well as predictive maintenance and diagnostics are essential in the industries where critical processes are in place [7] [8] [9] [15] [13]. But the opportunities to provide these facilities are challenged with number of factors. For example, analysis of meeting notes show us that the people in this area are not sure about which parts are necessary to be embedded with digital capabilities as they cannot provide digital capabilities to all the parts. This will result as a limitation to provide e-maintenance. Moreover, technological limitations related to digital products, communications, managing information and so on also provide various challenges.

In case of business, e-maintenance serve as potential asset for business landscape by providing number of opportunities, such as:

- New services such as monitoring or providing predictive maintenance of equipment for fixed cost may generate revenue for the business.
- Our analysis reflected that most of the large firms in industries are connected through business to business relationship e.g. a vehicle manufacturing firm deal its major customers through dealers. E-maintenance provides the facility for such a firm to establish direct contact with customer for new e-maintenance services while maintaining the existing ones. Another opportunity is to provide e-maintenance through existing dealers.

Sources		Opportunities	Challenges/Limitations
Literature		More powerful condition monitoring	Provides results for an application where there are decentralized resources. It is not a commercial toolkit.
		Multi agent diagnostic system for chemical processes	Sensor validation, providing explanations for the propagation of faults, possible multiple fault situation handling
		Vibration analysis, condition analysis to be performed by non-expert technical staffs	Combining the VES expert system with an expert system for oil analysis
		24/7 capabilities, centralized data, field support, minimized investment	Maintenance strategy, Risk analysis
		RFID technology promises process freedom and near-perfect information visibility throughout the supply chain across different industries.	More detailed understanding of effective implementation strategies and best practices need to be undertaken.
		Optimizing the maintenance process	Most remote-condition monitoring programs have not achieved their expected return on investment
		Automatically integrating diagnostics, fixing, monitoring of equipment and fault prediction which are necessary to support the e-diagnostics/maintenance tasks in semi-conductor factories.	Meeting the requirements of e-maintenance/diagnostics systems for the semi-conductor industry.
Workshops	Workshop 1	• Initially small scale implementation of remote diagnostic systems in construction equipment to find out fatal errors. • Deploying remote diagnostic systems in the sub-components where troubles occur regularly. • The remote diagnostic system will bring goodwill to the company that will provide the service. • It might save good amount of money in maintenance	• Correct information about the errors without any chance of misinterpretation. • Time is a big issue in maintenance. Providing the service in time is a big challenge. • The information should be tied with instruction for the next step. • The business model needs to be reshaped. • Shifting the thinking from just manufacturing construction equipment to providing additional services to those equipment is the real challenge
	Workshop 2	Increase up-time of the vehicles, creating new commercial offerings through the remote diagnostic system.	Attracting all types of customer groups will be tough; lowering the operating costs will be a challenge.
Documents	Meeting notes	Increased uptime for the services enabled by remote diagnostics.	• Choice on parts to be digitized • Technological limitations • Managing information • Data storage, retrieval and processing
	Weekly project reports		

Table 2: Overview of opportunities and challenges

- Time and money has always been important and especially in the contemporary fast growing and highly competitive business environment. E-maintenance is believed to reduce manual efforts and time in addition to low cost maintenance.
- Intangibles are of high strategic importance in the networks where externalities exist [22]. One of the intangible as ‘enhanced goodwill’ is recognized as opportunity for sustainable business by one of the business area manager during our workshops.
- The availability of services to the intended users whenever and wherever needed is considered as uptime for service. E-maintenance is one of the sources to provide services with such characteristics.

But, these opportunities like others are not free from challenges and/or limitations. Some of the identified challenges are:

- Converting business-to-business (b2b) relationships to business-to-customer (b2c) is not an easy task and involves many factors e.g. strategic, political, competitive
- Moreover, attracting customers to change existing relationships is difficult as they are
- Besides other, there is a risk of high cost to establish and maintain new business-to-customer relationships.
- Current business models are based on traditional value chain approach and hence are rigid. The meeting notes show that e-maintenance adds dynamic characteristics to the business; hence a more flexible model is required.

Areas	Opportunities	Challenges/Limitations
Technology	• Condition-based monitoring • Predictive maintenance and diagnostics	• Choice on parts to be digitized • Technological limitations • Managing information • Data storage, retrieval and processing
Business	• Introduction of new services in the business • Extending existing b2b relationships to b2c • Establishing new b2c and b2b relationships • Cost efficient with the use of technology as compared to traditional method • Introducing new stakeholder, change roles of existing, and even omitting some from the network • Intangible benefits • Increase uptime for e-maintenance services	• Converting b2b relationships to b2c • Attraction for customers to change existing relationships • Cost of establishing and maintaining new b2c relationships • Providing services whenever and wherever needed • Communication management and cost • Current business models are rigid

Table 3: Opportunities and challenges in different areas

5 Conclusions

The point of discussion in this paper is: to find out opportunities and challenges regarding e-maintenance.

Based on the literature review and empirical work we tried to shed light on some of the opportunities and challenges as mentioned in the purpose of the paper. We have

made an analysis of these opportunities and challenges and identified two main areas: technology and business.

This paper will serve as the basis for more in-depth study based on extensive literature review and empirical findings. In future work, a study can be done on how e-maintenance can influence business model of an organization.

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