Potential of Technology-Integrated Mobile Maintenance for Total Productive Maintenance

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Abstract *In the last decade the potential of M-Business for a great variety of areas within Production and Operations Management, for instance Supply Chain Management, has been widely discussed. However, the integration of M-Business and Maintenance has been neglected so far. In this paper Technology-Integrated Mobile Maintenance as a concept based on M-Business will be introduced. The five pillars of Total Productive Maintenance as the elementary concept for improving maintenance are used as a basis for the application areas of mobile devices. The paper discusses the potential of mobile devices in the different pillars of Total Productive Maintenance. It will be concluded that Technology-Integrated Mobile Maintenance has the potential to raise the overall equipment effectiveness in different ways. Additionally, the wireless communication technologies Bluetooth and Wireless LAN are introduced as approaches for implementing Technology-Integrated Mobile Maintenance. A comparative discussion of both technologies indicates that Wireless LAN is advantageous for a successful implementation of Technology-Integrated Mobile Maintenance.*

The Need for Total Productive Maintenance in a Dynamic Environment

In recent years, the environment of manufacturing companies has become more and more demanding. In the last decades a shift evolved concerning the meaning of different success factors. During the 1960s and 1970s, the cost factor was the dominant driving force of competition, thus manufacturing companies strove for a superior cost position by experience curve strategies realized by e.g. high production volume or capacity utilization (Henderson, 1984). As a consequence for operations management process efficiency has become crucial and must be regarded as a main objective.

This period was followed by the 'quality era'. In the 1980s, companies changed their focus to efforts concerning quality aspects like product variety, customization, reliability, and longevity. Quality had become the new order winner (Hill, 1993). This development can be regarded as one important incision in terms of manufacturing strategy paradigms. Accordingly, companies have to offer products on a high quality level. Consequently, aspects of quality improvement have become very popular (Deming, 1982; Feigenbaum, 1983; Crosby, 1982). As a consequence for operations management the production process must produce on a high quality level to meet quality specifications thus high quality products can be guaranteed. Correspondingly, process capability can be regarded as the most critical measure regarding quality assurance.

In many industries, quality, although still an important success factor, can no longer be seen as a source of unique competitive advantage (Carter, Melnyk, Handfield, 1995). The movement from quality to time can be regarded as another important turning-point for operations management. After the quality era, time has evolved as a major success factor. In the early 1990s Stalk and Hout introduced the concept of time-based competition, followed by a great amount of authors dealing with time (Stalk and Hout, 1990; Handfield, 1995; Blackburn, 1991; Bockerstette and

Shell, 1993). Although many authors stress the meaning of time in terms of innovations (e.g. Meyer, 1993), time is important for manufacturing as well (e.g. Koufteros, Vonderembse, Doll, 1998; Bozarth, Chapman, 1996). In this context competition is based on fast and on-time deliveries. This leads to the necessity of a cycle time reduction of the manufacturing process.

Altogether, it can be stated, that manufacturing companies are faced with a wide spectrum of demanding requirements with significant consequences for manufacturing. The major difficulty of the mentioned developments is based on the fact, that the requirements are not mutually exclusive but mainly cumulative (Ferdows, De Meyer, 1990): Manufacturers have to offer a great variety of products in the least amount of time on a high quality level for an acceptable price. Beside these aspects some authors stress the importance of flexibility (e.g. Upton, 1994). As main consequence, machine dependability has become increasingly important for manufacturing companies to accomplish these requirements. Correspondingly, machine maintenance is a crucial aspect, because a high-level maintenance standard is the key for supporting challenging quality standards, achieving high efficiency, and reaching time competence, which can be seen as the main source of competitiveness. Consequently maintenance activities should strive for high process efficiency, high process capability, and a cycle time reduction of the underlying process.

In the light of the discussed requirements, i.e. cost, quality, and time, Total Productive Maintenance has become one of the most expedient approaches to guarantee high machine dependability. The requirements are reflected by the six big losses. Following Nakajima the six big losses include aspects like down time, speed losses, and defects (Nakajima, 1988; Shirose, 1989), which correspond with a cycle time reduction of the underlying process, lowering the defect rate by increasing process capability, and an increase of process efficiency by eliminating down time. The elimination of these losses fosters the accomplishment of the requirements. A measure, which considers all of these aspects is the Overall Equipment Effectiveness described in the context of Total Productive Maintenance. This concept acts on the six big losses and aims to improve process efficiency, process capability, and process cycle time. The described relations are depicted in figure 1. The pillars of Total Productive Maintenance as a basis for Technology-Integrated Mobile Maintenance will be introduced in the following.

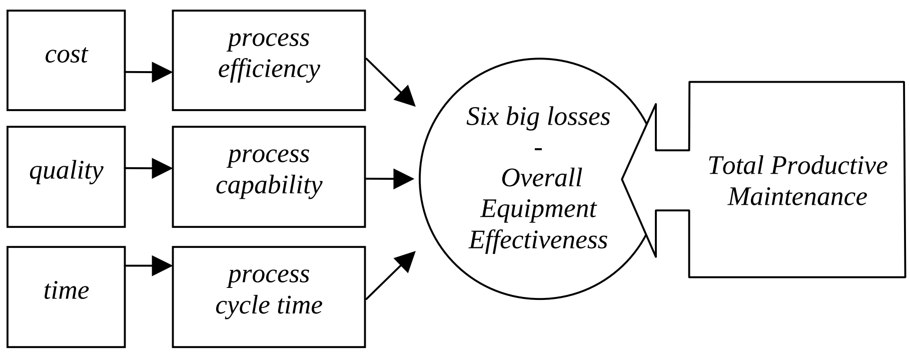

figure 1: Linking market requirements to OEE and Mobile Maintenance

Total Productive Maintenance as Concept for increasing Overall Equipment Effectiveness

Total Productive Maintenance is a concept based on different techniques with the goal to maximize the Overall Equipment Effectiveness. The Overall Equipment Effectiveness is calculated by multiplying the availability of the equipment, the performance efficiency of the process and the rate of quality products (Nakajima, 1988; Dal, Tugwell, Greatbanks, 2000; Ljungberg, 1998). It considers the most important factors derived from the developments in the field of operations management. By measuring the availability, the efficiency, and the quality of a production system Overall Equipment Effectiveness functions as an indicator for meeting market requirements in terms of machines.

Total Productive Maintenance has a long history. To evolve to its today's standard it passed through several development stages (Nakajima, 1988). The first stage, which has to be seen as preliminary period, is referred to as Breakdown Maintenance. During this stage maintenance was characterized by fire-fighting activities. In the second stage Preventive Maintenance was introduced featuring mainly periodic servicing and overhaul. Then Preventive maintenance was replaced by predictive maintenance with its diagnosis of the condition of equipment during operation to identify signs of deterioration or imminent failure. The fourth stage stands for Total Productive Maintenance with its five characteristic elements including maximizing equipment effectiveness, establishing a thorough system of preventive maintenance for the equipment's entire life span, implementation by various departments (engineering, operations, and maintenance), involving every single employee, and the basis on motivation by autonomous small group activities.

Nowadays, the following five pillars are fundamental in the context of Total Productive Maintenance: Elimination of the "six big losses", Preventive Maintenance, Autonomous Maintenance, Training, and Maintenance Prevention. The first pillar acts on the "six big losses", i.e. down time by *equipment failures from breakdowns* or *setup and adjustment*, speed losses by *idling or minor stoppages* or *reduced speed* due to discrepancies between designed and actual speed of equipment, defects like *process defects* due to scraps and quality defects to be repaired or *reduced yield* (Dal, Tugwell, Greatbanks, 2000). Primary malfunctions are identified and eliminated in an initial setup project. This is done by project teams consisting of maintenance staff, machine operators, and engineers. The approaches of the pilot maintenance project will be transferred to other maintenance projects, thus resulting insights concerning maintenance diffuse through all machines. The main project mission is to fight against the "six big losses". The managerial benefits of the maintenance projects are twofold: The effectiveness of Total Productive Maintenance can be proven resolving possible doubts about the concept and the engineering and maintenance staff is given hands-on experience, which can be used to improve other equipment (Nakajima 1988).

The second pillar deals with a scheduled maintenance program. The maintenance department should do maintenance activities on a regular basis following a given time schedule. Such a scheduled maintenance program is a tool for realizing the idea of preventive maintenance. The approach is best illustrated with the example of dental care. Most people brush their teeth on a daily basis and do not wait until a tooth is affected. In greater intervals a general check-up is done by a dentist. The same should be done with machines in the framework of Total Productive Maintenance.

The third pillar is the development of an autonomous maintenance program (Got∗, 1989a). This may be the most ambitioned step for implementing Total Productive Maintenance. Autonomous maintenance means that shop-floor workers are involved in maintenance activities. In terms of autonomous maintenance workers perform simple maintenance tasks like cleaning and lubricating. People should get rid of attitudes like “I operate – you fix.” To establish autonomous maintenance workers must be trained by the maintenance department.

Training is the fourth pillar of Total Productive Maintenance. By implementing autonomous maintenance activities, formerly done by the maintenance personnel, are assigned to the machine operators. To fulfil the new requirements the operators have to be trained to guarantee the necessary maintenance skills. By training, machine operators will improve their understanding of the machines and build up knowledge about maintenance activities. Additionally, the maintenance personnel must be as competent as doctors to improve their patient’s condition

(Nakajima 1988). Therefore, they must be trained as well to accomplish demanding maintenance tasks.

Finally, maintenance prevention within the framework of an early equipment management program strives for making maintenance activities unnecessary by developing and purchasing "maintenance-free" machines. In terms of development maintenance prevention includes activities during construction, fabrication, and installation. The aim is to raise equipment dependability, maintainability, and the ease of operation (Got∗, 1989b).

The basis for Total Productive Maintenance is a set of practices for shop-floor workers called the 5S-Programm. The term "5S" comes from the Japanese expressions Seiri, Seiton, Seiso, Seiketsu, Shitsuke, i.e. organization, tidiness, purity, cleanliness, and discipline (Osada, 1991). The 5S-program supports the pillars of Total Productive Maintenance, because a tidy and clean working environment fosters the "Parlor Factory", which is a factory-floor tidy and clean like a living room (Nakaima, 1988). Autonomous maintenance mostly relies on the 5S-program, because it is based on the shop-floor-worker as well. An important question for maintenance in the M-Business era is, how Total Productive Maintenance can be supported by mobile devices. To answer this question it has to be examined how M-Business can act on the different pillars of Total Productive Maintenance. Therefore, the origin of mobile maintenance will be discussed first.

E-Business, M-Business, and Mobile Maintenance

E-Business can be regarded as the antecedent of M-Business. Following IBM E-Business can be defined as "… the transformation of key business processes through the use of Internet technologies." But this definition is quite restrictive because by focussing on the Internet it excludes E-Business with electronic devices like mobile communication. Chaffey defines E-Business as "… all electronically mediated information exchanges, both within an organization and with external stakeholders supporting the range of business processes." (Chaffey, 2002)

Closely related to E-Business is the term M-Business. Kalakota and Robinson state, that "… M-Business is the application infrastructure required to maintain business relationships and sell information, services, and commodities by means of the mobile devices." (Kalakota, Robinson, 2001) This definition includes the importance of mobile devices but it does not stress the internal potential for companies, e.g. in the framework of manufacturing. Kalakota and Robinson state, that "…mobile applications will change the way we all live, play, and do business." (Kalakota, Robinson, 2001) Although this statement is quite rhapsodic, it shows that there might be a great potential for different areas.

M-Business can be regarded as the logical advancement of E-Business, because M-Business additionally involves mobility (Kalakota, Robinson, 2001). Mobility is characterized by the ability of an entity to move within a system. Accordingly, ubiquity (access from many locations), reachability (users can be reached when not in their normal location), and convenience (it is not necessary to have access to fixed line connection) are the main characteristics of mobile or wireless services (Chaffey, 2002). M-Business can be defined as the electronic transaction of business processes via wireless mobile devices among economic entities.

Wireless communication technology is not a radical new concept. Broadcast radio and television are two popular examples of wireless communication. Other examples are satellites, cellular phones, automobile door locks, etc. (Miller, Bisdikian, 2001). An example for a business process supported by a mobile device is a waitress receiving orders in a beer garden serving guests and sending the order via a mobile device to the barkeeper, thus the order is booked and an ordered cocktail can be mixed instantly without the waitress coming back to the bar.

Accordingly, in terms of maintenance Technology-Integrated Mobile Maintenance – or simply "Mobile Maintenance" – can be defined as the support of maintenance activities by the employment of mobile devices. A fundamental approach of operations management is to integrate the three basic "M", i.e. machine, material, and manpower. Technology-Integrated Mobile Maintenance fosters the integration of two of them: manpower and machines. How Technology-Integrated Mobile Maintenance can assist the different pillars of Total Productive Maintenance will be discussed in the following. Therefore, the particularities of mobile business will be adapted to the characteristics of modern maintenance, i.e. the pillars of Total Productive Maintenance.

The Application of Technology-Integrated Mobile Maintenance in the pillars of Total Productive Maintenance

Foremost, the idea of Technology-Integrated Mobile Maintenance is illustrated with a short example. A person has a car break down. He calls for help with a mobile phone. Based on this call the car can be located and identified easily by the corresponding technology. A mechanic in the next garage receiving the call makes a first remote diagnosis and takes along necessary spare parts and required tools. His mobile device guides the mechanic to the car. On the way, the mechanic receives information about the construction of the car or essential details from the instruction manual. Eventually, the mechanic can retrieve information concerning similar problems and their solution from other car break downs. This example can be transferred to the approach of Technology-Integrated Mobile Maintenance, because this approach is based on wireless communication technology as well.

Firstly, Technology-Integrated Mobile Maintenance fosters eliminating the “six big losses” and improves equipment effectiveness. Machine failures can be documented more efficiently by sending information to the maintenance hub, i.e. the maintenance information pool. The maintenance project team can transmit an identified problem with its solution worked out to the maintenance data base, thus this information can be retrieved from other maintenance project teams. The documented problems give valuable hints for improvement for other machines via mobile devices. Finally, using mobile devices the data collection process it is easier to setup the maintenance information pool.

Secondly, the approach of Technology-Integrated Mobile Maintenance evolves a great potential in terms of the second pillar of TPM, i.e. preventive maintenance. The maintenance personnel receive a maintenance logbook, thus the mobile device can tell when to do maintenance activities and what to do at a particular machine. The different maintenance activities for a particular machine are listed etc. Furthermore, the maintenance history can easily be documented as well. Additionally, maintenance video streams and pictures can be transmitted to the maintenance personnel; therefore the technology has to be powerful in terms of the data transfer rate. Finally, the personnel of the maintenance department can easily be reached by the mobile device in case of a machine breakdown. By Technology-Integrated Mobile Maintenance the maintenance personnel is relieved, thus they can contribute to the improvement of other pillars of TPM, e.g. maintenance prevention or training of machine operators.

In terms of Technology-Integrated Mobile Maintenance the activities of autonomous maintenance can be documented more efficiently by mobile devices. The maintenance personnel can send information concerning the maintenance check-list, i.e. the execution of the autonomous maintenance tasks by the operators. The possibility of transmitting pictures of machine components with the corresponding maintenance activity can be useful as well showing the machine operator at which area and how he has to perform the maintenance task. Altogether it can be stated, that autonomous maintenance can be supported by the use of mobile devices raising the effectiveness.

Training for autonomous maintenance can be provided more efficiently by Technology-Integrated Mobile Maintenance, because machine-related maintenance characteristics like construction plans or maintenance activities can be shown easily by the personnel of the maintenance department with mobile devices giving necessary information. Additionally, the operator is informed about the maintenance tasks he has to do and what the maintenance personnel will do.

In terms of the fifth pillar of Total Productive Maintenance, Maintenance Prevention, Technology-Integrated Mobile Maintenance provides valuable information about maintenance related aspects of a particular machine. This information can be used for the planning and purchasing of new machines. Altogether, it can be stated that maintenance activities can be supported very efficiently by mobile devices. The way Mobile Maintenance impacts the pillars of Total Productive Maintenance is depicted in the following picture.

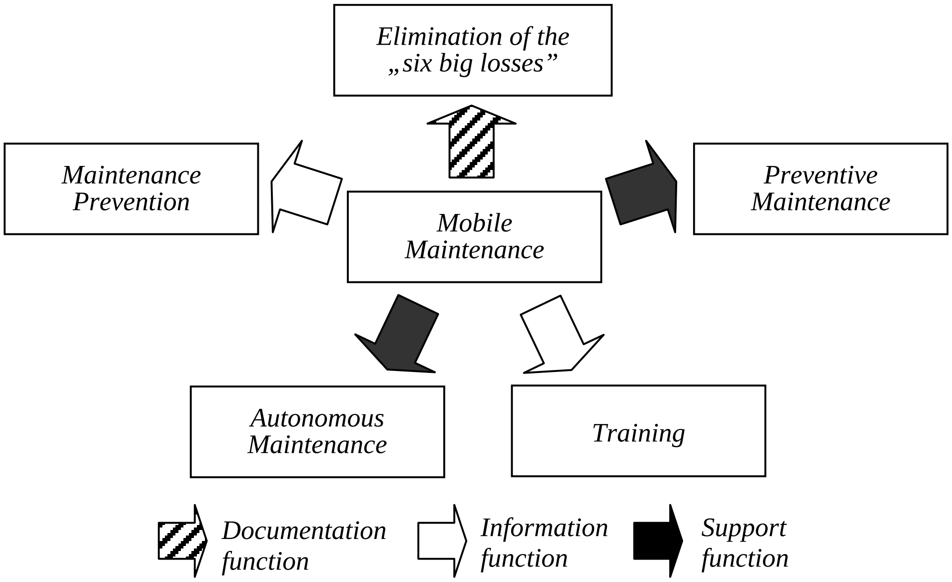

figure 2: Mobile Maintenance in the context of Total Productive Maintenance

The Functionality of a Maintenance Hub

Although Total Productive Maintenance might be implemented on a high level machine breakdowns cannot completely be prevented. In this regard, mobile maintenance provides a number of valuable features. In case of a machine breakdown the maintenance personnel can react quicker and more problem-oriented. The machine can "communicate" via the mobile device with the maintenance personnel. The mobile device can give information about the maintenance history of the machine. Like a doctor getting information of the anamnesis of his patient, the maintenance personnel receive information about the historical report of the machine instantaneously. When has the last planned maintenance been done? How long ago was the last machine breakdown and what has happened? Furthermore, solutions to similar breakdown problems can be transmitted from a data base. The maintenance engineer receives a construction plan of the machine, thus he is well informed about the machine characteristics.

The following figure shows a shop floor with a Maintenance Hub. While a machine operator is doing regular maintenance tasks autonomously with a mobile device, the engineer of the maintenance department performs activities of scheduled maintenance supported by the maintenance hub. He receives necessary information about the maintenance history, maintenance tasks that have to be done etc. via his mobile maintenance device. If another machine shows a malfunction, the Maintenance Hub will send an alarm signal, thus the engineer can react instantaneously. In this case he can receive the information needed, like construction plans of the machines and the proceeding at previous machine breakdowns.

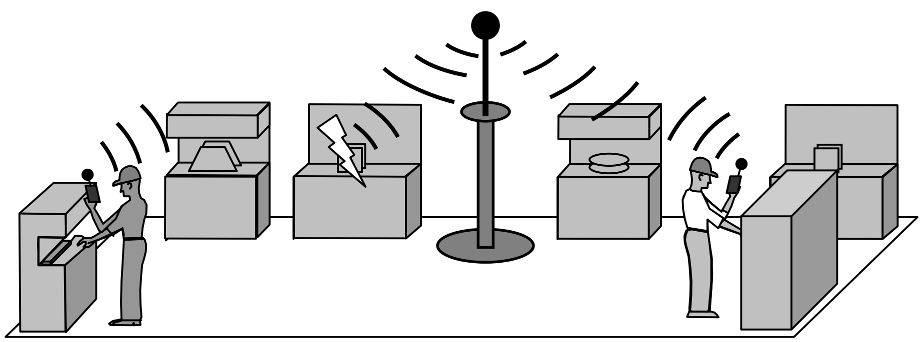

figure 3: The Maintenance Personnel and the Maintenance Hub

The maintenance hub is the focal point of Technology-Integrated Mobile Maintenance. All important information related to maintenance is centralized in a maintenance data pool. By this maintenance hub the maintenance activities are managed via the use of wireless communication technology. So, in terms of Technology-Integrated Mobile Maintenance the question is important, which technological solution is best as hardware framework. Before, the technical side of Technology-Integrated Mobile Maintenance will be considered the potential of this concept for improving the Overall Equipment Effectiveness will be discussed.

The Potential of Technology-Integrated Maintenance for the Improvement of Equipment Reliability

Due to the fact that maintenance personnel will be informed faster in case of machine breakdowns it can react faster and more efficient. It receives necessary information about the particular machine, its construction plan, former breakdowns etc. Problems of machine breakdowns can be solved faster leading to an increase in Overall Equipment Effectiveness, thus the elimination of the six big losses is supported.

Preventive maintenance is supported by Technology-Integrated Mobile Maintenance. Advanced maintenance tasks can easily be described. Furthermore the accomplished maintenance activities can be documented better. The support of the execution of maintenance tasks and the control, if maintenance activities are conducted, will improve the machine condition, thus availability, performance efficiency, and quality rate can be increased.

In terms of training Technology-Integrated Mobile Maintenance contributes to a better learning environment. It supports the maintenance department to teach the new maintenance activities. Furthermore the machine operators can learn better using the mobile devices with One Point Lessons. Increased efficiency in terms of teaching and learning results in a better understanding of machines and maintenance aspects. Better understanding and higher identification with machines will lead to higher equipment effectiveness.

As stated before Technology-Integrated Mobile Maintenance improves both training and learning. Additionally machine operators can be supported fulfilling simple maintenance tasks. By using instructions of mobile devices autonomous maintenance tasks can be simplified and extended. A result is a discharge of the maintenance department, thus there is further potential for maintenance improvement.

Maintenance prevention will be supported by valuable data of mobile devices. Information about machine breakdowns, equipment malfunctioning, etc. can give hints for better design or purchasing of new machines. The improvement of purchasing and development raises the degree of "maintenance free machines", i.e. maintenance activities are prevented.

Altogether it can be stated that Technology-Integrated Mobile Maintenance has a great potential to increase the overall equipment effectiveness. Although the extent is different, in all pillars improvement potential can be identified by the use of Technology-Integrated Mobile Maintenance raising the efficiency of Total Productive Maintenance.

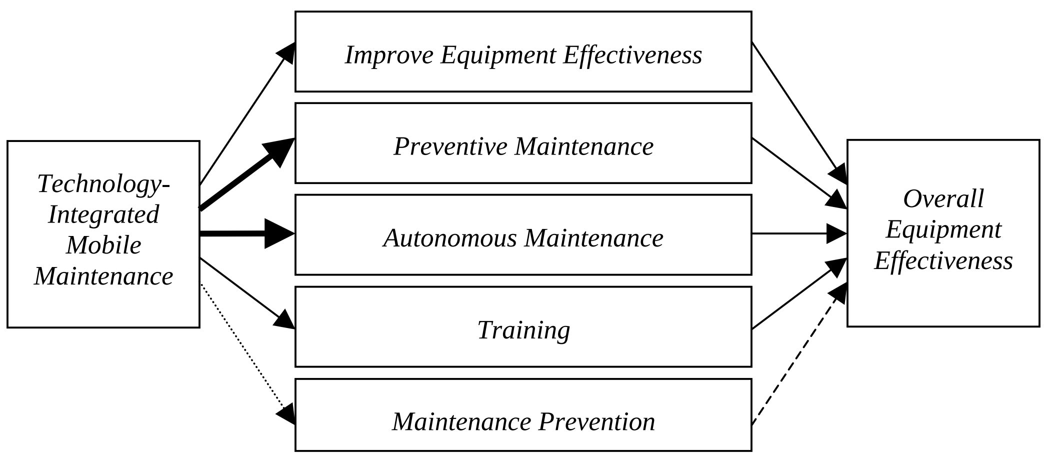

figure 4: Relationships between Technology-Integrated Mobile Maintenance and Overall Equipment Effectiveness

But, in terms of Technology-Integrated Mobile Maintenance there are critical aspects as well that might limit the success of this approach. Using mobile devices machine operators might by swamped with the new technological requirements. A negative attitude against Technology-Integrated Mobile Maintenance might be the consequence. Furthermore, a misuse of the mobile device can hinder effectiveness of this approach. Additionally, the use of mobile device is cost-intensive. Finally, security aspects are critical, too. These aspects have to be considered when implementing Technology-Integrated Mobile Maintenance.

The Technical Side of Mobile Maintenance

For the installation of Technology-Integrated Mobile Maintenance two main possibilities exist: Bluetooth and WLAN. The Bluetooth technology enables devices to communicate seamlessly without cables (see for the basics Robert, 2001; Miller, Bisdikian, 2001). The name "Bluetooth" was the unofficial project name and it comes from the Danish King Harald Blåtand. Like King Harald Blåtand united the Danes and the Norwegian, Christians and Heathens, more than 1000 years ago Bluetooth connects electronic devices (see for the history of Bluetooth Miller, Bisdikian, 2001).

The first version of Bluetooth came out in 1999, but it started earlier in 1994, when Ericsson Mobile Communications began a study to examine alternatives to the cables that linked their mobile phones with accessories. The study looked at using radio links, because these are not directional, and they do not need line of sight, thus they have obvious advantages over the infrared links previously used among handsets and devices (Bray, Sturman, 2001). Bluetooth devices can communicate at an at least 1 Mbps connection by wireless signals within a small range. Today, Bluetooth it is a standard. It is a wire substituting technology that simplifies the interplay between people as well as machines. This technology provides a way of achieving low-cost remote connection between mobile phones, personal digital assistants, notebook computers etc.

Bluetooth employs radio frequency technology, using radio waves to communicate through the air similar to conventional radio. Radio frequency technologies use transmitters and receivers tuned to send and, respectively, to receive radio waves of a given frequency range. Short range communications generally require few power, thus they can be done with small, mobile battery powered devices. The power of the particular device is one of the determents of the possible range such as handheld organizers (Miller, Bisdikian, 2001). As it is true for many other wireless technologies, there exist some concerns with Bluetooth like e.g. security and interoperability with other standards.

On the other hand Mobile Maintenance can be implemented by the use of WLAN. This is the commonly used short form for wireless local area networks. Contrary to LAN this technology has the great advantage that a connection to a network can be built wirelessly without being tethered by cables to a port in the wall (Stambaugh, Chamberlain, 2001). Like Bluetooth WLAN uses radio links instead of cables, freeing users to access network services from many different locations with no plugs, no wires, and no hassles (Kalakota, Robinson, 2001).

The answer to the question which of the two technologies is more appropriate for implementing mobile maintenance depends on several criteria. One aspect is the distance that has to be bypassed. Here, Wireless LAN has a great advantage contrary to Bluetooth, because today's standard limits Bluetooth to a 35 foot range. WLAN has a range up to 300 feet between access point and client (see for the performance characteristics of WLAN Muller, 2001). The second criterion is the amount of data that can be transmitted in given time period. In terms of the transfer rate Wireless LAN is favourable as well, because 55 Mbps – as the maximum ratio of Megabits/sec – is much higher contrary to Bluetooth that can normally transmit 1 Mbps. Additionally, the cost for building up the particular technology is an important criterion. Here

Bluetooth seems to have an advantage because it is more expensive to install WLAN. The security level of the different technologies is another critical aspect, which is often mentioned discussing wireless technologies. In terms of Technology-Integrated Mobile Maintenance this problem can be neglected more or less at least for WLAN, because the danger of external access can be excluded by established mechanisms like encryption (e.g. WEP), filters (e.g. MAC), or tunnels (e.g. VPN). Finally, the ease of use should be considered as mentioned before. In summary, WLAN seems to be the technology with the greater potential installing Technology-Integrated Mobile Maintenance.

Conclusion and Further Research

In this paper the potential of mobile business for Total Productive Maintenance was examined. Because Total Productive Maintenance can be supported easily by several data bases including information about machine construction plans, maintenance history, maintenance logbook, etc. the use of mobile devices can improve business processes, i.e. mobile maintenance. Two different technologies are discussed concerning their potential in order to implement mobile maintenance: Bluetooth and WLAN.

In future research a mobile maintenance standard should be developed supporting high level maintenance activities. Therefore the wireless communication technology and maintenance should be coordinated better thus mobile maintenance can unfold its whole potential to increase overall equipment efficiency. Another research question is to show the impact of Technology-Integrated Maintenance on the overall equipment effectiveness empirically in order to stress the importance to support maintenance with mobile devices.

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