E-MAINTENANCE: IMPACT OVER INDUSTRIAL PROCESSES, ITS DIMENSIONS & PRINCIPLES

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

During the course of the industrial 4.0 era, companies have been exponentially developed and have digitized almost the whole business system to stick to their performance targets and to keep or to even enlarge their market share. Maintenance function has obviously followed the trend as it's considered one of the most important processes in every enterprise as it impacts a group of the most critical performance indicators such as: cost, reliability, availability, safety and productivity. E-maintenance emerged in early 2000 and now is a common term in maintenance literature representing the digitalized side of maintenance whereby assets are monitored and controlled over the internet. According to literature, e-maintenance has a remarkable impact on maintenance KPIs and aims at ambitious objectives like zero-downtime.

KEYWORDS

E-maintenance, Maintenance, industry 4.0, industrial performance, zero-downtime

1. INTRODUCTION

Maintenance has become one of the major influencers toward strategic objectives of companies in today's extremely competitive markets. Some results have shown that maintenance activities could range from 15% to 70% of the total production cost [1,2,3]. The cost is considered as the second largest after energy expenditures of the operational budget [1,4,6,7]. In the United States, the maintenance cost has tripled in 10 years to reach $600 billion in 1989 [1]. One more important figure related to product price structure that considers maintenance operating costs value up to 28% of the product's global cost [5].

The maintenance process is a set of required activities to keep an asset at maximum availability. These activities are mainly carried out according to certain maintenance strategies [1]. In the past, maintenance had been based mainly on corrective operations. Later, maintenance became an independent function, rather than a production sub-function [1]. A decade before, as the technologies grew and systems became more complex, maintenance has been developed as well and became enclosing technical and management knowledge. Indeed, preventive maintenance, including Time Based Maintenance (TBM) and Condition Based Maintenance (CBM), has followed the Corrective Maintenance (CM) as an upgrade, Design-Out Maintenance (DOM) and Total Productive Maintenance (TPM) have arrived gradually [1].

CM occurred in the early industrial days spontaneously when the maintenance belongedto the production process and was also known as firefighting or emergency maintenance. CM is mainly carried out after the failure [8].

DOI:10.5121/acij.2021.12501

Contrary, the preventive maintenance which intends to reduce the probability of failure or degradation of functioning of an equipment [1,9]. Preventive maintenance is divided into TBM and CBM. TBM operations are time-based and carried out following a pre-designed schedule, rolled out by the maintenance engineering team. Whereas in the CBM, the machine's parameters are monitored using sensors like vibration, temperature and pressure. In other words, preventive maintenance operations are carried out before failure. It’s also considered a double edge weapon as it prevents failure and downtime, however, some good parts are replaced though.

Design-Out Maintenance is acting proactively, by focusing on equipment design in order to eliminate the cause of maintenance. DOM makes the maintenance easier in the life cycle of a product [22]. We can even say that DOM enhances one of the most important maintenance parameters, maintainability.

Maintenance strategy choice is a crucial phase to every organisation and it has a direct impact on business results and market share. Kumar Pinjala discovered a true correlation in his empirical investigation on the relationship between business and maintenance strategies; his survey’s results of 150 companies in both Belgium and the Netherlands indicated that quality competitors have more proactive maintenance policies, better planning and control systems and decentralized maintenance organisation structures when compared to others [11].

The main objective of this work is illustrate a clear image about the maintenance, how it was seen? How it looks like nowadays? What would be the e-maintenance impact? And what are the tools and means required to reach desired performance.

To answer clearly all above questions mentioned, we decided to present our work as follow: First, we are going to describe the classic form of maintenance and to explain its pejorative image as it’s seen as a necessary evil which is inherent, roughly, to all production systems and wherever machines would be. By next, we are going to give an insight over maintenance key parameters, in order to be able to measure properly the maintenance function performance. Afterward, an introduction, over the new concept of e-maintenancealong withe-maintenance mind-set, will be presented.Finally, we discuss e-maintenance tools as described in many papers and how they can influence industrial processes.

In the long run, this paper will help authors to select the most adequate industry 4.0 tools related to maintenance. These tools are going to have a clear and direct impact avec industrial processes

2. CLASSIC MAINTENANCE LIMITS AND KPI’S

Classic maintenance is every maintenance strategy as described before. In spite of the fact that maintenance is a necessity, most industrial actors are still considering maintenance as a necessary evil (without optimizing)[12]. This negative image was attributed to maintenance a long time ago, when only CM operations were carried out and maintenance teams came just to fix things when they broke, even more when things break down maintenance has failed [13].

A few decades ago, maintenance function was viewed as an inherent part of the production function and very tough to manage. As we go, this thought has changed and maintenance became an independent function. Table 1 shows maintenance timeline progression:

Table 1. Maintenance management on time perspective [14]

Period	Progression	How it is viewed
1940 – 1960	Maintenance as a production task	Necessary evil
1960 - 1980	Maintenance as an independent department	Technical specialization
1980 – 2000	Integration efforts	Profit contributor
2000 <	External and internal partnership	Positive cooperation

It's mandatory for the maintenance to be optimal, in order to have the same objectives of organisation ones. These objectives are mainly: cost, reliability, availability, safety, productivity, quality, environment and maintainability. However, with rapidtechnological progress, classic maintenance is no longer able to keep these KPIs above targets. Many papers were processed in different domains such as Food industry [15], Wastewater Treatment Plant WWTP [16], Aviation [17] and General industry [18]. They all suggest moving up from classic maintenance in order to be aligned with organisation objectives.

It has been noticed that e-maintenance is encompassing many of the solutions proposed for the maintenance to take off that pejorative image and give up suffering from deficiency of understanding and respect.

3. E-MAINTENANCE AND THE NEW WAY OF THINKING

The new way of thinking starts by giving up looking at the maintenance as a necessary evil. Maintenance has to ensure production systems availability and functionality in order to contribute to business objectives[12]. Likewise the new thinking aims to change the maintenance role from fixing breakdowns to taking into account the product life-cycle management [19].

Among the e-maintenance roles we can identify the eco-efficiency. The eco-efficiency consists of considering the maintenance in all product life phases and not only as a set of operations during the production phase. The four product life cycle phases are as follows: product design, manufacturing and assembly, usage and finally disassembly and recycling. The objective won't be producing efficiently anymore but it will be sustaining the equipment usage as late as possible while preserving equipment characteristics in terms of its availability, reliability, safety, cost, productivity and products' quality and also maintainability [21].

B. Iung, E. Levrat, A. Crespo Marquez, H. Erbe[12] have defined maintenance objectives to each product life-cycle while maintaining the global maintenance objective which is to maintain the product conditions and expected services all along its life cycle, objectives by phase are as shown below :

Table 2. Product life-cycle maintenance objectives

Phase	Objective
Design Engineering	Ensure characteristics like : Maintainability, Reliability, Durability
Manufacturing	Preserve the above characteristics
Usage	Ensure availability, reliability
Disassembling and recycling	Ensure the durability, circular economy

The concept of eco-efficiency has convertedmaintenance into a major strategic tool with objectives perfectly aligned with business' ones such as: product quality, increasing production capacity, reducing products cost and optimizing deadlines.

As the maintenance is contributing to the value creation during each phase of the four product's life cycle steps and thus to the whole enterprise, we can therefore talk about a maintenance value chain. This value chain must be supported at each cycle step to ensure that assigned objectives have been fulfilled properly. If all objectives are reached, then the global chain is working correctly.

The value chain aims to keep the functional level of the product and to preserve all its characteristics as well as to be in line with business objectives.

Hence, e-maintenance is a philosophy striving to go from "fail and fix" operations to "predict and prevent" strategies [13, 22, 23]. In other words, B. Iung, E. Levrat, A. Crespo Marquez, H. Erbe[12] proposed to shift from considering MTBF [Mean Time Between Failure] to MTBD [Mean Time Between Degradation].

4. E-MAINTENANCE: DIFFERENT DEFINITIONS

E-maintenance has had different definitions. The web site www.mtonline.com [12] has considered it as a network that integrates the various maintenance and reliability applications to gather and collect, then deliver asset information when needed. On the other hand, Harvard has defined the e of e-maintenance by "Excellent" or "Efficient". Whereas www.deicesword.net states that e-maintenance is a maintenance management concept whereby assets are monitored and managed over the internet.

… After these controversies what would be the real e-maintenance?

E-maintenance is rolling out the principles already defined by Tele-maintenance which are added to web and data services to achieve a true definition of pro-activity or the 'connected plant'.
E-maintenance relies on Intra-Net, Extranet and Internet to processes its IN and OUT. In order to fulfil its tasks, e-maintenance uses means of communication, processing and storage [12]. IT systems play a major role to make e-maintenance tasks successful.

That said, other concepts with the same meaning of e-maintenance exist and may create an eventual confusion. These concepts are like: Smart maintenance, Prognostics and health management, Predictive maintenance, Maintenance 4.0 and of course e-maintenance.

Hence for concept clarity, a comparison between these concepts has been carried out.

To start with "e-maintenance", many authors like Hung et al, Han and Yang, Lee et al, Muller et al, Candell et al, Iung et al and Aboelmaged respectively [24], [25], [26], [27], [28], [29] and [30] have considered e-maintenance as a monitoring system or even a real time system health data collection and distribution. Likewise, data generated plays role of information support that will be leveraged in many maintenance and business activities, for example: Diagnostics, Prognostics, Monitoring, Condition based maintenance, Decision making to stakeholders, Integration, Maintenance strategy selection, Information and Communication Technology, Remote operations,…

The second concept is "Prognostics and health management", which is, according to Cheng et al. and Qiao and Weiss, a confirmed discipline enclosing methods and technologies or even a strategies portfolio to measure asset's reliability and its actual life cycle conditions to pretend upfront every failure occurrence. Some key attributes could be like Diagnostics, Prognostics, Health assessment, Condition based maintenance, assessment of remaining product’s lifetime. [31], [32]

“Predictive maintenance”, some well-chosen parameters are sensed and stored periodically or continuously in order to optimize and strengthen decisions in maintenance operation [33]. Lee et al. has also define it as a capability to translate raw data into practicable information ready to be used in strategic decision-making. This data collected will mainly be used in diagnostics, prognostics, condition based maintenance, maintenance scheduling and decision-making [34].
Kumar and Galar consider “Maintenance 4.0” as a predictive analytics based on industry 4.0 tools and especially those that deals with data collection, storage, analysis, visualisation and asset’s decision-making, in order to deliver a feasible solution. The objective is basically the diagnostics, prognostics, big data analytics, maintenance scheduling and decision-making [35].
To end up, “Smart maintenance” is a set of tools and technologies, either embedded or by the use of sensors and actuators, which aim to create a clear image of the equipment health. Smart maintenance aims as well to lower human intervention, in other words, nobody is no longer needed in the assets nearby. Key attributes could be diagnostics, prognostics, big data analytics, monitoring and remote operation. [36], [37]

Even though the concepts are numerous and different, it was crystal clear that key attributes are more or less common between these concepts and roughly all of them aim to assure a diagnostics, prognostics, maintenance scheduling, remote operation condition based maintenance, data processing….

In this paper we will considerably overlook the tiny difference between the concepts, as the main objective is the same, and we will use all concepts names in what follows.

5. E-MAINTENANCE NEW TECHNOLOGIES IMPACT

In this section, some technology issues related to e-maintenance will be presented:

- Web services which allow universal access, connectivity and multimedia support for interactivity and interoperability [38],
- Database and its management is also considered as a mandatory tool used in digitalization, globally and in e-maintenance specifically
- Transducers with “built in” Internet modules allow users to connect to internet without PC connection,
- Wireless technology gives the right to flexibility on the floor. Remote data management facilitates transmitting, monitoring and controlling via a network [39],
- New communication pathways in industry allow for more collaboration possibilities…

More specifically, M. Ghouat[40] has studied the impact of new technologies over maintenance and business through some indicators such as the availability. In his study Mr. Ghouat has considered the following technologies : Enterprise resource Planning ERP, Manufacturing Execution Systems MES, Business intelligence BI, Cloud technology, Big data analytics, Machine to machine communication, The Internet of things IoT, Automatic Identification and data collection, Radio frequency identification RFID, Virtual and augmented reality, 3D printing, Simulation, Cybersecurity, Miniaturization of electronics and Robotics, drones and nanotech.

On top of that, Jon Bokrantz et al.[41]consider that Machine Learning is one of the most impactful technological tools overs maintenance and business at all. Actually, further the survey they conducted, some informants are willing to delegate most of maintenance decision tasks to machine learning.

Here-below is an outline of technological tools impact overs maintenance process

The impact could be characterized as follow:

Important impact
Elevated impact
Normal impact
No impact

Table 3. New technologies and their impact

Technologie	Impact
Enterprise resource Planning ERP	Elevated
Manufacturing Execution Systems MES	Normal
Business intelligence BI	No impact
Cloud technology	Elevated
Big data analytics	No impact
Machine to machine communication	Important
The Internet of things IoT	Normal
Automatic Identification and data collection	No impact
Radio frequency identification RFID	Normal
Virtual and augmented reality	Important
3D printing	No impact
Simulation	Normal
Cybersecurity	Normal
Miniaturization of electronics	Normal
Robotics, drones and nanotech	Normal
Machine Learning	Important

6. E-MAINTENANCE: DIMENSIONS & PRINCIPLES

John Bokrantz et al. and B.Iung et al. have given certain architecture and framework to e-maintenance. The first has extracted the e-maintenance four dimensions from a questionnaire to more than 110 participants and 20 Swedish firms, whereas, the second has brought the principles from MEGA Suite^{TM} and the famous framework of Zachman [42]

6.1. E-Maintenance:Four Dimensions

In this paragraph, the four underlying dimensions of e-maintenance are presented as well as the relationship between them:

Dimension 1: Data-driven decision-making

Maintenance is a profession driven mainly by decision-making based on intuition and experience. Some practitioners are even ready to discard the old time-based preventive maintenance plans and would rather base their decisions on the real conditions of equipment.

The dimension of data-driven decision-making leads into two ends, the first is Decision Automation (figure 1) on which decision is taken based on data and the entire flow is automated from the data collection to decision-making, whereas, the second one is Decision Augmentation (figure 2) where the human decision is assisted by data for eg. ADAS in vehicles (*Advanced Driver-assistance System).* Both results have almost the same process with a slight difference:

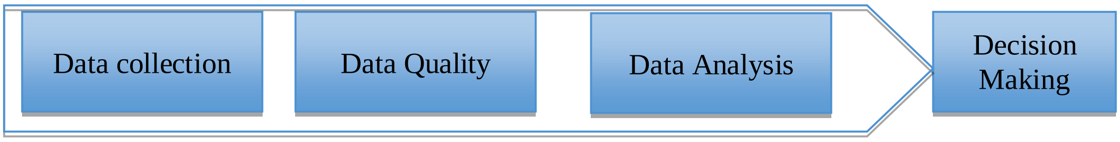

Figure 1. Decision Automation

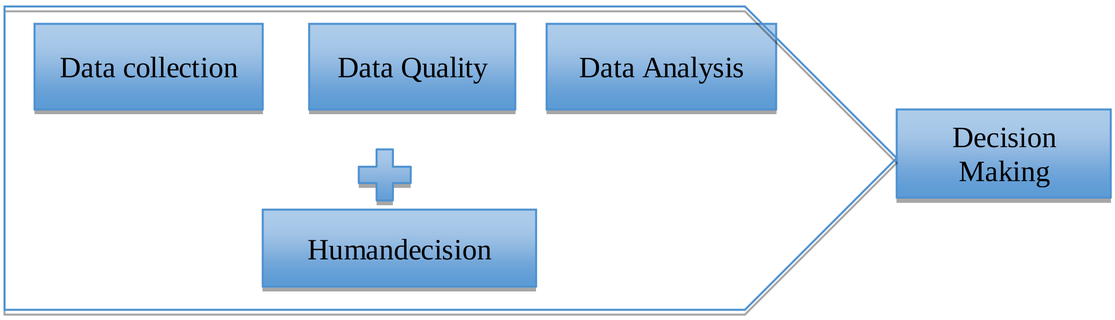

Figure 2. Decision Automation

Data collection, data quality and data analysis are means that should be performed meticulously to have the right decision-making. Many companies starting the e-maintenance have succeeded so far in data collection and storage but no decision has been made yet.

Dimension 2: Human capital resources

It was pretty clear that human resources is still playing a great role in decision-making through the decision augmentation, since some tasks and operations still don't accept to be thoroughly automated. Nonetheless, maintenance human resources need some unavoidable skill requirements [30]as shown in the table below:

Table 4. Human resources skills

Skill	level	Requirement
Analytical	Proficient	- Without being a data scientistbut being able to communicate with these people, - Being able to read collected data, - Identify quality data, - Analyse collected data and decide what actions to be taken , - Use data related tools and new technologies.
ICT *(Information and communication technology)*	Advanced	- Measuring machine parameters with sensors, - Good at IT tools.
Social	Proficient	- Capability of communicating internally and externally, - Explaining the daily operation to the rest of colleagues , - Debate and fight for ideas, - Manage conflicts.
Business	Proficient	- Being able to translate maintenance issues to economic and financial talks, - Understand the contribution of maintenance in financial business objectives, - Consider financial factor in decision-making.
Adaptability	Advanced	- Quick learn how to perform new tasks, - Continuous learning of new things, - Being agile and able to adapt with the continuous evolving technologies.
Technics	Expert	- Competence in all existing processes , - Understand well how things run in the work floor.

Dimension 3: Internal integration

An enterprise is a set of departments and services in close collaboration. It's also important to emphasis the business flows which are: physical flow, information flow and cash flow. Maintenance department is concerned by handling and processing correctly these internal processes.

The flow of data and information knowledge is fundamental, therefore, maintenance staff has to make data available to their collaborators in business. Moreover, cross-functional is not to be overlooked, a close collaboration between maintenance and other departments like production must be in place. Finally, it's important to use data to make a common decision.

Dimension 4: External integration

On the same way, external is beyond plant's wall internal integration. Actually, data are shared with stakeholders, and sometimes knowledge about failure causes are shared between companies in forums or digital platforms. This leads to the creation of inter-organizational networks for the external collaboration with similar companies. Even more, this might integrate customers and suppliers in a strategic partnership and make them work jointly thus the supplier will use the data to improve products and services quality [41].

6.2. E-Maintenance: Five Principles

As affirmed before, e-maintenance framework could be divided into five principles [42] as shown below:

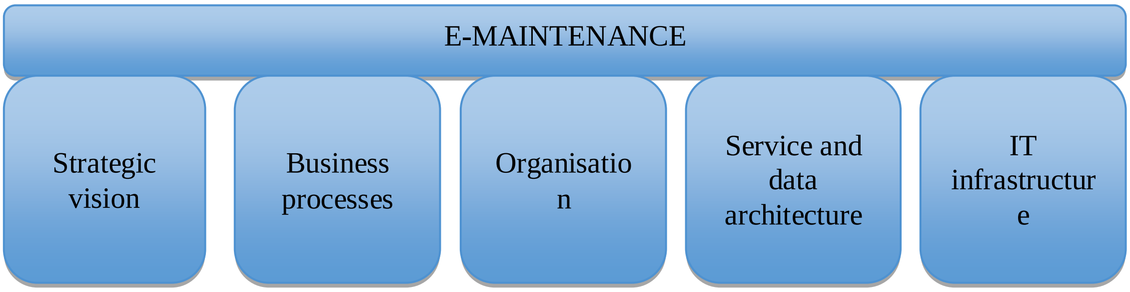

Figure 3. E-maintenance principles

E-maintenance has to be aligned with business strategic vision, thus it has to better understand the business processes as well as supporting the architect's view through the organisation. Data and information must be correctly used and the IT tools shouldn't be overlooked.

7. UPCOMING WORK

Future work will be a survey targeting different enterprises in France and Morocco categorized as follow:

- primary sector: also known as extractive industries (raw material extraction). This type of company can be oil extraction companies, mining companies, forestry companies or maritime companies …
- Secondary sector: also known as manufacturing, which affects raw material processing companies into finished or semi-finished products including agri-food, textiles, steel and metallurgy, mechanical engineering and chemical industries
- Tertiary sector: referred to as the service sector, includes companies that are active in sales, trade, finance, real estate, etc. and other non-market activities including education, care and social.

It will also cover all cross-cutting classifications of enterprises, for-profit corporations[small and medium-sized businesses and large groups], private non-profit enterprises that are linked to the social economy and also public structures. To conclude all companies regardless of their sales figures is our target.

This questionnaire will refer to the organization of the maintenance department still in the context of reducing the probability of degradation or failure of operation. It will consider the techniques of maintenance, a dozen of which have caused devastation in the world of the industry for the fluidity of the industrial maintenance of the equipment that several experts have approved.It will deal with maintenance policy, companies are considering technical-economic objectives relating to the management of the equipment so that the actors and the related services have a base. It is necessary to distinguish two levels: the overall level of the company (basic maintenance policy), and the level of equipment (adjusted maintenance policy).

The preparation of the budget and the maintenance costs will also be highlighted given the complementarity and the obligatory nature of their presence in companies.

The means of digitalisation used within companies will also be discussed in order to know and analyse the techniques and digital solutions used. Modern industrial maintenance processes are essential for reliable production.

8. CONCLUSION

E-maintenance is a philosophy and not a technique nor a platform. All industry 4.0 tools and means could be used in e-maintenance. Nevertheless, some are definitely impactful, while others aren't. Maintenance shouldn't be seen as a necessary evil but should be considered a value stream that starts and takes place even before the product's manufacturing.

Our next step will be an empirical work based on market survey. The blocs of questions will be basically around company size, maintenance department organization and the industry 4.0 tools used in maintenance field. We will try to reach the highest number of companies with different activities in two different countries who coped successfully with COVID19 pandemic: France, one of the most developed and industrial European economies, with huge consumer market and Morocco which is considered as one of the fastest growing economies in Africa and in the world with ambitious objectives and a versatile economy encompassing local and international companies.

The survey result will come soon and will refer to the current paper to complete this prior work based on literature review.

ACKNOWLEDGEMENT

We would like to express our very great appreciation to our team members for their valuable and constructive suggestions.

REFERENCES

[1] SherifMostafaa*, JantaneeDumrakb and Hassan Soltan. Lean Maintenance Roadmap. PP 2-3Volume 51, Issue 30, 2018, Pages 800-802. https://doi.org/10.1016/j.ifacol.2018.11.192

[2] K. Fraser, 2014, Facilities management: the strategic selection of a maintenance system, Journal of Facilities Management. 12, 18-37.

[3] S.K. Pinjala, L. Pintelon, A. Vereecke, 2006, An empirical investigation on the relationship between business and maintenance strategies, International Journal of Production Economics. 104, 214-229

[4] M. Bevilacqua, M. Braglia, 2000,The analytic hierarchy process applied to maintenance strategy selection. Reliability Engineering & System Safety. 70, 71-83.

[5] B.S. Blanchard, 1997, An enhanced approach for implementing total productive maintenance in the manufacturing environment, Journal of Qualityin Maintenance Engineering. 3, 69-80.

[6] T. Santos, F. J. G. Silva*, S. F. Ramos, R. D. S. G. Campilho, L. P. Ferreira. Asset Priority Setting for Maintenance Management in the Food Industry. Volume 38, 2019, Pages 1623-1633.https://doi.org/10.1016/j.promfg.2020.01.122

[7] P. Neves, F. J. G. Silva, L. P. Ferreira, T. Pereira, A. Gouveia, and C. Pimentel,2018,Implementing Lean Tools in the Manufacturing Process of Trimmings Products, Procedia Manufacturing 17 696-704.

[8] Márquez, A.C., 2007, The maintenance management framework: models and methods for complex systems maintenance. Springer.

[9] M.M. Fouladgar, A. Yazdani-Chamzini, A. Lashgari, E. K. Zavadskas, Z. Turskis, 2012, Maintenance strategy selection using AHP and COPRASunder fuzzy environment, International Journal of Strategic Property Management. 16, 85-104.

[10] G.Waeyenbergh, L. Pintelon, 2004, Maintenance concept development: A case study, International Journal of Production Economics. 89, 395-405.

[11] Srinivas Kumar Pinjalaa, Liliane Pintelona,_, Ann Vereecke . An empirical investigation on the relationship betweenbusiness and maintenance strategies? Volume 104, Issue 1, November 2006, Pages 214-229. https://doi.org/10.1016/j.ijpe.2004.12.024

[12] B.Iung, E.Levrat, Crespo.Marquez, H.Erbe E-Maintenance: Principles, review and conceptual framework. Volume 40, Issue 19, 2007, Pages 18-29. https://doi.org/10.3182/20071002-MX-4-3906.00005

[13] Blann Dale R. (2003), Reliability as a Strategic Initiative: To Improve Manufacturing Capacity, Throughput and Profitability Asset Management & Maintenance Journal, 16(2).

[14] Pintelon, L., Gelders, L., VanPuyvelde, F., 2000. MaintenanceManagement, second ed. Acco Belgium, Leuven.

[15] T. Santos, F. J. G. Silva*, S. F. Ramos, R. D. S. G. Campilho, L. P. Ferreira. Asset Priority Setting for Maintenance Management in the Food Industry. Volume 38, 2019, Pages 1623-1633. https://doi.org/10.1016/j.promfg.2020.01.122

[16] Vicent Hernández-Chover∗, LledóCastellet-Viciano, Francesc Hernández-Sancho. Preventive maintenance versus cost of repairs in asset management: An efficiency analysis in wastewater treatment plants. Volume 141, September 2020, Pages 215-221 https://doi.org/10.1016/j.psep.2020.04.035

[17] Tseko Mofokeng, Paul T Mativenga, AnnlizéMarnewick. Analysis of aircraft maintenance processes and cost. Volume 90, 2020, Pages 467-472. https://doi.org/10.1016/j.procir.2020.01.115

[18] XhMehmeti, B Mehmeti, RrSejdiu .The equipment maintenance management in manufacturing enterprises. Volume 51, Issue 30, 2018, Pages 800-802. https://doi.org/10.1016/j.ifacol.2018.11.192

[19] Takata S., F. Kimura, F.J.A.M. van Houten, E. Westkämper, M. Shpitalni, D. Ceglarek, J. Lee (2004), Maintenance: Changing Role in Life Cycle Management, Annals of the CIRP, 53/2, pp 643 – 656

[20] Van Houten F.J.A.M., Tomiyama T., Salomons O.W., (1998), Product modelling for model-based maintenance, Annals of the CIRP, 47/1, pp123-129

[21] DeSimone, L. D., Popoff, F. with the WBCSD (1997), Eco-Efficiency, MIT Press.

[22] Lee J., J. Ni, D. Djurdjanovic, H. Qiu and H. Liao (2006), intelligent prognostics tools and emaintenance, Computers in Industry, Special issue on e-maintenance, 57(6), pp 476-489

[23] Iung B., Morel G., Léger J.B. (2003) Proactive maintenance strategy for harbor crane operation improvement, Robotica, Special issue on Cost Effective Automation, Eds H. Erbe, 21(3), pp.313-324.

[24] Hung, M.-H., Chen, K.-Y., Ho, R.-W., Cheng, F.-T., 2003. Development of an E-diagnostics/maintenance framework for semiconductor factories with security considerations. Adv. Eng. Inf. 17, 165–178.

[25] Han, T., Yang, B.-S., 2006. Development of an E-maintenance system integrating advanced techniques. Comput. Ind. 57, 569–580.

[26] Lee, J., Ardakani, H.D., Yang, S., Bagheri, B., 2015. Industrial big data analytics and cyber-physical systems for future maintenance & service innovation. Procedia CIRP 38, 3–7.

[27] Muller, A., Marquez, A.C., Iung, B., 2008. On the concept of E-maintenance: review and current research. Reliab. Eng. Syst. Saf. 93, 1165–1187.

[28] Candell, O., Karim, R., S€oderholm, P., 2009. Emaintenance—information logistics for maintenance support. Robot. Comput. Integr. Manuf. 25, 937–944.

[29] Iung, B., Levrat, E., Marquez, A.C., Erbe, H., 2009. Conceptual framework for E-maintenance: illustration by E-maintenance technologies and platforms. Annu. Rev. Contr. 33, 220–229.

[30] Aboelmaged, M.G.S., 2015. E-Maintenance research: a multifaceted perspective. J. Manuf. Technol. Manag. 26, 606–631.

[31] Cheng, S., Azarian, M.H., Pecht, M.G., 2010. Sensor systems for prognostics and Health management. Sensors 10, 5774–5797.

[32] Qiao, G., Weiss, B.A., 2016. Advancing measurement science to assess monitoring, diagnostics, and prognostics for manufacturing robotics. Int. J. Prognostics Health Manag. 7.

[33] Carnero, M.C., 2005. Selection of diagnostic techniques and instrumentation in a predictive maintenance program. A case study. Decis. Support Syst. 38, 539–555.
[34] Lee, J., Jin, C., Liu, Z., Ardakani, H.D., 2017. Introduction to data-driven methodologies for prognostics and Health management. In: Probabilistic Prognostics and Health Management of Energy Systems. Springer, pp. 9–32.
[35] Kumar, U., Galar, D., 2018. Maintenance in the era of industry 4.0: issues and challenges. In: Quality, it and Business Operations. Springer, pp. 231–250
[36] Fumagalli, L., Macchi, M., Colace, C., Rondi, M., Alfieri, A., 2016. A Smart maintenance tool for a safe electric arc furnace. IFAC-PapersOnLine 49, 19–24.
[37] Holgado, M., Macchi, M., 2014. Exploring the Role of E-Maintenance for Value Creation in Service Provision. Engineering, Technology and Innovation (ICE), 2014 International ICE Conference on. IEEE, pp. 1–10.
[38] Lee J. (1998). Teleservice engineering in manufacturing: challenges and opportunities. Int. Journal of Machine Tools & Manufacture. 38, pp 901-910.
[39] Egea-Lopez E., Martinez-Sala A., Vales-Alonso J., Garcia-Haro J. and Malgosa-Sanahuja J-M. (2005). Wireless communications deployment in industry: a review of issues, options and technologies. Computers in Industry, 56 (1), January, pp. 29-53.
[40] M.GhouatA.Haddout, M.Benhadou. Impact of industry 4.0 concept on the levers of Lean Manufacturing approach in manufacturing industries. International journal of automotive and mechanical engineering (IJAME). ISSN: 2229-8649 e-ISSN: 2180-1606 VOL. 18, ISSUE 1, 8523 – 8530 DOI: https://doi.org/10.15282/ijame.18.1.2021.11.0646
[41] Jon Bokrantz , Anders Skoogh, Cecilia Berlin, Thorsten Wuest, Johan Stahre . Smart Maintenance: A, Empirically Grounded Conceptualisation. International Journal of Production Economics Volume 223, May 2020, 107534. https://doi.org/10.1016/j.ijpe.2019.107534
[42] Sowa J.F. and Zachman J.A. (1992), Extending and Formalising the Framework for information Systems Architecture, IBM systems journal, 31(3), 590-616

AUTHOR

Yassine MOUMEN. 28 November 1990. Engineer in maintenance