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APPLYING THE INTERNATIONAL DELPHI TECHNIQUE IN A STUDY OF MOBILE COLLABORATIVE MAINTENANCE REQUIREMENTS

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Abstract

This paper focuses on the multiperspective requirements that influence mobile collaborative maintenance adoption and implementation in engineering asset management organizations. Mobile technologies have developed rapidly and they are viewed as business enablers, and have the potential to support asset maintenance practice. Nowadays, several specialized systems have been invested in by engineering asset organizations to enhance their asset management and maintenance systems, however most experts agree that the success rate of such systems is less than thirty per cent. The main reason for unsuccessful implementation is that there is no agreement as to what types of collaborative maintenance systems are required. To the best of our knowledge, this research is among the first in attempts to identify the mobile collaborative maintenance requirements through eliciting the expert panel points of view via a Delphi study. The aim was to develop and propose an appropriate framework for guiding engineering organizations to implement new mobile technologies in facilitating asset maintenance collaboration. The Round two of the three-round Delphi iterations identified 31 of the mobile collaborative maintenance requirements which cover technological, organizational and people perspectives.

Keywords: mobile technology, collaborative technology, engineering asset maintenance

1. INTRODUCTION

The importance of maintenance function has increased since it plays an important role in retaining and improving system availability and safety, and product quality (Tsang, 2002). Hodkiewicz and Pascual (2006) state that engineering assets in industries rely heavily on their maintenance division to maintain and ensure that assets are delivered properly. Research has revealed that in the last 30 years, the practice of performing maintenance has significantly changed due to the development of equipment design, information and communication technology, cost pressures, customer acceptance of risk and failures (Hodiewicz & Pascual, 2006) as well as the existence of multiple stakeholders and departments (Snitkin, 2003). Moreover, current working circumstances are becoming more complex and therefore need to be managed by multiple and interlinked activities (Camacho et al., 2008). Hence, an integrated high-level maintenance system containing multiple sub-systems requires the collaboration of multiple stakeholders such as dedicated 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 (Laszkiewics, 2003). Based on a review of relevant literature (Besten, Dalle & Galia, 2006; Ferrario & Smyth, 2001; Rein, 1993), it has been found that many organizations already have a collaborative maintenance system in place. However, that system could be expanded in scope and improved in effectiveness with more proper collaboration and commitment.

To enable and to ease the maintenance process in an organization at the strategic, tactical and operational levels, IT need to be better structured as one of the basic supporting structure (Marquez, 2007). The most popular IT system that has been implemented for engineering asset maintenance is the Computerized Maintenance Management System (CMMS) (Tam & Price, 2006). A proper utilized of such system can assure effective management of this costly equipment. In addition, Zhang et al. (2006) conclude that successful utilisation of CMMS can lead to increased quality, better decision-making, and increased efficiency. However, most experts agree that success rate is less than 30% of total systems applications. Olszwesky (n.d) outline the main reasons for unsuccessful implementation of computerized maintenance systems, including 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. It is clear that most of the main reasons for unsuccessful implementation are organizational and personnel factors although, unfortunately, existing research and the current literatures have mostly studied the technological side in the area of hardware, software, and networking, with a lack of attention payed to the systematic approach, or the specific requirements to implement computerize maintenance information systems including the mobile collaborative asset maintenance system.

The aim of this research is therefore to develop a unique framework to guide engineering organizations implementing new mobile technologies that addresses the following issues:

- Business process alignment at all three levels (strategic, tactical and operational) in company activities through the variable of mobile collaboration technologies.
- Engineering asset management with a specific focus on the most critical process – asset maintenance.
- Comprehensive framework that meet all requirements (technological, organisational and people perspectives).

This paper is structured as follows: the second section describes research on mobile collaborative maintenance, and Section 3 presents the methodology used in this study. Preliminary findings are presented in Section 4 and the final section discusses the results in light of the current literature and also purports adiscussion and conclusion.

2. MOBILE COLLABORATIVE MAINTENANCE

Through the continuing development of mobile technologies, the processing of information can be performed by technical personnel away from the central production office or site. While performing their tasks away, maintenance personnel require relevant information in different sites and need to communicate interactively with experts in the back office (Emmanoulidis, 2009). In regard to the maintenance task, Sinha et al. (2007) explain that using mobiles allows maintenance personnel to continually receive a daily schedule from the head office, which leads to the saving of time as well as improving customer service and profitability. Luff and Heath (1998) and Campbel et al. (2006) agree that increased mobility of special artifacts can enhance tasks and responsibilities. In addition, Emmanoulidis (2009) argues that in order to support maintenance task, the use of mobile collaboration technologies is a visible and effective approach. The maintenance task can be supported by mobile collaborative technologies, such as information about machine state, process state, work orders and scheduling, a list of experts and their availability, as well as condition monitoring and data diagnosis.

Emmanoulidis (2009) explains that, with reference to production machinery, the right information and tools are present, but they are, typically, 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 while on the move. Such technology enables the availability of data/information and engineering tools anytime and anywhere to anybody. Furthermore, as stated by Emmanoulidis (2009), maintenance practice involves doing complex tasks such as maintenance planning, inspection, and diagnostics, which usually requires cooperation with another person. This type of collaboration is not new but is a normal way in engineering industries whereas having the availability of mobile collaboration technology in place offers a new perspective to support the asset maintenance action. Indeed, crew involved in maintenance activity requiring collaborative effort including inspection, monitoring, routine maintenance, overhaul, rebuilding, and repair (Marquez, 2007), consider this mobile collaboration technology to be a necessity (Emmanoulidis, 2009).

2.1 Collaboration Requirements by Maintenance Crew

The industry as a whole is focusing on ways to better manage the complex processes performed by maintenance crews in their production facilities as a way to meet the target. Managing activities in a complex engineering organisations 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.

In order to improve quality and reliability, maintenance people are required to access physical asset information related to maintenance from a mobile device on-site, not back in the head office. Mobile technologies play a key role in this setting, by facilitating the establishment of tightly integrated environments between different groups and organizations that bear stakes on the performance of the industrial assets (Liang et al., 2007). Despite the fact that the use of advanced application solutions in manufacturing, production, or process facilities occurs 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, by uilding agile information and knowledge networks, regardless of the geographical location. (Monostori et al., 2006).

Mobile collaboration technology required for asset maintenance should 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. These requirements include technological, organisational, and personnel (TOP) perspectives.

2.2 TOP Approach

Mitroff and Linstone (1993) claimed that any phenomenon, system or subsystem 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 (1999) and Mitroff and Linstone (1993).

Mitroff and 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 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 in the context of the problem 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-personnel of collaborative maintenance requirements reflects the idea 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.

3. METHODS

This study is conducted to identify collaboration requirements, current collaborative maintenance practice and mobile technology roles in support of 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 (Dalkey & Helmer, 1963). Consensus agreement can vary from 51% (Loughlin and Moore, 1979), 70 % (Sumsion, 1998) to 80% (Green et al., 1999) among participants. The Delphi method is employed for several reasons: 1) The topic 'Mobile collaboration technology in engineering asset maintenance' is a relatively new, and complex issue, 2) limited literature has discussed the topic, and 3) not many empirical data were available. The Delphi study carried out in this research comprised three rounds (Linstone & Turoff, 1975) and aimed to address the following research questions:

RQ1: What are the mobile collaboration requirements in engineering management organizations for asset maintenance activities?
RQ2: What is the existing state of collaboration technologies being used in engineering management organizations for asset maintenance activities?
RQ3: What is the current role of mobile technologies in the above collaboration technologies?

Nomination of experts. A total of 47 experts who have strong academic backgrounds, research experience and professional careers in the area of mobile asset maintenance were invited to participate in the Delphi survey. Of these, 20 were willing to participate in the research project. Eight of them were academics and 12 were 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. Respondents were asked mainly about three basic questions, corresponding to three research questions. Specifically, the questionnaire asked experts to list general and the collaborative asset maintenance specific requirements, selecting criteria, benefits as well as initiatives issue that may hinder maintenance collaboration in order 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 possible solutions. Respondents were asked to list the roles of mobile technology in support of the current collaborative asset maintenance in order to address the third research question (RQ3). 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. In the analysis of this round, the consesnsus level of agreement was set at 70% to 100% agreement or disagreement. **The third round** (obtaining consensus, in progress) is about 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 focused on.

4. PRELIMINARY FINDINGS

4.1 Mobile Collaboration Requirements

From Round 1 responses of 19 panel members (n=19), we analyzed 123 individual statements. We grouped into similar requirements and then mapped into Technology (T), Organization (O) and People (P) approaches in Round 2. In the second round, participants were asked to rate each of requirements and the result, including participants rate, the degree of agreement (%), means (M) and standard deviations (SD) illustrated in Table 1 for Technology requirements, Table 2 for Organisation requirements and Table 3 for People requirements.

Technology Requirements	Agree=3 Freq. (%)	Unsure=2 Freq. (%)	Disagree=1 Freq. (%)	Mean	SD
1. Autonomous	16 (85)	2 (10)	1 (5)	2.79	0.54
2. Interoperability	17 (90)	2 (10)	-	2.84	0.32
3. Security/Trust	18 (95)	1 (5)	-	2.95	0.23
4. Configurability	19 (100)	-	-	3	0
5. Hardware resources (multimedia support - long time/battery support, ruggedness, portable, barcode readers, direct report printing)	17 (90)	2 (10)	-	2.84	0.32
6. Accessible	18 (95)	1 (5)	-	2.95	0.23
7. Localization	18 (95)	1 (5)	-	2.95	0.23
8. Mobility	19 (100)	-	-	3	0
9. Linking the maintenance plabbibg and dispatching	17 (90)	2 (10)	-	2.84	0.32
10. Synchronised multi-user access over a feature-populated dashboard	19 (100)	-	-	3	0
11. Ability to perform in both online and offline modes	18 (95)	1 (5)	-	2.95	0.23
12. Provides different mode for specific maintenance role	18 (95)	1 (5)	-	2.95	0.23
13. Provides a platform for knowledge sharing across maintenance crew	19 (100)	-	-	3	0
14. Social networking platform	3 (16)	2 (16)	14 (74)	1.42	0.77

Table 1. Mobile Collaborative maintenance of Technology requirements

As shown Table 1, a high degree of consensus was reached for 13 of 14 requirements identified. While the majority of the panel members disagreed (disagreemenet consesnsus) with the requirements of no. 14 which is social networking platform. One panellist's comment on item 14 was as follows: "Not so sure about the need for a social networking as part of the tool as this can become a distraction. Social interaction is more healthy face to face in a team environmet. Often times in social networking a comment ment to tease or joke with a person can be taken out of context. This can then build into something far more than it was ever intended". Another person stated, "social networking requirement must have proper implementing guidelines so as not compromise the main purpose".

Organization Requirements	Agree=3 Freq. (%)	Unsure=2 Freq. (%)	Disagree=1 Freq. (%)	Mean	SD
1. Simplify process (maintenance - Business) Flows	17 (90)	2 (10)	-	2.84	0.32
2. Using unify communication (to cut cost)	16 (85)	3 (15)	-	2.84	0.37
3. Reachability and readiness all of maintenance resources	16 (85)	2 (10)	1 (5)	2.79	0.54
4. Cross-organisational management communication	17 (90)	2 (10)	-	2.89	0.32
5. Appropriate coordination mechanism of the team	18 (95)	1 (5)	-	2.95	0.23
6. Involving Maintenance stakeholders in the system/ technology selection process	18 (95)	1 (5)	-	2.95	0.23
7. The regulation about information security have to be considered (as security more crucial)	17 (90)	2 (10)	-	2.84	0.32
8. Organizational awareness of new system's implications	17 (90)	2 (10)	-	2.84	0.32
9. Maintenance must be profit and customer-cantered	14 (74)	4 (21)	1 (5)	2.68	0.58
10. Clear maintenance vision (maintenance strategy-business objective)	18 (95)	1 (5)	-	2.95	0.23
11. Combine professional experiences to support team work	19 (100)	-	-	3	0
12. Provide team building activities to develop team work and skills	17 (90)	1 (5)	1 (5)	2.84	0.50

Table 2. Mobile Collaborative maintenance of Organisation requirements

Table 2 shows the items, which are group of organisational requirements elicited from the panel. It can be seen that there are high degree of consensus between the experts in this Round two Delphi study, with the majority of the elicited requirements achieving in excess of 70% agreement.

People Requirements	Agree=3 Freq. (%)	Unsure=2 Freq. (%)	Disagree=1 Freq. (%)	Mean	SD
1. Mobile technology competence, training/skills	18 (95)	-	1 (5)	2.95	0.23
2. Work culture, motivation	19 (100)	-	-	3	0
3. Trust and commitment the other crews will do their part	19 (100)	-	-	3	0
4. Common understanding of maintenance process	19 (100)	-	-	3	0
5. Common understanding of the system	17 (90)	2 (10)	-	2.89	0.32
6. Informal social networking between personnel	15 (79)	4 (21)	-	2.79	0.42

Table 3. Mobile Collaborative maintenance of People requirements

The people requirements elicited from the participants together with the degree of aggreement reached in Round two of this study are shown in Table 3. All of the items reached a consensus higher than 75% agreement rate.

In Round three (Final round) we further, present the requirements in three groups (technology, organisation and people) and ask the partipatory experts to rank the importance of the individual requirements for each group and offer them a chance for any additional comments.

4.2 Current Collaboration Technology Being Used

Table 4 lists current computerized maintenance information systems Technical/Features which are currently available or serve on the **collaborative** maintenance systems according to the panel member's feedback, together with participants rate, the degree of agreement (%), means (M) and standard deviations (SD) reached in Delphi survey Round two iteration.

Area	Category		Agree=3 Freq. (%)	Unsure=2 Freq. (%)	Disagree=1 Freq. (%)	Mean	SD
Technical	Portability, Wireless, Voice communication, Speech recognition, Display, Video capture, Input Devices		16 (85)	2 (10)	1 (5)	2.79	0.54
Features	General	System security, Easily expandable, Simple setup, Built in backup and restore	14 (74)	4 (21)	1 (5)	2.68	0.58
	Scheduling	Preventive maintenance wizard, Task library, Work order list, Copy option, Generate work orders	17 (90)	2 (10)	-	2.89	0.32
	Managing	Work order reminder, Cost tracking, Staff assignments, Inventory maintenance, Purchase order status	17 (90)	2 (10)	-	2.89	0.32
	Productivity	Customizable list, Sort, Query, Filter and Find, Import & Export Utilities	15 (80)	3 (15)	1 (5)	2.74	0.56

Table 4. Current technology/features of collaborative maintenance computer system

Table 4 contains summary findings for Round two of current collaboration technology being used in engineering asset organisations. Overall agreement of the majority of participants was achieved with the agreement rate of greater than or equal to 85% and 74% for technology and features respectively.

In Round three (Final round) we present the technology/features in three groups (format data, technology and feature) and we ask the partipatory experts to rate the importance of the individual requirements each group in five likert scale (Extremely important, Very important, Moderatly important, Somewhat important and Not important) and provide them with a chance for any additional comments.

4.3 Current Mobile Technology Roles

We analysed 42 individual statements from nineteen responses (n=19) in Round one. The statements were then clustered by similarity into categories and finally mapped to high-level feature areas in round 2. The Participants rate, the degree of agreement (%), means (M) and standard deviations (SD) resulted from Delhi survey Round 2, are demonstrated in Table 5 for Flexibility theme, Table 6 for Empowering management theme and Table 7 for Others comments on current mobile technology roles.

Flexibility (initiate application at flexible sites in unstructured networked)					
Feature category	Agree=3 Freq. (%)	Unsure=2 Freq. (%)	Disagree=1 Freq. (%)	Mean	SD
Visualising of collected data, parameter history and trending.	17 (90)	2 (10)	-	2.84	0.32
Contextualising access over remote data and services: task-related services and data entry ubitously available to authorised users.	14 (74)	5 (26)	-	2.74	0.45
Critical for response time for data or information that can lead to early correction and or identification of failures.	18 (95)	-	1 (5)	2.90	0.46
Providing the notification of failure through mobile devices	17 (90)	1 (5)	1 (5)	2.84	0.50
Detecting the location of skilled maintenance personel nearby an asset that has experienced a failure through GPS.	15 (80)	2 (10)	2 (10)	2.68	0.67
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.).	16 (85)	2 (10)	1 (5)	2.79	0.54

Table 5.Current mobile technology of flexibility roles

Consensus was reached for all categories on the Flexibility theme as shown in Table 5, with a consensus rate of 74% to 95%.

Empowering Management					
Feature category	Agree=3 Freq. (%)	Unsure=2 Freq. (%)	Disagree=1 Freq. (%)	Mean	SD
Resources management (material, maintenance people) facilitator for continous task monitoring/assignment/reporting.	17 (90)	2 (10)	-	2.84	0.32
Building and identifying process verification tasks, approvals.	14 (74)	5 (26)	-	2.74	0.45
It helps to report failure effectively and report labors actual working hours and availability.	17 (90)	2 (10)	-	2.84	0.32
Allowing to take the right maintenance decision, at the right time, at the right place, from the right information.	17 (90)	2 (10)	-	2.84	0.32
Enhancing accuracy of critical data entry for maintenance history.	19 (100)	-	-	3	0
Off-site (not in office) notifications and live feeds.	18 (95)	1 (5)	-	2.95	0.23
Q/A decisions	18 (95)	1 (5)	-	2.95	0.23

Table 6. Current mobile technology of management roles

Listed in Table 6 are the responses from panellist about empowering management theme. All of items were considered consensus items with the consensus rate of 74% to 100%.

Others					
Feature category	Agree=3 Freq. (%)	Unsure=2 Freq. (%)	Disagree=1 Freq. (%)	Mean	SD
Early adopters stage in the technology lifecycle	15 (79)	3 (16)	1 (5)	2.74	0.56
Still very limited use	14 (74)	4 (21)	1 (5)	2.68	0.58

Table 7. Others comments on current Mobile technology roles

Table 7 demonstrates the other comments from panellist. Almost 80% of them claim that the current mobile technology roles in support maintenance collaboration technologies/systems are still in the early adoptive stages, while 74% believe that such technology is still very limited in use within engineering organisations.

5. DISCUSSION AND CONCLUSION

Obtaining and distributing appropriate, consistent and up-to-date information between the maintenance crews of an organisation in real time is a complex process. Many engineering organisations have invested in collaborative maintenance systems to assist the information management of their asset maintenance processes. Due to the strong connection between the collaboration technology and the engineering asset maintenance process, such systems have become an important strategy to improve the way in which information is gathered, managed, distributed and presented to maintenance people.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 p erforming their tasks, require relevant information from different sites and need to communicate interactively with experts in the back office.

In summary, it is expected that the current research finding will develop a unique frame work 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 personal perspectives).

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