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Mobile Collaboration Technology in Engineering Asset Maintenance: A Delphi Study

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***Abstract*—Currently, doing maintenance has significantly altered due to changes in equipment design, information and communication technology, cost pressures and customer acceptance of risk and failures. Moreover, current working circumstances are more complex and require parallel multiple actions. An integrated high-level maintenance comprising multiple sub-systems requires the collaboration of many stakeholders including multiple systems and departments. They work together to improve coordination and sharing of information within the whole disparate maintenance process. The emerging mobile technologies are rapidly developing viewed as business enablers, and they have the impact, use and penetration of the marketplace to support asset maintenance practices. Mobile technology can maintain collaborative information sharing and provides a number of benefits to an organization such as working collaboratively or separately. To achieve high quality and efficiency of maintenance for engineering assets, this research proposes to develop an appropriate mobile collaboration framework based on a Delphi investigation. This framework is concerned with adopting and implementing new mobile technologies that meet all maintenance collaboration requirements, where organizations can expand the existing technology they are using.**

Keywords—mobile technology; collaboration technology; engineering asset maintenance; framework

I. INTRODUCTION

Today's asset maintenance practices rely on access to information and team expertise from dispersed sites [1]. In the last 30 years, the practice of doing maintenance has significantly changed due to developments in equipment design, information and communication technology, cost pressures, customer acceptance of risk and failures [2] and the existence of multiple stakeholders and departments [3]. Moreover, current working circumstances are more complex and therefore need to be managed by multiple and interlinked activities [4]. Hence, an integrated high-level maintenance system which contains multiple sub-systems requires the collaboration of multiple stakeholders such as departments or units to improve resources, information sharing and maintenance practices. Collaboration can generate a strategy to enhance operational effectiveness, even to adding income, particularly if internal and external collaboration plays a major role in maintaining production figures within maintenance departments [5]

The emerging trend of mobile technologies is rapidly developing and they are viewed as business enablers, and have the potential to support asset maintenance practice. Mobile system is able to maintain collaborative information sharing and is providing a number of benefits to the organization such as facilitate of working collaboratively or separately. By implementing mobile collaboration technology, organizations can ensure that their maintenance personnel are always reachable 24/7, in the context of their site, meaning they are more available for planned and/or unplanned maintenance and provide information as quickly as possible [6], [7], [8]. In addition, a combination of mobile/wearable computers with wireless technology develops greater effectiveness and accuracy in maintenance. This technology allows maintenance personnel at a specified location to communicate with a remote expertise center through digital data, audio, and images. With these capabilities, even a non-expert maintenance crew is able to carry out simple repair duties with the assistance from a remote expert's desk [9].

To enable and to ease the maintenance process in an organization at strategic, tactical and operational levels, IT as one of a basic supporting structure needs to be built [10]. The very popular IT systems that have been implementing for engineering asset maintenance are Computerized Maintenance Management System (CMMS) [11]. A proper utilized of such system can assure effective management of this costly equipment. In addition, [12] conclude that a successful CMMS can lead to increased quality, better decision-making, and increased efficiency. However, although CMMS makes a great volume of information available for reliability and efficiency analysis of the delivery of the maintenance function, most experts agree that the successful is less than 30% of total CMMS applications [12].

Reference [13] outline the main reasons for unsuccessfully implementation of CMMS are summarized as follows:

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- Selection errors
- Insufficient commitment
- Lack of training
- Failure to address organizational implications
- Underestimating the project task
- Lack of project resources
- Lack of demonstrable use of system output

Indeed, in one hand, most of the main reasons for unsuccessful implementation of the CMMS as mentioned above are organization and personnel factors, in the other hand, most of available literatures and resources concerning to asset maintenance and collaborative maintenance are mainly explored the technological side in the area of hardware, software and networking. The lack of systematic approach, together with the lack of specific requirements to implement computerize maintenance information systems including mobile collaborative asset maintenance system requests a comprehensive framework for guiding engineering organization for implementing of new mobile technologies that meet all maintenance collaboration requirements.

In this context, this paper presents a preliminary finding of a Delphi study research that identify the mobile collaborative maintenance requirements in multi perspectives (Technology, Organisation and People)

This paper is organized as follows. Chapter II describes mobile collaboration technology in maintenance: mobile collaborative maintenance, collaboration requirements by asset maintenance crew and TOP approach. Chapter III presents the methodology: Delphi study method. In chapter IV the preliminary findings and discussion is presented. The conclusion is presented in Chapter V.

II. MOBILE COLLABORATION TECHNOLOGY IN MAINTENANCE

A. *Mobile Collaborative Maintenance*

Reference [14] explains that workers will perform their tasks at home, or go to a business as “corridor warriors”. Personal computers will not be replaced by mobiles, but mobile devices, according to [15]. For example, Smartphone and PDA and networks will be very centralized, will improve and accelerate work processes through timely provision of information, and better support the roles of communication and collaboration. Moreover, Smith states that each single organization uses a specific set of tools that is designated to support team collaboration to perform tasks in certain projects [16].

Through the development of mobile technologies, the processing of information can be performed by technical personnel away from the central production office or site. Maintenance personnel, when doing their tasks, require relevant information in different sites and need to communicate interactively with experts in the back office [17]. In regard to this task [18], using mobiles allows maintenance personnel to continuously receive a daily schedule from the head office. This leads to the saving of time and improving customer service and profitability. References [19] and [20] agree that mobility of special artifacts can enhance tasks and responsibilities. Hence, [17], in order to support maintenance task, the use of mobile collaboration technologies is a visible and effective approach. The maintenance task that can be supported by mobile collaboration technologies, are for example: information about machine state, process state, work orders and scheduling, a list of experts and their availability, condition monitoring and data diagnosis.

Reference [17] is also explains that with reference to production machinery the right information and tools are present but they, typically, are not available at the right time, at the proper place or given to the right personnel. The advances made in mobile technologies can support technical personnel and maintenance experts to collaborate in different locations who are on the move. Such technology enables the availability of data/information and engineering tools anytime and anywhere to anybody. Furthermore, [17] maintenance practice involves doing complex tasks such as maintenance planning, inspection, diagnostics, requires cooperation with another person. This collaboration is not the new but is a normal way in engineering industries. The availability of mobile collaboration technology in place makes a new perspective to support the asset maintenance action. Maintenance activity that needs collaborative effort including inspection, monitoring, routine maintenance, overhaul, rebuilding, repair [21], considered the MCT to be a necessity [17].

B. *Collaboration Requirements by Asset Maintenance Crew*

The industry as a whole is focusing on ways to better manage the complex processes performed by operators and managers in their production facilities as a way to meet the target. Hence, organizations need to understand the business process flow and its factor from operational perspectives in order to well identify the critical potential problems. Once the problems within the process flow are found then it becomes easy to determine which technology services should be used. Example for the technology services such as network services, communication services, collaboration services or composite services [22] (see Figure 1).

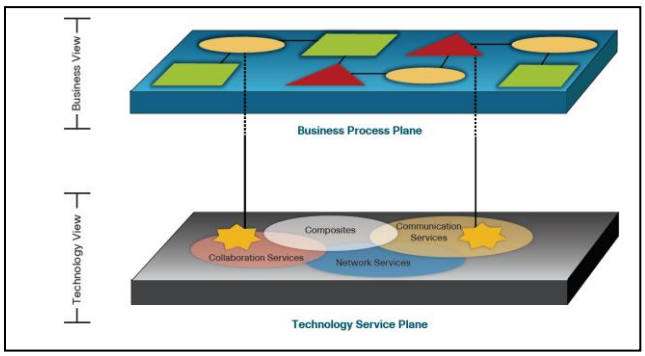

Figure 1. Business process-Technogy services alignment (Source: CEBT-Cisco)

Managing activities in a complex engineering organizations environment demands a comprehensive, integrated software system that not only optimizes performance, but can also be implemented quickly and adapted to the specific procedures and processes without compromising safety. But in fact, when it comes to the actual maintenance actions, they can only be performed at the location of the machine. This implies that relevant information is needed by technical personnel like engineers and technicians in distinctive locations, irrespective of where the machine is under operation, and the voluminous of information needed has to be sent back and forth between the experts, the monitored machinery and the back office. Moreover, although the right information and engineering tools are often available at the central office, they are rarely available at the right time, at the right place to the right personnel operating at the site. To improve quality and reliability, maintenance people require the ability to access physical asset information related to maintenance from a mobile device out at the point of performance and not back in the head office.

Mobile technologies play a key role in this setting, facilitating to establish tightly integrated environments between different groups and organizations that bear stakes on the performance of the industrial assets [23]. Despite the fact that the use of advanced application solutions in manufacturing, production, or process facilities takes place at a different scale, the emerging trend has already shown that mobile technologies have a great potential to redefine and re-engineer the conventional setting. They have already begun to offer advanced and smart solutions to remotely manage complex, high-risk, and capital-intensive assets, regardless of the geographical location, building agile information and knowledge networks [24].

In order to encounter good asset maintenance and meet the optimum performance of engineering assets, organizations require a collaborative teamwork within key functional areas (stakeholders) of the engineering organizations. Shared understanding, coordination, cooperation and collaboration across maintenance stakeholders of what asset maintenance is and how the entire maintenance teams influence the ability to achieve organizational objectives through those assets are one of the critical success factors of asset management. Collaborative asset maintenance is applicable to all those who have a role in the maintenance of engineering assets including directors, managers, supervisor, engineers, plant operators, IT and maintenance technicians.

Collaboration technology that is required for asset maintenance need to be capable of simultaneously handling, processing and delivering technical and operational information to multiple maintenance crews at multiple locations at any time to enhance asset maintenance planning and implementation within the three levels of business activities. The requirements are including technological, organizational, as well as personal perspectives.

C. TOP Approach

Reference [25] implies that any phenomenon, subsystem or system needs to be analyzed from what they call a Multiple Perspective method – employing different ways of seeing, to seek perspectives on the problem. These different ways of seeing are demonstrated in the TOP model of Linstone [26] and [25]. The TOP model allows analysts to look at the problem context from either Technical or Organizational or Personal points of view:

- The technical perspective (T) sees organizations as hierarchical structures or networks of interrelationships between individuals, groups, organizations and systems. For Examples, science-technology, optimization, need validation, cause and effect etc.;
- The organizational perspective (O) sees the world through a different filter, from the point of view of affected and affecting organizations; and considers an organization's performance in terms of effectiveness and efficiencies. For examples, unique group or institutional view, reliance of experts, need SOP, institutional compatibility, etc.;
- The personal perspective (P) focuses on the individual's concerns. For examples, learning, experience, prestige, intuition, need for certainty, etc.

Reference [25] suggest that these three perspectives can be applied as "three ways of seeing" any problems arising for, or within, a given phenomenon or system. Reference [19] further notes that the dynamic exchanges of ideas which is emerge from using the TOP perspectives are essential because they take into account "the fact that each of us individually, or as groups, organizations, or systems, creates and frames the world through a series of mental models, each of which, by it, is incomplete". In other words, a single perspective on the problem context is not sufficient to elicit an insightful appreciation of it.

It is found that the collaborative maintenance requirements can be best described by using the TOP multiple-perspectives approach. Incorporation of technology-organization-personal of collaborative maintenance requirements reflects the fact that the whole is more than the sum of its parts. In other words, using only one perspective is similar to seeing only a one-dimensional representation of a three-dimensional object.

III. RESEARCH METHODS

This study is conducted to identify collaboration requirements, current collaborative maintenance practice and mobile technology roles in support collaborative engineering asset maintenance. The Delphi technique is employed to more accurately build the consensus from the panel expert's perception. The Delphi study is a group process to solicit expert responses toward reaching consensus on a particular

problem, topic, or issue by subjecting them to a series of in-depth questionnaires, interspersed with controlled feedback [27].

The Delphi method is employed for several reasons. The topic 'Mobile collaboration technology in engineering asset maintenance' is quite new, it is complex, a few literatures series have been found, and not much empirical data was available. Those are the reasons why Delphi study is useful to confront a mobile maintenance expert's panel. Delphi study is carried out in this research which comprised three rounds [28].

Nomination of experts. A total of 47 experts who have strong academic backgrounds, research experience and professional in the area of mobile asset maintenance were invited to participate in the Delphi survey. Of these, 20 are willing to participate in the research project. They are 8 from universities and 12 professionals worldwide. The expert's profiles are illustrated below in Table I and II.

TABLE I. PARTICIPANTS BY ROLES

Background of expert	Participants	
	Frequency	Percentage (%)
Academia	8	40
Professional	12	60
Total	20	100

TABLE II. PARTICIPANTS BY GEOGRAPHIC LOCATION

Location of expert	Participants	
	Frequency	Percentage (%)
Australia	2	10
Canada	3	15
France	1	5
Germany	1	5
Greece	1	5
Malawi	1	5
Qatar	1	5
Singapore	1	5
United Arab Emirates	1	5
US	8	40
Total	20	100

Delphi Design. Three-round Delphi email-based questionnaire is designed. **The first round** is initial collection of requirements consisted of open-ended solicitation of ideas. Respondents were asked mainly about three basic questions, each corresponding to one of the research questions. The questionnaire asked experts to list general and the collaborative asset maintenance specific requirements, selecting criteria, benefits as well as initiatives issue that my hinder maintenance collaboration to address the first research question (RQ1). To address the research question two (RQ2), the questionnaire asked the experts to list the technical and features of current collaboration technology being used, the problems and the possible solution. Respondent were asked to list the roles of mobile technology in support the current collaborative asset maintenance in order to address the third research question (RQ3). **The second round (**being conducted**)** is validation categorized list of requirements. The experts were asked to verify the list that the researcher have correctly interpreted and placed them in an appropriate category/group based upon first round responses. In this round the experts were also requested to remove, added or regrouped the item (s) into other group/category. **The third round** is ranking relevant requirements. The consensus in the ranking order of the relevant group/category about requirements will be achieved in this final iteration. They will also be asked about the correlation between requirements (if any) as well as the critical requirements that need to be focus on.

IV. PRELIMINARY FINDINGS AND DISCUSSIONS

A. *Mobile Collaboration Requirements*

Please mention mobile collaborative maintenance requirements.

From the responses of 19 panel members, we analyzed 60 individual statements. We then grouped into similar requirements and then mapped into Technology (T), Organization (O) and People (P) approaches as illustrated in Table III.

TABLE III. MOBILE COLLABORATIVE MAINTENANCE REQUIREMENTS

TOP	Delphi Round 1
Technology	Autonomous
	Interoperability
	Security/Trust
	Configurability
	Responsiveness
	Usability - for maintenance crew (input methods, long time/ battery support, ruggedness, portable, health and safety)
	Multimedia support
	Accessible
	Easy to deploy
	Localization
	Mobility
	Low coordination effort for maintenance crew in performing task.
	Can print report directly (wire and wireless)
	Ability to perform in both online and offline modes
	Loads work order information to their system.
	Data persistency and/or transparent synchronous/ asynchronous operations to the user.
	Bar code readers for parts check out
	Asset ID during wrench time at the job.
	Must be intrinsicaly save in hazardous environment.
Organization	Simplify process (maintenance - Business) Flows
	Using unify communication (to cut cost)
	Awareness of maintenance people's reachability
	Readiness of maintenance resources
	Organisation commitment
	Involving Maintenance stakeholders in the system/ technology selection process
	The regulation about information security have to be considered (as security more crucial)
	Awareness of organizational implications of new system
People	Mobile technology competence, training/skills
	Work culture, motivation
	Trust and commitment the other crews will do their part

B. *Current Collaboration Technology Being Used*

The following (see Table IV) are the list of current computerized maintenance information systems

Technical/Features which are currently available/serve on the **collaborative** maintenance systems according to the panel member's feedback in Delphi survey Round1.

TABLE IV. CURRENT TECHNOLOGY/FEATURES OF COLLABORATIVE MAINTENANCE SYSTEM

Area	Category	
Format Data	Text, Audio, Visual, Hyperlinks, Graphic, Document (word, spreadsheet, pdf)	
Sub-systems	Portability, Wireless, Voice communication, Speech recognition, Display, Video capture, Input Devices	
Features	General	System security
		Easily expandable
		Simple setup
		Built in backup and restore
	Scheduling	Preventive maintenance wizard
		Task library
		Work order list
		Copy option
		Generate work orders
	Managing	Work order reminder
		Cost tracking
		Staff assignments
		Inventory maintenance
		Purchase order status
	Productivity	Customizable list
		Sort, Query, Filter and Find
		Import & Export Utilities

C. Current Mobile Technology Roles

Please mention the current role of mobile technology in support asset maintenance collaboration technical/system.

We coded 19 responses into 42 individual statements. The statements were then clustered by similarity into categories and finally mapped to high-level feature areas as can be seen in Table V.

TABLE V. MOBILE TECHNOLOGY ROLES

Area	Feature category
Flexibility *(initiate application at flexible sites in unstructured networked)*	Visualising of collected data, parameter history and trending.
	Contextualising access over remote data and services: task-related services and data entry ubitously available to authorised users.
	Critical for response time for data or information that can lead to early correction and or identification of failures.
	Providing the notification of failure through mobile devices
	Detecting the location of skilled maintenance personel nearby an asset that has experienced a failure through GPS.
	Mobile technology allows at the right place to access directly to a set of information coming from all the potential actors involved in the decision (CMMS, ERP, sensors, etc.).
Empowering management	Resources management (material, maintenance people) facilitator for continous task monitoring/assignment/reporting.
	Building and identifying process verification tasks, approvals.
	It helps to report failure effectively and report labors actual working hours and availability.
	Allowing to take the right maintenance decision, at the right time, at the right place, from the right information.
	Enhancing accuracy of critical data entry for maintenance history.
	Off-site (not in office) notifications and live feeds.
	Q/A decisions
Others	In the technology adoption lifecycle I'd say it's at the "early adopters" stage. Somehow there are big expectations on the role of mobile technology, but I think we're approaching the "peak of inflated expectations".
	I have seen it in action and it is a must in today's maintenance environment from time keeping for work orders, PM applications and storeroom operations
	Extremely limited use at moment, still structured and static approach.
	It is still very limited as maintenance organizations don't tend to invest in such luxury features. Also the current mobile solutions are still immature and suffer performance and synchronization issues.

V. CONCLUSIONS

Through the development of mobile technologies, the processing of information can be performed by technical personnel away from the central production office or site. Maintenance personnel, when doing their tasks, require relevant information in different sites and need to communicate interactively with experts in the back office. Using mobiles allows them to continuously receive a daily schedule from the head office. This leads to the saving of time and improving customer service and profitability. Furthermore, it is expected that the research finding will develop a unique framework that addresses the following issues (1) Business process alignment at all three levels (strategic, tactical and operational) in company activities through the variable of mobile collaboration technologies, (2) Engineering asset management with a specific focus on the most critical process – asset maintenance, and (3) Comprehensive framework that meet all requirements (technological, organizational and people perspectives).

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