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MOBILE INFORMATION SYSTEMS IN MAINTENANCE ENGINEERING AND ASSET MANAGEMENT

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Abstract. *The objective of this paper is to provide a profound insight into important characteristics with regard to the integration of mobile technology into the area of industrial maintenance. The aspects highlighted in the paper uncover, for instance, acceptance models and best practices, as well as the financial impact of mobile technologies in the domain of interest. Moreover, the paper pinpoints some important characteristics that impede full integration of these technologies into this area. In addition, the economic benefits and the current situation with regard to mobile integration are highlighted. In addition, relevant literature and theories are analysed and discussed. Furthermore, the industrial integration of mobile technologies is outlined. The results indicate that there is a tendency to place an emphasis on the technical aspects of mobile devices rather than on understanding the organisational context, which affects the integration of mobile technologies into this domain. The work provides a thorough understanding of best practices and aspects to consider for the successful integration of mobile technologies in this area. This is because the use of mobile devices enables maintenance staff to gain access to information and services pertaining to the task in hand in real time, as long as some form of network access is provided. Users of these devices thus become mobile actors who dynamically interact with the physical environment in the workplace and support information systems, leading to a faster response to events and improved organizational performance.*

Keywords: *mobile technologies, industrial maintenance engineering, technology acceptance models, asset management best practices.*

Introduction

Information and communication technologies (ICTs) are significant enablers for the enhancement of decision-making and the generation of supporting knowledge within an organisation. Companies that are unable to keep up with the pace of the latest ICT developments may lose their competitive advantage and the ability to compete under the same conditions as their competitors, leading to shrinking market share and profitability[1]. Decision support systems used to aid maintenance departments in addressing important tasks in industrial maintenance engineering, i.e. maintenance, such as data acquisition, processing, analysis and interpretation, as well as the extraction of information and

1 Turban, E., Sharda, R., & Denlen, D. Decision support and business intelligence systems (9th ed.). Upper Saddle River, NJ: Pearson Prentice Hall. 2011.

knowledge, have seen drastic changes, which have been attributed to a large extent to advances in ICTs. Artificial intelligence (AI) for industrial decision-making, particularly in relation to maintenance departments, started to appear in the 1980s in the form of expert systems. In the 1990s, a shift occurred from traditional AI to computational intelligence, with fuzzy logic and artificial neural networks as the prime constituents. Comprehensive reviews of artificial intelligence techniques and their application in condition monitoring and maintenance highlighted relevant opportunities and potential benefits (Kalogirou[2]; Liao[3]; Warwick et al.[4]; Wang[5]). In the late 1990s, a major ICT push came with the extensive use of the internet and associated web-based computing, which also had a significant impact on condition monitoring applications. With the distributed nature of web resources, a parallel trend was the adoption of Distributed Artificial Intelligence (DAI). This was particularly the case with regard to the use of agent technologies, which were soon applied in maintenance and condition monitoring. In addition, other efforts were made with regard to mobile device applications for use in the same areas, as well as in e-maintenance. Reference to some of these developments can be found in Campos and Prakash[6], and Holmberg et al.[7] Furthermore, industrial efforts have been made with regard to the development of mobile devices for industrial maintenance that are in an experimental phase, such as the IBM Smart Mobility prototype that supports maintenance, repairs and operations (www.qualitydigest.com). The prototype assists in identifying the right machine for a particular task, ensuring that the engineer has the correct task sheet and provide possibilities for calling an expert if needed. There are thus many expected benefits from the use of mobile technologies, such as improved organisational performance. However, the devices involved have not been exploited sufficiently in industrial practice on a daily basis by maintenance departments. It is therefore important to understand the factors that impede the integration of mobile technologies in this field. With regard to this, technology acceptance theories are becoming key in contributing to a better understanding of the state of current practice. Therefore, it is crucial to discern those factors, as mentioned above, because mobile technologies have the potential to help maintenance managers to automate data collection and analysis

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2 Kalogirou, S.A. Artificial intelligence for the modeling and control of combustion processes: A review. *Progress in Energy and Combustion Science*. 2003, Vol. 29, No. 6: 515-566.

3 Liao, S.H. Expert system methodologies and applications - a decade review from 1995 to 2004. *Expert Systems with Applications*. 2005 Vol. 28, No. 1: 93-103.

4 Warwick, K., Ekwue, A.O. and Aggarwal, R. (Eds.) Artificial Intelligence Techniques in Power Systems, Power & Energy, Publishing & Inspec. Technology: Toward a Unified View. MIS Quarterly. 1997, 27: 425–478.

5 Wang, K. Intelligent Condition Monitoring and Diagnosis System: A Computational Intelligent Approach, Frontiers in Artificial Intelligence and Applications. 2003, Vol. 93.

6 Campos, J. & Prakash, O. Information and communication technologies in condition monitoring and maintenance, in Dolgui, A., Morel, G and Pereira, C.E. (Eds.) *In-formation Control Problems in Manufacturing*. Elsevier. 2006, Vol. II: 3-8.

7 Holmberg, K., Adgar, A., Arnaiz, A., Jantunen, E., Mascolo, J. and Mekid, S. E-maintenance. Springer. 2010.

to support processes and reduce costs[8]. Reviews in the field highlight the significant potential and rapid advances of ICTs for use in condition monitoring and maintenance[9]. In addition, cost-effectiveness analysis is key as a way to identify whether any profit or competitive advantage can be achieved by using ICTs for more automatic maintenance tasks, especially in predictive maintenance[10]. This paper highlights important aspects in terms of mobile integration in industrial maintenance. Academic literature emphasises the importance of technology acceptance models, with regard to understanding the use and will to adopt various information technologies[11]. This paper is an extension of previous work by the authors first presented in 2015[12] .

There are several studies in different areas that place a significant emphasis on the acceptance models for the understanding of the phenomena that contribute to the barriers, such as those mentioned by Chaveesuk et al.[13], Venkatesh et al.[14], Chen et al.[15], Phan and Daim[16], Wu and Wang[17], and Legris et al.[18]. It is therefore important to understand how the factors highlighted, with the help of the above mentioned models, can affect the acceptance of mobile technologies in the domain of interest. In this study, the authors also point out other important aspects connected with this area, such as best

8 Lee, J., Ramji, A, Andrews, K. , Darning, L., Dragan, B. An integrated platform for diagnostics, prognostics and maintenance optimization. In: *E-Proceedings of Intelligent Maintenance System*. France.2004; Baglee, D., Knowles.M. Maintenance Strategy Development in the UK Food and Drink Industry. *International Journal of Strategic Engineering Asset Management*. 20131 (3): 289 – 300.

9 Campos, J. & Prakash, O. Information and communication technologies in condition monitoring and maintenance, in Dolgui, A., Morel, G and Pereira, C.E. (Eds.) *In-formation Control Problems in Manufacturing*. Elsevier. 2006, Vol. II: 3-8.;Campos, J. Development in the application of ICT in condition monitoring and maintenance. Computers in Industry 60. 2009: 1–20.

10 Conde, E., Fernandez, S. and Arnaiz, A., Maintenance methodology for selecting the most cost-effective predictive strategies. *37th ESReDA Seminar 2009*, Baden, Switzerland. 2009; Alrabghi, A. and Tiwari, A. A Review of Simulation-based Optimisation in Maintenance Operations. *15th International Conference on Computer Modelling and Simulation* (UKSim). 2013: 353–358.

11 Chen, S.C., Shing-Han, L. and Chien-Yi, L. Recent related research in technology acceptance model: A literature review. *Australian Journal of Business and Management Research*. 2011, Vol. 1, No. 9:124-127.

12 Campos, J., Jantunen, E., Baglee, D., Gilabert, E., Fumagalli, L., Emmanouilidis, C. The Use of Mobile Technologies and Their Economic Benefits in Maintenance. In: *10th World Congress on Engineering Asset Management – WCEAM*. 28-30 *Sep* 2015, Springer, 2016: 113-119.Tampere, Finland.

13 Chaveesuk, S., Vongjaturapat, S., Chotikakamthorn, N. Analysis of factors influencing the mobile technology acceptance for library information services: Conceptual model. In: 2013 *International Conference on Information Technology and Electrical Engineering (ICITEE)*. 2013: 18–24.

14 Venkatesh, V., Morris, M.G., Davis, G.B., Davis, F.D. User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly*. 2003, 27: 425–478

15 Chen, S.C., *supra* note, 11.

16 Phan, K. and Daim, T. Exploring technology acceptance for mobile services. *Journal of Industrial Engineering and Management*. 201, 4(2): 339-360.

17 Wu, J.H, & Wang, S.C. What drives mobile commerce?: An empirical evaluation of the revised technology acceptance model. *Information & Management*. 2005, Vol. 42, Issue 5: 719-729.

18 Legris, P., Ingham, J., & Collerette, P. Why do people use information technology? A critical review of the technology acceptance model. *Information & Management*. 2003, Vol. 40, Issue 3: 191-204.

practices and the economic importance of using mobile technologies, as well as their current integration into the industry. The paper examines technology acceptance models and best practices for asset management in Section 2. Section 3 discusses the economic benefits of using mobile technologies in maintenance. Section 4 highlights the industrial integration of these technologies, and Section 5 comprises a discussion and the main conclusions of the study.

1. Technology acceptance models and best practices for asset management

ICTs enablers can support enterprises in achieving expected benefits such as improved performance and productivity, insofar as the ICTs are accepted and used by an organisation's employees[19]. The acceptance of information systems (IS) by users has been studied for several years, and these analyses have involved such domains as sociology, psychology and informatics, with a particular focus on explaining the intentional variance in ICTs acceptance by users and understanding technology acceptance. For instance, technology adoption models have been developed by authors such as Fishbein and Ajzen[20], with their theory of reasoned action. In addition, the theory of planned behaviour of Ajzen[21], the technology acceptance model of Davis[22] and the diffusion of innovation theory of Rogers[23] are concepts developed with regard to technology acceptance. Among these studies, one approach has been to seek to explain the factors that influence individuals' acceptance of technology through variables linked to intention of use or actual use of the ICTs [24]. Another approach has been to link technology acceptance to the success of ICTs implementation at the organisational level. These theoretical developments with regard to possible motives and barriers on the way to accepting and adopting technologies are manifold and have resulted in several acceptance models. Hence, the unified theory of acceptance and use of technology (UTAUT) is the result of the combination of several models of IT adoption, with the aim of better representing the reality of IT acceptance by addressing the limitations of earlier models (Venkatesh[25]; Straub[26]). The UTAUT summarises developments in acceptance

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19 Venkatesh, V. et al., *supra* note, 14.

20 Fishbein, M., and Ajzen, I. Belief, attitude, intention and behavior: An introduction to theory and research. Reading, MA: Addison-Wesley series. 1975.

21 Ajzen, I. The Theory of Planned Behavior. Organizational Behaviour and Human Decision Processes. 1991, 50(2): 179–211.

22 Davis, F. D. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly. 1989:13(3): 319–339.

23 Rogers, E. M.. Diffusion of innovations (3rd ed.). New York: Free Press. 1983.

24 Venkatesh, V. et al, *supra* note, 14.

25 Ibid.

26 Straub, E.T. Understanding Technology Adoption: Theory and Future Directions for Informal Learning. *Review of Educational Research*. 2009, 79(2): 625–664.

models (Chan et al.[27]), with many examples in the research community about different efforts to develop the UTAUT model. In conclusion, the UTAUT is a result of research associated with several models of IT adoption, with the aim of better representing the reality of IT acceptance by addressing the limitations of earlier models[28]. The UTAUT incorporates four concepts that affect behavioural intent and usage behaviour in the area of ICTs: performance expectancy, effort expectancy, social influence, and facilitating conditions. Performance expectancy is the assessment of user expectation with regard to something that will help the user enhance their performance in executing various work tasks; effort expectancy is the expected ease of use of ICTs social influence is concerned with the assessment of social aspects affecting the extent to which a user is likely to use a specific information system; and facilitating conditions refer to the degree to which a user believes an organisation and its technical infrastructure support use of the system. Other factors such as age, gender, experience and willingness of use are believed to have less importance at the acceptance level of ICTs. The concern with the UTAUT model is that it does not include attitude and self-efficacy as direct determinants of behavioural intention, factors that technology acceptance research has indicated as being key[29]. The UTAUT model has been extensively used in different studies of technology adoption and diffusion as a framework for researchers to perform empirical studies of behaviour and user intention[30]. Theories of acceptance and the article by Venkatesh et al.[31] have been extensively studied with reference to concepts that affect behavioural intent and usage behaviour in different user groups. Nevertheless, little effort has been made to examine such issues related to maintenance departments and e-maintenance adoption at companies. A recent report that highlights the acceptance of technologies in organisations and is among the first attempts to link prominent technology adoption models to e-maintenance technology is that by Aboelmaged et al.[32] The author predicts the dimensions of a technology readiness index (TRI) that uses the determinants of the technology–organisation–environment (TOE) framework. The author uses prominent frameworks in innovation adoption to highlight advances in e-maintenance adoption, i.e. the TOE framework and TRI. The work proposes a research model, which is later

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27 Chan, F.K.Y., Thong, J.Y.L., Venkatesh,W., Brown, S.A., Hu, P.J.; Tam, K.Y. Modeling Citizen Satisfaction with Mandatory Adoption of an E-government Technology. *Journal of Association for Information System*. 2010, 11(10): 519–549

28 Venkate+sh, V., Morris, M.G., Davis, G.B., Davis, F.D. User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly*. 2003, 27: 425–478; Straub, E.T. Understanding Technology Adoption: Theory and Future Direction for Informal Learning. *Review of Educational Research*. 2009, 79(2): 625–664.

29 Venkatesh, V., et al, *supra* note, 14.

30 Williams, M.D, Rana, N.P & Dwivedi, Y.K. The unified theory of acceptance and use of technology (UTAUT): a literature review. *Journal of Enterprise Information Management*. 2015, Vol. 28 Issue: 3, pp.443 – 488

31 Venkatesh, V., et al, *supra* note, 14.

32 Aboelmaged M.G (2014) Predicting e-readiness at firm-level: An analysis of technological, organizational and environmental (TOE) effects on e-maintenance readiness in manufacturing firms. *International Journal of Information Management*. 2014, 34:639

validated, that uses eight TOE factors: technology infrastructure, technology competence, perceived e-maintenance benefits, perceived e-maintenance challenges, company maintenance priority, company size, ownership type, and competitive pressureon four TRI factors, namely optimism, innovativeness, discomfort and insecurity. Moreover, the author says that the framework for e-maintenance should be integrated around three unified pillars. The objective of the first pillar is to improve staff awareness, knowledge and skills with regard to planned ICTs through measures such as training. The second pillar is associated with the implementation and use of e-maintenance ICTs such as wireless and networked sensors as part of a condition-based maintenance (CBM) strategy. The last pillar concerns the organisational and technical aspects that a manager must deal with to successfully implement ICTs. It is crucial to consider all the factors mentioned above for the acceptance and successful implementation of e-maintenance and the relevant ICTs in a maintenance department.

Aside from studies on technology acceptance theories, others have focused more on the specific domain of maintenance and asset management. The European Federation of National Maintenance Societies (EFNMS), through its European Asset Management Committee (EAMC), carried out a survey of EU industry on best practices in asset management titled "How organizations manage their physical assets in practice" (EFNMS/EAMC, www.hms-gr.eu/t). This provides a useful assesment of how organisations manage data related to their assets and it was of particular interest to note that although maintenance-related events were typically recorded in systems such as computerised maintenance management systems (CMMS), the systems were not optimised enough, leaving much room for improvement with regard to the use of ICT enablers. According to the EFNMS report, part of the problem with the data is related to the fact that high-quality or actionable data may not, in most cases, be available at the right time and in the right place to people authorised to access it.

This highlights the need for greater penetration and adoption of ICT, especially mobile ICT solutions. A key area for improvement in asset management to which mobile ICTs can contribute is the enabling of true mobile collaboration[33]. Specifically, it can help to remove time and space constraints, as well as enable mobile maintenance staff to take advantage of portability, accessibility, reachability, identification and localisation features when interacting with maintenance-oriented information systems and the relevant physical environment in the workplace. It should be taken into account that the main factors that impede successful CMMS implementation in industry are selection errors, insufficient commitment, poor training, limited addressing of key organisational issues and underestimation of difficulties, along with consequent limited allocation of resources and lack of a demonstrable use of these systems.

Consulting experts in the field, the study considered technological, organisational and human capital issues relevant to mobile ICT adoption and prospects in this

33 Emmanouilidis, C., Liyanage, J.P. and Jantunen, E. Mobile solutions for engineering asset and maintenance management. *Journal of Quality in Maintenance Engineering*. 2009: 15 (1), pp. 92–105.

domain[34]. The study suggested that the adoption effort should be aided by the alignment of relevant business processes in the three broad organisational layers (strategic, tactical and operational) of a company's activities and should prioritise implementation, targeting the most critical processes or assets to demonstrate impact. Leaving the broader picture to focus on individual projects and specific aspects of implementation and technology adoption, the results may follow not only the general pattern, but can also provide additional and more focused insight on specific technological solutions. For example, the adoption of e-training solutions in the area of maintenance and asset management depends on aspects of introduced technological elements and functional features, as well as content type and quality[35]. Relevant technological innovation brings greater flexibility, efficiency, mobility and ease of use to specific functional design features, such as navigation patterns while using the graphical user interfaces (GUI), short paths to relevant knowledge, GUI design patterns and content-related features that facilitate adoption by users. In addition, with regard to the adoption of e-maintenance solutions, one should appreciate efforts made in the industry to reduce the fragmentation of information and services through appropriate integration mechanisms that remain technically transparent and not-noticeable by users and, at the same time, increase the seamless experience of service usage and information delivery to maintenance personnel (welcom-project.ceti.gr)[36].

2. The economic benefits of using mobile technologies in maintenance

When addressing the use of mobile technologies for maintenance, both business process analysis and an assessment of impacts need to be conducted. Financial benefits potentially offered by e-maintenance technologies should be carefully examined, relying on the principles of cost-benefit analysis (CBA). CBA is a well-established methodology that is based on the evaluation of a project's possible costs and benefits (see Prest and Turvey[37]). It is generally carried out in this area by paying specific attention to the fact that the introduction of new technologies results in costs and benefits. A methodology previously developed to assess the use of new technologies in logistics is one of the main and possible areas to exploit. Examples of this methodology are provided by Miragliotta

34 Syafar, F., and Gao, J. Mobile collaboration technology in engineering as-set maintenance: A Delphi study. *Procedings of the 2013 IEEE 17th International Conference on Computer Supported Cooperative Work in Design* (CSCWD), 27-29 June 2013, Whistler, Canada. 2013: 483 - 488.

35 Papathanassiou, N., Pistofidis, P., and Emmanouilidis, C. Competencies Development and Self-Assessment in Maintenance Management e-Training, Eu-ropean Journal of Engineering Education. Taylor and Francis. 2013, 38(5): 497-511.

36 Pistofidis, P., Emmanouilidis, C., Koulamas, C., Karampatzakis, D., Papathanassiou, N. A Layered E-Maintenance Architecture Powered by Smart Wireless Monitoring Components. *Procedings of the 2012 IEEE International Conference on Industrial Technology (ICIT 2012)*. Athens, Greece 19-21 March 2012, (IEEE). 2012 : 390-395.

37 Prest, A., R., Turvey, R. Cost-Benefit Analysis: A Survey. *The Economic Journal*. 1965: 683-735.

et al.[38] the methodology consists of three steps: the first of these is the analysis of the chosen processes, i.e. AS-IS processes in line with the activity-based costing (ABC) method to identify cost drivers for each activity; the second step is the development of a technical solution for the process concerned; and the final step is an assessment of the impacts of the solution and the evaluation of costs and benefits carried out through a comparison between AS-IS and TO-BE scenarios, i.e. the future state of the processes. When assessing impacts, a classification of typical costs and benefits can be kept in mind. In particular, these can be divided into tangible and intangible cost and benefits[39], as summarised in Figure 1.

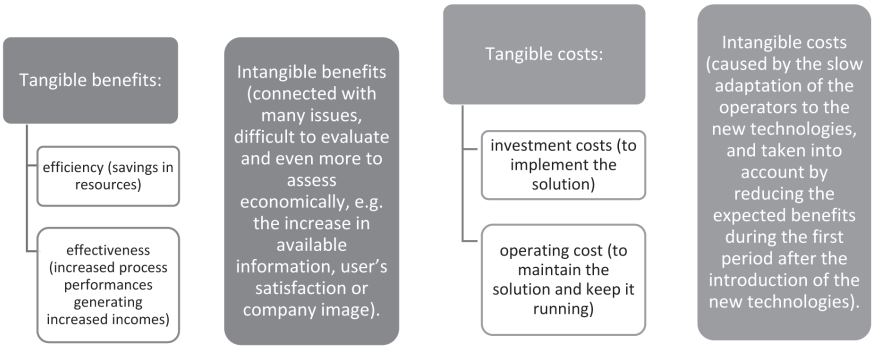

Figure 1. Classification of tangible and intangible benefits and costs.

A formal and clear understanding of the relationship between activities and mobile technologies is a key aspect to be considered during the assessment. With the aid of a case study analysis, Fumagalli et al.[40] demonstrated that significant benefits can be obtained with a small-scale investment, with a payback time (in 2010) of well under three years in all cases. Interestingly, 2010 can still be considered a time when mobile devices was not so widespread. As an example, the Apple iPad was only launched in January that year and can be considered as leading to the increased use of tablets. Moreover, the mass

38 Miragliotta, G., Perego, A., Tumino, A. RFId and Returnable Transport Items Management: An Activity-Based Model to Assess the Costs and Benefits in the Fruit and Vegetable Supply Chain. *Proceedings of the 3rd International Workshop on RFId Technology & Concepts, Applications, Challenges, IWRT 2009 in conjunction with ICEIS 2009* (*International Conference on Enterprise Information Systems*). Italy. 2009.

39 Fumagalli, L., Di Leone, F., Jantunen, E., Macchi, M. Economic Value of Technologies in an eMaintenance platform. In: 1st IFAC Workshop, A-MEST'10, Advanced Maintenance Engineering, Services and Technology. Lisboa, Portugal. 2010: 23- 28; Jantunen, E., Macchi, M., Fumagalli, L., Di Leone, F. 2010. Financial analysis of e-maintenance. MAINTWORLD. 2010, 2: 38- 43.

40 Fumagalli, L., Di Leone, F., Jantunen, E., Macchi, M. Economic Value of Technologies in an eMaintenance platform. In: 1st IFAC Workshop, A-MEST'10, Advanced Maintenance Engineering, Services and Technology. Lisboa, Portugal. 2010: 23- 28.

diffusion of this kind of portable device started in 2010. Of course, such mobile devices are not comparable with industrial ones, but the diffusion of the tablet as a mass-market product has contributed to cost reductions in devices as a whole, allowing one to foresee that payback time could be within one year and at least take no longer than two years. This depends on the type of business and the way the company is organised. Fumagalli et al.[41] showed that large companies offering a wide range of maintenance services to many different types of customer and carrying out their activities in a formal and procedure-driven way can benefit from newly introduced mobile technologies by improving process efficiency. On the other hand, original equipment manufacturers (OEMs) with less developed maintenance divisions can benefit from efficiency, but this hardly compensates for the cost of introducing a mobile solution into the service. It is always beneficial to consider developing an effective business model for a mobile-based maintenance service first, and trying to avoid pushing it in terms of technological advantages.

In addition, Gilabert et al.[42] have outlined how simulation tools can help to identify a new predictive maintenance approach through use of ICTs in the cost-benefit stage of the product life cycle or aid plant productivity. The reliability information on which this maintenance strategies simulation relies is the probability density distribution of failure for the system or component. Such a function determines the possibility of a failure occurring at a given time.Further, the Weibull distribution is as well frequently employed because it is applicable to different phases in the life cycle of a component or system. This type of distribution is flexible enough to model a variety of failure occurrences, whether they are decreasing, increasing or constant, allowing it to describe any phase of a component's life. Given this function, it is possible to apply the Monte Carlo method to carry out random sampling and thus obtain possible times at which failures occur. One way to do this is this is using the inverse of the cumulative Weibull distribution function, by means of carrying out random sampling to obtain estimates of time until a failure. As the process is repeated, the series of values obtained will produce a more faithful description of the Weibull distribution. With this methodology, it is possible to estimate the expected time of failure occurrence, and thus to anticipate the type and number of actions to perform in line with a particular maintenance strategy and the cost. This process can be repeated according to the Monte Carlo analysis method to offer a realistic description, and time and costs are accumulated. The cost per unit of time is used to compare the results obtained using different maintenance strategies. Figure 2 shows an example of the impact of different strategies on maintenance of a mechatronic component within a system, taking into account a global key performance indicator (KPI), i.e. cost, segmented at different cost categories (namely, cost of repairs and loss of revenues when the component fails; cost of preventive activities; and cost of monitoring activities, whether remote or on-site).

41 Ibid.

42 Gilabert, E., Fernandez, S., Arnaiz, A., Konde, E. Simulation of predictive maintenance strategies for cost-effectiveness analysis. Proceedings of the Institu-tion of Mechanical Engineers, Part B: Journal of Engineering Manufacture. doi:10.1177/0954405415578594. 2015.

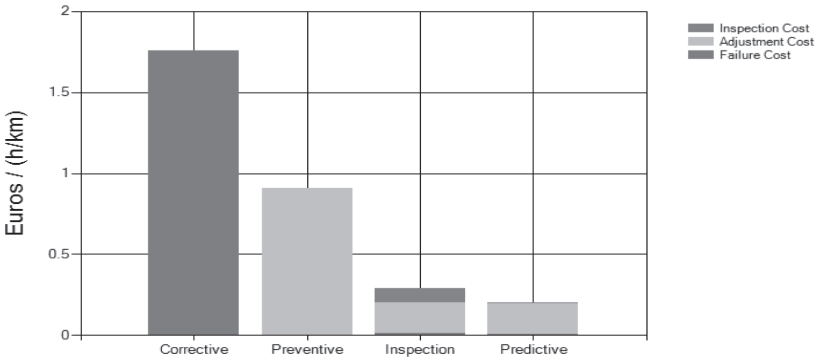

Figure 2. The impact of maintenance strategies segemented by cost categories on mechatronic component.

This improvement analysis ends with an estimation of the potential impact of the different strategies (corrective, time-based and inspection) measured in euros, comparing the maximum cost of the selected technologies and alternative strategies, and considering several known or estimated variables, such as frequency of inspections, reliability, and cost of failures, inspections and preventive actions.

3. Industrial integration of mobile technologies

To provide empirical evidence on the diffusion of ICTs as well as mobile solutions for maintenancea a permanent unit was created in December 2010 as part of the Observatories of the School of Management of Politecnico di Milano, i.e. the observatory on technologies and services for maintenance (TeSeM), (www.tesem.net). This established a collaborative platform for a network of several Italian universities to monitor state-of-the-art maintenance choices in the field of industrial plants. TeSeM observes small, medium-sized and large companies in Italy, where it should also be noted that many multinational European and worldwide companies are located. TeSeM has collected information about the use of personal digital assistants (PDAs) and thus mobile solutions, with information coming from 277 companies interviewed between 2011 and 2015. The survey shows that 10% of the companies adopt such solutions for purposes of industrial maintenance. In the more recent years of this period, between 2013 and 2015, more detailed analysis was performed for specific sectors. Further results reveal, for instance, that in the food and beverages sector, 21% of companies had adopted mobile solutions, compared with 5% in the metalworking sector. Moreover, looking at small and medium-sized enterprises (SMEs) compared with large ones, the following statistics have been calculated in line with the results of an interview conducted with the aforementioned companies: at SMEs, 6% of companies had adopted mobile solutions, compared with 13% at large enterprises. Finally, expectations with regard to the use of mobile devices have been investigated. The results of the survey are based on the number of companies that use mobile solutions – namely 10% of them – and show that in some cases companies use these solutions for more than one purpose. For instance, 18% of the companies that adopt mobile solutions use them to manage work orders, 2% to manage safety procedures for maintenance activities, 20% to support inspections, 18% for condition monitoring, 29% to support warehouse management for spare parts, and 13% to consult technical documents and drawings.

4. Discussion and conclusions

It is important to understand best practices for ICTs adoption and the different factors that contribute to this, in order to facilitate acceptance in maintenance departments – particularly with regard to mobile technologies. Technology adoption theories can be used to understand a company's maturity stage and serve as a framework for developing strategies for ICTs acceptance. This can help to understand where to place an emphasis to stimulate acceptance and organisational willingness to invest in ICT innovation, resulting in a more widespread integration of mobile technologies into the maintenance department. A recent survey of employees in various industries was carried out to help understand the benefits of using mobile devices, looking at important aspects such as work performance[43]. The study showed that work performance improved with the support of mobile technology. This emphasises the importance of understanding factors that can facilitate the integration of mobile technology in the industrial sector, particularly with regard to industrial maintenance.

Maintenance strategies such as CBM and predictive maintenance can benefit from mobile technologies, which can become valuable for all types, sizes and complexity of machinery. In addition, there is a growing demand for the efficiency, availability and safety of systems, along with product quality and customer satisfaction. Moreover, taking into account the trend towards a decrease in profit margins, the importance of implementing effective maintenance strategies becomes unquestionable. In this setting, the maintenance function plays a critical part in a company's ability to compete on the basis of cost, quality and delivery performance. It is therefore important to understand the reasons why mobile devices are not yet fully integrated into maintenance departments, given that they provide many expected benefits and can result in improved organisational performance.

Current research emphasises the need to understand the context when considering technical aspects, so mobile technologies that are adopted will be accepted by users in the specific context. Sein et al.[44] highlight a need to recognise that the value contributed by information systems (IS) and ICTs emerges from interaction in an organisational

43 Yueh, H.-P., Lu, M.-H., Lin, W. Employees' acceptance of mobile technology in a workplace: An empirical study using SEM and fsQCA. *Journal of Business Research*. 2016, 69: 2318–2324

44 Sein, M.K., Henfridsson, O., Purao, S., Rossi, M. and Lindgren, R. Action design research. *MIS Quarterly*. 2011, Vol. 35, Issue 1: 37- 56.

context, even when the primary design is research-driven. It is therefore crucial to consider a multidisciplinary approach for the mobile technologies for sustainable ICTs in industrial maintenance departments. In line with this, important experiences from the integration of mobile technology in the area of interest, including methodological aspects, are discussed in Campos[45].

Furthermore, this study shows the importance of the business context, indicating that a clear alignment with the underlying business processes is needed to successfully integrate ICTs. Authors such as Peppard and Ward[46] highlight the importance of alignment between the ICTs with business strategies, while taking into consideration the resources of the organization, such as the knowledge of the employees (business and technical skills, knowledge and experience) and their behaviour and attitudes.

Also, it is well known that one way of reducing the cost of production is to cut the cost of operations, including maintenance. In some industries, this is the second-highest or even highest element in operating costs. Swanson[47] highlights that to achieve world-class performance, companies have started to undertake more efforts to improve quality and productivity, and reduce costs. This has led to an examination of the activities of the maintenance function, with the recognition that effective maintenance is crucial for many operations because it extends the life of equipment, improves availability and keeps equipment in a good condition. Mobile devices are thus crucial in the field of maintenance for leveraging the dynamic nature of operations and maintenance workers, with the ability to provide the right information and access to services to the right user in the right format – leading to an increased personnel and ultimately organisational performance. Moreover, if an enterprise handles maintenance effectively, it will benefit directly from improved availability and dependability, leading to production and revenue advantages.

The importance of mobile ICT adoption in maintenance is highlighted by the fact that e-maintenance has triggered a radical change in practices in the field. Having the correct information at hand can provide operational and financial benefits to most organisations. Advances in wireless technologies and the availability of low-cost and easy-to-use mobile devices allow this to become a reality through portable, available and affordable systems, enabling organisations to exploit a vast amount of potential from a financial point of view.

In conclusion, ICT-enabled innovation provides enormous opportunities. The most important functional benefit is the availability of relevant and reliable information and services where they are needed. The creation of effective strategies using methods such as CBM relies on this type of availability, because it enables the planning of maintenance

45 Campos, J. Information Systems development aspects for the mobile web technologies. *Social Technologies.* 2015, Vol. 5: 62-72.

46 Peppard, J. and Ward, J. Beyond strategic information systems: toward an IS capability. *Strategic Information Systems*. 2004, Vol. 13, Issue 2: 167–194.

47 Swanson, L. Linking maintenance strategies to performance. *International Journal of Production Economics.* 2001, Vol. 70, No. 3: 237-244

actions based on evidence of need rather than merely on the basis of predetermined schedules. Furthermore, it is easy to understand how much support a maintenance engineer needs from an information system for carrying out practical maintenance tasks. In all available economic studies, the introduction of e-maintenance has proved to be justified. Naturally, the more complicated the industrial environment, the greater the economic benefits and the shorter the payback time for investments. Therefore, the comparative advantages of implementing e-maintenance are greater if the industrial environment is more complicated, i.e. expensive and complex equipment where there is a need to implement maintenance strategies such as conditon based maintenance (CBM) with all what it concerns.

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MOBILIOSIOS INFORMACINĖS SISTEMOS PASLAUGŲ INŽINERIJOJE IR VADYBOJE

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Santrauka. *Straipsnio tikslas – įsigilinti į mobiliųjų technologijų integracijos į industrines paslaugas svarbiausius bruožus. Svarbūs šiame straipsnyje paliesti aspektai sudaro sąlygas, pavyzdžiui, atskleisti mobiliųjų technologijų įsisavinimo modelius ir gerąsias praktikas bei finansinį mobiliųjų technologijų poveikį interesų sferai. Straipsnis išryškina svarbias prielaidas, dėl kurių mobiliųjų technologijų negalima iki galo įdiegti į dominančią sferą. Be to, pabrėžiama mobiliųjų technologijų ekonominė nauda ir jų bendra situacija mobiliųjų technologijų integravimo rinkoje. Su šiais klausimais susijusi teorinė literatūra išskaidyta į sekcijas ir aptariama atskirai. Aprašomas industrinis mobiliųjų technologijų diegimas. Gauti rezultatai parodo, jog susiformavo tendencija akcentuoti mobiliųjų technologijų diegimo techninius apsektus, bet ne organizacinį kontekstą, nors jis ir lemia mobiliosios įrangos diegimo aplinką. Šiame darbe plačiai aptariamos gerosios praktikos ir sėkmingas mobiliųjų technologijų diegimas į tam tikrą sferą. Be to, svarbu suvokti skirtingus integravimo aspektus, kad mobiliųjų technologijų diegimas vainikuotųsi sėkme. Šio suvokimo svarba išryškėja dėl to, jog mobiliosios technologijos atveria prieigą paslaugas teikiančiam personalui prie informacijos ir prie paslaugų realiame laike ir realioje aplinkoje, jei sukuriama tinkama prieiga prie tinklo. Todėl, mobiliosios įrangos vartotojai tampa ir mobiliaisiais veikėjais, dinamiškai bendraujančiais su fizine darbo aplinka ir informacinėmis sistemomis, kas padeda greičiau reaguoti į įvykius, o organizacijų veikla tampa rezultatyvesnė.*

Reikšminiai žodžiai: *mobiliosios technologijos, industrinių paslaugų inžinerija, technologijų įsisavinimo modeliai, gerosios turto vadybos praktikos.*

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