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Mobile Collaboration Technology in Engineering Asset Maintenance – What Technology, Organisation and People Approaches Are Required?

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Abstract. Engineering asset maintenance consists of coordinated activities and practices for retaining or restoring a piece of equipment, machine, or system to specified operable conditions to achieve its maximum useful life. An integrated high-level maintenance comprising multiple sub-systems requires the collaboration of many stakeholders including multiple systems and departments. Several of specialised technical, operational and administrative systems have been invested by engineering asset organisations to enhancing their asset management and maintenance systems, however there is no common ground among engineering asset organisations about what are collaborative maintenance are required for adoption/implementation. The lack of systematic approach, together with the lack of specific requirements to implement mobile collaborative maintenance requests a comprehensive framework for guiding engineering organisation to implement of new mobile technologies that meet all maintenance collaboration requirements. This research proposes to develop an appropriate mobile collaboration framework based on Delphi and Case Study investigation.

Keywords: Mobile technology, Collaboration, Engineering asset, Framework.

1 Introduction

An imperative element of business management is having engineering asset management (EAM). It is essential to realize a business organization's mission which is having or operate assets. EAM is concerned with the life cycle of engineering or physical assets. It is also a critical stage of the continuous life cycle of assets, which includes acquisition, design, installation, maintenance and operation, and disposal stages [1]. The purpose of EAM is to maximise the total benefits of an enterprise by effectively using these assets throughout the whole life cycle.

The importance of maintenance function has increased because it plays an important role in retaining and improving system availability and safety, and product quality [2]. Reference [3] states that engineering assets in industries rely highly on their maintenance division to maintain and ensure assets are delivered properly. This

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author also revealed that 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 [3] and the existence of multiple stakeholders and departments [4]. Moreover, current working circumstances are more complex and therefore need to be managed by multiple and interlinked activities [5]. 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.

Collaborative maintenance is not a technology or a software solution; rather, it is a customized business strategy unique to each situation [6]. Based on a review of some relevant references [7][8][9], it is found that many organizations already have a collaborative maintenance system in place. However, with proper collaboration and commitment, that system can be expanded in scope and effectiveness.

To achieve the quality and efficiency of maintenance for engineering assets, this research proposes a framework to guide the adoption and implementation of new mobile technologies. It aims to facilitate asset maintenance collaboration, where organizations can expand their existing technology. In this context, efficiency means maintaining engineering assets without interrupting the production process for unnecessary breakdowns.

This research is structured as follows: the first section describes the motivation of this research. The second section provides a brief review of the concept of mobile collaboration technology for engineering or physical asset maintenance (PAM). This is followed by a brief description of the proposed framework, research methods, and the last section outlines a conclusion.

2 Research Motivation

This research is motivated by five factors. **First**, today's asset maintenance practices rely on access to information and team expertise from dispersed sites. Many businesses or companies have several interdependent departments and sub-systems that collaborate on various issues. Maintenance personnel in the form of individual and/or groups communicate, coordinate, integrate and distribute work. **Secondly**, information exchange in the form of direct communication, discussion, negotiation and decision making to complete the integrated maintenance (including strategic, tactical and operational levels) as well as maintenance information systems for structures a share pool of maintenance knowledge between certain maintenance roles (managers, directors, supervisors, engineers, technicians) in different site (between maintenance personnel in different offices, between maintenance and a remote help desk expertize centre, and between maintenance personnel in the field force in different sites) in any time are not supported by current PAM system/technology. **Third**, 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. **Fourth**, some frameworks for mobile collaboration have been identified in this preliminary literature review, however, only a few of these frameworks are relevant and applicable in

this research. Most of the design frameworks in the last decade refer to the technological approaches for hardware, software and network. **Last but not least**, only a few studies have explored how mobiles in the context of technological, organizational, and personnel requirements support collaborative maintenance in engineering asset organizations. Few survey and case studies have been conducted to understand the current state of collaboration technologies including mobile technology support engineering asset organizations.

3 Literature Review

3.1 Engineering Asset Maintenance

Maintenance is a combination of actions intended to retain an item in, or restore it to, a state in which it can perform the function that is required for the item to provide a given service. This concept leads to a first classification of the maintenance actions in two main types: actions oriented towards retaining certain operating conditions of an item and actions dedicated to restoring the item to supposed conditions. “Retention” and “restoration” are denominations for action types that are then converted into “Preventive” and “Corrective” maintenance types in the maintenance terminology by European Committee for Standardization.

Reference [10] acknowledges that maintenance processes consists of several tasks that must be in line with three levels of business activities, namely: strategic, tactical and operational. At the *strategic* level, business priorities will be transformed into maintenance priorities. The transformation process is done by supporting expertise within a certain period to address current and/or potential gaps in equipment maintenance action or strategy. A generic maintenance plans (middle and long range) will be obtained at this level. Actions at the *tactical* level will define the appropriate task of maintenance resources such as skills, materials, test equipment, etc. to fulfil a business’s maintenance plan. At this level, a detailed program consists of particular tasks and the resources allocated would be achieved. At the *operational* level, maintenance tasks would be done accurately by skilled engineers, in the time that has been allocated, following right procedures, and using the appropriate tools. Preventive and corrective maintenance procedures are carried out so tasks receive a high level of attention. All maintenance tasks will be completed and the maintenance data history would be recorded in the information system at this level.

3.2 Current IT/IS Capabilities for Engineering Asset Maintenance

Reference [11] emphasise that in order to manage the sophisticated AM process and to provide its data requirements, particular technology and systems are required. The system that captures, maintains, and manages all the needed asset information throughout the entire asset lifecycle is critical in providing effective asset management. Currently, several of specialised technical and operational systems have been invested by EAM organisations to enhancing their asset maintenance systems. These technologies and systems aimed at support the whole asset lifecycle.

The very popular maintenance information systems that have been implementing for engineering asset maintenance are Computerised Maintenance Management Systems (CMMS) [12]. 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 successful CMMS is less than 30% of total CMMS applications [13]. The main reasons are [14]: Selection errors , insufficient commitment, lack of training , failure to address organizational implications, underestimating the project task, lack of project resources and lack of demonstrable use of system output.

3.3 Collaboration Requirements by Asset Maintenance' Stakeholders

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 [15]. 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 [16].

In order to encounter good asset maintenance and meet the optimum performance of engineering assets, organisations require a collaborative teamwork within key functional areas (stakeholders) of the engineering organisations. Shared understanding, coordination, cooperation and collaboration across maintenance stakeholders of what asset maintenance is and how the entire maintenance team influence the ability to achieve organisational 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, IT and maintenance technicians.

Mobile collaboration technology required for asset maintenance need to be capable of simultaneously handling, processing and delivering technical and operational information to multiple maintenance crew 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, organisational, as well as personal perspectives.

3.4 Proposed Framework

In order to develop the mobile collaboration PAM framework, the research questions need to be answered. The major question is: How can mobile collaboration technologies assist asset maintenance in engineering asset management organization?

Based on the extensive literature review, a conceptual research framework was developed as shown in Figure 1. It encapsulates the core concept of [17] TOP model as a means of studying collaboration requirements from either technical or organisational or personal perspectives. It also includes the alignment of maintenance processes with three levels of business activities: strategic, tactical and operational [10]. This conceptual framework will guide the planning and activities in the subsequent research for investigating collaboration requirements in physical asset maintenance.

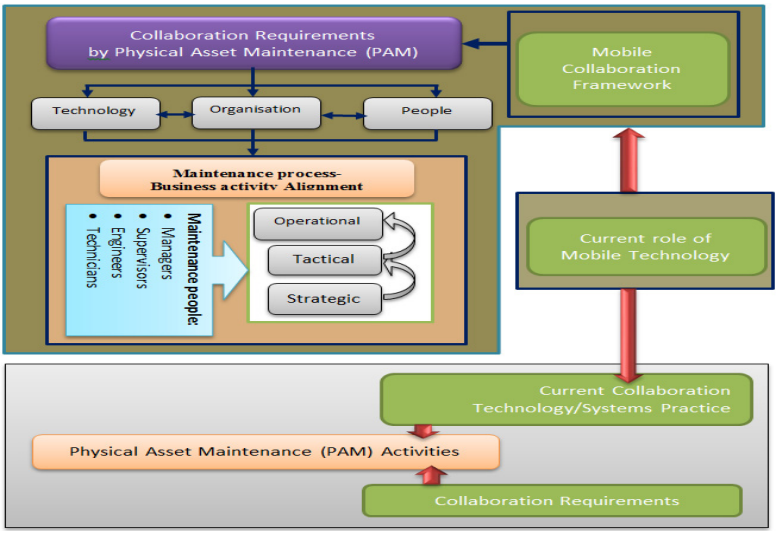

Fig. 1. Preliminary Maintenance Collaboration Framework

4 Research Methods

This research will be an interpretive study using both quantitative and qualitative methodologies. References [18][19][20] have reasoned that interpretive attempts to understand phenomena through the meanings that people assign to them are relevant. This understanding is particularly relevant in this research because the researcher is seeking to understand certain issues by industries survey, Delphi study and interviewing people on how mobile collaboration technologies will assist the asset maintenance process in a given organization's context. In order to create a complete set of requirements of collaboration maintenance in engineering organizations, the case study results here will be triangulated with the survey, Delphi study and case study findings. Triangulation is the use of more than one research strategy to explore the same phenomenon so that the credibility of research results is improved [21].

4.1 The Delphi Technique

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 [22]. 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 [22].

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 [23].

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 1 and 2.

Table 1. Participants by Role

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

Table 2. 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. **The second round** 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.

4.2 Multiple Case Studies

Semi-structured interview-based multiple case studies will be conducted to explore the collaboration requirements for asset maintenance practices, to obtain information on the deficiencies in existing collaboration requirements.

In order to create a complete set of requirements of collaboration maintenance in engineering organizations, the case study results here will be triangulated with the Delphi study findings. Triangulation is the use of more than one research strategy to explore the same phenomenon so that the credibility of research results is improved [21].

5 Preliminary Findings and Discussion

Delphi question 1: ***Please mention collaborative maintenance requirements.***
From the responses of 19 panel members, we analyzed 63 individual statements. We then grouped into similar requirements and then mapped into Technology (T), Organization (O) and People (P) approaches as illustrated in Table 3.

Table 3. Collaborative maintenance Requirements

TOP	Delphi Round 1
Technology	*1. Synchronised multi-user access over a feature-populated dashboard*
	2. Data and services access through contextualised and mobile interfaces
	3. Data and services functionality porting to the cloud
	4. Autonomous information/communication exchange
	5. Linking the maintenance planning and dispatching
	6. Provides different mode for specific maintenance role
	7. Support interoperability between maintenance role
	8. Provide a platform for maintenance knowledge sharing across maintenance crew
	9. Social networking
Organization	*1. Cross-organisational management communication*
	2. Appropriate coordination mechanism of the team
	3. Availability and readiness all of maintenance crews
	4. Maintenance must be profit and customer-centred
	5. Clear maintenance vision (maintenance strategy-business objective)
	6. Maintenance crew using common maintenance language on syntactic and semantic consideration
	7. Combine professional experiences to support team work
	8. Provide team building activities to develop team work and skills

Table 3. (*continued*)

People	1. *Informal social networking between personnel*
	2. *Craft skill and training*
	3. *Common understanding of maintenance processes*
	4. *Common understanding of the system*

Delphi question 2: ***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 4.

Table 4. 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.
	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	early adopters stage in the technology livecycle. stage.
	Extremely limited use at the moment

6 Conclusion

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 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. 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, organisational and people perspectives).

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