IMPACT OF E-MAINTENANCE AND ARTIFICIAL INTELLIGENCE TOOLS ON COSTS AND BENEFITS

Yassine MOUMEN, Mariam BENHADOU and Abdellah HADDOUT

LABORATORY OF INDUSTRIAL MANAGEMENT, ENERGY, AND TECHNOLOGY OF PLASTIC AND COMPOSITES MATERIALS HASSAN II UNIVERSITY – ENSEM CASABLANCA, MOROCCO

Abstract
In the current era, the market has extremely developed, and the introduction of new technologies, and digitalization, AI… becomes a must. Indeed, only a few companies could be competitive nowadays in a digitized environment. This said, most companies today have introduced digitalization to all their strategic processes including maintenance as it’s considered as one of the development levers of many businesses since it has a direct impact on many key indicators i.e: costs, reliability, availability, safety, and productivity. Polemics about digitized maintenance have begun between the last decade of the previous century and the early 2000, it is commonly named “e-maintenance”. So far there is no standardized definition of the concept given by an official institution. Otherwise, as just a little attention was given to this subject in literature, this paper was written to give a global image of the impact of e-maintenance on costs and profit.

KEYWORDS: e-maintenance, maintenance, industry 4.0, costs, benefits.

1. INTRODUCTION
In the period 1940 to 1960 maintenance was only a production sub-function and it was seen as a necessary evil [1][2]. Corrective maintenance was the only policy applied, as production demands weren’t as high as they are today, downtime was not a major problem, and it was relatively rare. The maintenance of industrial equipment was therefore only carried out on an ad hoc basis when a machine broke down. It was also commonly named firefighting maintenance. Maintenance became more important between 1960 and 1980. Several companies have acknowledged the importance of maintenance functions. Although it started to be an independent department [1][2], maintenance function was still considered a background activity, its scope was very restricted and mainly limited to technical expertise, technicians worked only in electricity, mechanics, lubrication. Strategies laid down were only concerning repairing and major corrective operations.

During the last two decades of the previous century, maintenance policies became more popular and common as the industry became more sophisticated and production shutdowns started to lead to huge losses because equipment started to be integrated into the general system. All of this has pushed many companies to change their maintenance policies and started rolling out preventive maintenance in all its forms either systematic or conditional.

Nonetheless, this change hasn’t banned corrective maintenance; in fact, the appropriate maintenance policy is a result of a decision-based cost.

Furthermore, companies paid more attention to the safety aspect, as equipment had evolved, combining more advanced technologies that might cause more accidents and expose people to high risks. We can say that human reasons get more importance than economical ones.

In the 21St century, maintenance has known major changes such as the introduction of outsourcing policy with its internal and external partnership [1][2]. E-maintenance has also emerged since early 2000 [3][4] which is mainly focusing on process digitalization and real-time data as a support for the decision-making process, as a tool to make predictions or prognosis analysis [3][5]

Maintenance strategies or policies consist of the organization of the required maintenance activities to keep assets available. Corrective maintenance appeared naturally at the beginning of the industry it was simply a set of service actions carried out after breakdown [1]. Preventive maintenance policy, including Time Based Maintenance (TBM) and Condition Based Maintenance (CBM), is performed before the failure occurrence but it’s still presenting some shortcomings though [1]. Unlike all of this, Design Out Maintenance and Total Productive Maintenance are two approaches that arrived gradually as an upgrade to make up for all gaps and shortcomings.

Corresponding author email address: yassine.moumen@ensem.ac.ma
2. IMPORTANCE OF MAINTENANCE INSIDE COMPANIES

2.1 Some figures

Digitalization is a set of technologies that has invaded almost all businesses. In every specific company, it's complicated to digitize a fragment of the business and manage the rest in a normal conventional way. The enterprise processes are interdependent and have to move the same way at the same pace. The maintenance department is comprising many processes that influence one of the most critical key indicators which is cost. Maintenance activities could value up to 70% of the total production cost [1][6][7] and 15%-40% of manufacturing cost, it is considered as the second largest after energy expenses [1][2][3][8][10]. In Europe for instance, an estimated amount of approximately 150 billion Euros is expended annually for industrial maintenance, whereas in the United States maintenance cost has tripled in a decade to reach $600 billion in 1989 [1][10], another benchmarking exercise was carried out by Wireman gave that the maintenance cost for industrial firms in the USA has increased by 10 – 15% per year since 1979 (Wireman 1990). Likewise, in the price structure, the pricing department considers that maintenance costs represent up to 28% of the product’s entire cost. To ensure the reliability of equipment, maintenance would be considered the costliest in the Operational Expenditure (Opex). In other industries, approximately one-third of the maintenance budget is lost to unnecessary unplanned maintenance activities due to improper maintenance plans [1][9].

2.2 Product life cycle

Maintenance objectives are omnipresent in all product life cycles. B. Jung, E. Levrate, A. Crespo M Crespo Marquez, H. Erbe provide maintenance objectives along product life cycle phases. During the design phase, for instance, engineers have to make sure that characteristics like maintainability, reliability, and durability are verified.

In the manufacturing phase where the product is physically created or assembled, method engineers have to take into consideration the product maintainability to optimize the probability that the failed component will be restored or repaired to a specified condition within a specified period. Reliability, which is the quality of being trustworthy and of performing consistently well, must be confirmed.

The usage phase which is considered highly critical, is mainly measured by a couple of maintenance KPIs which are availability and reliability. Availability refers to the duration of time that particular equipment can perform its intended task [11]. The last phase of every product cycle is disassembling and recycling. Durability and circular economy have to be respected.

2.3. International standards

Many international norms started to give more interest to maintenance processes and therefore they have deployed specific rules to handle them. On the notion of maintainability of equipment, the French X60-000 series of standards defines the criteria and requirements relating to this subject. We can find for example the standards: [12]

<table>
<thead>
<tr>
<th>X 60-010</th>
<th>X60-301 series</th>
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<tr>
<td>Has the mission of preserving your fleet of machines as much as possible, in terms of the value of the equipment, performance and safety</td>
<td>Takes into account the maintainability criteria of durable goods for industrial and professional use.</td>
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![Fig.1 French X60-000 series of standards](image)

European norm NF EN 13306 addresses the different terminology used in maintenance (Preventive, corrective, predictive, etc...). This is probably one of the most important standards because it describes and gives indications of the maintenance operations to be implemented [13].

To complete the standard for maintenance indicators, the NF EN 15341 standard must be taken into consideration, which integrates indicators into a dynamic maintenance process. Once the right indicators have been defined, their implementation goes through dashboards allowing monitoring and the associated corrective actions. Its objective is clear: to allow you to properly assess and improve the performance of your machine park [13].

As for operational safety management, the NF EN 60300 series of standards describes the framework. Thus, it deals with the operational safety of products, processes, systems,
or services integrating human, software, or hardware aspects. This standard is important to plan and implement dependability activities while integrating requirements relating to, for example, safety or the environment [13]. The NF EN 16646 standard integrates the management of physical assets within the framework of maintenance activities. Concretely, it describes the interactions between the maintenance processes and the physical asset management processes, more particularly the importance of maintenance throughout the life cycle of an asset [13]. One of the related perimeters impacted by the maintenance process is the quality management system, described by the ISO 9001 standard. Indeed, the perimeter covered by the quality management system of a company is being very vast, and certain maintenance is concerned by the ISO 9001 standard, such as the compliance of production assets or physical assets [14].

The 21 CFR Part 11 standard was drafted by the US Food and Drug Administration to ensure the validity of electronic documents, the authenticity of electronic signatures, and their reliability. This standard concerns all aspects of the production activities of companies. Therefore, all maintenance-related documents (e.g. service history) must meet the requirements of 21 CFR 11 [15]. ISO 55001 specifies requirements for establishing, implementing, maintaining, and improving an asset management system that manages the life cycle of an organization's assets regardless of asset type. It is intended for use by those involved in establishing, implementing, maintaining, and improving an asset management system and can be applied to all types of assets by all types and all sizes of organizations. Good asset management enables business objectives to achieve their maximum potential for achievement and is reflected in a significant increase in customer and stakeholder satisfaction as well as improved trust. Maintenance is considered one of the prominent tools in assets management as it represents an important part of the use phase of the product lifecycle [14].

3. E-MAINTENANCE COMPONENTS AND TECHNOLOGIES

E-maintenance can be made of different components and technologies, below are some of the most known components.

Enterprise Resource Planning ERP is therefore a type of software that encompasses the majority of needs related to the management of a company. The ERP will computerize the different data of each service of a company: purchases, accounting, and management commercial, sales, expenses, working time, project management, and all other features of your company. According to Yassine et al, it’s with a medium impact on industrial processes. [1]

MES (Manufacturing Execution System) software is a computer system whose primary objective is to collect production data in real-time from all or part of a factory or workshop. This collected data then makes it possible to better control and manage production by monitoring production, managing traceability, quality control, managing preventive maintenance, etc. The MES provides the information to optimize production activities from the launch of the order to the finished product. It must focus on the critical information of production activities and distribute it throughout the company and the Supply Chain, via two-way communications. MES impact on industrial processes is considered normal.

Cloud Computing is a general term used to refer to the delivery of resources and services on demand over the Internet. It refers to storing and accessing data via the internet rather than via a computer hard drive. It is thus opposed to local storage, consisting in storing data or launching programs from the hard disk. In general, we speak of Cloud Computing when it is possible to access data or programs from the Internet, or at least when this data is synchronized with other information on the Internet. All you need to access it is an internet connection. The picture below represents the common architecture to better understand the cloud computing concept. This technology is used in e-maintenance and it is considered as with medium impact on industrial processes. [16]

Machine-to-Machine communication (M2M) is a new technology that enables machines to communicate without human intervention [17][18][19]. It describes the automated exchange of information between several terminals, without human manual intervention. Machine to machine technology is used in various fields, including the monitoring, control, or command of machines and automatons and even the indexing of
websites by search engines. This technology is considered with a very important impact on industrial processes.

The Internet of Things (IoT) is considered as the combination of electronic information technology with people's daily life, and the combination of information and data with communication networks, forming a close connection between things [20][21]. It describes the network of physical terminals, "objects", which integrate sensors, software, and other technologies to connect to other terminals and systems on the Internet and to exchange data with them. These terminals can range from simple domestic appliances to highly complex industrial tools. 10 billion terminals were connected in 2020, experts expect 22 billion connected terminals in 2025 [22]. IoT impact on industrial processes is considered normal [1].

Radio-identification, most often referred to by the acronym RFID is a method for storing and retrieving data remotely using markers called "radio-tags", which are small objects, such as self-adhesive labels, which can be stuck or incorporated into objects or products and even implanted into living organisms like animals or human. RFID tags include an antenna associated with an electronic chip that allows them to receive and respond to radio requests sent by the transceiver. This system is amongst e-maintenance pillars. [1]

Virtual reality is an expression that means the devices allow to digitally simulate an environment by the computer. Depending on the technologies used, it allows the user to feel a virtual universe through their different senses: sight most often but also touch, hearing, smell. Whereas augmented reality is relying on the real adding virtual elements to it could constitute a summary meaning of augmented reality. Augmented reality refers to all technologies that use real elements enriched by virtual elements. Concretely, what does all this mean? We speak of augmented reality when virtual objects are added to a real situation. It’s frequently used in videogames, training, culture but also maintenance. [1]

Smart sensors are the first devices making it possible to transform an observed physical quantity into a usable physical quantity. The term “smart” has been added because these devices incorporate digital data processing elements, which gives them autonomous interpretation capabilities. The smart sensor can receive, transmit, and elaborate data and commands through digital channels.[3][23]

Digital devices for mobile working: devices used help the maintenance team within their daily operations, for instance, by retrieving data from the production equipment. [3][24]

Computer Maintenance Management Software (CMMS) is a management method carried out using a CMMS software package to manage the maintenance tasks of a company, a local authority, or an administration. It’s used for many reasons: to keep a database recording all maintenance operations, to plan and schedule maintenance activities, to manage spare parts, to monitor performance, and to manage budget and costs. [3][25]

Tools for signal and data processing: all systems can make integrated data acquisition and signal processing to provide useful information to maintenance engineers (e.g., SCADA, Supervisory Control, and Data Acquisition). [3]

Wireless infrastructure is amongst e-maintenance fundamental tools and means, they are mainly used to build a communication network and overcome problems related to restricted space or long distances. [3]

A Personal Digital Assistant (PDA) contributes to the management of an address book or a diary and integrates increasingly sophisticated functions. The PDA has become a true pocket computer. It has various functions, the list of which is not exhaustive: a processor, RAM, a touch screen, a compact case, office tools (viewers, spreadsheet, and calculator), and a GPS. In maintenance it is adopted to support operators and maintenance field technicians to carry out maintenance actions operations, assess equipment condition, and evaluate maintenance service, even more, to retrieve data from machines and systems [3][5]. It has many advantages like; portability, accessibility, reach-ability, localization, and identification. [3]

We consider that well-organized maintenance, using lean manufacturing, six sigma, or based on some well-structured methodologies like Reliability Centered Maintenance (RCM), and TPM (Total productive maintenance), is also covered by the concept of e-maintenance.

4. IMPACT OF E-MAINTENANCE ON COSTS AND BENEFITS

Economical evaluation in maintenance refers basically to costs and benefits which are two oppositely different words. Benefits mainly refer to profit whereas cost is related to expenses. But in maintenance philosophy, both terms could lead to a profit either by generating benefits or optimizing savings. The schematic below is illustrating the
different types of economical evaluation with examples to better understand each case:

![Economical evaluation](image)

There are many methods to carry out an economic assessment of a maintenance department. Fumagalli et al. have chosen the Cost-Benefit Analysis (CBA) methodology which is used basically to assess all possible costs and benefits of a project [3][27]. CBA consists 3 steps:

- Cost-driver identification of each activity using the ABC (Activity Based Costing) method which considers 20% of activities lead to 80% of costs
- Brainstorming and designing appropriate solutions to the concerned processes
- Solution impact assessment and evaluation of costs and benefits by comparing AS-IS to TO-BE

As for Key Indicator Performance (KPI), Net Present Value (NPV) is one of the most reliable KPIs. It is a tool of Capital budgeting to analyze the profitability of a project or investment. It is calculated by taking the difference between the present value of cash inflows and presenting the value of cash outflows over some time. From another hand, Payback Time (PT) which is also called recovery time, represents the time required for the projected cash flows generated by an investment to make the initial investment cost profitable.

Both listed KPIs could give a clear idea of the maintenance economic evaluation.

In the food industry, the application of some maintenance methodologies like Reliability Centered Maintenance (RCM) has resulted in a decrease of 201.6 men hours per year, a decrease in unavailability due to failure rate by 0.73%, and better control of maintenance cost. [28]

In Wastewater Treatment Plants (WWTP) effective preventive maintenance tasks reduce the probability of breakdowns. It was also confirmed that costs and efficiency are linked, in other words, by applying preventive maintenance, repair costs decrease, and then plant efficiency becomes greater. [29]

In-Service Level Agreements company, it was decided to switch from paper use to the use of PDA. A total benefit of 16000/years was obtained. A payback time of 1.6 years was estimated. Intangible benefits weren’t included in the research as data- poor data was available. [3]

A Finnish company providing full maintenance service from on-call repair to full SLA. The introduction of a performant PDA system has allowed the company to reach an annual benefit of 32000 euros. Payback time was estimated at 2.11 years. By considering intangible benefits Overall Equipment Effectiveness might rise by 1 – 2%. [3]

5. CONCLUSION

Maintenance is one of the most important functions in every company. Maintenance supports production to reach set objectives, it contributes even to sales improvement and company effectiveness optimization. Nonetheless, as industrial processes get developed rapidly, maintenance is also get developed and e-maintenance appeared. Despite still being fuzzy as a definition and so hence no official organization has shared a well-structured statement on the subject. Many companies have started laying down e-maintenance technologies and systems to improve their performance.

As we have been confirmed in the previous paper [1], e-maintenance has an impact on many KPIs inside the company. Particularly, this paper has given more attention to the impact of e-maintenance on cost as it’s considered the most critical maintenance indicator. Costs or benefits or simply economic assessment have been split into many categories. We can find tangible i.e., savings, investment, and intangible i.e. training cost, customer satisfaction. This impact is evaluated by different KPIs such as NVP and PT which give a clear image of the performance.

As part of the impact of e-maintenance on performance indicators, our upcoming research will concern the impact of some activities on e-maintenance performance. Activities could be listed as; external expertise, consultancy, training … We are going to focus on training to study its impact on e-maintenance. Professional training is becoming a prominent activity consumed by almost all companies. In many countries, the government encourages companies’ management to carry out training sessions by refunding a very important part of the training cost. This upcoming research will cover two great industrial countries with different maturity levels which are: Morocco and France. Morocco with its resilient economy and reliable
systems guided by the wise vision of his majesty King Mohamed VI and France with its very large industrial field and its great future programs like “France Relance” or “France2030”.

The next empirical work will be based on a survey with different blocks of questions which will be basically around company size, maintenance department organization and number of trainings carried out per year, training providers, impact on performance.

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REFERENCES


[12] https://www.afnor.org/
[14] https://www.iso.org/fr/home.html
[16] https://www.lenigdata.fr/definition-cloud-computing
[17] http://creativecommons.org/licenses/by-nc-nd/4.0/; secured energy-efficient machine-to-machine communication for telerobotic system

[20] Li Long 2021 6th International Conference on Clean Energy and Power Generation Technology(CEPGT 2021), September 10–12, 2021, Shanghai, China


