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Lean Maintenance 4.0: An application of the IoT Technology in the facility management industry

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ABSTRACT

Industry 4.0 technologies and techniques have contributed to the companies' improvement and business management strategy. Maintenance and Lean are two real examples that have benefited from this fourth revolution advantages, hence the creation of these strong and powerful new versions: Maintenance 4.0, Lean 4.0 or Lean Maintenance 4.0 which reflects a strategy of maintenance without waste and supported by the latest technologies. This article presents an example of the Lean Maintenance 4.0 project framework implementation with the use of the internet of things IoT. The case study describes the different stages of the IoT solution choice as well as its internal functioning in the company, precisely for the FM Facility Management sector.

Key words: Lean, Maintenance, Lean Maintenance, IoT, waste, Industry 4.0, Case study.

1. INTRODUCTION

The industry history started in the UK in the second half of the 18th century with the vapor engine, then the introduction of electricity and petroleum, towards automated production through the integration of electronic and computer technologies, and today we are facing a revolution stronger than ever with new technologies such as the Internet of Things, the Cloud, Big Data, additive manufacturing, artificial intelligence and more. In this fourth industrial revolution, companies are facing hard competition and small details should also make a big difference[1]-[2]. Many firms then opt for collaboration to face competition [3].However the technologies and techniques of Industry 4.0 have participated in improving the competitiveness of many companies and even for business management strategies where Lean Management and maintenance are two of the concepts that have been able to develop and take advantage of Industry 4.0.

"Maintenance 4.0" as a concept, includes all aspects related to the application of Industry 4.0 technologies and techniques to maintenance. [4] , based on its policies and supported by its tools [5]. Big data and IoT technologies, for example, play a key role in creating data-driven applications such as predictive maintenance [6]and having the ability to aggregate and analyze data to generate better predictive analysis models [7].
The same applies to the concept of Lean Management, which has been supported by the 4.0 industry either through its technologies or through the development and improvement of Lean toolbox. Reference[8]addressed the evolution of Lean tools in the context of Industry 4.0 to take advantage of technology and industry automation 4.0, le Poka-Yoke which became Automation in Error-Proofing where the system is interconnected via bar code scanners, electric fastening tools and RFID tags , Standardized work to Augmented Reality based work standardization , Heijunka to Digitized Heijunka and the same thing for the other tools which were reinforced by the advantages of this industrial revolution.

The integration of the three concepts "Maintenance", "Lean" and "Industry 4.0" gives more advantage to the efficiency and effectiveness of maintenance strategies. But historically, the Lean concept has limited applications in the maintenance environment [9]and especially in facility management.This article is a part of the Lean application in a company specialized in facility management, the IoT solution which allowed the avoidance of several types of waste and allowed the technicians to remove several painful tasks during the technical rounds.

For the structure of the article, a review of the literature on lean maintenance 4.0 in facility management is presented in the second section. The case study which includes the different stages of the choice and implementation of the IoT is provided in the third section. Finally, the article will be concluded in the last section.

2. LITERATURE REVIEW

2.1 Lean concept

Today, the Lean philosophy and its practice is considered one of the most successful and widely used systems in the world [10]. This concept is not just a fancy term thrown around, it is a philosophy [11]that aims at eliminating waste and maximizing the processes value in an efficient manner [12]and making the process faster [13].

The term "Lean" was coined by researchers at the International Motor Vehicle Program at the Massachusetts Institute of Technology [14]. This term is generally associated with the automotive company Toyota [15]where the engineer Taichi ohno and the legendary shigeo shingo built the temple of the Toyota production TPS. Their philosophy contributes directly to the reduction of waste , thanks to important tools such as value stream mapping and workforce balancing which are good alternatives to optimize existing resources before investing in new technologies [16]. This optimization is generally achieved through the reduction of all types of waste. Its forms are generally considered as follows: waiting, overproduction, retouching, movement, transportation, processing, inventory and intellect.[17].

In order to implement Lean, there are several models and frameworks to follow, but the generic implementation of Lean is to follow its five principless [15] (see figure 1). These principles are mainly focused on the shop floor and production lines, but they can be applied to all aspects of an organization, including business processes [12]. At each phase of Lean implementation, there is a big toolbox containing more than a hundred Lean tools, including tools for continuous improvement and quality.

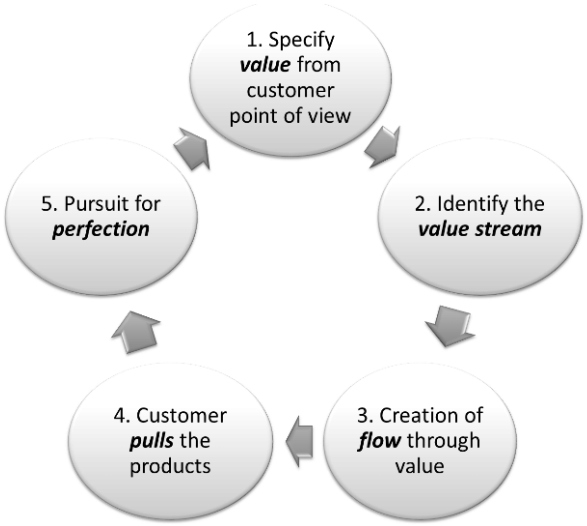

Figure 1: Lean management Principles [19]

The most important lean tools are 5S, Bottleneck Analysis, Continuous Flow, SMART goals, Value Stream Mapping (VSM), Heijunka (Level scheduling), Poka-Yoke (Error Proofing), Overall Equipment Effectiveness (OEE), Jidoka (Autonomination), Just-In-Time (JIT), Kaizen (Continuous improvement), Kanban (Pull System), Standardised Work, Takt Time, Key Performance Indicators (KPIs), Muda (Waste), Plan-Do-Check-Act analysis (PDCA), Root cause analysis, Single-Minute-Exchange of Dies (SMED), Visual Factory, , Total Productive Maintenance (TPM), Hoshin Kanri (Policy deployment), Gemba (The real place) [20].

2.2 Lean Maintenance 4.0

The lean maintenance philosophy is one of several techniques that have been used to achieve greater efficiency in maintenance[21] .This philosophy means doing good maintenance in the most efficient and cost-effective way, and involves fewer failures and easier maintenance [22].Its implementation improves the maintenance department performance, brings about sustainable changes, enhances the profile of maintenance as a value-added function rather than as a cost, and improves the maintenance "product" quality by reducing measurable process results (number of maintenance-related failures, number of rework, ...)[10].

But the main objective of Lean Maintenance is to give your company the uptime and equipment reliability it requires, while reducing your maintenance expenses, often by 50% or more. [23].These expenses are minimized by reducing all forms of waste and no added value activities. The table 1 details the types of waste from a maintenance perspective and more precisely in Facility Management area.

Table 1: Forms of Facility Maintenance Waste

Form of waste	Facility Maintenance Waste
Transportation	Movement of installation teams between buildings that do not add value to the process either to access equipment, parts , manuals or data sheets
Inventory	Overstocking of consumables, spare parts and documentation.
Motions	Unnecessary movements and processes in the maintenance operation especially in preventive maintenance.
Waiting	Expectations related to parts, documentation, information, instructions, work orders, ... Expectations between procedures and maintenance activities[21]
Overproduction	Over maintenance that includes any action or task in preventive or predictive maintenance that does not add value or the customer is not willing to pay for it
Over processing	Duplication and redundancy of interventions and maintenance work.
Defects	work Repetition due to improperly performed repairs
Skills	Under-utilization of staff capacity or insufficient training.

The introduction of Industry 4.0 in Lean and Maintenance concepts has enabled these two concepts to take advantage of new technologies and digitalization.From the interactions of Lean tools mainly with Big Data Analytics, The Cloud, virtual simulation and augmented reality have highlighted the main contributions of Just in Time 4.0 (JIT 4.0), Kaizen 4.0, Kanban 4.0, Poka-Yoke 4.0, Value Stream Mapping 4.0 (VSM 4.0) and Total Productive Maintenance 4.0 (TPM 4.0) [24]. The technologies provided by Industry 4.0 also improve Lean practices, but the principles and concepts of Lean need to be very well understood in order to effectively take advantage of these new technologies[25].

The same is true for maintenance where intelligent devices allow integration between operators and machines, improving the predictive decision making capabilities of operators through access to real-time information [26]. It enables even better collaboration, faster problem resolution and innovation at all levels of the organization[26].
Finally by integrating "Maintenance", "Lean" and "Industry 4.0" we obtain a unique concept which can be presented under several names: "Lean Maintenance Industry 4.0", "Lean Maintenance 4.0" "Lean Maintenance 4.0" or "Lean Smart Maintenance". This combination, which is created in order to follow the technological evolution by the importance of supporting the maintenance concept development in the era of Industry 4.0[27].

Lean Smart maintenance is a sophisticated maintenance concept that is characterized by a lean and learning orientation as well as a risk and resource oriented alignment[28]. Lean Maintenance 4.0LM 4.0 where maintenance has to be intelligent in order to be adaptable due to changing environmental conditions, cost effective maintain market position in the long term and for efficient asset management[29].

The core essence of Facility Management FM is to continuously demonstrate value and optimize performance [30]Hence the application of the LM 4.0 concept is an opportunity for this type of organization to improve the effectiveness and efficiency of asset management. The FM sector needs to be lean to avoid waste and control its value chain [31] and at the same time take advantage of Industry 4.0 and IoT technologies to enhance Facilities Management operations , given its evolution from a few operations and maintenance works on a few buildings to operations and maintenance of multiple facilities, energy management, strategic outsourcing and portfolio management, etc[32]. Table 2 presents some of the advantages of adopting Lean and Industry 4.0 in the maintenance department of Facilities Management organizations.

In the following section we will present the implementation of IoT within the framework of the Lean Maintenance 4.0 implementation, in order to reduce the wastage related to technical rounds. the IoT as an industry 4.0 technology gives the possibility for objects (machines, equipment, etc.) to connect, to communicate [33], generate and process data in real time without involving humans[34] . In maintenance, Industry 4.0 and IoT revolutionize operations through improved visibility, connectivity and predictive maintenance (PdM) capabilities, resulting in improved reliability and service delivery[26].

3. CASE STUDY

This case study is carried out on three sites in different cities in Morocco where facilities management operations are realized by the host company, which is considered the leader in facilities management in Morocco with a turnover exceeding 200 million dirham. This implementation concerns a big Lean maintenance 4.0 project which is part of the adoption of Lean Facility in the context of the perfection seeking.It concerns the implementation of the IoT solution for the temperature supervision of the air conditioning equipment on 200 machines distributed between the three sites. This Lean Maintenance 4.0 project allows to the company to minimizenon-value added activities with a negative effect on the maintenance planning process.

Table 2: Some benefits of adopting Lean and I4.0 in the FM maintenance department

	I4.0 technologies	Lean Management
Technicians and foremen	Makes the operator a Smart operator connected with his machine Facilitates and improves the daily operations of technicians	Provides Training and continuous improvement of technicians and foremen Minimizes the efforts provided during maintenance operations.
Service	Makes the service more intelligent where the information is obtained from the machine	Reduces non-value added activities
Equipment	Gives the possibility to the equipment to send and receive information about the status of the equipment.	Optimizes the equipment and its functionalities
Planification	Optimizes maintenance operations, e.g. CMMS which help to visualize all the maintenance operations in a common automatic planning system.	Optimizes service delivery times

3.1 Problem Statement

The company's maintenance policy includes preventive, corrective and predictive maintenance with the objective of achieving an availability rate of more than 95%. In table 3, we find the equipment concerned by this policy.

Table 3: Maintenance types with the equipment concerned

Preventive maintenance	Corrective maintenance	Predictive maintenance
Carried out on all site equipment and installations.	Carried out on all site equipment and installations.	Realized on specific equipment: Oil Compressors, Transformers , pumps and Engine-generator

For preventive maintenance, it is divided into two categories:

- Systematic maintenance
- Technical rounds

The systematic maintenance is carried out via the CMMS and is performed according to an annual schedule where the

frequency depends on the equipment, either quarterly, semi-annually or annually.

On the other hand, the technical rounds must be carried out daily in order to inspect and monitor the installations from the specific points to be checked. This operation generates a huge number of the preventive orders BPs that the technicians cannot manage via CMMS and the solution of grouping the equipment of the same family and their treatment via CMMS is not feasible.

The time allowed for the completion of the round is one hour per technician and includes:

- Transportation
- Verification and inspection
- Report redaction

The technicians should not exceed one hour to ensure the completion of other types of maintenance and to respect the deadlines of the schedules. In reality these rounds are carried out between 2 hours to 3 hours per technician and that's for the following reason:

- The huge number of BPs
- Big buildings that include installations in the terraces.
- The tedious reports redaction and their insertion in the CMMS
- The large surface area of the sites where mobility becomes an overwhelming task

As part of the perfection seeking through the company's Lean implementation, this project is considered one of the Lean-Kaizen projects applied in the maintenance process with the aim of minimizing the waste of time allocated to this operation. Figure 2 illustrates the problem of high time in the rounds realization via the Ishikawa diagram.

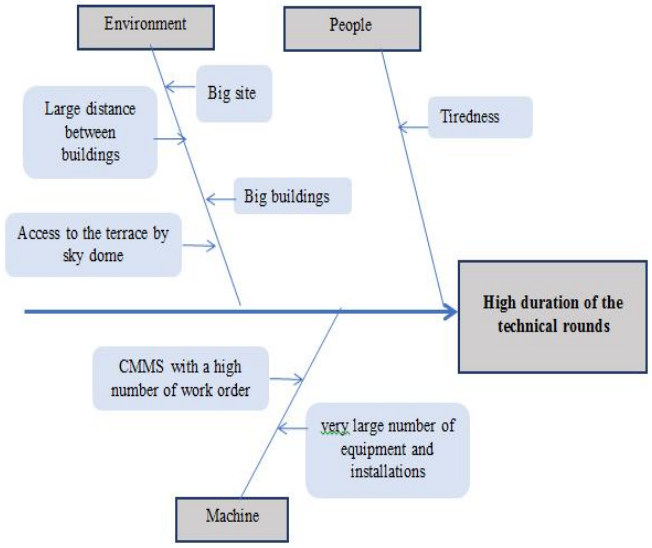

Figure 2:ISHIKAWA of high duration in the technical rounds realization.

3.2 IoT solution

2.2.1 Choice of IoT

During the Lean team meetings and via Brainstorming sessions, the company decided to implement the IoT for the following reasons:

- Obtaining information in real time which is not valid actually for the rounds
- Reduction of the rounds realization time
- Elimination of daily rounds for specific equipment
- Improvement of the quality of service

The implementation of IoT for buildings provides connectivity for integrated devices [35]with more robustness and efficiency[36] ,but the IoT solution is expensive in order to be installed on all large sites equipment with limited budgets. For this reason, the company decided to start the installation just on the heat pumpsPAC and water chiller GEG equipment's since they are installed on the terraces, the access to this equipment requires a lot of time and effort as the access is via skydome and these critical equipment are among the customer's priority services. Adding that these installations (PAC and GEG) are characterized by the operations instability where they encounter many problems without giving a signal during the day despite the completion of rounds. For other installations such as Engine-generator or transformers, they do not encounter much problem and their access is very easy since they are located in the basement.

2.2.2 IoT's deployment in the company

The supervision of the GEGs and PACs is carried out via the temperature difference ΔT which is controlled by the input and output temperature (see figure 3).

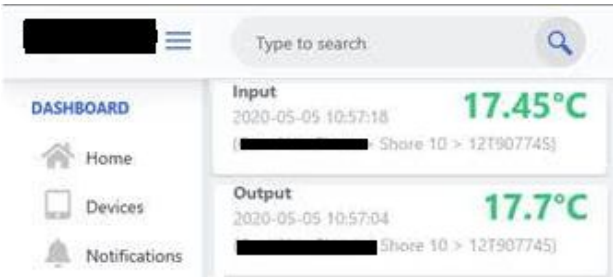

Figure 3: Example of an entry and exit temperature record for a building.

In order to supervise the GEGs and PACs equipments and also their productivity, two temperature sensors are installed on each equipment with the determination of two levels (maximum and minimum levels) for the input and output temperatures. The equipment temperatures are reading via a program that contains the level to be respected. If an anomaly occurs, an automatic email including the temperature curve (see figure 4) is sent to the controller who must then create a BP to deal with the anomaly.

3.3 Solution effectiveness

Industry 4.0 Thinking and the Internet of Things (IoT) are revolutionary in operations through the improvement of Predictive Maintenance (PdM) organizational capabilities, better connectivity and visibility which leads to improved service delivery and reliability of all equipment [26]. On the other hand, Lean Maintenance aims at increasing the efficiency and effectiveness of technical infrastructures [10]where its activities and operations are linked to the elimination of all kind of maintenance waste [37].

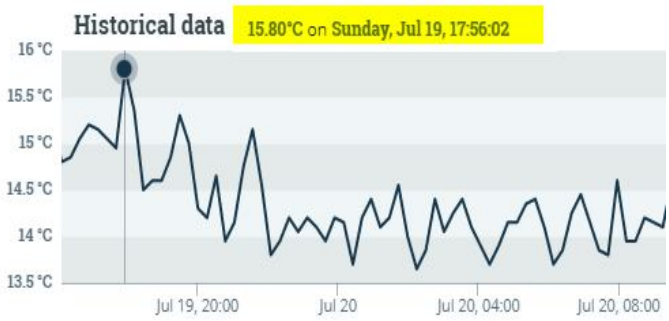

Figure 4: Example of error curve sent by email.

The adoption of Lean and Industry 4.0 in the maintenance department allows efficiency and effectiveness in all operations and exploitation of the equipment park. In this company, the implementation of LM4.0 has allowed:

- Reduction of the number of technical lots interventions of air conditioning with a percentage of 60
- Minimization of round times from an average of 2 hours to one hour
- Increase in the rate of schedules completion (operations related to other types of maintenance) from 87 to 96.7%.
- Minimization of spare parts related to failures not automatically detected

The implementation of the LM 4.0 has also contributed to other qualitative improvements such as:

- Minimization of the energy provided by technicians and foremenin the round execution
- Information credibility
- Customer satisfaction
- Elimination of several waste types related to transportation and waiting

5. CONCLUSION

This paper unveils a case study on LM 4.0, an application that aims at minimizing the time required to complete technical rounds. These rounds which meet wastes of the following types: Waiting, Motion and transportation. Through the implementation of the IoT as a solution of the LM 4.0 project, the company was able to:

- Get real-time information on the status of PACs and GEGs
- Reduce the time required to complete the rounds from 2.5 hours per technician to one hour.
- Eliminate daily rounds for specific equipment
- Reduce the effort applied by the technicians
- respect the daily schedule of maintenance operations

Due to the criticality of PAC and GEG in the customer's service, the prediction of failures is currently ensured via the IoT. Today the data and information related to it are sent to a control and supervision room and error messages are received by email, for this reason the company is looking to integrate the IoT with the CMMS to minimize the intervention time.

To conclude, the advantages and capacities of the IoT are enormous, Things have become smarter than it was before[38]but its security must also be taken into consideration [34] to ensure efficient operation in good conditions.

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