PAPER NAME

Mobile-Enabled collaborative maintenance-Pacis 2014.pdf

AUTHOR

Faisal Syafar

WORD COUNT

7047 Words

CHARACTER COUNT

42273 Characters

PAGE COUNT

16 Pages

FILE SIZE

433.0KB

SUBMISSION DATE

Nov 17, 2022 3:58 PM GMT+8

REPORT DATE

Nov 17, 2022 4:00 PM GMT+8

5% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

- 3% Internet database
- 1% Publications database
- Crossref database
- Crossref Posted Content database
- 2% Submitted Works database

Excluded from Similarity Report

- Bibliographic material
- Quoted material
- Cited material
- Small Matches (Less then 10 words)
- Manually excluded sources
- Manually excluded text blocks

2014

MOBILE-ENABLED COLLABORATIVE MAINTENANCE

Faisal Syafar
University of South Australia, Faisal@postgrads.unisa.edu.au

Jing Gao
University of South Australia, jing.gao@unisa.edu.au

Jia Tina Du
University of South Australia, Tina.Du@unisa.edu.au

MOBILE-ENABLED COLLABORATIVE MAINTENANCE

Faisal Syafar, School of Information Technology and Mathematical Sciences, University of South Australia, Adelaide, Australia, Faisal@postgrads.unisa.edu.au

Jing Gao, School of Information Technology and Mathematical Sciences, University of South Australia, Adelaide, Australia, Jing.Gao@unisa.edu.au

Jia Tina Du, School of Information Technology and Mathematical Sciences, University of South Australia, Adelaide, Australia, Tina.Du@unisa.edu.au

Abstract

This paper focuses on the benefit of collaborative maintenance and current supported mobile technology. Mobile technologies and solutions are very popular in consumer applications and the exploitation of these technologies is expanding. In large-scale industries, maintenance of mobile solutions has not yet attracted much attention. One explanation is the lack of competence and knowledge for adopting mobile solutions successfully in professional use. Many companies have experienced problem in adopting the maintenance of mobile solutions due to inoperative telecommunication connections, lacking of suitable devices or insufficient implementation preparation. Another reason is that the benefits of mobile solutions have not been well-recognised, for example in maintenance domain. To the best of our knowledge, this research is of the first to investigate the roles of current mobile technologies in support of collaborative maintenance by eliciting an expert pane's perspectives using a Delphi study. This paper seeks to present the benefits of collaborative maintenance, and the current roles of mobile technologies in supporting collaborative maintenance work in engineering assets organisations.

Keywords: Mobile technology, Collaborative maintenance, Engineering asset.

1. INTRODUCTION

Mobile technologies made rapid advances in recent years, being viewed as business enablers, and have the potential to support asset maintenance practice. On one hand mobile technologies are able to maintain collaborative information sharing and on the other hand provide a number of benefits to the organisation such as maintenance people working collaboratively or individually. By implementing mobile collaboration technology, organisations can ensure that their maintenance personnel are always reachable at anytime, in the context of their workplace. Specifically, they are, to undertake planned and/or unplanned maintenance and provide information as quickly as possible (Koseoglu & Bouchlaghem, 2004; Saran, 2006; Tsirulnik, 2009). Moreover, Smailagic et al. (1997) argue that a combination of mobile/wearable computers with wireless technology leads to greater effectiveness and accuracy in maintenance. This technology allows maintenance personnel at a specified location to communicate with a remote expertise centre through digital data, audio, and images. With these capabilities, even a non-expert maintenance crew is able to carry out simple repair maintenance tasks with the assistance from a remote expert's office.

The aims of this paper are to identify the benefits of collaborative maintenance, and to investigate the current roles of mobile technologies in supporting collaborative maintenance work in engineering assets organisations. The identified mobile technology roles presented in this paper were obtained from an international Delphi study. Twelve maintenance professionals and eight highly credentialled academics with research experience participated in this study. The Delphi study was conducted from September 2012 to May 2013.

The rest of the paper is structured as follows: the second section describes strategic implementation in maintenance. Section 3 explains the process of collaboration, while section 4 presents the methodology used in this study. Findings and Discussion are presented in Section 5 and 6 respectively, and the paper concludes with a summary of the main themes.

2. STRATEGIC IMPLEMENTATION IN MAINTENANCE

In large industries, such as automotive, metals, mining, oil and gas, process manufacturing, utilities, the reliability and productivity of capital assets is essential to an organisation's financial success. Managing capital assets is often regarded as a complex business process which require a large number of informations systems (e.g. conditioning monitoring, work order management, incident reporting, etc.) as well as human experts (e.g. technicians, engineers, etc.). Additionally, considering the physical location of capital assets (e.g. a train network can spread across the entire country), any improvement in existing maintenance activities is worthy of investigation.

At the operational-level, maintenance of these assets can dramatically impact on the overall performance and useful life of an asset. Accordingly, asset owners/operators and asset service providers are continually trying to improve their maintenance practices by executing a proper maintenance strategy (Meredium, 2006). A good maintenance strategy according to Laszkiewics (2004) is about having the correct equipment and technology (asset management) and personnel and processes (system support) incorporating the right combination of predictive, preventive and reactive maintenance methods to produce the desired results. In general, the ideal maintenance strategy should be a mix of predictive, preventive and reactive methods, depending on the desired goal and part of the process being maintained.

Morover, while most manufacturers have taken steps to implement a more preventive and predictive strategy, one thing is clear: no matter how proactive your strategy is, there will always be a need for a certain amount of reactive activities. Unexpected problems and changes do happen and companies need to have reactive maintenance methods defined and ready to implement in order to limit emergency costs and quickly facilitate change requests (Laszkiewics, 2004).

To overcome the issue of longer repair time and shutdown of equipment which can hamper service/product quality or higher revenue generation, today's asset maintenance practices rely on the access to information and team expertise from dispersed sites to support the three maintenance methods (Burmeister, 2006). Many businesses or companies have several interdependent departments and sub-systems that collaborate on various issues. Maintenance personnel in the form of individuals 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).

The literature review shows that the current collaboration studies are not closed related to mainteance activities in capital asset management organisations. Very little focus has been place on meeting the collaboration requirements such as obtaining information from multiple systems, supporting a wide range of human experts with different requirements and remote operations. In order to address these issues, this study tries to combine the general collaboration theories and asset mainteance studies together. During this process, a specific focus is placed on the mobile enablement.

3. COLLABORATION

Himmelman (2001) determined that in order to achieve a common goal that would not otherwise be possible, or be more expensive to do, if attempted individually, is required. This involves sharing risks, resources, responsibilities and rewards in a business or joint entity (working as a virtual organisation). Typically, collaboration is recognised as a mechanism to control competitiveness. As a result it is about increasing survivability in turbulent market conditions. Collaboration can be achieved by encouraging mutual trust, but this strategy requires time, effort and dedication. In the organisational perspective, Winer and Ray (1994) defined collaboration as the effort made by two or more organisations to achieve results that they cannot achieve by themselves.

Collaboration has become more important to global organisations as their activities are increasingly dispersed geographically. For example, they experience an increase in offshore business activities, growing number of business partnerships, the need to work more closely with customers, etc. Within this context, organisations are seeking ways to improve performance (market share, revenue, profitability, etc.) by streamlining and better managing complex business processes. A specific area of interest is how to get increasingly dispersed teams of knowledge workers and decision-makers – tasked with carrying out business processes – to work together in more efficient and effective ways through the adoption of collaborative technologies (Fulk and DeSanctis 1995; Jarvenpaa and Leidner 1998).

Obtaining correct, consistent and up-to-date information across an organisation is a complex process. Therefore, organisations have been seeking to develop a number of information technology systems to assist with the information management of their business processes. Such systems aim to improve the way in which information is gathered, managed, distributed, and presented to the people in key business functions and operations, in other words, these systems aim to improve the collaboration and information management (Liang & Huang, 2002).

A system to support collaboration and information management should be able to offer a shared information work space; a communication space to negotiate collective interpretations and shared meanings; and a coordination space to support cooperative work action. In other words shared information work space that facilitates access to information content, organisational communications, and group collaboration (Pereira & Soaresa, 2007).

3.1 Collaborative Asset Maintenance

In general, maintenance collaboration can be defined as an information exchange between two or more maintenance crews/stakeholders. Maintenance jobs require individuals to collaborate with one another to complete certain tasks. These tasks can range from very simple, single step tasks, to the

extremely complex one. The degree of collaboration is often directly proportional to the complexity of the task and the experience level of maintenance personnel. In current physical assets maintenance, where the systems are more complex, collaboration is essential to successfully completing the job. Just as in every task, the more uncommon or difficult the repair, the more collaboration is needed among the maintainers.

Central to collaborative maintenance is the concept that all maintenance stakeholders must contribute to the improvement of the whole, growing the relationship, and attaining the business goal of the organisation. The rapid development of computer technology as well as information systems has enabled maintenance crews to collaborate, and share knowledge and information, across time and/or space.

3.1.1 The Uniqueness of Collaborative Maintenance Requirements

The uniqueness of collaboration requirements in asset maintenance during operations and maintenance (O&M) of industrial facilities in the modern dynamic environment, critical decisions rely very much on whether the required information is always available where and when is needed. These requirements are needed especially in solving a very difficult and complicated tasks associated with a high level risk and cost. Data and/or information including preventive and corrective maintenance for both normal and emergency (unplanned) maintenance. Normal maintenance provides narrative description of normal operating procedures, for example, parameter history and emerging trends as well as a response for data or information that can lead to early correction and/or identification of failures. Whhile emergency maintenance including emergency procedures for equipment malfunctions to permit a short period of continued operating or to shutdown the equipment to avoid further damage to the entire system and equipment.

In asset engineering maintenance, collaboration is critical factor in the technicians' quest to complete an immediate or unplanned 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 tas completion. The requirements for collaboration increases by the complexity of the tasks. In the case of physical asset maintenance in large and complex industries such as minings, utilities, telecommunications, etc. where large amount of knowledge, experience and skill are required, only few mainteners and/or technicians having all the skill necessary to solve all possible scenarios. In fact, according to Curtis, et al., (2006) that expert mainteners argue that contacting another technicians or maintenance expert for advice is a logical way in solving a very difficult jobs.

In general a technicians and/or maintainers will collaborate when the data does not provide sufficient information for a successful repair, and the strategy adopted by the technicians to collaborate depends on what is available. Current modes of collaboration involve common communication technologies, such as a phone call or email. However, the state-of-the art in collaborative technologies clearly includes additional higher technology capabilities, for example, instant messaging, real-time multimedia, and shared workspaces (Curtis, et al., 2006).

Technology provides a multitude workspace of possible collaborative tools and techniques, and this must be balanced against the requirement to leverage the goal of collaboration is to facilitate and/or support maintainers' existing interaction skills, rather than requiring them to adapt to the technology.

Mobile technologies play a key role in this setting, facilitating to establish tightly integrated environments between different groups and organisations 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 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.

3.2 Mobile Collaborative Asset Maintenance

In regard to maintenance tasks, Sinha et al. (2007) explain that using mobiles allows maintenance personnel to continuously receive a daily schedule from the head office, which leads to the saving of time and improving customer service and business profitability. Luff and Heath (1998) and Campbel et al. (2006) agree that mobility of special artifacts can enhance tasks and responsibilities. In addition, Emmanoulidis (2009) argues that in order to support a given 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, and condition monitoring and data diagnosis.

Eden and Ackerman (2001) indicated several forms of collaboration technology that provide special benefits to users. Building on this theme, Knot et al. (2006), Dennis, Wixom, and Vandenberg (2001), Oslon, Malone and Smith (2001), DeSanctis and Gallupe (1987), Nunamaker et al. (1991), Zigurs and Buckland (1998), and Rein (1993), all concluded that generally, collaboration technology is a package of hardware, software, people, and/or processes that can offer one or more of the following:

- Enhance effectiveness of shared communication, awareness and decision quality, such as team performance efficiency in command and control;
- Support for communication among participants, such as electronic communication to augment or replace verbal communication;
- Information processing support, such as mathematical modelling or voting tools;
- Support to help participants adopt and use technology, such as agenda tools or real-time training; and
- Support for organisation design, such as through the development of a multi-user, computer-based environment.

Massey (2008) states collaborative technologies enable members to communicate and collaborate as they deal with the opportunities and challenges of asset maintenance tasks. Collaboration technologies improve the efficiency and effectiveness of organisational work processes and decision-making as well as reduce costs. Coupled with technology, dispersed knowledge workers across different divisions and functions, can provide input, share knowledge, negotiate, and coordinate work to solve problems and make decisions.

3.2.1 Mobile Collaborative Scenario and Industrial Environment

Neyem et al. (2007) assumed that depending on the context of the next collaboration scenario and its characteristics; mobile users require autonomous, flexible and interoperable collaborative solutions, irrespective of the availability of centralised resources or communication infrastructure. Mobile users' physical location should not be a constraint to collaborate if two or more of them are meeting. Some examples of such collaboration have been identified in research, namely: construction management (Neyem et al., 2006), health care (Tentori and Favela, 2007) and disaster relief (Neyem et al., 2007).

Collaborative mobile work systems/technologies that are supported by MANETs (Mobile Ad-hoc NETworks) according to Aldunate et al. (2006) have to be designed to support communication and coordination. This means, considering the major features of these networks, such as small communication range, dynamic topology and high disconnection rate Rosa et al. (2005). Furthermore, mobile collaboration technologies have particular features and these are explained as follows:

- *Portability*. The physical characteristics of mobile devices that enable users to employ them more easily. Such features allow users to collaborate with others anytime and anywhere (Sarker et al., 2010).
- *Reachability*. With such technology, a person can be in touch and reached by other people at any time (Sarker et al., 2003; Junglas, 2003).

- *Localization*. The ability of MCT to track the geographical position of a mobile user (Sarker et al., 2003; Junglas, 2003).
- *Identification*. The ability of a device to confirm a user's identity (Sarker et al., 2003; Junglas, 2003).
- *Accessibility*. The extent to which an individual is able to get access to a mobile network at a given time and geographical location (Sarker et al., 2003; Junglas, 2003).

These requirements are significant to help us understand the type of applications and capabilities required to work in a mobile collaborative scenario and are relevant for future industrial environments.

3.2.2 Mobile Force Field Scenario

The combination of mobile wearable computers and wireless technology improves the efficiency and accuracy of maintenance work (Smailagic and Siewiorek, 1996). This technology enables maintenance personnel to communicate through digital data, audio, image and video. Such an advance in mobile technology allows for real-time transmission of maintenance data in the following scenarios:

- Between maintenance personnel in different offices,
- Maintenance personnel in the field to communicate with an expertize remote help desk office,
- Between maintenance personnel in the force field in different sites.

With these capabilities, even non-expert maintenance personnel in the field can accomplish simple repair tasks with the aid of remote experts at the office help desk. The images and text are displayed on a display, which is also equipped with a microphone and earphones (Smailagic and Bennington, 1997).

4. METHODS

This study was conducted to identify current collaborative maintenance practices and mobile technology roles in support of collaborative engineering asset maintenance. The Delphi technique was employed to build a more accurate picture based on the panel experts' perception. The Delphi study is a group process that solicits experts' 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. In this study's analysis, the consensus level of agreement was set at 70% to 100% agreement or disagreement in all three rouds. This consensus level has been used in previous study (Anderson, 2010).

The Delphi method was employed for several reasons. Firstly, the topic 'Mobile collaboration technology in engineering asset maintenance' is a relatively new and complex issue. Secondly, there is only limited literature that has discussed the topic. Thirdly, not much empirical data is currently available. The Delphi study carried out in this paper comprised three rounds (Linstone & Turoff, 1975) and aimed to address the following research questions: What is the benefit of collaborative maintenance and what is the current role of mobile technologies in support of collaborative maintenance in engineering assets organisations?

A total of 47 experts who have strong academic backgrounds, research experience and professional careers in 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. Respondents' profiles are presented in Tables 1 to 2 below.

Characteristic (Variables)		**Frequency**	**Percentage (%)**
Level of Academic Education	Bachelor	-	0
	Master	-	0
	PhD	8	100
Experience in Mobile Technology and	1 – 5 Years	-	0
	6 – 10 Years	2	25

Collaborative Maintenance	10 – 15 Years	2	25
	More than 15 Years	4	50

Table 1. Respondents' (Academicians) profile

Characteristic (Variables)		Frequency	Percentage (%)
Level of Academic Education	Bachelor	5	42
	Master	5	42
	PhD	2	16
Maintenance Professional Qualification	CPMM	5	42
	CMRP	12	100
	CMRT	12	100
Experience in Mobile Technology and Collaborative Maintenance	1 – 5 Years	-	0
	6 – 10 Years	2	17
	10 – 15 Years	3	25
	More than 15 Years	7	58

Table 2. Respondents' (Professionals) profile

A three-round Delphi email-based questionnaire was designed. **The first round** (generating ideas/issues) was an initial collection of the benefits of collaborative maintenance and mobile technology roles consisting of open-ended solicitation of ideas. Respondents were asked to list the benefits of collaborative maintenance and the roles of mobile technology in supporting the current collaborative asset maintenance. In this stage, we did not receive a response from one of the twenty experts, despite reminding that person twice. One respondent withdrew from this stage. **The second round** (Eliciting agreement). The experts were asked to verify the list that the researcher had correctly interpreted and place each item in an appropriate category/group based on their 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) is about rating the agreement level of the benefit of collaborative maintenance and the current roles played by mobile technologies in supporting each collaborative maintenance practice category.

The following benefit of collaborative maintenance and current mobile technology roles (see Tables 3-7) were verified in the previous round. These lists have been elicited from the set areas/categories submitted by 19 expert panel members in the second round, and enhanced with a literature review of relevant fields (Syafar et al., 2013). These sets were then rated by 18 expert panel members in this final round, during which the respondents were asked to rate the issues using a 5-point Likert-type scale. The scale ranged from 1-Not Important to 5-Very Important. The respondents were also encouraged to add and briefly explain any additional comments that they elicited.

For each agreement level of collaborative maintenance benefit and current mobile technology roles, the frequency, mean (M) and standard deviation (SD) of the ratings were analised using IBM SPSS Statistic software analysis. Those with the highest rating and smallest SD were considered to have the greatest consensus (Jones and Hunter, 1955).

5. RESULTS AND DISCUSSION

5.1 Benefits of Collaborative Maintenance

According to the final round Delphi survey finding illustrated in Tables 3 to 6, the benefits of collaborative engineering asset maintenance were classified to four categories: Networking/Communication, Coordination, Cooperation and Productivity (collaboration). We listed opinion of expert panel members in the Tables 3 to 6, and discussed them consecutively.

5.1.1 Networking/Communication

Networking/ Communication	Not important	Of litle importance	Moderately important	Important	Very important	Mean	SD
Reduction of waste (time, task overlap, task complementarity)			1	8	9	4.44	0.62
Coupling of different people's views, self-organisation and emerging approaches for conducting the tasks			1	8	9	4.44	0.62
Able to take the right maintenance decision, at the right time, at the right place, using the right information.			2	4	12	4.56	0.70
Direct input in the field might eliminate the need for someone later to enter the information.		2	3	5	8	4.06	1.06
Remote viewing of feedback by a supervisor			3	7	8	4.28	0.75
Track spareparts inventories and maintenance personel in realtime.		1	1	8	8	4.28	0.83

Table 3. Benefits of collaborative maintenance-Networking/Communication

Communication is essential to any group maintenance in organisations. It reduces time being wasted to that maintenance task is completed due to technicians' better information exchange. It also assists in the development of a shared group understanding. Networking includes communication and information data triangulation or coupling of different maintenance people/technicians' views/understanding for conducting routine maintenance tasks to achieve a mutual benefit. Another benefit of networking is the scenario in which a group maintenance crew share information about having used a specific tool for maintenance anywhere, anytime. They can all benefit from the information made available/shared and can take the right maintenance decision based on correct information. Maintenance supervisors are able to provide a feedback or track the availability of spare parts and maintenance personnel in real-time.

5.1.2 Coordination

Coordination	Not important	Of litle importance	Moderately important	Important	Very important	Mean	SD
Scale responsiveness and team coordination		1	1	9	7	4.22	0.81
More eyes over shared items leads to better ability to identify weak points and problems		1	2	3	12	4.44	0.92
Improved coordination between maintenance-operations-total operation		1	1	5	11	4.44	0.86
Effectively deploy available maintenance resources		1		4	13	4.61	0.78

Table 4. Benefit of collaborative maintenance-Coordination

Whenever maintenance people communicate so that their views/experiences or information concerning joint tasks or for accessing shared maintenance resources are shared with others (e.g.

supervisor), this is known as coordination. According to the Delphi study results, the benefits of collaborative maintenance in terms of coordination were:

- Scale of responsiveness and team coordination
  - Providing factual data
  - Providing a central source of information

- Effectively deploy available maintenance resources (personel, skills and support equipment)
  - Accurately forecasting labour and material needs
  - Establishing expected workload and analysing the variations
  - Improving efficiency through avoiding delays
  - Improving coordination between maintenance-operations-total operation
  - Increasing useful life of assets
  - Improving preparation, management and control of major shut-downs

- More eyes over shared items leads to better identification of weak points and problems
  - Improving employee safety
  - Improving regulatory compliance
  - Achieving the optimal economic level of maintenance
  - Challenging the need for work requests

Coordination involves aligning/altering routine maintenance activities so that more effective results are achieved. It also requires mutual planning and open communication among technicians/maintenance people, as missions and goals begin to be shared for achieving the organisation's goals.

5.1.3 Cooperation

Cooperation	Not important	Of litle importance	Moderately important	Important	Very important	Mean	SD
Build a better understanding of responsibilities and hierarchy		1	3	9	5	4.0	0.84
Faster and more effective performance enhancement and action plan implementation		1	2	6	9	4.28	0.89
Increased sense of confidence in staff			2	10	6	4.22	0.65
Establishing a shared and commonly perceived organisational culture		1	2	9	6	4.11	0.83
Standardisation of tasks , language, approach, solutions		1	3	10	4	3.94	0.80
Cumulative learning-reducing the learning curve		1	2	12	3	3.94	0.73

Table 5. Benefit of collaborative maintenance-Cooperation

Cooperation refers to information exchange and adjustments of activities, as well as sharing resources to achieve common goals. According to the expert panel members, the key benefits of collaborative maintenance particularly with reference to cooperation include:

- Building a better understanding of responsibilities and hierarchy
- Faster and more effective performance enhancement and action plan implementation throughout the organisation
- Increased sense of confidence as staff would feel thet they have support system available to them, and they can build on each other's contribution

- Establishing a shared and commonly perceived organisational culture: supervising team members and managers can participate in and oversee the collaborative environment; staff interacting at peer level, having team-wide scope and goals in their actions
- Standardisation of tasks , language, approach, solutions
- Cumulative learning-reducing the learning curve.

Cooperation could be achieved by dividing of some maintenance people into particular groups. Each party maintains its own authority and maintenance resources. Cooperation can take place among maintenance crew group that have different goals and function without a clearly defined and shared maintenance mission.

5.1.4 Productivity

Productivity	Not important	Of litle importance	Moderately important	Important	Very important	Mean	SD
Sustainability – the system will continuo to run even if one person leaves			1	12	5	4.22	0.55
Provides an intelligent repository of data		1	2	9	6	4.11	0.83
Improved craft labor productivity: Overall Craft Effectiveness (OCE)			3	10	5	4.11	0.68
Ability to develop a complete maintenance strategy		1	1	9	7	4.22	0.81
Develop teamwork environment and raise maintenance crew's morale.			2	8	8	4.33	0.69
More planned work leading to greater uptime and Overall Effectiveness (OEE)		1	1	12	4	4.06	0.73
Increased capacity, throughput and profits		1	2	8	7	4.17	0.86
Real-time information enabling correct and quick decision-making			1	5	11	4.33	1.24
Greater probability of achieving THE GOAL-Total Operations Success			2	8	7	4.06	1.21
Visibility of problems		1	1	12	4	4.06	0.73
Increased staff productivity		1	1	14	2	4.94	0.64
Increased transperency			1	5	9	4.17	1.04
Help departments to reduce costly downtime- control expenses			2	16		4.89	0.32
Log and record members' performance as a part of group		1	2	15		3.78	0.55

Table 6. Benefit of collaborative maintenance-Productivity

The selected items in concerning productivity below were assigned by the expert panel members and considered to benefit maintenance collaboration:

- Sustainability – the system will continuo to run even if one person leaves
- Provides an intelegent repository of data. Historical data can be used to enhance the job plans and support better decesion-making
- Improved craft labor productivity in terms of Overall Craft Effectiveness (OCE)

- Ability to develop a complete maintenance strategy that includes Condition-Based, Preventive Maintenance, Redesign, Failure Finding consequence reduction tasks; this strategy includs the assesment of critical spares
- Develop teamwork environment and raise maintenance crew's morale.
- More planned work leading to greater uptime and Overall Effectiveness (OEE)
- Increased capacity, throughput and profits
- Real-time information enabling correct and quick decision-making
- Greater probability of achieving THE GOAL-Total Operations Success
- Visibility of problems
- Increased staff productivity
- Increased transperency
- Help departments to reduce costly downtime- control expenses
- Log and record members' performance as part of group.

In effective collaboration, maintenance people no longer run parallel maintenance tasks at a common site. They can instead generate a new task that is that offers contributors more than the individual organisations can offer. The sharing of decision-making, power, authority, and resources by maintenance collaborators requires comprehensive maintenance planning. These synergistic efforts often result in innovations that benefit all maintenance stakeholders.

Collaborative maintenance solutions make it possible to optimise the organisation productivity. Collaborative maintenance infers sharing maintenance resources, responsibilities, rewards, and risks, which if preferred by the maintenance group can create sense of unity among its members.

5.2 Current Mobile Technology Roles

Regarding current mobile technology in supporting collaborative maintenance, the expert panel members categorised it as a form of flexibility and empowering management as shown in Table 7.

Area/Categories	Not important	Of litle importance	Moderately important	Important	Very important	Mean	SD
Flexibility							
Visualising of collected data, parameter history and trending		**2**	2	10	4	3.89	0.90
Contextualising access over remote data and services		**2**	3	9	4	3.83	0.92
Critical for response time for data or information that can lead to early correction and/or identification of failures.		1	2	9	6	4.11	0.83
Providing the notification of failure through mobile devices		1	1	7	9	4.33	0.84
Detecting the location of skilled maintenance personnel nearby as an asset		2	2	1	13	3.39	1.09
At the right location, allows access directly to a set of information coming from the people involved in making the decision		1	3	3	11	4.33	0.97

Empowering Management							
Resources management, facilitator for continuos task monitoring/assignment/ reporting.		1	2	10	5	4.06	0.80
Building and identifying process verification tasks, approvals.		2	3	8	4	3.83	0.92
Report failure effectively		1	2	6	9	4.28	0.89
Report technicians' actual hours and availability.				7	11	4.61	0.50
Allowing the organisations to allocate maintenance resources to the site from anywhere at anytime			1	4	11	4.0	1.68
Enhancing the accuracy of critical data entry for maintenance history.				7	11	4.61	0.50
Store/warehouse management			1	10	7	4.17	0.71
Q/A decisions			1	12	3	3.67	1.41
Others							
Early adopter stage in the technology lifecycle		1	2	15		3.8	0.55
Still very limited use		1	2	13	2	3.9	0.68

Table 7. Current mobile technology roles in supporting collaborative maintenance

As can be seen in Table 7 above, mobile collaboration technology is very limited in regard to routine maintenance practices in a number of ways. Four of expert panel members argue that "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". Integrated and more complicated engineering assets maintenance working settings in recent times mean that maintenance people must communicate, coordinate and collaborate better when they execute their everyday tasks. The flexibility of mobile collaboration devices allows real-time communication to take place at any location where maintenance jobs are being scheduled, planned or even unplanned. Moreover, mobile technology is able to provide data collection visualisation, parameter history and emerging trends as well as a response for data or information that can lead to early correction and/or identification of failures. These capabilities enable supervisors or maintenance managers to detect asset breakdown spots, to coordinate an unplanned maintenance job, and locate skilled technicians who may nerby more quickly.

Improved mobile technology influences many aspects of complex maintenance such as production line maintenance, supply chain management and equipment field service. By applying these technologies, order and purchasing of maintenance resources can be done anytime anywhere. Futhermore unexpected failures can be reported immediately, the condition of assets can be continuously monitored or intermittently while their operation and crew can do the job they were assigned to whilst on the move.

Advances in mobile technology hardware and software include enormous boosts in processing speed allowing such technology to handle complex mobile work schedules now that wireless internetworking connection are available. Maintenance organisations can centralise their maintenance helpdesk to assist personnel at a specified location to communicate with a remote expertise centre through digital data, audio, and images as needed.

6. CONCLUSION

Collaboration is recognised as a mechanism to control competitiveness. It is increasing business survivability in uncertain marketplace conditions. Collaborative maintenance in particular can be achieved gradually by implying mutual trust which takes time, effort and dedication to achieve. The benefit of collaborative maintenance according to the Delphi study results are divided into four pillars. The first pillar is networking which involves communication and information exchange for coupling of different maintenance people's view/understanding. The second pillar, extending networking, is coordination which not only means exchanging information, but also aligning/altering maintenance activities so that outcomes can be achieved more efficiently. The third pillar, extending coordination, is cooperation which not only involves information exchange and adjustments to maintenance routine jobs, but also sharing maintenance resources for achieving compatible goals. The fourth pillar, extending cooperation, is productivity which is represents collaboration as a process where maintenance people/technicians share information, maintenance resources and responsibilities to jointly plan, implement and evaluate maintenance activities to achieve a goal.

Mobile technologies and solutions are very popular in consumer applications and the exploitation of mobile technologies will keep on expanding. In large industry, using mobile collaborative maintenance have still not become very popular. One reason is there is a lack of competence and knowledge for adopting mobile solutions successfully in professional use. Many companies have poor experiences in adopting mobile solutions in maintenance due to previously inoperative telecommunication connections, lack of suitable devices or just for insufficient preparation for adoption process. Another reason is that the benefits of mobile solutions is not seen or not known for example in maintenance domain. Mobile technologies as such are nowadays mature enough to face the challenge and requirements of professional use in engineering industry.

It is evident that current maintenance working circumstances are more complex and therefore need to be managed by multiple and interlinked activities. Hence, an integrated high-level maintenance system which contains multiple sub-systems requires the collaboration of many stakeholders such as departments or units to improve resources, information sharing and maintenance practices. Combined improvement in processing that empower maintenance management and make it flexible allows organisations to use their maintenance resources faster, more properly and profitably.

References

Aldunate, R., Larson, G., Nussbaum, M., Ochoa, S., and Herrera, O. (2006). Understanding the role of mobile ad hoc networks in non-traditional contexts. IFIP Int. Conf. on Mobile and Wireless Comm. Networks, 199–215.

Anderson, V.A. (2010). Defining the EdD and PhD in education: a delphi study. A dissertation. North Dakota State University of Agriculture and Applied Science. Fergo, North Dakota.

Besten, M.d., Dalle, J.M. and Galia, F. (2006). Collaborative maintenance in large open-source projects. International Federation for Information Processing, 23, 233-244.

Camacho, J., Galicia, L., Gonzales, V.M. and Favela, J. (2008). MobileSJ: managing multiple activities in mobile collaborative working environments. International Journal of e-Collaboration, 4, (1), 61-73.

Dalkey, N.C. and Helmer, O. (1963). An experimental application of the delphi method to the use of experts. Management Science, 9, 458-467.

Dennis, A.R., Wixon, B.J., and Vanderberg, R.J. (2001). Understanding fit and appropriation effects in group support systems via meta-analysis. MIS Quarterly, 25 (2), 167-197.

Desantic, G. and Gallupe, R.B. (1987). A foundation for the study of group decision support systems. Management Science, 33 (5), 589-609.

Eden, C., and Ackerman, F. (2001). Group Decision and Negotiation in Strategy Making. Group Decision and Negotiation, 10 (2), 119-140.

Emmanoulidis, C. (2009). Methodology and theory: mobile solution for engineering asset and maintenance management. Journal of Quality in Maintenance Engineering, 15 (1), 92-105.

Ferrario, M.A. and Smyth, B. (2000). Collaborative maintenance-a distributed, interactive case-base maintenance strategy. Lecture Notes in Artificial Intelligence, 898, 393-405

Green, B., Jones, M., Hughes, D. and Williams, A. (1999). Applying the delphi technique in a study of GP's information requirements. Health and Social Care in the Community, 7(3), 198-205

Himmelman, A.T. (2001). On coalitions and the transformation of power relations: collaborative betterment and collaborative empowerment. American Journal of Community Psychology, 29 (2), 277-284.

Jenab, K and Zolfaghari, S. (2008). A virtual collaborative maintenance architecture for manufacturing enterprises. Journal of Intelligent Manufacturing, 19 (6), 763-771.

Junglas, I. (2003). U-commerce: an experimental investigation of ubiquity and uniqueness. ICIS Proceeding. Paper No. 35.

Knott, B.A., Bolia, B.S., Nelson, W.T. and Galster, S.M. (2006). Effects of collaboration technology on the performance of tactical air battle management teams. Proceedings of the Human Factors Issues in Network-Centric Warfare TTCP Symposium, Sydney, Australia.

Koseoglu, U. (2008). Mobile visualisation for on-site collaboration. International Journal of Interactive Mobile Technologies (iJIM), 2 (4), 43-53.

Laszkiewics, M. (2003). Collaborative maintenance: a strategy to help manufactures become learn, mean, and agile. Plant Engineering, 57 (9), 30-36.

Laszkiewics, M. (2004). Reaping the rewaed of strategic maintenance. Support Connection, 57, 14-24.

Liang, T.-P., Huang, C.-W. and Yeh, Y.-H. (2007). Adoption of mobile technology in business: a fit-viability model. Industrial Management & Data Systems, 107, 1154-69.

Linstone, H.A. and Turoff, M. (1975). The delphi method: techniques and applications, Addison-Wesley, London.

Loughlin, K. & Moore, L. (1979). Using delphi to achieve congruent objectives and activities in a pediatrics department. Journal of Medical Education, 54, 101-106.

Luff, P. and Heath, C. (1998). Mobility in collaboration. In Proceedings of the CSCW. ACM Press, New York, 305–314.

Márquez, A.C. (2007). The maintenance management framework, Springer-Verlag, London.

Massey, A.P. (2008). Collaborative Technologies. Book Chapter, Department of Operations, Decision and Information Technologies, Indiana University, Bloomington, IN, USA, 341 – 354.

Meridium (2006). Collaborative asset maintenance strategies: redefining the roles of product manufactures and operators in the services chain. Aberden Group.

Neyem, A., Ochoa, S.F., and Pino, J.A. (2007). Designing mobile shared workspaces for loosely coupled workgroups. Groupware: Design, Implementation, and Use, Lecture Notes in Computer Science, 4715, 173-190.

Nunamaker, J.F., Dennis, A.R., Valacich, J.S., Vogel, D. and George, J.F. (1991). Electronic meeting systems to support group work. Communication of the ACM, 34 (7), 40-61.

Oslon, G.M., Malone, T.W. and Smith, J.B. (2001). Coordination theory and collaboration technology. Lawrence Erlbaum Associates, Publisher, New Jersey, London.

Pereira, C.S. and Soaresa, A.L. (2007). Improving the quality of collaboration requirements for information management through social networks analysis. International Journal of Information Management, 27 (2), 86-103.

Rein, G.L. (1993). Collaboration technology for organisational design', Proceedings of the 26th Hawaii International Conference.

Romero, D., Galeano, N. and Molino, A. (2008). Readiness for collaboration assessment approach in collaborative networked organisations. IFIP International Federation for Information Processing, 266, 57-56.

Rosa, F.D., Malizia, A. and Mecella, M. (2005). Disconnection prediction in mobile ad hoc networks for supporting cooperative work. IEEE Pervasive Computing, 4 (3), 62-7.

Saran, C. (2006). Mobile collaboration is priority for CIOs, Technology.

Sarker, S. and Wells, J. (2003). Understanding Mobile Handheld Device Use and Adoption. Communications of the ACM, 46 (12), 35–40.

Schaffers, H., Carver, L., Brodt, T., Fernando, T. and Slagter, R. (2006). Mobile workplaces and innovative business practice. Book Chapter (15) Mobile Virtual Work, 343 – 368.

Sinha, A., Lahiri, R.N., Chowdhury, S., Chowdhury, S.P. and Song, Y.H. (2007). Complete IT soulution for enterprise asset management (EAM) in Indian power utility business. Presented at the 42nd International Conference of Universities Power Engineering, UPEC.

Smailagic, A. and Bennington, B. (1997). Wireless and mobile computing in train maintenance and diagnosis. Proceedings of the 47th IEEE Vehicular Technology Conference, IEEE Press, Piscataway, N.J.

Sumsion, T. (1998). The delphi technoque: an adaptive research tool. British Journal of Occupational Theraphy, 61(4), 153-156.

Syafar, F., Gao, J. and Du, J.T. (2013). Applying the international Delphi technique in a study of mobile collaborative maintenance requirements. PACIS 2013 Proceeding, paper 221.

Tam, S.B. and Price, J.W.H. (2006). Optimisation framework for asset maintenance investment. Monash Business Review, 2 (3), 1-10.

Tentori, M. and Favela, J. (2007). Activity-aware computing in mobile collaborative working environments', Groupware: Design, Implementation, and Use. Lecture Notes in Computer Science, 4715, 337-353.

Trappey, A.J.C, Hsiao, D.W, Ma, L, Chung, Y.L. and Kuo, Y.L. (2008). Agent-based collaborative maintenance chain for engineering asset management. Advance Concurrent Engineering, Part 1, 29-41.

Tsirulnik, G. (2009). Mobile collaboration for increase employee productivity: Study, Mobile Marketer.

Wang, A.I. and Norum, M.S. (2007). A peer-to-peer framework for collaboration. 10th IASTED International Conference on Software Engineering and Application.

Wang, C., Ghenniwa, H., Shen, W. and Zhang, Y. (2005). Agent-based distributed collaborative monitoring and maintenance in manufacturing. International Federation for Information Processing, 159, 129-138.

Zigurs, I. and Buckland, B.K. (1998). A theory of task/technology fit and group support. Management Information system research Centre, University of Minnesota, 22 (3) 313-334.

5% Overall Similarity

Top sources found in the following databases:

- 3% Internet database
- Crossref database
- 2% Submitted Works database
- 1% Publications database
- Crossref Posted Content database

TOP SOURCES

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

1	**University of Johannsburg on 2015-05-09** Submitted works	2%
2	**mafiadoc.com** Internet	1%
3	**researchgate.net** Internet	<1%
4	**pt.scribd.com** Internet	<1%
5	**works.bepress.com** Internet	<1%
6	**highland.gov.uk** Internet	<1%

Excluded from Similarity Report

- Bibliographic material
- Cited material
- Manually excluded sources
- Quoted material
- Small Matches (Less then 10 words)
- Manually excluded text blocks

EXCLUDED SOURCES

aisel.aisnet.org Internet	5%
pacis2014.org Internet	5%

EXCLUDED TEXT BLOCKS

MOBILE-ENABLED COLLABORATIVE MAINTENANCEFaisal Syafar, School of Infor...
aisel.aisnet.org

Respondents' (Professionals) profileA three-round Delphi email-based questionnai...
aisel.aisnet.org

Communication is essential to any group maintenance in organisations. It reduces...
www.pacis2014.org

Still very limited use121323.90.68Table 7.Current mobile technology roles in supp...
www.pacis2014.org

Table 4.Benefit of collaborative maintenance-CoordinationWhenever maintenance ...
www.pacis2014.org

Cooperation refers to information exchange and adjustments of activities, as well ...
www.pacis2014.org