SUPPORT OF PREDICTIVE MAINTENANCE PROCESSES USING MOBILE DEVICES

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Abstract: The popularity of wireless electronic devices such as laptops or smartphones led to the development of maintenance support applications, which gave rise to the concept of m-maintenance. This paper classifies functions of m-maintenance applications, recommending that these applications be enhanced to enable predictive maintenance. In addition, the paper proposes other practical solutions to make these applications universal and thus applicable in various industrial branches.

Keywords: m-maintenance, predictive maintenance, mobile equipment

1. Introduction

The evolution of approach to maintenance management is best reflected in the types of maintenance strategies employed by production companies. Given the growing awareness of significance of technical infrastructure reliability, maintenance operations are no longer considered auxiliary. Rather, they are now considered to be essential processes in nearly all sorts of enterprises. The operational effectiveness of technical infrastructure was greatly improved owing to the integration of maintenance-dedicated computer software with other enterprise management support applications. The use of modern communication technologies such as the Internet considerably facilitated maintenance management, too, since a faster flow of information enabled the real-time monitoring of machine stock. All these factors combined led to the formulation of the concept of e-maintenance.

The development of modern wireless technology resulted in greater user mobility, while the widespread availability of wireless devices led to the application of this technology in maintenance operations, thus giving rise to the concept of m-maintenance. The use of mobile devices by the producers of maintenance service support software also enabled preventive maintenance. Based on the available information, about the, the present paper classifies the functions of applications for enhancing technical infrastructure operational effectiveness. The classification is illustrated with examples of operations that can be executed using mobile maintenance software. The paper also proposes that these applications be equipped with new features to enable the use of mobile devices in diagnostics as well as user-to-machine and user-to-user communication.

2. Computer-aided maintenance management

The problem of machine reliability poses many challenges for companies particularly due to intense competition on the market, demanding the improvement of their production systems and manufacturing techniques as well as the introduction of production automation. The effectiveness of maintenance services depends on the quality and efficiency of transmitting processed information based on the generated data. In addition to this, the development of such maintenance-related concepts as Total Productive

Maintenance (TPM), Reliability Centered Maintenance (RCM) or Condition Based Maintenance (CBM) combined with high expectations with regard to desired machinery effectiveness led to the development of computer tools for rapid processing of collected data. The development of computerized maintenance management systems was dictated by the need of gaining competitive advantage by increasing the direct share of maintenance costs in variable costs, developing automation as well as acquiring and managing tacit knowledge, i.e. the kind of knowledge that is intuitively possessed by employees. This, combined with the advances in computer tool design, resulted in the development of Computerized Maintenance Management Systems (CMMS) (Fig. 1).
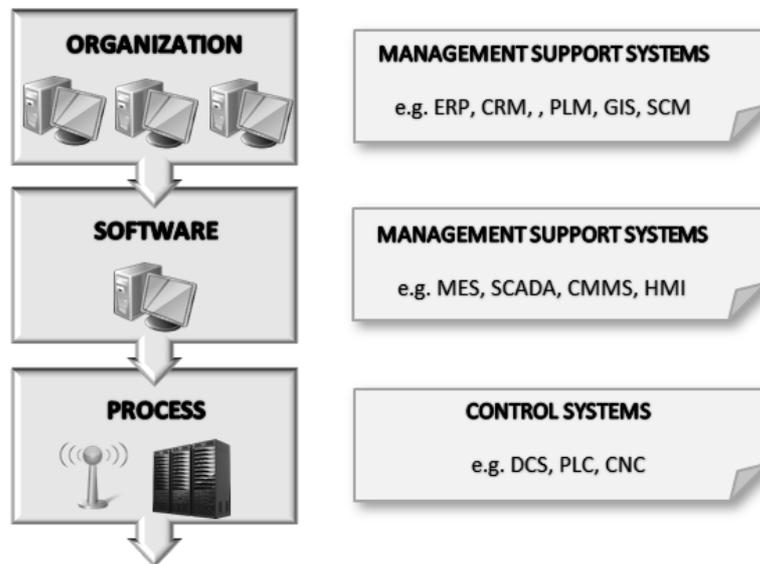

Fig. 1 Computerized enterprise management systems
(prepared by the authors based on [1])

CMMS perform the following functions (Fig. 2):
– keep equipment records,
– schedule inspections,
– keep logs of events involving production equipment (i.e. inspections, repairs, breakdowns),
– plan maintenance management budget,
– manage storerooms with spare parts.

Fig. 2 Functions of CMMS software
(prepared by the authors based on [2])

Since the implementation of a computer maintenance management system entails higher investment costs, the decision about implementing such system is preceded by a thorough analysis of its potential benefits, which is mainly done by estimating a Return on Investment Factor. The research conducted by the Gartner Group and ARC Advisory [3] demonstrates that the implementation of CMMS leads to:

– reduced inventory levels (by approx. 15-35%),
– lower logistics expenses (by approx. 10-20%),
– improved use of company assets (by approx. 3-10%),
– improved use of human resources (by approx. 10-20%).

The dynamic development of CMMS software packages results from the demand for computerized solutions for maintenance management reliability. The effectiveness of these systems can particularly be increased if they are integrated with formerly used systems for enterprise management support. The CMMS software can be integrated, among others, with ERP systems [4] in order to enable the exchange of data concerning operating costs, inventory levels (and their updates), staff working time or scheduled maintenance operations. Although the flow of information between the integrated systems results in better maintenance, it must, however, be noted that the implementation of this solution involves considerable expenses on IT development of a company's maintenance department.

In order to have a professional and efficient maintenance department as well as to ensure effective use of technical infrastructure, companies often outsource maintenance work. The main reasons for outsourcing maintenance services include the company's policy, enforced central directives or the need of reducing operating costs. Moreover, the outsourcing of maintenance work also results from high costs of employing top maintenance specialists [5]. The outsourcing companies mainly use their own professional diagnostic tools and equipment, which – combined with precise requirements of entrepreneurs – allow a substantial reduction in maintenance expenses.

Despite the fact that the methods and tools used for the diagnostics of machines and devices are more and more precise, the maintenance outsourcing companies must deal with complaints about delayed reaction time to machinery breakdowns. The flow of breakdown messages was greatly improved due to the application of state-of-the-art communication and information technologies, which gave rise to the concept of e-maintenance, i.e. maintenance management using updated information obtained via the Internet (Fig. 3).
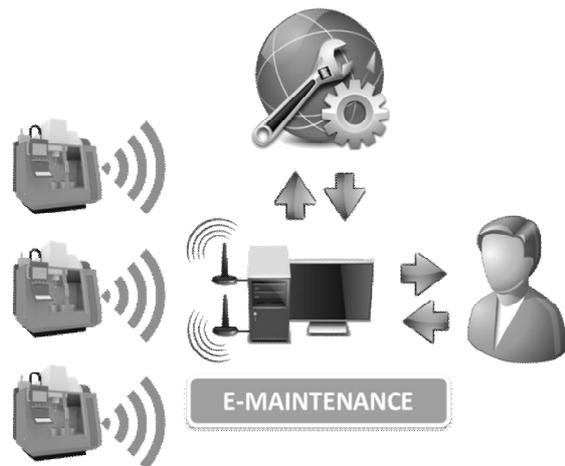

Fig. 3. Schematic of the e-maintenance concept
(prepared by the authors based on [6])

E-maintenance ensures:
– monitoring the company's technical infrastructure,
– communication between production and maintenance systems,
– data acquisition.

The concept of e-maintenance pertains to maintenance activities both within a single company and between the machinery manufacturer and the company that purchased these machines, integrating diagnostic, decision-making, expert, planning and management subsystems [7].

3. Maintenance management support using mobile devices

The possibility of estimating breakdown risk using the dedicated software for monitoring company machines and devices led to distinguishing a new type of service, namely – diagnostic service. The use of computers along with wireless devices such as laptops, palmtops and mobile phones to monitor technical infrastructure gave rise to the concept of m-maintenance. The essential property of mobile devices used for maintenance operations is their constant wireless access to the web, which enables both the mobility of a technician who supervises maintenance works and interaction with the company's machinery stock (Fig. 4) [8].
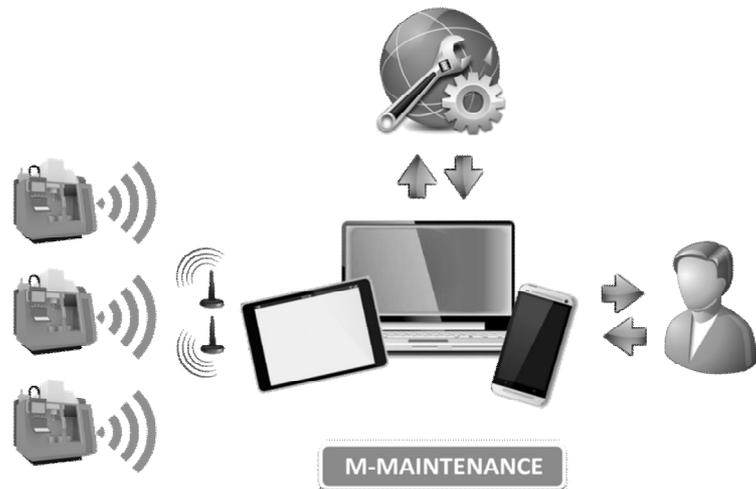
Fig. 4. Schematic of the m-maintenance concept
(prepared by the authors)

The growing IT demands of companies led to the development of maintenance service support software packages that are compatible with mobile equipment standards. The data provided by producers of such packages [8, 9] reveal that these packages are an effective means of preventive maintenance support, which stresses the importance of maintenance planning and control as well as prolonging service life of technical equipment.

On close analysis, it can be observed that such software packages [8, 9] do the following:

- receive reports about ensuing breakdowns,
- produce machine breakdown frequency diagrams,
- generate ad-hoc reports on machine work status,
- provide information about causes of stoppage,
- communication with storerooms with spare parts,
- track the history of machinery.

Given the above, we can distinguish their acquisition, information, analytical and warning functions.

The acquisition function involves all operations connected with collecting maintenance data. These operations include receiving breakdown reports and data acquisition even in a private cloud. This function also provides access to the reports on breakdown history of all machines in the company.

The information function provides the technician with information about the technical condition of supervised machines and devices. The m-maintenance applications inform about dates of scheduled inspections, part replacements or oil changes, thereby supporting all periodical operations. They also enable communication with the storeroom with spare parts, generate reports on inventory levels and transfer information about the type of breakdown to the maintenance services. In addition to this, these applications also generate machinery breakdown frequency reports, ad-hoc reports on machine work status and repair work, as well as event logs. In some cases, too, the m-maintenance applications provide information about the causes of stoppages.

The analytical function comprises a failure analysis module, including breakdown consequences and causes. Moreover, the function is equipped with the features for measuring machinery reliability, e.g. by calculating an Overall Equipment Effectiveness (OEE) ratio.

The warning function is responsible for issuing alerts about maximum and/or minimum machinery performance parameters, such as minimum levels of lubricants and oils or maximum allowable machine operating temperatures.

4. Innovative functions of mobile maintenance applications

The aforementioned functions of m-maintenance software applications do not enable, however, predictive maintenance operations, since – due to its focus on reliability – predictive maintenance generates predictions about the infrastructure's technical condition. Given the lack of reference for m-maintenance in terms of predictive maintenance support, we propose new solutions to these problems, including standard functions that do not require prediction.

The proposed, additional features of the maintenance software should include prediction, communication and monitoring functions.

In order to equip the mobile applications with prediction features, the maintenance system should, first of all, be integrated on the level MACHINE $\Leftrightarrow$ E-MAINTENANCE $\Leftrightarrow$ M-MAINTENANCE. This high-level synergic approach would produce a channel for a faster information flow. In effect, the information is not duplicated, and all preventive and repair maintenance can thus be greatly improved.

The proposed predictive function is an intelligent solution based on heuristic methods that consist in making predictions based on the history of breakdown alerts. All users would receive the alerts via the application that would additionally rank them in terms of repair priority based on the devised production schedule. The ranking function would be applied to all incoming alerts to make sure the high priority messages are not read too late and, thus, avoid incurring additional costs.

When developing m-maintenance software packages, it is important to take into consideration their communication functions. The exchange of communication would proceed on the user-to-machine and user-to-user levels. In the user-to-machine communication, the user responsible for the technical condition of a machine could respond to the messages sent by the machine and either let it continue with the work or order immediate stoppage if the received information about the machine's technical condition is alarming. Moreover, thanks to the communication function of the dedicated software, the machine operator would be provided with repair guidelines displayed on a mobile device. The database with the information about machinery repair methods and techniques would regularly be updated based on the know-how of maintenance service staff. The key feature of this software would enable receiving messages about shortages in storerooms with machinery spare parts in terms of scheduled repairs as well as predictions made based on monitored parameters.

The user-to-user communication should allow the head of the maintenance department to send maintenance service workers to handle the ensuing breakdowns if the application shows that they are available and can undertake the required repair operations. The types of status updates to be displayed on the user's profile should be as follows:
–   available – displayed when the worker is on shift but is not doing any repair work,
–   break – displayed when the worker is at break,

    –   repair work – displayed when the worker is doing the scheduled repair work or unplanned breakdown repair,

    –   unavailable – displayed when the worker is not at work,

    –   holiday – displayed when the worker is on holiday.

All status updates should be stored in a database that could be used to generate reports and analyses to support the monitoring of working time. It is also proposed that the GPS signal be used to locate the logged workers. The m-maintenance application would thus also become a mobile communicator for the logged users to hold voice and video conversations, send messages and share files.

The last function of the proposed application for maintenance support is a monitoring function. With this function, specific users could access the images from an industrial camera to supervise machines, devices and workers. The above recommendations about the functions of maintenance-dedicated software packages should be defined in detail based on software engineering knowledge.

5. Conclusions

Companies can improve operational effectiveness of their technical infrastructure in two ways: by running regular and scheduled maintenance works and by examining machine reliability predictions along with operational uncertainty.

The m-maintenance applications supporting maintenance operations lay foundation for a reliability-oriented approach to maintenance management. More and more often, companies take advantage of mobile devices to monitor and control their machine stocks since these devices can be used in any place and time. Given the world trends [8], by 2017 about half of companies in the world will have introduced the Bring Your Own Device (BYOD) programs that require staff to use their own equipment. In the paper, it is recommended that the mobile maintenance applications be enhanced to include predictive maintenance functions that will support maintenance operations based on generated predictions. The paper also proposes that the information flow channel be improved while m-maintenance be integrated with the company's existing computer systems in order to provide access to crucial information about the technical infrastructure.

It should be emphasized that the implementation of systems that send data via the Web and store them in a cloud poses a risk that confidential information may be intercepted by unauthorized persons. The providers of system solutions based on the cloud technology should therefore take responsibility for the quality of data storage protection.

It is essential that entrepreneurs recognize the need of improving maintenance operations and see the benefits it brings. However, state-of-the-art and intelligent solutions for predictive maintenance can only be implemented if companies keep histories of machine reliability. If the above solutions concerning predictive maintenance and information flow are taken into consideration, the functioning of maintenance services can undoubtedly be improved.

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