Degree Project

On the Requirements to Implement E-maintenance Cost effectively: Survey Study

Author: Nizar Abu Daqqa & Serkan Alan
Supervisor: Anders Ingerwald & Martin Jacobsson
Examiner: Basim Al- Najjar
Date: VT 13
Course Code: 2SE09E, 15 credits
Subject: Terotechnology
Level: Bachelor

Department of Teknik
Summary

Nowadays, companies started to realize the impact of a good maintenance strategy on the production process. Quality, performance as well as availability are affected by maintenance; existing maintenance strategies help to optimize the production process to achieve high quality products with a low production cost. A new strategy of maintenance has immerged recently, e-maintenance provides an easy solution to follow up with maintenance, it provides condition monitoring, documentation, and it also gives you the best maintenance solution that fits your goals and vision. Articles related to e-maintenance was studied and analyzed to know the steps to implement a cost-effective e-maintenance. The authors came up with a model that describes the implementation process in three main steps.
**Contribution List**

Although this thesis was written by both authors, some parts were written individually, these chapters are as follows:

<table>
<thead>
<tr>
<th>Serkan Alan:</th>
<th>Nizar Abu Daqqa:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.1</strong> Research approach</td>
<td><strong>2.3</strong> Research strategy</td>
</tr>
<tr>
<td><strong>2.2</strong> Research perspective</td>
<td><strong>2.4</strong> Research method</td>
</tr>
<tr>
<td><strong>2.5</strong> Data collection method</td>
<td><strong>2.6.</strong> Validity and reliability</td>
</tr>
<tr>
<td><strong>3.1</strong> Impact of maintenance</td>
<td><strong>3.2.1</strong> Run to failure</td>
</tr>
<tr>
<td><strong>3.2.4</strong> TQMain</td>
<td><strong>3.2.2</strong> Preventive maintenance</td>
</tr>
<tr>
<td><strong>3.3</strong> Maintenance planning</td>
<td><strong>3.2.3</strong> Condition based maintenance</td>
</tr>
<tr>
<td><strong>3.4</strong> Overall equipment</td>
<td><strong>3.5</strong> Cost breakdown structure</td>
</tr>
<tr>
<td>effectiveness</td>
<td></td>
</tr>
<tr>
<td><strong>4.1</strong> Introduction to E-maintenance</td>
<td><strong>4.2</strong> Strengths and weaknesses</td>
</tr>
<tr>
<td><strong>4.4</strong> E-maintenance services</td>
<td><strong>4.3</strong> Strategies of e-maintenance</td>
</tr>
<tr>
<td><strong>4.6</strong> ICT for E-maintenance</td>
<td><strong>4.5</strong> Economic of e-maintenance</td>
</tr>
</tbody>
</table>
Acknowledgement:

First, we would like to thank anyone who had contributed along the process of writing the thesis.

We also thank the examiner Professor Dr. Basim Al-Najjar for his help in finding the problem and guide us through the whole process as well as providing us with books and resources, also our tutors Dr. Anders Ingwald and Mr. Martin Jacobsson for their help, and Dr. Mirka Kans for her useful tips and feedback.

We are also thankful to Professor Dr. Basim Al-Najjar for providing us with his company’s website (www.e-maintenance.com), that had articles related to the thesis.
## Contents

Summary ................................................................................................................................. 2

Contribution List ................................................................................................................ 3

Acknowledgement: ............................................................................................................. 4

Contents ................................................................................................................................ 5

List of Abbreviations ........................................................................................................... 7

List of Figures ...................................................................................................................... 8

List of Tables ........................................................................................................................ 8

Definitions ............................................................................................................................. 9

1. Introduction: ..................................................................................................................... 10
   1.1 Background ..................................................................................................................... 10
   1.2 Problem Discussion ...................................................................................................... 11
   1.3 Problem Presentation ................................................................................................... 12
   1.4 Problem Formulation .................................................................................................. 13
   1.5 Purpose ........................................................................................................................ 13
   1.6 Relevance ..................................................................................................................... 13
   1.7 Delimitations ................................................................................................................ 14
   1.8 Time Frame .................................................................................................................. 14

2. Research methodologies .................................................................................................... 15
   2.1 Research approach ....................................................................................................... 15
   2.2 Research perspective .................................................................................................... 16
   2.3 Research strategy ......................................................................................................... 16
   2.4 Research method ......................................................................................................... 17
   2.4.1 Qualitative method ................................................................................................. 17
   2.4.2 Quantitative method ............................................................................................... 17
   2.4.3 Mixed method ......................................................................................................... 18
   2.5 Data collection method ............................................................................................... 18
   2.6 Validity and reliability ................................................................................................. 19
List of Abbreviations

CBM : Condition Based Maintenance
CMMS : Computerized Maintenance Management System
ICT : Information and Communication Technology
IT : Information Technology
GPS : Global Positioning System
OEE : Overall Equipment Effectiveness
OPE : Overall Process Effectiveness
MEMS : Micro electro mechanical systems
MTTF : Mean Time to Failure
MTTR : Mean Time to Repair
PDA : Personal Digital Assistant
PM : Preventive Maintenance
RCM : Reliable Centered Maintenance
RFID : Radio Frequency Identification
TPM : Total- Productive Maintenance
TQMain : Total Quality Maintenance
WPAN : Wireless Personal Area
WLAN : Wireless Local Area Network
WMAN : Wireless Metropolitan Area Network
WWAN : Wireless Wide Area Network
List of Figures
Figure 1: Gantt Chart of Time Frame
Figure 2: The logic of argument
Figure 3: The frame of Research Methodology
Figure 4: The essential components of the e-Maintenance concept
Figure 5: A hypothetical framework of the proposed e-maintenance system
Figure 6: Strategies of E-maintenance
Figure 7: Local Maintenance subsystem structure
Figure 8: Cost breakdown structure

List of Tables
Table 1: Searches that have been made and articles
Table 2: Model of the Requirements to implement e-maintenance cost effectively
Definitions

1. E-Maintenance (Electronic maintenance): “Maintenance support which includes the resources, services and management necessary to enable proactive decision process execution. This support includes e-technologies (i.e. ICT, Web-based, tether-free, wireless, infotronics technologies), but also, e-Maintenance activities (operations or processes) such as e-monitoring, e-diagnosis and e-prognosis”. Marquez (2008)

2. Condition monitoring: according to Mike Sondalini, The process of systematic data collection and evaluation to identify changes in performance or condition of a system, or its components, such that remedial action may be planned in a cost effective manner to maintain reliability.

3. Condition-based maintenance (CBM): “is a maintenance program that recommends maintenance decisions based on the information collected through condition monitoring. It consists of three main steps: data acquisition, data processing and maintenance decision-making”. (Andrew K.S. Jardine 2006).

4. Predictive maintenance: monitoring symptomatic conditions when a process of failure is active. (Al-Najjar, 1996)

1. Introduction:
The introduction chapter is presenting and introducing the readers to the subject of this study. This chapter gives general overview of the study. The reader is going to get background, problem discussion and presentation of the problem formulation which clarifies to the reader what the problem is. This is followed by definition of purpose, relevance, delimitation and the time frame of this study.

1.1 Background
Nowadays, industrial environment which is global competitive marketplace press to continuously reduce costs of unscheduled downtime, unexpected breakdowns and delaying because of repair time. These are non-value activities and cause the costs. Automation and mechanization are increased and more important than before. Therefore, maintenance became more complex, Alsyouf (2007). Thanks to well maintenance operations, these costs can be reduced. Maintenance is one of the important subjects in improving company's competitiveness; also maintenance affects the future of the company. (Campell and Jardine, 2001).

Al-Najjar (2007) states that maintenance influences the company’s internal effectiveness, also maintenance performance affects quality, production and their cost. Although maintenance is closely related to production and quality, most of the companies see maintenance as a cost center and not profit activities (Al-Najjar, 2007). If there are no well maintenance functions, machines fail too often and it may cause speed losses and low performance. Also maintenance policy increases the production capacity and capability of the machines (Al-Najjar and Alsyouf, 2003). Maintenance effects on production and quality could be seen by the OEE. Al-Najjar (2007) claims that maintenance is one of the most important cause for losses that can cause low OEE. Moreover, production losses, failures and technical faults could be corrected by effective maintenance functions. Therefore optimizing maintenance functions helps the company’s competitiveness and it is not a cost center, maintenance should be seen as a profit center (Al-Najjar, 2007).

Holmberg et al (2010), claims that maintenance is directly linked to management of people, asset and technologies. He also states that the aim of these areas in maintenance perspective is using expensive resources with high performance to take advantage of them and use limited resources effectively to better service. Because of that maintenance has become important and methods such as condition-based maintenance (CBM), Total quality maintenance (TQMain), reliability-centered maintenance (RCM), total- productive
maintenance (TPM) developed for working efficiently in the last 30 years (Campbell and Jardine, 2001). Tsang (2002), claims that the term of e-Maintenance has emerged in 2000. At the present there are many different definitions of e-Maintenance but still there is no well-defined and established definition. According to Karim (2010), most of the researchers describe e-maintenance only limited perspective and mainly these definitions are technical. He claims that the reason of the lack of well definition is that there is no any definition which is multidisciplinary and not limited set of perspective.

Marquez (2008) defines the term of e-Maintenance as “Maintenance support which includes the resources, services and management necessary to enable proactive decision process execution. This support includes e-technologies (i.e. ICT, Web-based, tether-free, wireless, infotronics technologies), but also, e-Maintenance activities (operations or processes) such as e-monitoring, e-diagnosis and e-prognosis”. He also thinks that e-Maintenance is a philosophy, which predict and prevent strategies concept, failures and the actions associated to them.

As mentioned before, the “E” refers to electronic, but Baldwin (2001), has another idea, he said that the “e” could be seen as a description of e-maintenance: “e(efficient)” which means do more with less resources like people and money, “e(ffective)” which means doing the job better but productively, mainly based on doing the right job. Also he identified “e” as: “e(enterprise)” that it adds value directly to enterprise performance. Baldwin (2001) claims that result of adding up the “e”s and e-maintenance means e(xcellent) maintenance.

1.2 Problem Discussion
Mostly it is not always a good strategy to perform maintenance actions after a breakdown occurs. The breakdown may cause more cost and unexpected stoppage when it happens in a non-convenient time. Also the breakdown may cause secondary problems or it could become sources of other big problems. Scheduled maintenance may become a solution for this problem in the form of stopping the equipment routinely for checking and repairing. The weakness of scheduled maintenance is that sometimes the equipment may stop in unnecessary cases; also the stop for checking may cause a problem. Knowing the condition of equipment in real time also controlling component information, repairing and service activity time is the optimal solution (Holmberg et al, 2010).

Existing and new technologies open a new possibility for maintenance. As E-Maintenance, observing the device performance is available to use low cost micro size integrated sensors also technology provide condition data collection, data mining, signal
analysis, reasoning and decision making. Communications and transport data is so easy by using wireless techniques with mobile handheld computers (PDA, Personal digital assistant), (Holmberg and Helle 2008).

By using the e-maintenance, availability and customer value can be increased also life cycle cost can be reduced. It provides various benefits like remote capabilities of connectivity, data collection, configuration, performance monitoring, and analysis of equipment to maintain the equipment. Also through e-Maintenance, equipment may have near zero downtime, Hung (2004).

Karim (2010), states that industrial systems can have more proactive, effective, efficient and more cost-sustainable maintenance by using e-maintenance. In addition, he claims that e-Maintenance is an immature and challenging field. It helps the company’s competitiveness but it lacks of common definitions, widely accepted underlying theories and credible experimental base. The problem is implementing e-maintenance because of the lack of the experimental base.

Maintenance in general has a huge impact on the economical aspect of the company. Performance, quality and availability are associated with the maintenance level that is applied in the company. E-maintenance provides new data-collection techniques and alarm systems that will result in immediate maintenance actions after studying the signals provided.

1.3 Problem Presentation
Al-Najjar (2001), states that maintenance policy in production system can help to achieve unproblematic operation in the production process. Efficient maintenance policy also helps to have production with the right quality and competitive price. E-Maintenance has emerged around 2000 to have a better maintenance policy, strategy and activities by using new technologies. It is a new concept, therefore it is hard to fully understand and implement it correctly. Also it is hard to know what the requirements to implement it are.

This research will study the requirements to implement of e-Maintenance. The research mainly tries to find an answer for what are the requirements and outcomes of implementing e-Maintenance and what are the strengths and weaknesses in ICT and economic perspective of e-maintenance.
1.4 Problem Formulation
The study is progressing according to the problem formulation which is elaborated in problem discussion and problem presentation.

- What are the requirements, needed to implement cost effective E-maintenance?

1.4 Purpose
The purpose of that study is:

- To classify, identify and describe the requirements required to implement e-maintenance cost effectively. E-maintenance includes web-based services, ICT technologies and maintenance related IT systems, also to highlight the strengths and weaknesses of these systems for better implementation. Also describe e-maintenance activities, strategies and weaknesses that are needed to know to apply e-maintenance cost effectively.

1.5 Relevance
In these days companies need to focus on maintenance because of its impact on the production’s performance and quality. Also maintenance has a significant role in having a better system availability, product quality as well as safety (Macchi, 2006). Existing and new communication and information technologies helped the emergence of the new maintenance concept which name is e-Maintenance. (Marquez, 2008). E-maintenance has become important to the industry recently but it still is lack of practically experienced. (Karim, 2010).

There are many convenient researches about e-maintenance strategy (Karim 2010). Also some of them include technical gathered information. Even though, e-maintenance still an immature area that requires different perspectives researches and still lacks of practical examples (Karim 2010). This paper is about finding out implementing e-Maintenance what its requirement, strength and weakness in IT and economic perspective. There are plenty of scientific articles about the concept of e-Maintenance structure but there is not much about how to implement and its requirement, also what its economic effect on companies. This study will try to answer these questions and fill some of these gaps.
1.6 Delimitations
The limitation of our thesis is that created model will not be able to test at case company and specific process to see result of implement this model in this thesis.

1.7 Time Frame

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>MARCH</th>
<th>APRIL</th>
<th>MAY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Weeks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Introduction</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>Research methodology</td>
<td></td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>Theory</td>
<td></td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>Model development</td>
<td></td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>5</td>
<td>Literature Review</td>
<td></td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Analysis</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>Results</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>Conclusion</td>
<td></td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Overall modifications</td>
<td></td>
<td></td>
<td>18</td>
</tr>
</tbody>
</table>

Figure 1: Gantt Chart of Time Frame

<table>
<thead>
<tr>
<th>Figures</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Just start</td>
</tr>
<tr>
<td></td>
<td>Progressing</td>
</tr>
<tr>
<td></td>
<td>Progressing</td>
</tr>
<tr>
<td></td>
<td>Almost finished</td>
</tr>
<tr>
<td></td>
<td>Finished</td>
</tr>
</tbody>
</table>
2. Research methodologies

In this chapter, readers will find explanations of different research methodology that have been used. Other research methodologies’ short definitions are written in order to show the whole picture of the research methodology. Also the kind of actions and thoughts that have been taken for this search is presented.

2.1. Research approach

According to Rothchild (2003), induction, deduction and abduction are diverse kind of research approaches that can be used for relating theory and empirical findings. Induction is a research approach as finding theoretical conclusion from collected data. It is basically estimating or bring the issue the general rules with start to find result from empirical data. Also Rothchild (2003), claims that proving hypothesis is not possible since it is tentative and it could be disproved. Inductive approach makes use of a number of observations to collect data and analyze. In addition it searches the reliability of observation that used for analysis.

There is no need to find a true representation of reality in deduction approach. It is mainly based on consequential result. Existing theories are used to provide methods to construct a reasonable conclusion. Inductive approach takes longer time than deductive approach. The main reason for this doing data collection and analysis step-wise in a long period (Karlsson, 2009).

According to Graziano (2007), there is another research approach that called abduction. This approach is a combination of the induction and the deduction perspective. The aim of abduction approach is using empirical data or observations to find logical conclusion. Karlsson (2009), states that this approach is testing results with analyzing methods and comparing them with theoretical concepts. These three approaches’ framework presented below as Figure 2.
2.2. Research perspective

There are two main scientific paradigms that are positivistic and hermeneutic perspectives when doing a research. Hermeneutics perspective has originated from human science; positivism’s origin is natural science. The aim of hermeneutics is trying to understand the basic conditions for the human existence. It is mainly opposite of the positivism. (Patel et al., 2003). The hermeneutics researcher long for the holistic view of the problem and they believe more in the personal explicative process against understanding.

On the other hand positivism’s resource is empirical sciences, scientific examinations of reality and real experience. In this perspective, researches should be based on data that are observations and real facts. Physical and mathematical laws are the roots of this kind of research (Patel et al, 2003). According to Karlsson(2009), positivist perspective covers the most of case study requirements.

2.3. Research strategy

Yin (2003) states that there are four common research strategies those are case study, experiment, surveys, and history. Each strategy has its own strength and weakness and their own collecting and analyzing methods. Yin (2003) claims that there are three phases which can be used for each research strategy. These phases are exploratory, descriptive and explanatory.

Case study is defined by Yin (1994) as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context especially when the boundaries between phenomenon and context are not clearly evident”. When research is about
limited group, case study is useful. The first step of the case study is gaining general perspective then collects relative data as much as possible Yin (2003). Another strategy is experiment study. This is mostly preferable for scientist studies in the laboratory.

These strategies have their own strength and weakness and it is based on type of research. Case study is feasible if research includes exploratory phase, surveys and histories are most commonly used for investigation which has a descriptive phase also experiment strategy is preferable in order to do research that has explanatory phase (Shavelson and Townes, 2002).

2.4. Research method
Mainly there are three different methods of research; qualitative, quantitative and mixed method that is a combination of both qualitative and quantitative methods (Karlsson, 2009). These methods explain in below.

2.4.1. Qualitative method
The qualitative method refers to words rather than numbers or calculations. It investigates the characteristics and identification moreover it is an objective way to mention reality what you see. That is why some say that it is not a scientific way because it is based on how the human being sees the reality and their experience. Qualitative studies need to be motivated to have a scientific value. Qualitative analysis does not use formula existing to change over from data to the findings. It is hard to make sense of data without motivation. Individual experience is both strength and weakness to qualitative study and analysis, Patton (2002). Mainly qualitative searches could show the reality from different peoples’ eyes. Also this method helps to explain some human experience that cannot be measured or quantified.

2.4.2. Quantitative method
Quantitative method mainly consists of numbers and research process statistically with measurable parameters. Measurement, observation and connection between them are in the central to quantitative research, Cresswell (2009). Normally quantitative methods are formalized and every step is defined. Free random and the systematic selections are used for quantitative research to select data and data population. Free random works as firstly number all units in the population and then chose the numbers randomly. Systematic selection also begins with numbering but then chose numbers according to criteria which chosen by the researcher.
2.4.3. Mixed method
Both qualitative and quantitative methods have the same purpose that provides a better view of the reality. Mixed method is a combination of these two methods and gives a better solution rather than each of them (Creswell, 2009). The mixed method is could be that doing a qualitative investigation first then a quantitative investigation. First part could provide understanding and second part could provide the answer of questions that had decided before. General overview and deeper knowledge could be presented in this way. (Creswell, 2009).

2.5. Data collection method
Data collection is important to gather information and materials in order to analysis or prove any phenomenon (Saunders, 2007). The data could be primary, secondary, qualitative or quantitative methods which depend on which data type is collected. Collecting primary data is necessary if there is not enough available data from the previous research. Besides, fresh data can be collected without assaying other works. On the other hand secondary data are already existed. Collecting this kind of data saves time because there is not necessary to collect it. The important thing is finding reliable and up-to-date information (Creswell, 2009).

Yin (2003) states that six different methods could be used for data collection and these are: archival records, documentation, interviews, physical artifacts, direct and participant observation. Explanation of these methods presented below.

Archival records are data that is collected from computer files or records. Maps, calendars, organizational charts, list of names are some example for archival records. The documentation consists of written reports of events, agendas, newspaper, etc. Reach reliable information is not easy in this method also document may not be accessible or blocked but the strength of documentation is involving exact and detailed information, Yin (2003). Another method is the interview. At least two people are needed to do interviews; one of them is an interviewer who asks questions another one is interviewee who answers the question. Interviews method is chosen when interviewer want to have opinions, hesitation or more knowledge about topic. According to DePoy and Gitlin (1998), there are three different categories for interview method as standardized, semi-structured and unstructured. Standardized interview means that the interviewer has same question which strictly followed. However, this kind of interview is not always suitable because sometimes explanations of questions are needed. Therefore semi-structured method is more preferable. In this way following questions are reformed after the answers
that responded before (DePoy and Gitlin, 1998). Some data can gathered by visual, hearing, touch or smell. It is the collecting data methods called observation. In this way the researcher can gathered data directly. According to Yin (2003), the last data collection method is physical artifact that gathered data from technological device.

Furthermore, the literature review method is a different data collection method from Yin(2002) perspective. A literature review is one of the most important data collection methods in order to meet the researchers need and give knowledge about the chosen subject, Bell (2005). Systematic way of work could help to find the relevant information effectively. The data could be collected from scientific articles, books, questionnaires, essays, library databases and internet Bell (2005). This method could be good in order to clarify the problem and get a deeper understanding moreover literature review combines different theories and could develop a process of theoretical findings (DePoy and Gitlin, 1998).

### 2.6. Validity and reliability

Validity shows how well study done in order to the aim of the purpose also suitability of final study paper and what was planned. DePoy and Gitlin (1998) state that there are two types of validity one of them is external validity is showing the ability of with finding conclusion that can be generalized , another of them is internal validity indicate suitability between research design and purpose of research.

Reliable research means that measurements should be in the correct way, the measurement should give same result every time by the same method. The purpose of reliability is to reduce the errors. High reliability does not mean always high validity also high validity does not guarantee high reliability (Yin, 2003).

### 2.7. Generalization

According to Saunders et al. (2007) generalization is related to external validity. External validity interrelated with analysis and results of hypothesis to nearly the same event but then, generalization interrelated with usefulness of hypothesis with not considering its limitation. A generalized research should have results that are able to being use in general.
2.8. Summary of the designed research methodology

The qualitative method will be used in this study because this study is mainly based on describing and finding requirements, there are almost no quantitative data. The data will be gathered from literature review for using theoretical concepts to compare analysis and result. Also literature review helps to understand current situations and analyze it. University’s library database will be searched to gather more information and clarify the picture of existing situation and to be ensure the validity peer review scientific articles will be used. This study is not based on a specific case company’s problem. It is a descriptive research which could be applied in most of the survey methods moreover the problem is more or less could be seen in most of the manufacturing companies. During the literature review, deductive way will be used. Different theories are read to get knowledge. Research methodology frame is presented below. The methods will be used presented in a circle in the figure 3.

Figure 3: The frame of Research Methodology
3. Theory:

In this chapter, theoretical methods and concepts concerning maintenance will be presented.

3.1. Impact of maintenance

Companies strive themselves to be better in the global competitiveness. To achieve this goal the companies have to satisfy their customer with high quality products in time, delivering quickly and good after sales functions (Artiba and Abdelhakim, 2005). As previously mentioned, maintenance has an important role to maintain and help the company’s competitiveness. Al-Najjar and Alsyouf (2003) claims that maintenance function's role increased gradually on the companies’ competitiveness and internal working areas such as production and quality. Because of the increasing usage of automation in their manufacturing area, companies pressure the maintenance functions to prevent failures from occurring on these high level capital intensity machines. It means that this pressure and changes in the manufacturing make maintenance task more complex (Swanson, 2003).

Artiba and Abdelhakim (2005) claim that maintenance strategies influences the product quality, equipment availability, zero defect, energy control, human safety also maintenance affect the company’s profit. Maintenance costs contribute significantly in the whole production cost. The impact could vary between 15-60% of the whole production cost depending on the type of industry you are dealing with. (R. Keith Mobley, 2002).

Surveys showed that the third (33%) of every dollar spent on maintenance is due to bad maintenance strategies and actions, and the dominant reason behind the bad strategies is the lack of actual data that will quantify the need for maintenance. According to Cornelius Scheffer and PareshGirdhar (2004), maintenance strategies could be listed under three main categories:

- Breakdown or run to failure maintenance
- Preventive or time-based maintenance
- Condition Based Maintenance (Predictive and Proactive maintenance)

10-20 years ago, industries dealt with maintenance as an “unnecessary evil” and there is nothing they can do to reduce maintenance costs, and that philosophy is changed now due to the inventing processors and instruments that can monitor the machine’s status with
respect to different parameters that could be indicators of a coming failure. (R. Keith Mobley, 2002).

3.2. Maintenance Strategies
To understand how Condition-based maintenance works; we must first explain the traditional two strategies:

1. Run to failure.
2. Preventive maintenance.

3.2.1. Run to failure
Run to failure means: to take maintenance actions only when a breakdown occurs.

The philosophy of this method is: “if it ain’t broke, don’t fix it”. This method was introduced from the don of industries. At first, it seems as a reasonable and cheap approach; however it is the most costly method between all other techniques. The major expenses that are associated with this technique are: high spare parts inventory cost, overtime labor costs, high machine downtime, and low production availability. (R. Keith Mobley, 2002).

3.2.2. Preventive maintenance
All preventive maintenance actions are time based; it bases maintenance actions on the MTTF statistics. (Mean Time to Failure).

Programs that implement preventive maintenance vary from a case to another, some has a narrow range of applications such as lubrication and adjustment, and others adapt with every activity associated with maintenance. (R. Keith Mobley, 2002).

3.2.3. Condition Based-Maintenance

Condition monitoring:

Condition monitoring is the continuous or periodic measurement and interpretation of data to indicate the condition of an item to determine the need for maintenance.

Condition Monitoring is an information source for CBM where the condition of the primary equipment is monitored and analyzed for early signs of impending failure. It monitors mechanical condition, equipment efficiency and other parameters and attempts to derive the approximate time of a functional failure.
It consists of scheduling maintenance activities only when a functional failure is detected. Mechanical and operational conditions are periodically monitored, and when unhealthy trends are detected, the troublesome parts in the machine are identified and scheduled for maintenance. The machine would then be shut down at a time when it is most convenient, and the damaged components would be replaced. If left unattended, these failures could result in costly secondary failures.

Condition Monitoring has various techniques such as:

(a) **Vibration monitoring**: to detect the changes in the vibration level of the machine.
(b) **Corrosion monitoring**: Ultrasonic thickness measurements are done to follow up on the occurrence of corrosive wear.
(c) **Thermography**: Thermography is used to analyze active electrical and mechanical equipment. The method can detect thermal or mechanical defects in generators, overhead lines, boilers, misaligned couplings and many other defects. It can also detect cell damage in carbon fiber structures on aircrafts.
(d) **Oil analysis**: lubricants are analyzed in different ways to detect different particles that could indicate a certain failure.
(e) **Performance monitoring**: This technique is used to detect problems in the machinery. The level of efficiency for the machines will provide a good insight on their internal conditions.

(f) **Acoustic emission**: a technique used for failure localization and monitor cracks in pipelines structures.

(g) **Particle analysis**: derbis collected from worn components, and then analyzed and studied to know what went wrong in the machinery.

These methods can be different depending on the given situation, it varies from one industry to another.

Taking into consideration that these techniques require instruments and softwares to carry out their functions. The instruments could be of a high cost and also requires special education to be understood and handled properly.
On the other hand, predictive maintenance will carry maintenance to level that could pay off the new investments in a short time.

**Condition-based maintenance**

Al-Najjar (2012), states that CBM (Condition-based maintenance) plan and performs maintenance actions only when a symptom of a failure occurs. It means that current degradation and its changes are mainly used for developing a maintenance scheme which based on CBM. Lee(2006) claims that the main idea of CBM is minimizing system downtime by using equipment degradation information which is extracted from on-line and off-line sensing methods. CBM is trying to balance failure risk and achievable profits moreover CBM focuses on predictive maintenance for decision making (Lee 2006). CBM refers to maintenance actions taken as soon as a deviation in machine condition occurs. (Holmberg and all, 2010).

The benefits of CBM are:

a. Convenient repair times.
b. Less breakdowns
c. Less failure rates
d. Less inventory space for spare parts
e. Optimizing the number of workers.

One of the tasks covered by CBM is Predictive maintenance.

**Predictive maintenance**

Predictive maintenance: *is the process of monitoring symptomatic conditions when a process of failure is active*, (Al-Najjar, 1996). The data collected from different monitoring techniques will assure the longest time interval between repairs with the least breakdowns. (R. Keith Mobley, 2002).

Predictive maintenance is also a way to improve plant’s productivity, product’s quality and machine’s availability.

**3.2.4. TQMain**

This model developed by Prof. Dr. Basim Al-Najjar (1996). It is based on Deming Cycle which consists of plan, do, check, act phases also could be useful for improving technical and managerial systems. TQMain framework is a continuous improvement strategy and it is built on the life cycle concept. (Beveridge, 2007)
Total quality maintenance (TQMain) is a strategy to maintain a high quality production process at a low production cost by continuously improve the economic and technical aspects of a production process. Also this strategy doesn’t only repair failed machines rather than maintain the quality of production process. Al-Najjar (2006) defined TQMain’s role as: monitoring the status of the machine and controlling any deviations from the normal status and to interfere failures detecting failure root causes also all these activities should be performed continuously reducing costs of good quality product. Al-Najjar (2006) claims that data should be in common database also integration of the databases of relevant disciplines useful. Integration of the data which is collected production process and maintenance analysis could help to monitoring, and measuring reliability, availability and productivity.

Al-Najjar (2006) state that TQMain covers a wide range of production process when compared to traditional maintenance concepts such as total productive maintenance (TPM), preventive maintenance (PM), condition-based maintenance (CBM) and reliability –centered maintenance (RCM). Also he claims that TQM ain provides an overall view of the production process condition. Moreover TQM ain working on systematic maintenance which start by detecting the damage at an early stage. This systematic maintenance consists of technical, economic and organizational knowledge. By applying TQM ain, it becomes easier to detect potential failures and follow their development.

According to Sherwin (2000), modified version of the overall equipment effectiveness (OEE) which is called overall process effectiveness (OPE) can be useful to measure success in TQMain. The OPE is not measure just the properties of the individual machines. It is measure machinery system’s capability to make a product. TQM ain doesn’t deal just with the machine itself; it considers the whole machinery system.

3.3. Maintenance planning
According to M. Smith, Anthony (1993), the output of having maintenance functions is preserve the equipment from being failed, this could be done by applying preventive maintenance. The points of view of RCM can be categorized by four main features:

1- Preserve system function: the whole system function should be taken into consideration before before the equipments, this will lead to base maintenance decisions on an overall point of view of the system.
2- Functional failure: some small issues will be there, but still haven’t cause any failure. These should be known and studied to prevent major failures from happening.

3- Select only applicable and effective PM tasks: some parts that won’t affect the whole system if a failure occurs, so by addressing the failure modes, we can tell what PM actions should be considered and for what parts.

4- Prioritize function need: to know exactly what should be done, when, and for which part. It’s very essential to prioritize maintenance actions depending on their criticality.

According to Byron A. Ellis (2008), Condition based maintenance is maintenance actions performed on the analysis of data gathered from different condition monitoring techniques. This method gives the most suitable time to perform maintenance actions as well as trying to minimize the cost of doing so.

3.4. Overall Equipment Effectiveness

According to (R. Keith Mobley, 2002), OEE is one of measuring methods yield in a factory. It includes the most important parameters such as availability, performance and quality rates for machines. If we want to measure yield on machines, OEE helps to form an overall view of the machine’s status.

Capacity, speed, the amount of scrap/ rework and the downtime should be determined to be able to calculate the important parameters as follows:

a. \[ \text{Availability} = \frac{\text{operating time}}{\text{operating time} + \text{downtime}} \]

b. \[ \text{Performance} = \frac{\text{measured capacity}}{\text{theoretical capacity}} \]

c. \[ \text{Quality} = \frac{\text{total production} - \text{rework}}{\text{total production}} \]

And then, the OEE is calculated as follows:

\[ \text{OEE} = \text{Availability} \times \text{Performance Rate} \times \text{Quality Rate} \]
3.5. Cost Breakdown Structure (CBS)

CBS is very important for life cycle cost analysis. This is because the main detailed costs of different alternatives can be obtained through cost breakdown structure, and be classified into different cost categories which cover labor force, materials, energy, transportation, etc. (Zhu Hong, Hu Wenping, 2010)

The Cost Breakdown Structure can be divided into three phases which are cost of acquisition phase ($C_{BO}$), cost of operation and maintenance phase ($C_{OM}$) and cost of decommissioning and disposal phase ($C_{D}$). The cost can be further breakdown for analysis purpose. (Zhu Hong, Hu Wenping, 2010)

$$LCC = C_{BO} + C_{OM} + C_{D}$$

There are basic characteristics should take care when using CBS. These are:

- It should include internal costs and relevant costs
- Important to identify all cost elements and their context
- CBS should be compatible.
- CBS should be categorized costs to allow monitoring
- CBS should be devised to see different levels of data
- CBS should be flexible enough to allow cost allocation
4. Literature review

In this chapter, theories are gathered from relevant articles and books related to E-Maintenance. Articles were found using different search engines as presented below. During the search we limit the years of articles from 2003 to 2013 for gathering brand new scientific articles.

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Date of search</th>
<th>Database</th>
<th>No of Hits</th>
<th>Method for filtration</th>
<th>Hits after refined search</th>
<th>Number of relevant articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>“e-maintenance”</td>
<td>2013-03-18</td>
<td>Science Direct</td>
<td>1443</td>
<td>search on keywords</td>
<td>46</td>
<td>4</td>
</tr>
<tr>
<td>1. On the concept of e-Maintenance: Review and current research, Marquez, 2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Information requirements for e-maintenance strategic planning: A benchmark study in complex production systems, Macchi, 2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Development of an e-maintenance system integrating advanced techniques, Han, 2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“e-maintenance”</td>
<td>2013-03-18</td>
<td>Science Direct</td>
<td>1443</td>
<td>Search on title</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>2. On the concept of e-Maintenance: Review and current research, Marquez, 2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Development of an e-maintenance system integrating advanced techniques, Han, 2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“e-maintenance”</td>
<td>2012-03-19</td>
<td>Science Direct</td>
<td>1443</td>
<td>“e-maintenance” on except full text and implementation</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>1. Information requirements for e-maintenance strategic planning: A benchmark study in complex production systems, Macchi, 2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Intelligent prognostics tools and e-maintenance, Lee, 2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“e-maintenance”</td>
<td>2013-03-22</td>
<td>Emerald</td>
<td>48</td>
<td>“condition based maintenance and condition monitoring”</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>1. The maintenance management framework: A practical view to maintenance management, Marquez, 2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
“e-maintenance” | 2013-03-21 | Emerald | 48 | implementation | 16 | 1
---|---|---|---|---|---|---
1. The maintenance management framework: A practical view to maintenance management, Marquez, 2009

“e-maintenance” | 2013-04-06 | Science Direct | 1443 | “web services” | 20 | 4
---|---|---|---|---|---|---
2. On the concept of e-Maintenance: Review and current research, Marquez, 2008
3. Development of an e-maintenance system integrating advanced techniques, Han, 2006
4. Special Issue on e-maintenance, Marquez, 2006

Another articles which are found from these articles references
1. Information and Communication Technology Infrastructure in E-maintenance, Al-Qahtani, 2012
2. A review of e-maintenance capabilities and challenges, Marquez, 2008
3. Fundamentals of eMaintenance, Karim 2010
5. J. Lee 1995, Machine performance monitoring and proactive maintenance in computer-integrated manufacturing: review and perspective
6. Strategic dimensions of maintenance management, Tsang, 2002

Table 1: Searches that have been made and articles

Emerald, science direct are search engines, are used for all research. We used two different search engines to gather different articles because science direct and emerald has great database about engineering and science.

E-maintenance is used as a keyword first and then some methods that are search on keywords, search on title, another extra words regarding e-maintenance are used to filtrate them. The second column from the left shows the date of search and the third column explains what kind of database used. The last column explains how many articles relevant to this thesis. When we found articles after filtration, we read their title; keywords also looked at the abstract to be sure it is relevant. Then we named these articles as relevant articles also some articles founded from relevant article’s references. Some articles were excluded because they did not fit our problem formulation. Also the articles that we used were fitted to the problem formulation, these articles described e-maintenance and subjects related such as the implementation, strategies, economic impact and requirements, some articles were relevant but not used in this literature review, these articles were used just to get a general knowledge or used in the introduction part.
Except these articles which were found from databases, we used a book called “e-maintenance”. This book was useful to see different aspects, and it helped us from beginning of this thesis to the end. This book consists of different chapters about advanced techniques and holistic view of e-maintenance.

Another resource is e-maintenance.com. It helped to see the way of implementing e-maintenance and the requirements. We did not use this website as a reference to increase the validity and reliability but we used this website to gather general information about e-maintenance and also some of the articles on the website.

4.1. Introduction to E-Maintenance

E-maintenance has emerged around the year 2000 and companies started to pay attention to this subject (Tsang, 2002). Traditionally companies have failed and fix maintenance which is mainly waiting the equipment to fail and then fix it. Then with the internet and communication technologies, companies changed over from fail and fix strategy to predict and prevent strategy (Lee, 2006). This new concept called e-maintenance. E-maintenance is basically needs the predictive intelligence tools because it is not just detecting the faults. By using e-maintenance, proactive maintenance that prevents the machine from breakdowns could be enabled (Lee, 2006). According to Lee (2006), technology can help to gather data about the machine’s condition and performance by sensors and computerized components. Also this data could be visible and separate important information rather than others. He also claims that the main problem is not delivering data from the machine; however the problem is that there is almost no practical usage of this data. If machines are networked by IT system and monitored and if these machines’ data is analyzed permanently, maintenance works could be moved beyond predictive maintenance to intelligent prognostics. Information about the machine’s condition and their components status are possible to move e-maintenance which based on intelligent prognostics. (Lee, 1995). Also the overall operation of the system, spare parts and maintenance resources are synchronized to maintenance actions with e-maintenance.

Nevertheless, e-maintenance concept is widespread today. Muller et al. (2008) considered e-maintenance three different points of maintenance that are maintenance strategy, maintenance plan, maintenance type. He claims that e-maintenance could be defined as a maintenance strategy. By using digital technologies, real-time equipment data can be delivered and tasks about maintenance are managed electronically. E-maintenance is a
maintenance management process that tries to handle the expansion of the volume data from this point of view. Muller et al. 2008 also states that e-maintenance could be maintenance plan too. In this aspect e-maintenance can meet the needs of proactive, collaborative maintenance, service support and integration maintenance with manufacturing. Another point of view is e-maintenance as a maintenance type. Han (2006) claims that e-maintenance is more predictive and proactive type of traditional maintenance that changing day by day. Han (2006) also states that e-maintenance provides monitoring and predictive prognostics functions also it is a type of predictive maintenance system. The last point view is maintenance support. E-maintenance consists of web services and agent technologies that provide a clear way to notice cooperative features.

According to Karim (2010), there are ten different components to make understandable e-maintenance concept. These components are presented below in figure 4.

Figure 4: The essential components of the e-Maintenance concept. (Karim, 2010)

Definition: One of the accepted definitions of e-maintenance is already presented in the background part. There are many definitions that provide different perspective views. Karim (2010) identifies e-maintenance two parts which are e-part and maintenance part. Maintenance part is mainly about maintenance activities.
Business and organization: The main role of e-maintenance for organizational aspects is supporting customer, product and supplier. The aim is to do the guarantee of the continuity daily business activities, maintains products and services.

Product, Services, Information and Methodologies: E-maintenance provides tracking the relationship between manufacturing processes, maintenance, information system and services. In this way, knowledge of which products support by which services and which roles and what kind of information used could be easier to get and archive them.

Technology: Technology is one of the most important areas for companies. It is hard to follow new technologies also it affects to the company’s future and competitiveness. Using the right technology for e-maintenance helps to integrate internal services and external services, transferring data, providing security and authorization also communication could be easier with the wireless technologies.

Customer: When implementing an e-maintenance solution, understanding the customer value is important. Perspective and strategy of maintenance influence the business and its services in a short or long run.

Education and Training: Continuous education and training is one of the most important components of e-maintenance. Stakeholders of the system should be educated and trained to understand what is the e-maintenance purpose and duties.

Figure 5 presented below to clarify how e-maintenance works. This hypothetical framework includes two sub systems as maintenance center and local maintenance also structured on a sharable platform to interconnect research group, experts, manufactories by using internet and communications techniques. Maintenance center meet the need maintenance system. The function of local maintenance is handling internal maintenance in company. Monitoring the condition of machines is available by using wireless and another communication technology (Han, 2006).
4.2. Strengths and weakness

Strengths:

According to Marquez, 2008, the capabilities and strengths of e-maintenance can be summarized as follows in the two paragraph.

Offers opportunities for the development of new maintenance types and strategies, these improvements can be in the four different fields that are remote maintenance operations and decision making, business process integration and cooperative / collaborative maintenance, on-line maintenance and predictive maintenance. By the technologies available now a days, users could log in anytime and anywhere through the internet to
follow up, control and to make work orders. The availability of data is increased by using remote maintenance. E-maintenance provides a whole new level of cooperation and efficiency that will affect the whole process. It can maximize process throughput also maximize downtime costs which is so important for company’s competitiveness. Moreover synchronizing of maintenance with production could be easy by using e-maintenance. This synchronizing helps to collaborative works by providing remote connection between subsystems. E-maintenance provides access data on-line and fast. It enables the personnel to take immediate actions when a certain situation occurs.

Improving maintenance is supported by failures analysis and maintenance documentation. With the new technologies in condition monitoring techniques, it allows the maintenance department to understand the causes of failure and analyze them in an attempt to avoid them later on. Maintenance documentation is easy with e-maintenance. Maintenance tasks and actions are all documented and reports are available immediately to grant other users to follow up with everything. E-maintenance improves maintenance activities by fault diagnostic/localization. By sharing information online, this will result in higher information quality and reliability, thus the availability will increase and the MTTR (Mean Time to repair) will be reduced.

Weaknesses and challenges:

Of course as a newly developed system, E-maintenance will face some challenges also it would have some weaknesses in some areas. These weaknesses are (Karim, 2010):

1. Security and reliability concerns arising from transaction through the internet.

2. Applications of cross-platform information integration issues such as:
   a. Development of data transformation mechanisms.
   b. Design of communication messages.

3. Lack of cooperative systems, formal models: There are not so many programs that connect different department together.

And the challenges facing this new concept are, (Karim, 2010):

- Restructuring of the organizations involved in E-maintenance.
- Restructuring of the life-cycle process used for developing and maintaining e-maintenance services.
- Transitioning to e-maintenance mode.
- Planning of e-service resources.
- Management, interaction and interactivity of e-service.
- Enablement of configuration awareness in e-services.
- Management of heterogeneous organizations.
- Management of heterogeneous eService-environments.
- Integration of enterprise applications.
- Management of documentation and archiving.
- Management of life-cycle stages of e-maintenance services.
- Alignment and structure of content format.
- Enablement of context and situation-awareness in e-services.
- Enablement of integration capability across a multi-platform and technologies in e-services.
- Establishment of an overarching architecture for development of e-services.

These challenges are considered the requirements of implementing e-maintenance, these should be met in order to adapt to the new concept. Overcome the challenges and meet the requirements will pave the way to a cost-effective e-maintenance.

### 4.3. Strategies of e-Maintenance

According to Muhammad S. Al-Qahtani, (2012), existing e-maintenance strategies can be summarized in figure 6.
Data can be transferred remotely without the physical attendance of the personnel and maintenance actions are done immediately as soon as an alert happens by remote maintenance and real time maintenance. These two strategies are so important for e-maintenance for making easy to gather data and reach data which are gathered. This two strategies help to predictive maintenance which predicts maintenance actions based on the data provided from the condition monitoring techniques. In addition cooperative and collaborative maintenance are part of e-maintenance. Tasks are spread among the personnel and done individually, and then the results are gathered when writing the final report by cooperative maintenance. It helps to work together and understand different point of views. On the other hand in collaborative maintenance, all tasks are done in parallel towards achieving a common goal. It is important to achieve company’s goal and make easy to overcome problems.

4.4. E-maintenance services
By using e-maintenance so many services could be better. By using e-maintenance, diagnose and prognosis services helps to what is the problem. The aims of these two services are to understand the failures before they happened and identifying the root cause of failures also they helps to maintain predicting process for failures and their outcomes. By condition monitoring service, machine health and usage data are available to see. One of the other services is logistics services which aim is to support maintenance activities by integration logistics. This service deal with spare parts activities that prepares inventory reports, part request, checking condition of spare parts and purchase them at the right time and right condition and stores. (Karim, 2010).

The last service of e-maintenance is documentation service. This service provides information of maintenance to maintenance actors in right condition. Repairing orders, technical publications, planning documents, cost reporting can be example of data which documentation service deal with it (Karim, 2010).

4.5. Economic impact of e-maintenance
According Al-Najjar&Alsyouf (2004), the process of identifying the losses due to the lack of good maintenance actions is easy, however it is more difficult to assess the impact of maintenance on the whole production process.
Holmberg (2010), claims that maintenance cost causes 6% of the product price. It depends on the type of industry and sector. This percentage shows direct maintenance services. The important thing is to see the indirect maintenance cost and make it lower. The expectations of manufacturing area are a short reaction to failures, preventive maintenance and low cost maintenance. Also Holmberg (2010) stated that new technologies are useful ways to decrease gathering maintenance data complexity. His claims state that e-maintenance is available to contribute in three different levels which are strategic level, tactical level and operational level. This coordination can decrease the unnecessary activities such as gathering data by operator also it can help the optimization of all maintenance activities (Holmberg, 2010). The cost of gathering data by the operator could be seen insignificant, but if the operator is gathering data, this could lead to time waste in production, thus unnecessary cost. Or if you have a personnel his job is only going around and gather data, it will contribute in unnecessary cost.

Cost factors that are related to maintenance are divided into four main categories. (Holmberg et al, 2010):

1. Direct costs: costs that are clearly due to maintenance such as:
   a. Labor cost
   b. Spare parts
   c. Consumable material
   d. Instrumentations and software
   e. Locals and overhead
   f. Miscellaneous

2. Economic losses, potential savings or potential income sources: the losses due to having insufficient maintenance actions, i.e. unplanned stoppages and failures. These losses are:
   a. Less availability
   b. Lower performance
   c. Bad quality
   d. Production delays
   e. Extra operational costs
   f. Extra storage to preserve spare parts.
3. **Risk capital investment for improving maintenance performance**: the investment that is required to improve the current maintenance policy. These costs could be gained later from the profit of the new improvements. These investments could be:

   a. Instruments and software for better performance
   b. Training programs for personnel.

4. **Maintenance results**: the profit or losses that are gained after investing in a new maintenance strategy, such as:

   a. Savings due to maintenance more efficient performance
   b. Profits or losses that are gained.

4.6. **ICT for e-Maintenance**

Information and communication technologies are widespread area but e-technologies are one of the reasons for the emergence of e-maintenance. These technologies have been incorporated in almost every e-maintenance activities (Marquez, 2008). Holmberg et al. (2010) divided these technology sources in two. One of them is miniaturization technologies that use miniaturized devices to gather data. Data can be sensed by the sensors. Another one is communication technologies which include wireless and use internet or intranet.

Miniaturization Technologies: Sensor technologies became more important thanks to new micro-technologies that developed last years. RFID tags, smart mobile devices, sensor systems are the kinds of miniaturized devices.

Communication technologies: this technology helps to easily connect. According to Holmberg et al. (2010) there are many types of wireless communication system. He claims that when considering about physical area, wireless network could be divided four categories. These categories are wireless personal area network (WPAN), wireless local area network (WLAN), wireless metropolitan area network (WMAN), wireless wide area network (WWAN).

Marquez (2009) states that two types of technologies and other technologies that could be hardware and software needed to support e-maintenance activities. Integration of technologies is mainly important for the e-maintenance solutions. Some of these innovative technologies presented below briefly.
o MEMS are smart sensors that consist of autonomous power, memory cells, and converter. It is a micro sensor technology. Sensors are so important for the e-maintenance because they do basic but important process that is gathering data. Also sensors support some e-maintenance services as diagnosis, prognosis.

o RFID tag: It is an abbreviation of Radio Frequency Identification Device). By using RFID tags, maintenance tools could be geo-localized.

o GPS: It is an abbreviation of Global Positioning System. It is also can deal with calculating the operator or maintenance tools.

o Wireless: This technology helps to avoid wasteful networking cost. Wireless mainly include wireless local area networks as Wi-Fi, also Bluetooth as a personal area network.

o Smart Phones, PDA, and RFID reader: Handheld wireless device could be used for monitoring and control the task.

o Web services: It is internet based technology for monitoring, diagnosis, scheduling, and prognosis. It provides exchanging between applications.

o Web-CMMS: It is an abbreviation for Computerized Maintenance Management System. It helps to manage and monitor preventive maintenance activities.
5. Analyses

*In this chapter, the data which is already presented in literature review will be analyzed.*

5.1. Challenges of e-maintenance

To be able to implement e-maintenance, certain requirements should be considered. To assure the right process in the most cost-effective way, the company should be reorganized to fit the new system. Also a new system is required to support e-services.

An important aspect that should be considered is the management of the data and the archiving, everything should be documented and easy to find when needed. E-maintenance programs will provide real data that could be accessed anytime and anywhere. This will result in using your time more efficiently and it will reduce labor costs by not making personnel to go over different machines to collect data each time.

As a whole new way of dealing with maintenance activities, maintenance personnel should be registered to programs to teach them to adapt to the new software and the new techniques. At the beginning this could be seen as an unnecessary cost, but ultimately it will benefit the whole organization and will take the maintenance to a whole new level of cost-effectiveness.

Also different department should be motivated to start sharing data and information between each other so they will end up with having different points of view that could lead to the best solution to a problem. These challenges should be considered and done before starting to implement e-maintenance. Another main aspect is the structure of the content format, i.e. the layout of the programs. And also to enable the integration capability across a multi-platform.

5.2. ICT for e-maintenance

Information and Communication technologies help to implement e-maintenance. If technological background is not enough to meet e-maintenance needs, implementing e-maintenance could be impossible. E-maintenance activities includes object selection, planning maintenance operations, stock management (mainly spare parts), sensor installation, data analysis, and data transform. Moreover, if the amount of devices increase, the complexity and the management of maintenance activities could be harder. E-maintenance provides internet and tether-free communications technologies to manage all possible resources that could include operators, spare parts and time. As figure 6 shows that there is a flow about local maintenance and web-based support. E-maintenance
needs to use real time data and real time condition to analyze and predict failure. That is why real-time condition monitoring system is one of the most important requirements before implementing e-maintenance. This system requires miniaturized technologies such as RFID tags, MEMS sensors to gather data such as vibration signals, sound signal etc. Tether-free technologies provide the networking between database and equipment. By using this system data are available to be gathered directly from the equipment, but the problem is transforming, transferring and storage data. If raw data were to be transferred directly, it could be heavy traffic and long time in transferring data also it could need more storage space in the database. The database should have enough space for all data. Cloud solutions could be used for solving the space problem but it could be a threat to safety.

Hardware and software systems are needed to support e-maintenance activities. Integration and safety is so important for e-maintenance. Maintenance activities could be effective by well integration of technologies. Safety of all data storages is so important because nobody wants to lose data. CT should be considered before implement e-maintenance because requirement of ICT could be expensive and may affect the costs too much.
5.3. The economic impact

The cost elements of e-maintenance are divided into four main categories; these are the most important elements to assure the most cost effective way of implementing e-maintenance:

![Cost breakdown structure](image)

Figure 8: Cost breakdown structure

It is easy to calculate maintenance cost but it is not easy to calculate economic impact of maintenance to company profit. As presented in Figure 7, some economic factors which
are affected or affect to maintenance. To identify direct cost is not complex because these costs directly affect to maintenance cost.

Risk capital investment shows the new investment costs which helps to have better maintenance policy or helps to find new improvements. Software, training programs, and perhaps new instruments will be needed to apply E-maintenance; these costs would be higher than usual. But on the other hand, labor costs and overhead will be reduced; fewer people will be needed to help collecting data, because the new software will provide these data anytime and anywhere.

Maintenance results show that after investment on e-maintenance, what is the income and losses due to new strategy. These costs and incomes are based on performance of maintenance. The last categories shoes economic losses. This section is so important because these economic losses give chance to see potential savings. If maintenance performance will be better, most of these losses would be able to recover as savings. As the cost factors were discussed earlier in chapter 4, fewer personnel for the maintenance department will be needed, so labor cost is reduced. Also by knowing exactly when the maintenance actions will be done could reduce the amount of spare parts in storage by ordering them before doing maintenance, thus storage for spare parts cost will be lower. But on the other hand, new instruments and software will be needed, thus will result in new investments. But by combining all these together will result in higher performance, higher availability, no delays in production and higher quality, and over all will lead to a better income and high benefits.

5.4. Strategies of e-maintenance
A lot of existing e-maintenance strategies is included to maintain the high level of performance that is provided, E-maintenance programs can choose between different maintenance techniques to assure the best and most cost-effective solution to fit the company’s goals and vision.

Also the choice of strategy could be based on the part’s specifications and criticality. Preventive maintenance could be the best solution for some parts, but for other parts, it could be predictive or corrective maintenance.

Choosing between the different techniques could be difficult and time consuming, and this will cause longer downtimes which will ultimately affect the performance and the availability of the machine. E-maintenance programs will choose the best fit strategy in much faster and effective way.
E-maintenance also provides new strategies such as remote maintenance; this will help to follow up and also issue work orders without the physical attendance of the personnel. Also collaborative and cooperative maintenance will include different departments and different personnel to work together towards achieving the goals and vision.

5.5. E-maintenance outcomes
The outcomes of e-maintenance could be considered as positive outcomes and negative outcomes.

5.5.1. Positive outcomes
E-maintenance could affect the organization positively by offering the opportunities to develop new maintenance techniques that will be able to result in much faster reactions and the personnel will always be prepared to different situation. Also it offers remote maintenance and decision making that could be faster than being done manually. E-maintenance improves maintenance support and tools by failure analyses, also it provides documentation for every maintenance action or failures, this documentation are always available and easy to access.

One of the most important positive outcomes is remotely analyzing data. For example global companies that have plants in different location do not have to hire experts for each plant, by using e-maintenance experts can see data and analyze them because gathered data is online and easy to reach for experts. Still there is also a room for improvements in the area of maintenance activities such as to localize the area of the faults in the machine, to guarantee a faster and reliable fix.

5.5.2. Negative outcomes
On the other hand, e-maintenance has some weaknesses, these weaknesses could have a negative impact, but still they could be fixed. The lack of databases that is essential for e-maintenance could have a negative effect; these databases connect departments with each other so they can attack different issues from different perspectives.

Other issue concerning E-maintenance is the security and integrity of the information shared through the internet, this could cause leakage of information to the competitors.
6. Results

The rule of maintenance nowadays is very critical to the production status; it can change the whole process in a positive way by implementing the right maintenance strategy. Maintenance can affect production, quality as well as availability.

The analysis chapter indicates that even if it has some weaknesses, e-maintenance may be able to guarantee the best maintenance solution that suits different scenarios depending on company’s goals and vision. The criteria that should be considered before implementing e-maintenance are easy to be met, if companies consider the long terms. The four main cost elements are the most important to be considered if the aim is to be as cost-effective as possible. Different costs are shown through the cost breakdown structure in order to make visible to cost elements. Initial investment of e-maintenance could be high because new equipment and software are required but in a long terms this costs wouldn’t be important when compared to benefits. Everything in E-maintenance will lead to a cost-effective way, using sensors and software to collect and analyze data will save time and money, also the choice between different maintenance strategies will eliminate any useless additional costs, e-maintenance doesn’t require personnel to go over the machines to collect data, so labor cost will be lower when using e-maintenance. Also using e-maintenance can decrease the cost of data analyzing. A few experienced employees will analyze data in one center and control data remotely. They do not have to go over every single factory in which machines are located. It can decrease the cost of travel and hire more consultants. So all together can lead to a cost-effective way. Calculating the economic effectiveness of implementing e-maintenance is not easy because it does not affect only maintenance direct costs, it affects another department especially production line and quality. To see certain economic impact of e-maintenance, it should be implemented in different industrial area.

E-maintenance could provide a whole maintenance plan for the facility, including maintenance actions, time of maintenance, and the person charged for doing the maintenance. The common database between the different department helps for instance to involve the management and accounting department in the whole maintenance process. With the new ICT technologies, this has helped to increase the accuracy level of maintenance decision making with the new sensors and alarms. But using this ICT technology may cause security problems. Security could be an issue and can cause important problems, because e-maintenance depends on networks and internet moreover it is important to train and motivate the personnel to use e-maintenance. Adapting to new technology and using them could take time and effort.
From the analysis, the authors came up with a simple model to describe the implementation of e-maintenance by dividing it into three main phases. Which will answer to the problem formulation. The first phase is the pre-implementation which includes:

1. Challenges of e-maintenance: first, the organization should be restructured; also the data should be managed. The personnel should also be introduced to the new concept, how it works, and what should be done. Another main aspect is the structure of the content format, i.e. the layout of the programs. And also to enable the integration capability across a multi-platform.
2. ICT for e-maintenance: Apply condition monitoring techniques, install sensors and have a common database. Connect the personnel’s smartphones or PDA to the database, and also have different security levels depending on their authorization.

The second phase is the implementation:

1. The economic impact of e-maintenance: Considering the four main categories of the economic impact. Some new investments could add costs, like having new instruments and software, but on the other hand, we think some other costs will be reduced such as labor costs and overhead.
2. Strategies of e-maintenance: Choosing between different maintenance strategies depending on the company’s goals and vision. The choice could also depend on the part’s criticality specifications.

The third phase is the outcomes of implementing e-maintenance, which is the post-implementation:

1. Strengths of e-maintenance: faster decision making, also easy access to the data anytime and anywhere to follow up and make work orders.
2. Weaknesses of e-maintenance: the lack of common databases which has a huge impact on e-maintenance, also the security and integrity of the shared information using the internet which can be lost or stolen.
Table 2: Model of the Requirements to implement e-maintenance cost effectively model

<table>
<thead>
<tr>
<th>pre-implementation of e-maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Overcome the challenges of e-maintenance</td>
</tr>
<tr>
<td>- Apply ICT requirements</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>implementation of e-maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Do new investment (software, instruments) by</td>
</tr>
<tr>
<td>considered costs</td>
</tr>
<tr>
<td>- Chose strategies of e-maintenance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>post-implementation of e-maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Evaluate strengths of e-maintenance</td>
</tr>
<tr>
<td>- Evaluate Weaknesses of e-maintenance</td>
</tr>
</tbody>
</table>
7. Conclusions
This study describes the implementation of e-maintenance, its strength and weaknesses and possible benefits. Better maintenance functions can increase the efficiency of production, improve quality and reduce downtime. E-maintenance could help to make maintenance functions better.

To implement e-maintenance, challenges should be overcome and new investments should be made in order to achieve a cost effective e-maintenance. ICT systems also should be installed to have an efficient condition monitoring system. Every manufacturing company wants to have better maintenance functions but this cause cost. Also e-maintenance has some positive and negative outcomes. The positive outcomes outweigh the negatives.

The authors think that the model could be implemented in most of the companies. Having e-maintenance will be able to make maintenance functions and solutions easy for small to moderate companies, because it does not require to the physical attendance of the all personnel so the company is connected to a maintenance center that will be able to handle the maintenance issues, i.e. outsourcing.

Our recommendation is to improve the security level when using e-maintenance to protect the data from getting lost or stolen. Also motivation of the personal to use e-maintenance is another problem should be solved. Users should feel convenient and interested while using it.
8. References:

Books:


12. R. Keith Mobley, 2002,*Introduction to preventive Maintenance*.Elsevier Science, USA

13. Rothchild, Irving (2003), *Induction, Deduction and Scientific Method*, School of Medicine ofCase Western Reverse University


Articles:


**Websites:**
