Information and Communication Technology Infrastructure in E-maintenance

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***Abstract – The major objective of this p*aper is to provide further insights into the Information and Communication Technology (ICT) infrastructure for supporting e-maintenance processes in today's manufacturing environments. To achieve this objective existing e-maintenance models were investigated and an appropriate model was selected based on (i) its currency, (ii) its relevance to the manufacturing industry, and (ii) an explicit role being played by the ICT for enabling various e-maintenance activities. The ICT component of the selected framework is then further expanded by identifying specific ICT component technologies that are currently available for supporting various e-maintenance activities within the framework. Therefore the major contribution of the current study includes (i) identification of an existing e-maintenance framework with explicit focus on ICT, and (ii) to purposeful review of the current ICT literature in order to identify current ICT technology components that can be used in order to support various e-maintenance activities of the selected e-maintenance model.**

***Keywords** – manufacturing industry; maintenance; e-maintenance; conceptual model; Information and Communication Technology (ICT)*

I. INTRODUCTION

As a multidisciplinary field, e-maintenance is related to a variety of research fields ranging from operation & maintenance engineering, to software engineering, information systems, and business management [1]. As a result of such inter-disciplinary nature of e-maintenance, a variety of theoretical and research perspectives can be adopted I order to investigate the phenomena. The perspective adopted in the current study is the Information and Communication Technology (ICT) perspective.

E-maintenance addresses emerging requirements of today manufacturing industry and provides various benefits in form of increased availability, reduced lifecycle and set up cost, facilitated the integration of maintenance support technologies with existing material and personal resources, increased customer-value, continuous improvement of maintenance management, improved decision making process [1], [2], [3], [4], [5].

The current study is presented in the form of a review paper, and as a result, its findings are synthesized from the existing literature on e-maintenance and ICT domains. One major motivation for conducting the current study has been a lack of sufficient insights into the existing ICT component technologies that can be used for both supporting as well as enabling various e-maintenance activities in today's manufacturing environments. While practitioners have been busy with utilizing a variety of ICT technology components for supporting their e-maintenance activities, little academic research seem to have been conducted to provide a taxonomy-like knowledge representation of the current ICT technologies that can be used in today's manufacturing sector.

The current study extends existing work on e-maintenance by providing an ICT classification scheme for e-maintenance activities by identifying specific ICT components from the current literature that provide required support. Findings of the study which is represented in an ICT classification scheme, can in turn serve as a supplement to the selected e-maintenance model, and collectively referred to as *integrated e-maintenance architecture* incorporating ICT components and e-maintenance activities. The ICT classification scheme is presented textually in the section titled "ICT Infrastructure for E-maintenance".

II. E-MAINTENANCE STRATEGIES/PROCESSES

As a multi-disciplinary e-disciplinary research field, e-maintenance is a combination of two e-domains: 'e-manufacturing' and 'e-business' [6]. It is defined as "maintenance managed and performed by virtue of computing" [1], "it integrates ICT within the maintenance strategy to face the new challenges of supporting e-manufacturing" [7], and "provision of maintenance support services remotely with the aid of ICT" [5]. In this section a review of literature is provided to further clarify the e-maintenance side of the theoretical foundation of this study which primarily focuses on current e-maintenance strategies. The outcome of this review is identification of a recent ICT-oriented e-maintenance framework where ICT is given critical role of enabling and supporting various e-maintenance activities. Such bias in reviewing the current literature has been deliberate and consistent with the overall aim of the study in one hand, and the enhanced role of ICT in e-maintenance activities, from having a 'supporting' role to having an 'enabling' role. Below is a summary of the

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existing e-maintenance strategies adopted by today's primarily knowledge-based manufacturing organizations:

Remote maintenance: It is based on the notion of distance and transfers data from one site to another one remotely without the physical access to the item [8].

Predictive maintenance: It is concerned mainly with detecting hidden and potential failures and predicting the condition of the equipment [9].

Real-time maintenance: Maintenance operators can respond to any situation by the real-time remote monitoring of equipment status coupled with programmable alerts [10].

Cooperative maintenance: The work is divided to independent tasks, every actor assigned to a part of the resolution of the problem and the coordination is done during the assembly of partial results [10].

Collaborative maintenance: The work is synchronized and coordinated so as to build and to maintain a common vision of the problem [11].

Preventive maintenance: The objective of preventive maintenance is to decrease the probability of failure in the time period after maintenance has been applied [12].

Corrective maintenance: Corrective maintenance strives to reduce the severity of equipment failures once they occur [13].

On the other hand e-maintenance processes have been identified and classified by Kajko-Mattsson et al. [1] and Muller et al. [11] as (i) 'diagnostics', (ii) 'prognostics', (iii) 'planning and production control', (iv) 'documentation' such as technical publications, (v) 'electronic log books and technical records', (vi) 'repair order/work order', and (vii) 'quality assurance and reliability analysis'.

All above e-maintenance strategies and processes would require support from ICT in a variety of ways. For example, the 'remote maintenance' strategy would require ICT component technologies that maintain a ubiquitous environment for the maintenance workers whereas the 'predictive maintenance' strategy would need strong ICT support in the areas of *business intelligence* and *decision support* systems and technologies. The current study provides a generic guide to the ICT component technologies without adhering to a specific strategy. This will facilitate identification of matching each of the proposed ICT component technologies with a particular strategy.

III. E-MAINTENANCE FRAMEWORK

A comprehensive architectural framework for e-maintenance has been proposed by Han and Yang [6] and is widely used by researchers in the fields of management and ICT mainly because it assigns an explicit role for ICT as an enabling factor for supporting various maintenance activities. The current study adopts this framework and elaborates on the ICT component by exploring existing ICT component technologies that can be used in conjunction with the above conceptual framework.

The framework mimics the traditional holistic maintenance shops in multi-division environments with a centralized maintenance centre and several local maintenance centers, and closely resembles the model that has been adopted by the Saudi Aramco where the author is employed.

The maintenance center is a sharable platform that interconnects research groups, experts, repair shops, and manufacturing divisions via internet and communication techniques. The local maintenance centers provide routine services to their respective manufacturing sites that do not involve ad-hoc decision-making and/or fundamental changes to the existing local facilities. In the event when such needs arise the latter uses the shared facilities of the maintenance center both for problem-solving as well as for implementing change management and supporting relevant decisions. Maintaining an effective communication and coordination activities between the local and central maintenance centers is one major role of the ICT infrastructure that have been discussed in the next section.

The lower part of Figure 1 represents the ICT infrastructure component of the architecture that supports activities within the e-maintenance framework, and is the focus of the current study. In the following section the latter part of the architecture is described in more detail through a review of the current literature. The identified ICT components have been selected from the literature on the basis of their relevance and appropriateness in relation to supporting various e-maintenance activities.

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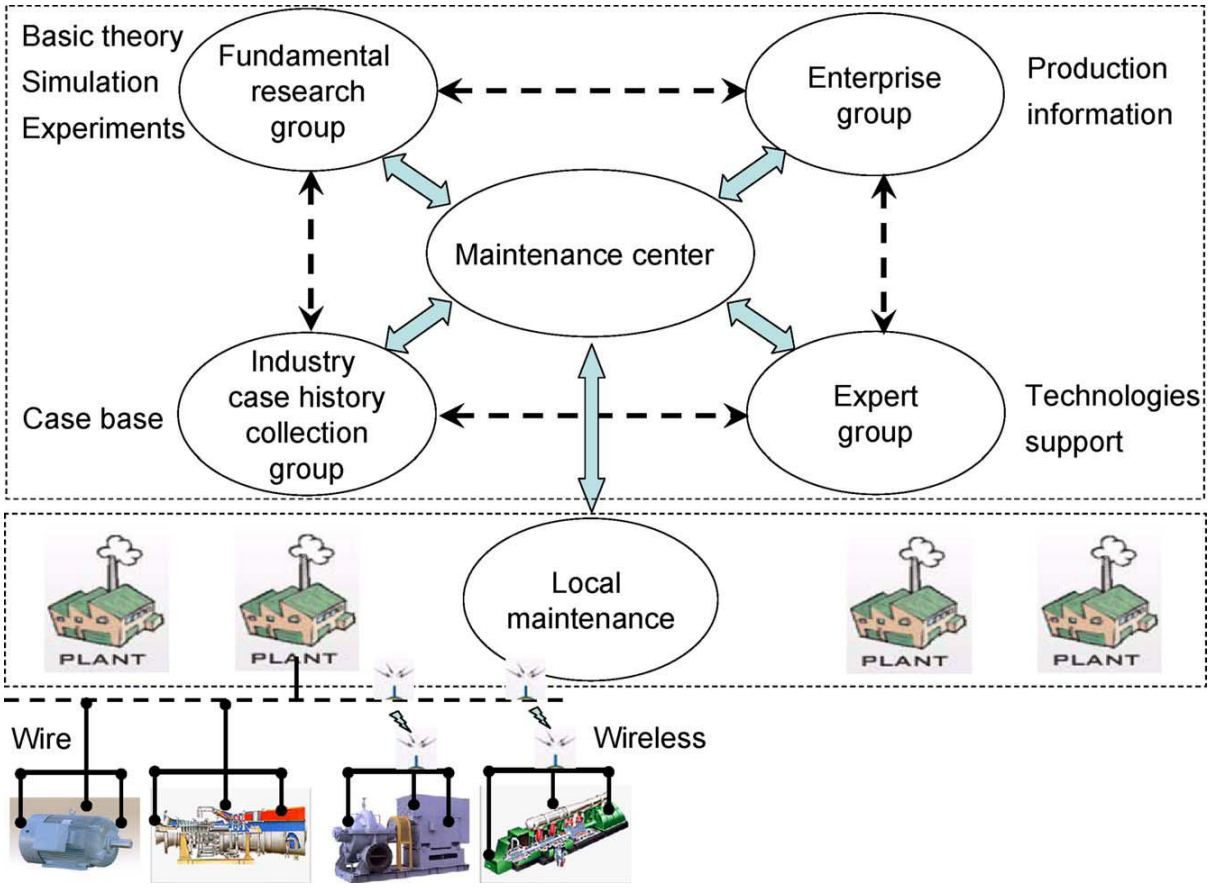

Figure 1 – Architecture of a hypothetical e-maintenance system; adopted from Han and Yang, 2006.

IV. ICT INFRASTRUCTURE

It is claimed that ICT infrastructure in e-maintenance must ensure that the level of service quality expected for the process execution is maintained for scalability and availability [14]. From the e-maintenance point of view the ICT infrastructure is composed of one or several networks with servers, workstations, applications, databases, smart sensors, PDA, and many more [14]. Furthermore, such role for ICT has also been characterized by its operating principles such as wireless infrastructure as well as deploying the right ICT related standards for presentation, storage, exchange, and process communication [15]. In the following section a summary of the most relevant categories of ICT technology components have been identified from the literature. Such categorization represents one major contribution of the current study.

- New sensors such as smart sensors—MEMS (micro-sensor technology equipped with autonomous power, memory cells, analogue amplification, converter, etc. well adapted for vibration analysis, oil analysis), wireless sensors, and sensor networks. The sensors are the main factor for performing the basic e-maintenance activities which materialize the ‘‘Condition-Based Maintenance’’ concept (CBM). Therefore, these sensors support more than conventional capacities (such as CM, diagnosis, prognosis) [15], [14].
- RFID tag (passive and active; Radio Frequency Identification Device) is used for operator and component identification, storage of conventional data, and traceability of the past maintenance actions. In addition, for it can be used for geo-localization of the maintenance tools.
- Global Positioning System (GPS) in a complementary technology to the RFID tags and is used for distinguishing location of an operator or the maintenance tools.
- Wireless technologies lead to considerable savings in networking costs and provide high degree of flexibility that are not normally provided by wired systems. Wireless Personal Area Networks (WPAN) such as IEEE 802.11, 802.15.4 ZigBee, 802.15.1 Bluetooth; Wireless Local Area Network (WLAN) such as WiFi, WiMax; GSM-UMTS (for long distance) are currently the main wireless technologies [15], [4], [17], [18].

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- Innovative communication equipment such as "virtual reality" for supporting man/machine or man/man exchanges for speaking, hearing, seeing, touch, and feel.
- Tools for diagnostics and prognostics that support maintenance decision-making include E-CBM and remote sensing devices. These technologies are deployed for monitoring the condition and performance of physical assets [19], [20]. Furthermore, in an e-CBM-enabled environment data are transmitted through the Web to a secure site for analysis and decision making [20].
- PDA, SmartPhones, Graphic tablets, harden laptops, etc. (equipped with WiFi, Bluetooth, RFID Reader, Windows Mobile).
- Specific standards for ensuring the integration between all the IT components and e-Maintenance solutions.
- Web services (for monitoring, diagnosis, prognosis, scheduling) protocols and technical standards (Internet-based technologies) used for exchanging data between applications within heterogeneous environments: SOAP (Simple Object Access Protocol) for message exchanging; WSDL (Web Service Description Language); UDDI for referencing the web services, etc.
- Full Web-CMMS (e-CMMS) is a CMMS (Computerized Maintenance Management System) able to monitor and manage the preventive maintenance activities of the organization but by offering new functionalities such as ASP (Application Service Provider/Providing) over the Web; link with mobile technologies for retrieving data, loading maintenance action; workflow module, etc [19].

V. AN INTEGRATED FRAMEWORK

According to the e-maintenance architectural framework of Figure 1 the 'wireless' component provides required ICT infrastructure for supporting various activities of the other architectural components. This study extends the model in Figure 1 by providing further insights into the ICT support of the e-maintenance. The argument raised in the study is that the identified ICT components when combined with the e-maintenance architectural framework of Figure 1 together provide an integrated framework for e-maintenance that can be used by today's highly information-intensive manufacturing and service organizations for managing their e-maintenance processes.

VI. SUMMARY AND CONCLUSION

This paper reviewed current literatures in the areas of ICT and Manufacturing/Maintenance in order to provide further insights into the specific ICT requirements of the e-maintenance process. A recent e-maintenance framework, representing the latest effort in the field, was selected on the basis of its relevance to the manufacturing as well as its explicit notion of ICT support as an enabler of e-maintenance activities. The study expanded the ICT component of the framework by investigating current ICT components technologies as a supplement to the existing model, hence the name 'integrated framework'; a framework that integrates a recent e-maintenance framework with specific ICT component technologies.

In future the author intends to extend the current study by providing taxonomy for ICT support of e-maintenance activities and apply the framework to manufacturing industries with the aim of evaluating its suitability to various industries as a step towards developing a generic integrated e-maintenance framework.

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