Mobile Collaboration Technology to Support Maintenance Enterprise Systems in Large Industry

Full Paper

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Abstract

Mobile collaborative maintenance system (MCMS) has the potential to offer significant advantages over existing maintenance systems. Moreover, in this context, an integrated high-level maintenance strategy 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. Several specialized systems have been invested in to enhance asset management and maintenance systems; however, experts argue that the success rate of such systems is less than thirty per cent. The lack of systematic approach, together with the lack of specific requirements may be the main cause, which calls for a comprehensive framework that engineering organization can implement. The objective of this research therefore is to propose a framework guiding the implementation of new mobile technologies enterprise that meets all collaborative maintenance requirements.

A. Introduction

Today's engineering asset maintenance practices rely on access to information and team expertise from dispersed sites (Burmeister 2006). 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. People and computer systems are the media that can simplify such activities (Hardi & Whittaker 2000). 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 (Laszkiewics 2003).

Collaboration is critical factor in the technicians' quest to in particular complete immediate or unplanned maintenance tasks. Normally, simple task that are typically accomplished by a single individual may require communication at the beginning to fully understand the requirements and goal essential to successful maintenance task completion. The requirements for collaboration are increased by the complexity of the large industries such as mining, utilities, telecommunications, etc. where large amount of knowledge, experience and skill are required, however there are only few maintainers and/or technicians having all the skill necessary to solve all possible scenarios. Hence, according to Curtis, et al. (2006) collaboration needed and contacting another technicians or maintenance expert for advice is a logical way in solving a very difficult or complex maintenance tasks especially in large engineering asset industries.

Mobile technologies and solutions are very popular in consumer applications and the exploitation of these technologies is expanding. But, in large-scale industries, maintenance of mobile solutions has not yet attracted much attention. One explanation behind this is the lack of competence and knowledge for successfully adopting and implementing mobile solutions in professional use. Many companies have

experienced problem in implementing the maintenance of mobile solutions due to inoperative telecommunication connections, lacking of suitable devices or insufficient organizational implementation preparation. Another reason is that the benefits of mobile solutions have not been well-recognized in maintenance domain (Backman & Helaakoski 2011). Fernández, Francisco and Márquez (2009) imply that the multidisciplinary problem solving in maintenance requires the knowledge of various application domains and assumes knowledge integration from various stakeholders' sources.

The perfect understanding of the requirements that support collaboration (coordination, communication and cooperation) and information management define the success of the system to be implemented (Mulligan, O'Sullivan, & Beck 2003). Therefore, a set of requirements to guide implement technology or system related to mobile collaborative asset maintenance in engineering organization seen as critical to effective decision making. From the above explanations, these raise the issue that mobile collaboration technology in the domain of engineering asset maintenance requires research attention to address the research question: How can a mobile collaborative maintenance system be implemented in engineering asset organizations through the provision of an appropriate framework that meets all maintenance collaboration requirements?

This study, therefore aims to investigate how mobile collaboration technologies can assist maintenance activities in engineering asset management organizations. This study, proposes an appropriate guideline for engineering asset management organizations to successfully implement MCMS that met multi perspectives: technological, organizational and personal (TOP) requirements.

This paper is structured as follows: the second section describes mobile technology to support collaborative maintenance. Section 3 presents technology implementation. The methodology used in this study described in Section 4. Section 5, discuss the research findings and MCMS framework. Section 6 concludes the paper.

B. Mobile Technology to Support Collaborative Maintenance

The use and implementation of mobile services has been studied globally and extensively from context-driven organizational problem solving of view (Bardram & Bossen 2005; Charterjee et al. 2009; Haaparanta & Ketamo 2005; Sheng, Siau & Nah 2010). When considering use of mobile solutions in industry and especially in maintenance the available studies and researches focus mainly on e-maintenance (Campos 2009; Marquez & Iung 2008; Muller, Marquez & Iung 2008). Term e-maintenance is still quite large concept where the mobile solutions can be one part of it. Some e-maintenance specific case studies focus on mobile device architectures where the mobile device can for example help the maintenance engineer to perform maintenance tasks (Campos 2009). Mobile solutions can bring maintenance management closer to the daily practice in the field and lead to more efficient maintenance operations. Mobile collaboration has progressively become a significant concern in CSCW. Some researchers have been conducted by Herskovic et al. (2009), Hislop (2008), and Milrad and Spikol (2007) in efforts to recognize the implications of mobile work and mobile collaboration on collaborative applications design.

C. Technology Implementation in Asset Maintenance

Although computerized maintenance system such as CMMS makes a great volume of information available for reliability and efficiency analysis of the delivery of the maintenance function, but most experts agree that successful CMMS is less than 30% of total CMMS applications (Zhang et al. 2006). Moreover, Weir (2000) found that actually it is not just CMMS implementations that are prone to failure. A 1998 study by The Standish Group in Massachusetts, USA found that 74% of all IT projects fail. Also, a 2001 survey conducted by MRO Today magazine in the US found that about 80% of CMMS users do not use all the available functions of their systems. This figure is confirmed by a 1999 study carried out by Tompkins Associates, which produced a figure of 70%.

The main reasons for unsuccessfully implementation of CMMS according to Olszwesky (n.d) are: selection errors, insufficient commitment, lack of training (no user training was developed or conducted), failure to address organizational implications, underestimating the project task, lack of project resources and lack of demonstrable use of system output. Similarly, Bradshaw (2000) found the success or failure of CMMS

depends on human factors like for example policies, rules, selection process, integration, training, support, resources, functionality, usability, usage, reviewing, work planners' motivation, work culture, skills, trust and commitment of management.

Technology implementation in asset maintenance has narrow focus and scope, which emphasizes technical aspects and does not give due attention to organizational, social, and human dimension of technology implementation. This approach to technology implementation at best serves as process automation and does not contribute to the cultural, organizational, and technical maturity of the organization. There is no attention given to application integration, information interoperability, and data accessibility. At the broader organizational level, such implementations face resistance from maintenance stakeholders and the consequent change management is difficult (Haider 2008). Hence, the technology, organization, and people (TOP) approach are essential to be considered as the same foundation for implementation.

C.1   TOP Approach

The success of technology implementation depends on an organization's interpretation of the role technology plays in attaining business objectives, other factors like organizational culture, acceptance from users, leadership style, the fit between task and technology, influence to some degree the success of technological implementation in an organization. This section specifically discusses three important perspectives that need to be taken into account in technology implementation in engineering asset management organizations. Mitroff & Linstone (1993) argue that any phenomenon, subsystem or system needs to be analysed 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 (1999) and Mitroff & Linstone (1993). 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.

Mitroff & Linstone (1993) suggest that these three perspectives can be applied as "three ways of seeing" any problems arising for, or within, a given phenomenon or system. Werhane (2002) 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".

It is found that the study about 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.

D. Research Methodology

This research was an interpretive study using both quantitative and qualitative methodologies. Klein and Myers (1999), Deetz (1996), and Orlikowski and Baroudi (1991) 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 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 in the form of MCMS framework, the case study results were triangulated with the Delphi study findings.

D.1   The Delphi Technique

The Delphi technique is employed to more accurately build the consensus from the panel expert's perception (Dalkey & Helmer, 1963). 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 (Linstone & Turoff 1975).

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. These categories were chosen because of their personal knowledge of work and information technology skills needed in a mobile collaborative maintenance setting.

Roles for potential participants come from two groups of expert in the field of MCT in relation to asset maintenance:

- academics—subject-specific experts and authors (research & publication)
- professionals—subject-specific experts working in the field.

All participants needed to meet at least three of four criteria below:

- current involvement in education in the field
- leadership in developing, implementing and evaluating IT projects related to the field
- publications in the field
- certified maintenance professional (management and/or technician)

Of these, 20 experts from ten different countries are selected and willing to participate in the research project. There are 8 from universities (academics) and 12 professionals from 10 different countries.

Delphi design: A three-round Delphi email-based questionnaire was designed. **The first round** (generating ideas/issues) was an initial collection of requirements consisting of open-ended solicitation of ideas. In this stage, we did not receive response from one of twenty experts, after twice reminder. One respondent are withdraw in this stage. **The second round** (Eliciting agreement) was the validation of categorized list of requirements. The experts were asked to verify the list that the researcher had 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, add or regroup the item (s) into other groups/categories. **The third round** (obtaining consensus) was about ranking relevant requirements. The consensus in the ranking order of the relevant group/category about requirements is achieved in this final iteration. In the analysis of this round, the consensus level of agreement was set at 70% to 100% agreement or disagreement.

D.2   Multiple Case Studies

Semi-structured interview of eight large sized of Australian and Indonesian industries of telecommunication, electricity, airline services, and oil and gas, in both the public and private sectors conducted to explore the collaboration requirements for asset maintenance practices. These interviews were conducted with key maintenance persons. There are four types of stakeholders—managers and directors; supervisors, superintendents, inspectors, planners and schedulers; technicians; and engineers. They are directly involved in maintenance activities and most had roles and responsibility for maintenance IS or IT project implementation - in their company.

Case study research provides the advantage of presenting a holistic view of a process (Yin, 2009). An in-depth investigation allows different aspects of a research topic and their relationships to be analysed (Markus, 1983). The primary goal of the case study is to examine the level of importance of the requirements, verify the Delphi findings, determine the ranking order of requirements of asset

maintenance collaboration, identify the main requirements that need to be focused on and examine the relationships between the requirements.

In order to investigate the MCMS implementation requirements in the case-study organizations, both within-case and across-case analyses were conducted. In theory, within-case analysis is often done before cross-case analysis when a multiple case study-strategy is adopted for research design (Perry 1998; Yin 2003). Therefore, the case-study analysis started with the analysis of each individual case, in which the cross stakeholder analysis within one case was included. The across-case analysis of all case organizations followed, with the focus of the factors being confirmation and disconfirmation.

D.3 Triangulation

In order to create a complete set of requirements of collaboration maintenance in engineering organizations, the case-study results are 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 (Greene & Caracelly 2003). By using quantitative and qualitative approaches, this method provides a powerful means for analysis and interpretation of data (Sieber 1973; Jick 1979). Similarly, Smith (1975) argues that researchers can enhance the accuracy of their decisions by gathering different kinds of data on the same phenomenon. A MCMS framework, as presented in the next section, is developed based on this triangulation method.

E. Findings and Discussions

A statistical comparison of the requirements identified from the Delphi study and case study is summarised in Table 1. The Delphi study identified 26 requirements, whereas 31 requirements were found in the case study. As expected, more factors were identified from the case study because the case study was designed to provide in deep insights into the requirements of MCMS implementation in engineering assets organizations. Furthermore, 23 requirements were found to be common to both analyses and 11 requirements were specific to one analysis – 3 are unique to Delphi study and 8 are unique to case study.

TOP	Delphi	Case Study	Common	Delphi Only	Case Study Only	Majority of Case Study Stakeholders' Support
Technology	10	13	10	0	3	4
Organization	10	11	8	2	3	3
Personal	6	7	5	1	2	3
Total	26	31	23	3	8	10

Table 1: Comparison of the number of the requirements identified from Delphi study and case study

E.1 MCMS Framework

As shown in Table 1 there are ten requirements received majority support from the case study's stakeholders in the research, and were identified as the important key requirements for successful implementation of MCMS in engineering organizations. Therefore, it appears to be appropriate to build the MCMS implementation framework based on these key requirements. The MCMS framework for asset management is proposed in Figure 1 below. The uniqueness of this research is the MCMS framework covers the longest stage of the basic asset lifecycle (Snitkin 2003; Lutchman 2006) specifically within the three levels (strategic, tactical and operational) of maintenance process-business activities alignment (Marquez 2007) and encapsulates of Linstone (1999)'s TOP concept to present the MCMS implementation requirements setting.

Figure 1: Proposed MCMS implementation framework
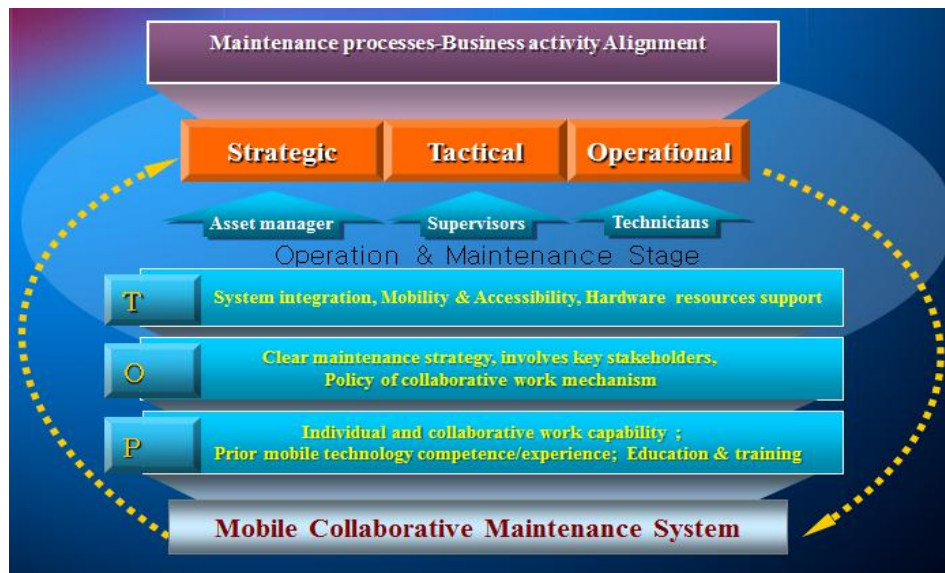
Ten key collaborative maintenance requirements identified through Delphi study and multiple case studies across technological, organizational and personal perspectives in this research. Each of the requirements in the framework is also discussed below.

E.1.1   System integration/interoperability

Engineering organizations typically use a diversity of technical and business systems such as CMMS, SCADA, SAP, and GIS for asset management/maintenance. As these systems normally are bought from multiple vendors and each is specialized to accomplish its task, system gaps exist not only among the disparate technical systems but also between the business and technical systems. As a result, the engineering data either becomes isolated, localized or requires manually repeated double data handling. It is not only difficult to access the data by other stakeholders or systems, but also increases the likelihood of enterprise data errors.

From the industry perspectives, this research has found that collaborative maintenance system should include technical functionality (architecture) that allows direct integration with other related departments such as finance and warehouse systems. This facilitates the automatic placement of orders to the appropriate vendor when stock levels reach the pre-defined minimum. To be interoperable in the context of maintenance data and information, a system should plug and play data and information expressed in different formats but having similar descriptions seamlessly, extract useful information from them automatically, and use such information in all system applications consistently. For example, potential integration opportunities exist with shop floor data systems and SCADA applications. Shop floor data systems in a manufacturing organization can offer data on production schedules and the availability of equipment for maintenance. Maintenance work orders can then be planned based on this information. SCADA software can deliver signals indicating the status of equipment or systems and corrective work orders can be raised based on the data received in MCMS.

E.1.2   Mobility of users, devices and services

Mobility refers to characteristics of device to handle collaborative asset maintenance data and information access, communication in state of motion. According to Kristoffersen & Ljungberg (2000), data/information and service can be accessed through particular mobile collaborative maintenance interface into three different forms: locational, operational and interactional. Locational mobility implies to geographical movement, whereas operational mobility refers to flexible coordination of operations and interactional mobility to intense interaction with maintenance people and data/information through mobile devices.

From the perspective of industries real maintenance activities, it was found that mobility of users, devices and service is required to improve collaborative asset maintenance, as highlighted in six case study organizations. Some maintenance people across those organizations mentioned some sub-requirements related to mobility, for example:

> Maintenance data/information should be made accessible by portable/mobile devices as technicians/engineers are working on the move,

The Asset manager in Case A acknowledged that by using mobile devices the technician can perform the actual work with structured instruction from the expert system. In addition, the supervisor in this organization explained that some of maintenance activities such as tracking maintenance resources can be done anytime anywhere by using mobile devices.

E.1.3   Hardware resources support

Collaborative mobile applications should operate with heterogeneous hardware resources. Handheld devices with constrained hardware resources are the typical equipment to be used: e.g., Personal Data Assistants (PDAs), smartphones or mobile devices. The ideal condition to support collaboration work, even this is not always possible, is to lightweight communication and coordination in mobile services (Alarcon et al., 2006).   Fulfil this requirement will directly affect the interoperability as mobile application, in many cases, operating with varied devices.

Requirements related to hardware resources supports identified in Delphi study described as multimedia support (can capture/record and present audio, picture, or video), can print report or document directly from outside of the office.

From industry perspectives, a number of requirements related to hardware resource support are expected by the case study's participant. For example, interview analysis identified:

> Multimedia data (picture, audio, and video) format requires for providing quality data and well-structured guidance in maintenance tasks.

As mobile device is become lighter and even smaller, battery life, screen size, keyboard, memory and data storage are important supporting resources for maintenance people to keep prompt accessing maintenance information such as equipment history and repair information in the field.

E.1.4   Data and information accessibility

At present, data and information accessibility plays a crucial role to support maintenance decision-making. The combination of modern information processing and communication tools offers the technical support required to access remote maintenance information (Iung, 2003).

Delphi study panel members rated of maintenance data/information and service functionality is porting to the cloud to make it easily accessible as the third ranking within technology requirements. Through maintenance cloud computing policy, maintenance task such as condition monitoring and asset diagnostic can be accessed online by maintenance people without involvement of IT staff in the office.

Case study analysis further revealed some sub-requirements as for example:

> Porting maintenance data to the cloud is another alternative to anticipate big maintenance data, and this data/information will be available and easily accesses from anywhere even when accessing by many users at the same times,

Since an organization's entire facilities maintenance team may be spread out across multiple facilities, ensuring access to a centralized work order system is often difficult or costly. This can be eliminated completely and collaboration enhanced by employing a cloud-based service. With a hosted solution in place, maintenance crews can receive their work orders directly on their smartphones or tablet computers. In addition, they can update the status of each maintenance tasks, schedule future tasks, view schedules, and more directly from their mobile devices.

E.1.5   Clear maintenance strategy

Organizations have to understand the business process flow and its factors from operational and maintenance perspectives. Defining the critical points and potential problems within the process flow enables to determine, easily, which technology services should be used to alleviate the collaboration issue. According to Murthy *et al.* (2002) that the strategic view of maintenance by the equipment state, the operating load, maintenance strategies and business objectives. Robson, Trimble and MacIntyre (2013) argue that maintenance strategies are important because they can bring significant benefits to manufacturing organizations.

From the perspectives of mobile maintenance's professionals and academician, the Delphi panel members have raised a clear maintenance vision (clear maintenance strategy-business objective) related requirement and this requirement are rated as the most important requirement in organizational approach.

Collaboration and teamwork make an important contribution to the success of business initiatives like quality improvement, product development or customer service. The maintenance goal, objective and scope are defined based on the business or organization's requirements, and therefore the implementation of the new software system such as MCMS, will get a very clear and correct direction from the initiation until implementation stages.

E.1.6   Involving stakeholders in system design/selection

Based upon Delphi study result, panel members rated of involving key maintenance stakeholders as a top four requirements for implementing collaborative maintenance system. Moreover, final system selection is made after consideration and evaluation of information provided and on-site demonstration by various system providers/vendors. The final decision is made by organization by the join selection team (involving maintenance crews), not by one individual. Delphi study has also found that one of the current problems of collaborative maintenance systems was resistance to adoption-staff reluctant to participate, believing that the implementation of such system will not change the maintenance practice.

In practice, this research has found that anyone whose job or workday will be directly impacted by MCM software should be involved in choosing/designing it. Organization makes an effort to understand, document, and address each stakeholder's needs when choosing/designing MCM system to ensure a comprehensive organization's requirements are fulfilled. Schneider and Sarker (2005) claimed that one of the problems of CMMS implementation, partly due to lack of stakeholders involvement in system selection.

E.1.7   Policy of collaborative work mechanism

It was identified by panel members of Delphi study in this research that appropriate coordination mechanism of maintenance team. The collaborative system should provide prioritised direct interaction, so that when needed, for example shop-floor personnel can prompt to managers and vice-verce. Regular meeting (at least weekly or bi-monthly) will develop rapport and sharing of information and exchange of ideas.

From the perspectives of industry, some key stakeholders from five participated organizations expected that the organization build a policy of collaboration work mechanism in support collaborative maintenance system. The reasons behind this requirement, for example:

> Awareness of coordination mechanisms is essential to support collaborative systems in order to transform irregular interactions of maintenance team into a consistent and insightful maintenance performance over time. Coordination mechanism in the form of policy aimed at coordinate maintenance crews' interdependencies.

It was found that, the goal of collaborative of maintenance information shared is to provide maintenance information to maintenance people, either proactively or upon request [by supervisor], such that the information has an impact on another maintenance person's [in team] in making a decision. In addition, collaborative working mechanism policy should arrange at least two courses, firstly: how multi-users

cooperate each other and secondly: how they controlling and coordinating to sharing maintenance resources.

E.1.8 Individual and collaborative work capability

The Delphi study has found that implementing collaborative maintenance system requires collaborative work culture, trust and motivation. By having a collaborative work culture, every maintenance crew is on an equal playing field, thus facilitating decision making processes which are expected to be more efficient because ideas and thoughts can be exchanged spontaneously across all maintenance levels.

From the industry perspectives, several sub-requirements related to individual and collaborative work capability were raised by the case study's research participants, such as:

> Teamwork togetherness is believed as an important requirement to achieve high quality of maintenance work. Individual and collaborative capability of technicians even, in some cases, more valuable than their technical skills.

Collaboration is more than just a willingness by one technician to work in a team or just sharing maintenance information with another. Collaborative maintenance is a process by which maintenance crews, maintenance system (MCMS) and organization working together as a team efficiently and effectively to achieve the best performance of the organization.

E.1.9 Prior mobile technology competency/experience

Personal mobile technology competence and experience is the ability of an individual to do a maintenance job properly with a support of mobile devices as a consequence of the interaction between an individual and mobile devices, system or service within certain period of time in the past.

Requirement of prior mobile technology competency/experience was not identified in the literatures and was not supported by Delphi study.

With regard to requirements of prior mobile technology competency/experience, case study's maintenance stakeholders nominated two related-sub-requirements, for example:

> The technicians/engineers who have a basic mobile technology competence are considered more capable working in supporting MCMS compare those who are new in mobile application.

The asset maintenance tasks requires person with technical skill who can work effectively with specific computerized asset management system. Recruiting the right people in the right position for asset maintenance for engineering asset organizations using collaborative maintenance system, encompasses recognizing the prior mobile technology skill and experience. This experience can positive significantly affect maintenance crew's self-efficacy in how they approaches maintenance tasks, goals, and challenges with a mobile technology supporting. Qualified maintenance person (in both maintenance processes and its technology solution) is one of the most valuable resources of every organization.

E.1.10 Education and training

As acknowledged by Romero et al. (2007) that migrating towards collaborative environment, requires a new organizational orientation and infrastructure based-on a collaborative culture which can be associated to a set of primary requirements such as: openness, commitment, leadership, trust-building, self-learning, continuous training, long-term and global vision, effective communication, knowledge sharing and innovation.

The panel members of Delphi study in this research rated the maintenance personal skill and training as the third ranking order in the final round. They believed that skilled people recruited will encourage a maintenance group motivation and related maintenance processes and collaborative information system training is required regularly to refresh their current knowledge.

From the perspectives of industry this research has found that without training, the implementation will take longer, adaptation will be more problematic and frustration will be higher. This is because, without

having the necessary skills to manage and control the system, even perfect systems are unable to support effective collaborative maintenance.

F. Conclusion

The MCMS framework covers the operation and asset lifecycle across the three assets maintenance-business strategy alignment levels of strategic, tactical and operational. In general, technology requirements are all about maintenance data/information integration and accessibility trough mobility of the users, devices and services, organizational requirements are related with engineering asset organization's role in supporting collaborative maintenance process to achieve business objectives, while personal requirements are concern to individual competency, knowledge and/or experience to perform maintenance task using new mobile maintenance system either in individual or collaboration maintenance context.

The most significant contribution, among others, of this thesis is establishing the interrelationship between technological, organizational and personal (TOP) implementation requirements approaches through the MCMS framework developed and empirically tested. Engineering organizations, thus will be better able to identify critical requirements includes be better able to understand the relationships among these key requirements for successful implementation.

This study does not provide particular technologies, mobile computing devices and/or tools that best fit in supporting particular maintenance, but the set of MCMS framework of implementation requirements (research result) as well as the set of collaborative maintenance uniqueness (extensive review of literatures) could be a basis for future research in order to investigate:

- Advantages and disadvantages of every type of mobile computing device to support the application functionality in collaborative maintenance work context,
- Which variants of a software application need to be developed in order to cover the specific collaborative maintenance work contexts, and
- What the functionality could be included in each variant.

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