MPMM

Maintenance Performance Measurement
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PREFACE

The *Maintenance Performance Measurement and Management Conference 2018* (MPMM2018) represents a forum where the academics and professionals converge to discuss the state-of-the-art of the conference topics and the future trends for those topics that are the following: Maintenance Trends (Maintenance 4.0; Remote maintenance; Predictive maintenance; Big Data; IoT, IoS, and Protocols); Maintenance Performance and Measurement (Efficiency, effectiveness, productivity; Life Cycle Cost optimization; Quality, risk and maintenance services; International Standards and Certification); Maintenance Technology and Management (Maintenance management systems; Maintenance tools and innovations; Performance measurement; Physical Asset management and Maintenance management).

MPMM has a special topic about Climate Change, according to the special theme from Ordem dos Engenheiros (OE) de Portugal – Year OE of Climate Change: Climate Change; Maintenance role to the future sustainability.

University of Coimbra together with Lulea University, Sunderland, Lapperanta and Oulu constitute a network of universities, through their research centers, actively involved in maintenance research and developing Maintenance, Performance and Management methodologies and technologies in close cooperation with international organizations like European Federation of National Maintenance Societies (EFNMS) and Society for Maintenance & Reliability Professionals (SMRP).

Moreover, the dissemination of maintenance research in doctoral thesis, education programs, conference and journals is a relevant contribution from universities and research centers. These activities are needful in order to place maintenance in the position that it deserves in the international arena due to its huge importance and impact on the industrial economy.

Nowadays maintenance is being given a new emphasis, because it is the strategic tool to increase the company’s competitiveness. Simultaneously, today’s technologies, both in innovation and price, permit to implement new solutions to reach those objectives.

The increasing capacity to store data, that can support the enormous amount of data generated from equipment sensors, associated to the facility to transmit data, using IoT, IoS, among other possibilities, has opened a new world for maintenance activity.

The many standards that support the several maintenance activities, added to the new ones related to Asset Management open new approaches to the maintenance activity that must be discussed and the best case studies shared.

It is a new Era of challenge for the maintenance activity, and MPMM 2018 Conference represents a strategic Forum whose communications are presented in these proceedings.

The committees in general, chairpersons, scientific, and local committee thank to all participants, speakers, keynote speakers, sponsors, and partners the efforts and commitment for the success of MPMM2018.

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A Vertical Predictive Maintenance Approach for Manufacturing 4.0

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***Abstract* - The Industry 4.0 paradigm enables manufacturers to improve two key business factors: costs and product quality. It proposes a new model of maintenance that goes beyond reactive and preventive maintenance. This innovative model called "Predictive Maintenance" aims to minimize production disruption and equipment downtime through the use of advanced algorithms and machine learning techniques, in conjunction with a company-wide array of connected sensors and an increased capability of digital real-time data processing. Predictive Maintenance aims to improve industry responsiveness to dynamic market conditions, to decrease production costs, improve product quality and production line and equipment availability.**

This paper proposes a vertical Predictive Maintenance model for the Industry 4.0 paradigm, describing its architecture and software management framework. This approach includes a real-time notification system for enhanced equipment condition awareness and avoidance of critical equipment failure by supporting decision making processes. It is also described the implementation of the model in a manufacturing company that produces machinery for the automotive sector.

Keywords — Industry 4.0, Predictive Maintenance, Management Software, Equipment Maintenance, Decision Support

I. INTRODUCTION

The Industry 4.0 concept, coined by the powerhouse of German manufacturing, envisions the global interconnection of industries, their production lines and factories, as a grid of interconnected cyber-physical systems [1]. Cyber-physical systems would be capable of interacting with each other, with humans, and should be capable of changing the manufacturing process due to massive data collection and processing, intelligent reasoning and decision making, improved product and process awareness. The most significant consequences of this new paradigm would be the cost reduction, improved flexibility for on-demand production models and improved quality. [2]

One of the key factors when considering costs is maintenance. According to several reports, the annual equipment maintenance accounts up to 40 percent of total cost [3], while in broad terms, maintenance costs represent between 15 and 60 percent of the cost of goods produced. From another perspective, surveys of maintenance management effectiveness indicate that one third of all maintenance costs is wasted as the result of unnecessary or improperly carried out maintenance[4]. In addition to this, equipment failure is often cause of expensive production shutdowns [5] (both planned or unplanned), which adds to the total cost and has serious consequences in the case of unplanned shutdowns due to the disruption in the whole value chain and company activities. Equipment availability is then directly related with the effectiveness and efficiency of the established maintenance practices. It was also demonstrated that machines subjected to inadequate maintenance often experience speed losses or lack precision, and hence tend to produce defects with direct impact on product quality [6]. This reveals a strong link between equipment maintenance and product quality [7].

Traditionally, industries and process plants typically employed two types of maintenance strategies: corrective (also called run-to-failure) and preventive maintenance[4]. Corrective maintenance is a pure reactive maintenance which waits for the equipment to fail, only then to initiate corrective measures like performing reparation, replacing old parts, etc. This model is rarely used in its purest form, as typically companies always perform some kind of basic maintenance procedures regularly (ex: adjustments, lubrication, etc.).

Reactive maintenance strategies have great disadvantages. The unpredictability of failure events makes budgeting hard to control, while it can cause production interruption as major repairs in the middle of the production often incur in enormous costs, not only in terms of direct revenue and unpredictable expenditures, but also in shipping time, reputation. Reactive maintenance may be also subjected to a “domino effect”, where a minor problem can turn into a major repair very quickly, or involve other company departments and escalate into serious problem. Other negative consequence is the increased probability of failure, as with unexpected failures, there is seldom enough time to find the root cause, leaving the door open to have the failure to repeat in future. Long term costs are also impacted by reduced equipment lifespan [8].

Preventive maintenance aims to prevent faults to occur. This strategy focuses on acting before failure occurs, by taking preventive actions such as condition-based maintenance and pre-determined (scheduled) maintenance[7]. This type of maintenance is planned and budgeted as the inspections of the equipment are carried out according to parameters of time, hours of operation, mileage, consumption, among other factors[9]. The implementation of preventive maintenance varies greatly, and may range from minor adjustments and actions (ex: lubrication) to extensive programs including all sorts of maintenance actions (adjustments, repairs, rebuilds, etc.). In all cases, the aim is to decrease the probability of failure through a planned schedule, with the main assumption that time and use increase the chances of a failure to occur. Preventive maintenance strategies represent an improvement in managing the uncertainty caused by corrective maintenance, and they are usually cheaper considering the overall costs. Nevertheless, they still have several downsides. One of them is that tight preventive maintenance strategies incur in unnecessary and excessive costs if the maintenances were not needed, causing waste of labor, material, time and money (over-maintenance). On the other side, light preventive maintenance strategies may transform into corrective maintenance if they fail to adequately decrease the probability of equipment failure. Another downside is that preventive maintenance prevents learning: since the equipment maintenance tasks are carried out with certain periodicity, they do not allow the depreciation or wear of the pieces of the equipment to be exactly determined.

The Industry 4.0 paradigm implements a type of strategy than can overcome the downsides of both corrective and preventive maintenance, called predictive maintenance. Predictive maintenance is a *"philosophy or attitude that, simply stated, used the actual operating condition of plant equipment and systems to optimize total plant operation"*[10]. Predictive maintenance has two aims: to predict when equipment is going to fail and to prevent the occurrence of the failure by performing maintenance (allowing maintenance to be done in a planned and orderly way before failure occurs)[11]. But conversely to preventive maintenance where action is taken in a regular, scheduled basis, in this case action is only taken when needed (where there are solid inference clues about when failure is about to happen). This means that an effective maintenance strategy implies a statistical approach to infer when and what will be the next equipment failure to happen. According to the literature, this strategy has several advantages over previous maintenance strategies[12]:

- Reduction of maintenance costs by 50%
- Reduction of unexpected failures by 55%
- Reduction of repair and overhaul time by 60%
- Reduction of spare parts inventory by 30%
- Increase of mean-time-between-failures (MTBF) by 30%
- Increase in 30% in equipment uptime

The statistical analysis of the possibility and location of failure runs on operation and maintenance data. This data comes from the equipment condition assessment and its parameters (such as vibration, temperature, current consumption, noise, etc.). In practical terms, predictive maintenance needs direct equipment monitoring. This data needs to be collected, analyzed through statistical processing and inference algorithms to predict the probability of failure and trigger the needed actions to avoid failure. Modern predictive maintenance strategies involve the use of state-of- the-art artificial intelligence algorithms that allow extraction of knowledge and inference from data in an automated way (machine learning), allowing the system to learn automatically by the historical of data to, in conjunction with real-time data coming from the equipment, draw conclusions about time and location of the next failures. Being so, the acquisition and storage of large amounts of data and computing power are key to this process. Generally speaking, predictive maintenance may comprehend 6 phases:

1. Determine the parameters to be measured[13]
2. Data acquisition, communication and storage – Equipment operation and condition data is the base for prediction and needs to be acquired. This is usually achieved through the use of built-in or retrofitted sensors to acquire data about the parameters selected for measurement. The data acquired will be then communicated from the place of acquisition (equipment) to the data storage place, as it is unlikely that individual equipments have the ability to store large amounts of data. The storage of large amounts of bottom-up data (i.e. data coming from the shop-flor base equipment) is not a straightforward process due to the large amounts of data involved and the need for fast queries. Typically, this phase can also involve some source of pre-processing (data cleaning, aliasing, discretization, etc.) and organization.
3. Data Processing – The data stored is fed to the statistical / Artificial Intelligence algorithms, which analyze, relate and process data from equipment operation and condition discover patterns which can be traced the occurrence of equipment failure.
4. Convolution of inferred data knowledge with stored and real-time data – Inferred knowledge is then applied to the real-time data and historical data to determine the likelihood of failure occurrence in the future and real-time alert to allow maintenance action to be taken to prevent unplanned failures to occur.
5. Data Visualization and ERP Integration
6. Feedback Learning – Modern strategies involve the automated and/or user assisted improvement of the data process algorithms, to allow to capitalize on history obtained knowledge and findings, outcome of actions taken, etc.

Predictive maintenance as a concept is hardly an innovation, with the first research works dating from the early

seventies[14]. Yet, recent technological developments in real-time data acquisition and processing (Industrial Internet of Things - IIOT), large data reposition ("Big Data"), and developments in the statistical and artificial intelligence fields laid the ground for its dissemination in industry. As a matter of fact, the Industry 4.0 paradigm of interconnected productive assets producing large amounts of high-frequency real-time bottom-up data, with universal data acquisition, sensing and tracking are the ideal infrastructure for the implementation of an effective predictive maintenance strategy. The quality of a predictive maintenance strategy largely depends on the amount and quality of data that is fed to the algorithms. Higher quality strategies can get also data from other non-production assets and environment (temperature and humidity of the facilities, for example) and combine it to infer the interrelations between them.

Fig. 1 depicts the relationship between repair and maintenance costs. As it is possible to observe, predictive maintenance presents the best balance between upfront costs (maintenance costs) and repair costs. While it preventive maintenance has the lowest repair costs (considering that regularly maintained equipment through a tight maintenance schedule largely avoids the occurrence of failures, its high maintenance costs offset the benefits. Corrective maintenance, on the other hand, has very high repair costs, despite having low maintenance costs.

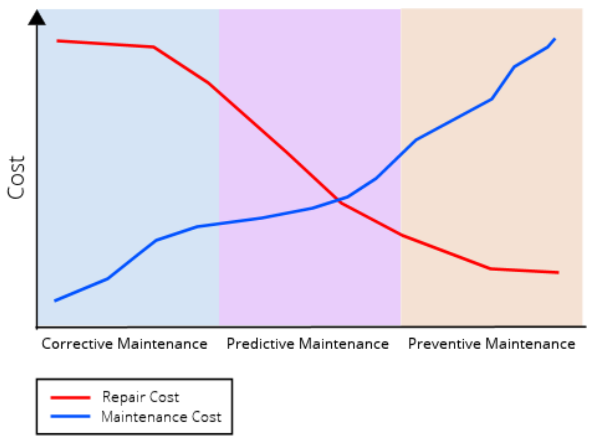

Fig. 1. Maintenance strategy comparison (Repair and Maintenance costs)

Despite its high desirability, implementing a predictive maintenance strategy in a company is not a straightforward process, and in many cases it is not used to its full extent. In this paper we propose a model for predictive maintenance and describe its ongoing implementation in a manufacturing company and draws conclusions and insights for future implementations in order to allow companies to fully extract the benefits from the implementation of a preventive maintenance strategy.

This article presents an ongoing implementation project in a real production environment following the Industry 4.0 paradigm by a consortium consisting in private companies and public research institutions, financed by a mix of public and private funds. SisTrade[1] was the project leader, developer and prototype builder and ISEP was the public research institute in charge of the technical project specifications. Facort was the manufacturing company were the pilot was deployed and tested, Evoleotech was the technological company in charge of the Industrial Sensor and IOT installation and ISQ was responsible for the assessment and evaluation of the equipment parameters and ecoefficiency tests.

This article is organized as follows: the present section introduces the main maintenance strategy types and the motivation for this article. Section II describes the predictive maintenance model proposed and section III describes its implementation. Finally, section IV draws the conclusions and explores some insights for future predictive maintenance implementations.

II. A Model for Predictive Maintenance

Following the 6 phases of the predictive maintenance strategy, the consortium has developed a model for the implementation of a modern predictive maintenance system.

A. *Determine the parameters to be measured and the way they will be measured*

The first step of the predictive maintenance is to elicit and select the operation and condition parameters of the equipment or environment to be measured and how they will be measured. When deciding what parameters to measure, it is important to know what are the relevant parameters that exhibit symptoms of a failure to occur. Knowledge of the past history of failures and operating symptoms is fundamental to lead the choice of the relevant parameters. The objective of predictive maintenance is to predict where and when equipment failure is going to happen, so operator, maintenance technician and equipment manufacturer knowledge is fundamental, and they should be involved in the process. If the equipment manufacturer is not available, at least the technical manuals of the equipment should be considered. As mechanical systems or machines account for most plant equipment, vibration monitoring is generally the key parameter to be measured. Nevertheless, there are other parameters such as thermography, tribology (wear, friction and lubrication), process parameters, ultrasonic, etc.) that can be measured. In the absence of any type of prior knowledge, obtaining sensor data from the usual

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[1] Sistrade is a private software consulting company with a large experience in the development and implementation of ERP. Its main product, the Sistrade ERP, has been successfully implemented in several industry and service contexts, from the printing to the flexible packaging and presents highly successful vertical industry solutions. The company has been involved in advanced R&D projects, building up its excellence in providing value to businesses internationally.

parameters would be a good start, yet the more diverse data can be obtained, the best.

The second important question is "how the parameters will be measured?". This question should be answered with the sampling frequency and accuracy and the sensors needed to obtain data from the determined parameters with the interval given by the sampling frequency. The sampling frequency depends on many factors (ex: process time, sensor capabilities, maintenance programme objectives). The choice of the sensors depends on the target equipment, the parameter(s) to be read, the sampling frequency and accuracy. In practical terms, it may also depend on economic considerations. It is important to involve also the sensor provider in this discussion. TABLE I. summarizes this approach.

TABLE I. DETERMINATION OF PARAMETERS

Question	What to Determine	Stakeholders involved
What?	Parameters (ex: vibration, temperature, part wear, etc)	Equipment Operators Maintenance Staff Management Equipment Manufacturer Technical Partner
How?	Sampling Frequency Sampling Accuracy Sensors Needed	Equipment Operators Maintenance Staff Management Equipment Manufacturer Technical Partner Sensor Provider

B. Data Acquisition, Communication and Storage

Having chosen the parameters to be read and the way they will be read, the sensors should now be installed into the target equipment. Legacy equipment may require sensor retrofitting. These sensors may have a processing unit to allow the data to be pre-processed (usually called "Smartboxes") and some form of communication, forming an IOT device. The sensor data obtained by the IOT device at the equipment is then streamed in real-time to the location where will be stored and processed. This means that the monitored equipments should be connected through a network that allows real-time data transfer. IOT devices usually provide IP networking capabilities for data transfer. The data acquisition, communication and storage module should be able to get data from different equipments only with minor adaptations.

The bottom-up data produced by IOT monitoring devices is often incomplete, inconsistent and noisy, as it is typical in real manufacturing environments. High frequency sensor reads in several equipments produce large amounts of distributed data which needs to be subscribed, consumed, cleaned, aliased and discretized prior to be stored. There is the need to use high performance distributed databases with parallel multithreading data filtering, sorting cleaning and marshalling. The use of distributed databases needs to be managed properly, avoiding deadlocks, and allowing data queries.

C. Data Processing

The data process phase comprises a set of machine learning algorithm running on the stored data to extract knowledge and forecast fault. This is usually achieved by using supervised and unsupervised machine learning algorithms. These algorithms run on batches of significant data and are used to build construct predictive models.

D. Convolution of inferred data knowledge with stored and real-time data

Knowledge, in the form of predictive models, needs then to be applied to the real-time data streamed from the equipments. This data is used as an input of the predictive models built, in order to obtain relevant statistics, alerts and predictions which may trigger maintenance actions to avoid equipment failure. There are many approaches which can be implemented to make inferences on equipment condition [15][16][17]. The resulting inferences (alerts, warnings, and advices) be integrated into the ERP used by the company to provide seamless integration with the manufacturing processes, enhanced monitoring and integration the maintenance module.

E. Data visualization and ERP integration

Data visualization is of fundamental importance for the management of a company, as well as it is the integration with production systems (ERP, MES, etc.). Therefore, a data visualization module shall be developed, taking advantage of the streaming data information for equipment condition monitoring. The integration with the ERP is also important, as the scheduling of maintenance actions and reports should be generated automatically. Advanced feedback to production planning should also be considered, by reorganizing production to avoid excessive load on the equipment which is about to fail. The equipment maintenance history could also benefit from the integration with the ERP.

F. Feedback Learning

The machine learning models must implement meta-learning feedback strategies, to allow the automated evolution and increased effectiveness and accuracy of the predictive models, as with time the information available for analysis also increases.

This should also be coupled with a manual feedback learning cycle, by allowing experienced users to provide their valuable input to further improve the algorithms, for example, through the definition of rule-parameter tuples do create alerts. The data visualization module would also allow for manual knowledge extraction.

III. IMPLEMENTATION

The model presented in the previous section is being implemented and tested a metallurgic small-medium enterprise specialized in the production of precision parts for the automotive industry. To be competitive, precision and trust in the production processes, times and finished product quality are key. The current project aimed to implement a predictive maintenance system following the model described in the previous section. The project has started by selecting two types of key equipments (Machine Centre and CNC Turning Centre (Fig. 2)). Despite the equipments already provide some internal sensor data through a UART-232 serial interface, they were connected to an Asus Tinker Board IOT device which an array of other sensors was connected (temperature, vibration, noise and energy sensors), strategically placed in the machine to complement the built-in sensor information. The IOT device runs software to gather the sensor data and communicates it through an Apache Kafka publish/subscribe service to the RDBMS database system remotely hosted at the Sistrade facility, and to ISEP processing cluster. ISEP machine learning algorithms are trained with batch data with the data stored at the Sistrade facility, and the convolution is performed at the ISEP processing cluster.

Fig. 2. The CNC Turning Centre machine. Image retrieved from https://www.hfochicago.com/products/specials/haas-st-30-entrustment-machine-slightly-used/

The implementation followed the Predictive Maintenance Model presented in the previous section as follows:

A. *Parameters to be measured and the how they were measured*

TABLE II. shows the selected parameters and their read frequency, according to a previous study on the predictive maintenance architecture in machinery industry[18].

TABLE II. PARAMETERS SELECTION AND MEASUREMENT [19] (ADAPTED)

Parameter	Description	Source	Frequency
Serial	The Machine Serial	Built-in Sensor	0.2Hz
Number Control	Number		
Control Software Version	Version of machine firmware	Built-in Sensor	0.2Hz
Machine Model Number	Model number of the machine	Built-in Sensor	0.2Hz
Tool Changes (total)	Number of times a tool was changed since Machine the machine was first powered on	Built-in Sensor	0.2Hz
Tool Number in Use	Turret station number currently in use Protocol	Built-in Sensor	0.2Hz
Dry Run	Indicates if the machine is running without producing a part	Built-in Sensor	0.2Hz
Power-On Time (total)	The time the machine has been running	Built-in Sensor	0.2Hz
Motion Time (total)	The time the machine is in motion	Built-in Sensor	0.2Hz
Last Cycle Time	Last production cicle time	Built-in Sensor	0.2Hz
Previous Cycle Time	Previous production cycle time	Built-in Sensor	0.2Hz
M30 Parts Counter #1	Number of times a progrem completes	Built-in Sensor	0.2Hz
M30 Parts Counter #2	Number of times a progrem completes	Built-in Sensor	0.2Hz
Maximum axis loads for X, Y, Z, A, B, C, U, V, W, T	Maximum load on an axis	Built-in Sensor	0.2Hz
Coolant Level	Emulsion level (cutting)	Built-in Sensor	0.2Hz
Spindle load with Haas vector drive	Simple Load	Built-in Sensor	0.2Hz
Present part timer	Production time for the part being worked	Built-in Sensor	0.2Hz
Last complete part timer	Production time for the part previously completed	Built-in Sensor	0.2Hz
Tool in spindle	Turret station number currently in use	Built-in Sensor	0.2Hz
Spindle RPM	Spindle rotation speed	Built-in Sensor	0.2Hz
Present machine coordinate position X, Y, Z, A, B	Current machine position for axes X, Y, Z, A, B	Built-in Sensor	0.2Hz
Present work coordinate position X, Y, Z, A, B	Position of the part at the start of production in axes X, Y, Z, A, B	Built-in Sensor	0.2Hz
Present Tool offset X, Y, Z, A, B	Distance of the tool relative to the origin in axes X, Y, Z, A, B	Built-in Sensor	0.2Hz
Machine Vibration	Vibration during the cutting process on axes	Retrofitted Sensors	100 Hz

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Parameter	Description	Source	Frequency
X, Y, Z	X, Y, Z		
Noise	Noise inside the machine	Retrofitted Sensor	100Hz

The equipment built-in sensors have a default reading frequency of 0.2 Hz as they are provided by equipment while the retrofitted sensors have a reading frequency of 100 Hz.

B. Data Acquisition, Communication and Storage

The data is acquired by the IOT devices (Asus Tinker Boards - Fig. 3) running a custom made software (programmed in Java) which publishes an Apache Kafka service.

Fig. 3. The IOT data acquisition device, installed into the equiments. Image retrieved from https://www.currys.co.uk/gbuk/computing-accessories/components-upgrades/processors/asus-tinker-board-10158412-pdt.html

The Kafka service is then subscribed by the Sistrade relational database and the ISEP machine learning cluster, which receive, store and process the streamed data.

C. Data Processing

The ISEP machine learning gets batch data from the Sistrade relational database to train the machine learning algorithms.

D. Convolution of inferred data knowledge with stored and real-time data

The machine learning models created through the previous step are then applied to the streaming data received to make inferences, advices, alerts, and warnings on the condition and possibility of failure of the equipment.

E. Data visualization and ERP integration

The visualization of data is of fundamental importance. Therefore, Sistrade has developed a data visualization software module used to provide real-time feedback on the equipment condition, valuable insights on the equipment condition and maintenance and alerts on the possibility of failure occurrence. This module presents and integrates the alerts generated by the machine learning algorithms and allows the user to manually define conditions for alarms (for example, if a parameter value surpasses a given threshold value). This is a valuable tool to allow the translation of user and maintenance knowledge into automated knowledge who takes advantage of having real-time monitoring information.

The Sistrade data visualization module comprises the following features:

- Real-time equipment condition monitoring and alerts (Fig. 4), presenting information about the machines and its parameter values.
- History of parameter values and comparison with critical values.(Fig. 5). History can be visualized by selectable data range, with different scales and compared with user or automatically defined critical values. This allow easy equipment monitoring, trend analysis and obtain insights for maintenance action planning.
- Real-time graphical monitoring of critical values per parameter via customizable dashboard (Fig. 6). Users can select the parameters to analyze in detail in real-time.
- Manual definition of critical values and alert rules (Fig. 7). Users can define alerts through conjunctions of rules which consist in *(variable, condition, value)* tuples. It allows users to define the alert state (active/not active) and whether an email should be sent in case conditions are met.
- Definition of user roles and access permission layers, allowing for different visualization profiles for different user types. For example, different users can visualize different machine parameters from different machines according to their organizational role and function. User roles are used to manage which user groups may receive alerts, email notifications and manage users. They may also be used to allow different user group permissions for defining threshold values for variable parameters.
- Visualization of the history of alerts (both manually created or automatically created by the ISEP machine learning cluster) and warnings about equipment condition, advices and equipment failures. Each message identifies the machine, the

type of alert (according to its severity), the description of the problem, the recipient (the user group(s) notified) and the critical values reached.

- Automatic Email notifications – each alert may trigger an email notification if the alert conditions are met or the machine learning models identify abnormal equipment conditions. Emails can also be sent in case there is a failure in the data communication or data acquisition. The emails are sent

The visualization module allows not only for warning users about potential failures but can also provide tips and advices on the usage of the machines and its parts, reducing part stress, allowing for longer equipment lifespan and reduced maintenance needs.

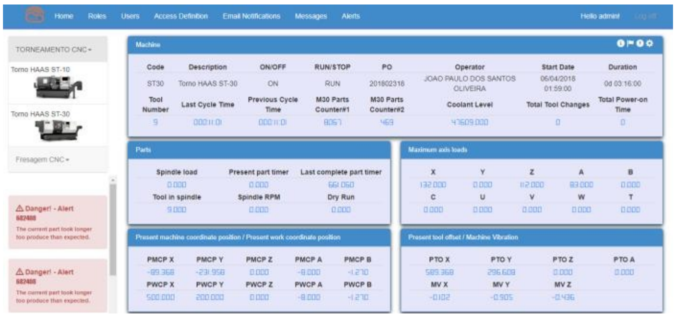

Fig. 4. The Sistrade data visualization main screen. parameters of the equipment (center), the monitored equipments (top left) and the equipment operation or failure alerts (bottom-left). Equipment parameter values are clickable and allow for contextual history visualization.

Fig. 5. The Sistrade data visualization module allows parameter value history visualization and critical value tracking. The data range is selectable and browsable. It also allows to present trendlines to help users to make assumptions on equipment condition and maintenance planning.

Fig. 6. Customizable dashboards allow for easy realtime parameter visualization and critical threshold monitoring. The dashboard panel is configurable by the users.

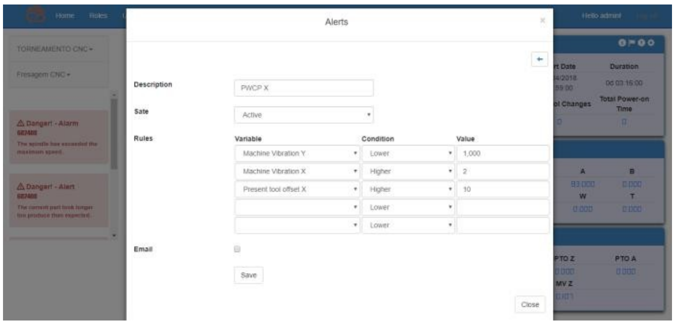

Fig. 7. Alerts can be created manually, allowing for translation of user knowledge to digital knowledge. Each alert consists in a conjunction (logical value *"and"* of *(variable, condition, value)* tuple. It also allows to configure email notifications.

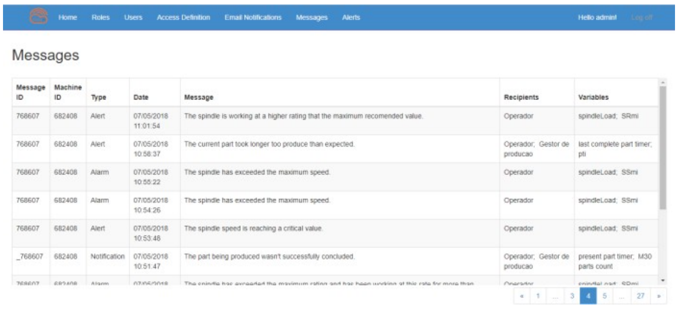

Fig. 8. Alert history records every alert fired by the system.

F. Feedback Learning

As mentioned previously, the current implementation is in progress. The feedback learning loop has not been implemented yet, but it can now also take advantage of the valuable user knowledge translation to improve the machine learning models.

IV. Conclusions and Future Insights

This article introduced a model for predictive maintenance taking advantage of the Industry 4.0 paradigm and provided an example of implementation of the model in a real world company through an in-progress project executed by consortium of private companies and public research institutes funded by public and private funds. The model comprises six phases in a vertical approach. It starts with the selection of the parameters to be measured and with the selection of the sampling frequency and the stakeholders involved. Then, the data needs to be acquired by sensors, requires the installation of Industrial IOT devices which receive data from built-in or retrofitted equipment sensors and communicate them to the database, through software service that allows publishing and

subscription of real-time data feeds. The data is consumed by the Machine Learning algorithms to build and train predictive models which are then applied to real-time information streams containing sensor data to analyze equipment condition and functioning and trigger automated alerts and advices.

The visualization module receives the alerts and presents them to the uses, in conjunction with real-time information about the equipment parameters. It also allows the translation of human knowledge into rules that can be used to trigger alerts, allowing the incorporation of maintenance technicians or equipment operator and the implementation of a continuous learning feedback of the machine learning models. It can also be used to integrate this approach with the ERP, providing a fully integrated predictive system for Industry 4.0 companies.

As future work, there is the need to develop the machine learning feedback loop to improve accuracy of the inference models and to fully integrate the visualization module with the ERP. This work is already planned and will allow the optimization of the implemented model and allow it to provide full value to the manufacturing company.

The Industry 4.0 paradigm opens new horizons for the maintenance landscape, and the presented model can be further enhanced with the flow of information from the equipments. Full integration with the ERP could be coupled with full communication and a higher degree of autonomy of the production equipments, by allowing them to negotiate, optimize and route (and recover in case of equipment failure) the production flow considering their condition, operation, manager-defined production and maintenance objectives, allowing for further downtime reduction, load balancing, and extraction of further economic gains.

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Blockchain Technology Helps Maintenance to Stop Climate Change

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***Abstract*—The development and interest in Industry 4.0 together with rapid development of Cyber Physical Systems has created magnificent opportunities to develop maintenance to a totally new level. The Maintenance 4.0 vision considers massive exploitation of information regarding factories and machines to improve maintenance efficiency and efficacy, for example by facilitating logistics of spare parts, but on the other hand this creates other logistics issues on the data itself, which only exacerbate data management issues that emerge when distributed maintenance platforms scale up. In fact, factories can be delocalized with respect to the data centers, where data has to be transferred to be processed. Moreover, any transaction needs communication, be it related to purchase of spare parts, sales contract, and decisions making in general, and it has to be verified by remote parties. Keeping in mind the current average level of Overall Equipment Efficiency (50%) i.e. there is a hidden factory behind every factory, the potential is huge. It is expected that most of this potential can be realised based on the use of the above named technologies, and relying on a new approach called blockchain technology, the latter aimed at facilitating data and transactions management. Blockchain supports logistics by a distributed ledger to record transactions in a verifiable and permanent way, thus removing the need for multiple remote parties to verify and store every transaction made, in agreement with the first "r" of maintenance (reduce, repair, reuse, recycle). Keeping in mind the total industrial influence on the climate change, we can expect that with the aid of the new advancements the climate change can be if not totally stopped at least reduced, and contribute to the green economy that Europe aims for. The paper introduces the novel technologies that can support sustainability of manufacturing and industry at large, and proposes an architecture to bind together said technologies to realise the vision of Maintenance 4.0.**

Keywords—OEE, Blockchain, CPS, IoT, Maintenance.

I. Introduction

Overall equipment effectiveness (OEE) is a popular metric that is used for evaluating the equipment effectiveness in a manufacturing environment. The measure was originally presented and explained by Nakajima (1988). He defined OEE as the measure for "unlocking the hidden factory" and improving resource utilization. Jeong and Phillips (2001) view OEE as a powerful benchmarking key performance indicator (KPI) focusing on three efficiencies; availability, performance and quality. Nakajima's original work identified six losses that reduced the utilization of a machine for the purpose of manufacturing. These losses are equipment failures, setup and adjustments, idling and minor stoppages, reduced speed, defects in process, and reduced yield (Nakajima, 1988). There have been certain alterations/ additions to the original definition by Nakajima. Authors like Blanchard (1997) and Ingemansson (2004) added stoppages like preventive maintenance and shortage of staff in order to calculate a more accurate OEE. Robinson and Ginder (1995) suggested seven stoppages by replacing "defects in process" stoppage of Nakajima with two different stoppages, namely time lost to inefficient start-up and time lost to tooling. The and Johnston (2015) combined some of these factors and included a few others to arrive at four operational production losses. These are Loss due to lack of demand for products, Loss due to availability of equipment, Loss due to slow or sub-optimal performance of process or equipment and Loss due to production of poor quality or recovery of product. Irrespective of the number and types of these losses, they are formulated as a function of a number of mutually exclusive components namely: availability (A), performance (P) and quality (Q) (Garza-Reyes, 2015). OEE is the result achieved by multiplying these three factors together.

OEE= [Availability*Performance*Quality]

Academia has differing views on what this OEE should be and what it practically is. Nakajima (1988) indicated that a good benchmark for manufacturing organizations is to have an OEE of 0.84. Kotze (1993) puts a figure of OEE less than 0.50 as being closer to the reality. Ericsson (1997) found out that OEE can vary in different firms from 0.30 to 0.80. Blanchard (1997) puts a figure of 0.85 as the world class OEE whereas Ingemansson (2004) reports the average OEE to be around 50 per cent. Ylipaa et al. (2017) analyzed 94 empirical data sets from the manufacturing industry between 2006 and 2012 and found the average OEE to be 51.5 per cent. Parida et al. (2014) argue that the OEE is generally 15-25 per cent below the targeted level. Edward and Hartmann (1992) propose that within most plants there is a hidden factory offering some 25-30 per cent more capacity. OEE is the measure that allows a calculation to be made of the current equipment efficiency and more importantly the improvement potential within the equipment.

New technologies that are changing the game for industries have the capability to do the same to the improvement in OEE and productivity. Cyber Physical Systems have made the computation of the physical quantities a reality. Both

Blockchain and Internet of Things (IoT) have the potential to further aid in the implementation of sound maintenance practices. This paper will explain these newer technologies and will illustrate how they can be used in asset management field. Section A will briefly discuss about the sustainability of the manufacturing field followed by how a better OEE can lead to more sustainable manufacturing in Section B. New technologies, i.e., CPS and Blockchain are presented in the next three sections. These technologies have been described solely in the context of asset maintenance. In the next sections, the effect of these technologies on Maintenance 4.0 and future of maintenance strategies is presented. The paper is finally concluded after this.

A. *Sustainability of Manufacturing Organizations*

Sustainable production consists of systems of production that integrate concerns for the long-term viability of the environment, worker health and safety, the community, and the economic life of a particular firm (Quinn et al., 1998). Sustainability of a manufacturing organization is measured in terms of economic, environmental and social sustainability. Some of the literature refers it as the triple bottom lines (Jovane et al., 2008). US Department of Commerce (International Trade Administration, 2007) define a sustainable manufacturing as "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound". Garetti and Taisch (2012) defined sustainable manufacturing as the ability to use natural resources in manufacturing intelligently in order to fulfil economic, environment and social aspects and thus, preserves the environment and improve the quality of life.

Legislations in different forms have made it mandatory for manufacturing firms to consider sustainability more seriously. This is more pertinent in case of large firms that are under stricter scrutiny by the Governmental agencies. Many larger companies have implemented corporate social responsibility (CSR) programs (Fallon, 2015) for the purpose of improving, and publicizing their efforts for sustainability. These CSR and Sustainability programs help the company progress on different sustainability dimensions. Companies have started to realize the economic and strategic advantages of being sustainable. While many larger companies already have initiated some kind of CSR/CS reporting, small- and medium-sized enterprises (SMEs) usually do not possess the resources necessary to focus explicitly on sustainability, and they are also not capable of running comprehensive CSR/CS programs by a separate CSR/CS function (Winroth et al., 2016).

B. *OEE for improving sustainability*

Although, sustainability refers to the three dimensions of economics, environment and society, most of the times, it is focusses on the economic sustainability. This is especially true for small and medium firms where the financial bottom line assumes bigger importance. For example, Pham and Thomas (2012) presented four measures of performance, i.e. overall equipment efficiency (OEE), manufacturing lead time from the point of enquiry, on-time delivery, and gross value added. These are all economic sustainability measures.

OEE as a measure of equipment effectiveness has an impact on the sustainability of the manufacturing firm. The impact of OEE is substantial in case of economic and environmental sustainability. The losses which affect the OEE are numerous, but the machine/ equipment failure is the major reason. This failure also has a domino effect on the production losses like tooling, start up, etc. It is easy to see the related economic losses, but the negative impacts on ecologic sustainability cannot be neglected (Ylipaa et al., 2017). In fact, studies have shown that 30 per cent of the energy consumption in industry is wasted on machines in repair, idle, and stand-by states (Skoogh et al., 2011). According to Yusuf et al. (2013), a reduction in energy consumption will lead to a reduction in manufacturing cost. High energy consumption impacts both the economic and environmental dimensions of the sustainability. Low OEE indicates that the utilization of current production resources is low, which in turn leads to insufficient productivity and resource efficiency. These facts are problematic for current production in terms of economic and ecologic sustainability. Bracho (2000) highlighted that it is crucial for manufacturers to prevent overuse of resources, which happens due to low OEE.

The role of OEE should be understood as being a measure that must be considered beyond mere monitoring and controlling (Dal et al., 2000). Garza-Reyes et al. (2010) highlighted the importance of OEE by presenting that it prevents the sub-optimization of individual machines or production lines, provides a systematic approach for defining performance targets, takes into account process improvement initiatives, and incorporates practical management tools and techniques to achieve a balanced view of process availability, performance and quality. Similarly, Bamber et al. (2003) remark that OEE is often used as a driver for improving the performance of a business by concentrating on quality, productivity and machine utilization issues and hence aimed at reducing non-valued adding activities often inherent in manufacturing processes. All these impacts of OEE bring about a positive change in improving the economic and environmental sustainability of the manufacturing firms.

II. RELATED WORK

This section considers previous work related to this paper, and lays the groundwork for the envisioned approach to efficient maintenance. In particular, two technologies are considered to be the enablers for novel maintenance strategies and practices, Cyber Physical Systems and the blockchain, which are described in the following two sections.

A. *Cyber Physical Systems (CPS)*

Advances in computation and communication technologies are impacting on every aspect of people's life, and how people work is not an exception (Francis and Grootings, 2018). There is an emerging interaction between the cyber world, where the main inhabitants are data, and the physical world, inhabited by physical objects. Cyber Physical Systems act as a bridge between the two worlds, in one direction by providing data collection from the physical world to the cyber world, and actuating on physical reality based on the result of computation activities to get back to the physical reality.

From a computational point of view, a work activity is a complex of data collection, processing, and consumption. Novel techniques in industrial settings are in fact focusing on the data themselves, as an advancement over traditional model-based approaches (Shen et al., 2015). The core of data-based techniques is to take full advantage of the huge amounts of available process data, and intend to provide efficient alternative solutions for different industrial, with a limited need for the modeling and configuration of the systems.

Even though the utilization of electronics in the industry is not new, CPS allow for the integration of advanced analytics into manufacturing, products and services. In the particular use case of maintenance, a number of techniques are applied on the data, comprising smart algorithms with self-aware, self-predict, and self-configure (Lee and Bagheri, 2015). In this sense, the application of CPS to maintenance is a way to facilitate all data collection activities that empower the application of intelligent techniques, for example to profile the behavior of machinery over different conditions and look for outliers and thus predict machine's malfunctions. CPS are thus the gateway for the data to get from the physical environment into the cyber world, and the other direction the data can take (computation results used in actuators) has usually lower importance in maintenance use cases.

Being an area that pertains inherently to applied research, most research work in the area of maintenance is driven by use cases. As an example, and quite important for this paper, in Lee et al. (2015) the authors considered the use case of maintenance, and provided strategies and architectures to facilitate the systematic integration of CPS with machinery, and the enabling of big data analytics to look for patterns of degradations and inefficiencies in the machines. A more focused view on software is in Algabroun et al. (2017), where the authors proposed a maintenance framework leveraging principles from self-adaptation, and focused on the maintenance of a bearing in an electrical motor.

A few works take a step back and instead of applying a synthetic approach (building a system), take on the analytic approach. For example Albano et al. (2018) analyzed and categorized the types of CPS and sensors that are used in different real-life scenarios related to the maintenance use case. One of the results is that, when the machinery under analysis get more complex and expensive, the CPS and sensors get more customized, specialized on the use case at hand, and more integrated with the machine parts.

From a communication viewpoint, the application of CPS depends on the capability to transport the data between the factories where the CPS are deployed, and the cloud. In fact, modern maintenance activities are asking for the support of complex distributed systems (He and Xu, 2014) that collect, preprocess and transport data from the shop floor to the cloud, then use advanced techniques to distil data into information, and then get back to the shop floor to implement actions based on the data. Several advances on computation and communication technologies are the enablers to extend and adapt to the industrial context several concepts and strategies already applied to the personal and home environments, and on the Internet of Things (IoT) to enclose the user in a "always on, always connected" environment (Kumar et al., 2011). This gave rise to the Industrial Internet of Things (IIoT) vision, where Machine-to-Machine (M2M) communication allows in-factory machinery and remote computers to interact, to empower the technicians and managers of a company with ways to monitor and control the machines and the shop floor in general (Xu et al., 2014).

Finally, a few works address the benefits of CPS as actuators, and thus how CPS can ease common chores (Leitao et al., 2016), and in that context provided an overview of research and development challenges that must be solved to raise the Technology Readiness Level of CPS and its acceptance in the industry.

B. Blockchain technology

The blockchain technology is a dispersed database of different records, or an archive of all transactions or digital events (Crosby et al. 2016). The importance of the Blockchain technology has increased since the idea was coined in 2008 (Yli-Huumo et al. 2016). The reason why it is so popular lies in its characteristics that provide security, privacy and integrity, and also because there is no need to involve a third party that controls the transactions. For instance, the blockchain technology utilises public key cryptography whereby each agent is assigned a private key, which is kept secret like a password (Pilkington, 2016). In addition, the blockchain technology has the potential to be implemented into many fields because of its characteristics (Zheng et al 2016). Bitcoin is the most well-known application based on blockchain, however blockchain can be applied to diverse applications far beyond cryptocurrencies.

Application of blockchain technology in industrial use cases has been focused in two main areas: the supply chain management (Abeyratne and Monfared, 2016), and the smart grid (Mengelkamp et al., 2018). These efforts aim at harvesting the appealing characteristics of the technology behind bitcoin (Hamida et al., 2018) and apply them in other application areas, and in particular want to capitalize on responsiveness (just in time production needs), traceability (ability to track position in supply chain), accountability (prevent poor quality control), and security (intellectual property and other digital asset protection).

In the supply chain that feeds any modern industry, the number of actors is high and leads to information coordination challenges. As a title of example (Debabrata and Albert, 2018), the factories that manufacture a product are just one of the cause for high information complexity, the others being the customer demands, the outsourcing and globalization effects, and any malicious actor that raises the need for high information confidentiality, authentication, and integrity. The application of the blockchain technology in the management of the interactions between the actors in a supply chain scenario (see Figure 1) can provide enhanced security, trust through transparency and traceability, with the enhanced flexibility enjoyed by means of decentralized data management (Abeyratne and Monfared, 2016).

The application of blockchain to the smart grid industry is instrumental in increasing the integration of renewable energy sources in the energy system (Mengelkamp et al., 2018), since renewable energy sources are inherently volatile. The distributed

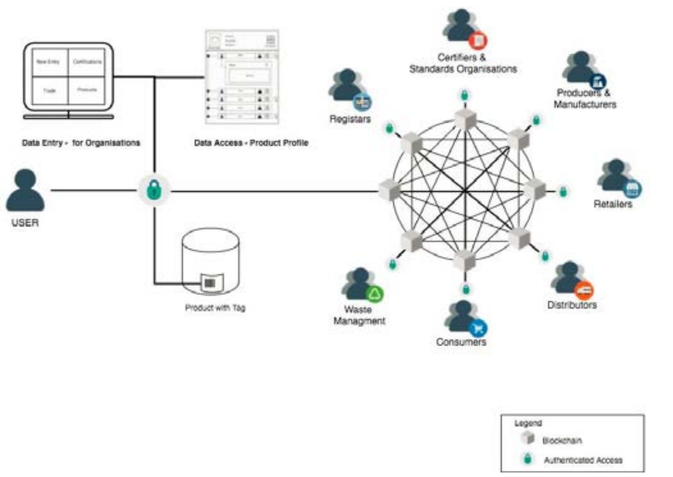

Figure 1 Blockchain in the supply chain (Abeyratne and Monfared, 2016)

ledger can be used in an efficient manner to allow an energy prosumer to trade-in its energy, exchange it with the grid in exchange for incentives (e.g.: discounts on future energy consumption). Moreover, it is possible to use distributed ledgers to allow prosumers in a neighbourhood to trade in their local community the energy produced from different kinds of renewable energy sources (Basden and Cottrell, 2017). This latter use case has been implemented for example in Brooklyn, where the prosumers pay a fixed amount to the energy grid to use the energy distribution system, and are allowed to trade excess energy with the grid operator as a whole, using blockchain to account for contribution from each prosumer.

The blockchain technology contains some technical challenges and limitations that might slow down its acceptance in the future (Swan, 2015). These are, for instance, throughput, latency and usability. Throughput means that the current network in, for example, bitcoin is maximised to seven transactions per second while other similar transactions networks, such as Twitter and VISA, manage 5000 respective 2000 transactions per second. When it comes to latency, bitcoin handle each transaction in 10 seconds to be able to keep the security at an acceptable level. Usability has to do with the difficulty to use the API of, for instance, bitcoin. There is, therefore, a need to develop more user-friendly APIs for the blockchain, which might be similar to the REST APIs.

In addition to the above mentioned, there are still some issues concerning the technology that might impede its successful implementation in other areas, if not considered, such as scalability problem and privacy leakage as well as wasted resources. The scalability problems that exist may be explained by the experience of the Bitcoin, which are based on the block size having a limitation of 1 MB, and a block is mined approximately 10 minutes, which results in a network that is restricted to a speed of seven transactions per second. In the case of larger block, it would result in larger storage space and slower transmission in the network. Consequently, the compromise concerning the block size and security has become an issue to consider when the blockchain technology is intended to be implanted. In addition, the private leakage is also possible to occur even when its use only allows transactions with their public and private key (Biryukov et al. 2014). Moreover, the user's IP address is also an aspect connected with the private leakage, since it is possible to track its physical IP address. Additionally, when it comes to the wasted resources, then the algorithms such as proof of work (PoW) or proof of stake, used in the blockchain technology, are experiencing serious issues because they waste too much electricity energy, i.e. the PoW protocol is heavily energy intensive (Zheng et al. 2016; www.cryptocurrencyhub.io). Also, as the network gauges and more miners move in the mining process to handle the demand for validating transactions, the mining process becomes tougher and as a result the energy used to support the protocol increases. Consequently, because of the enormous costs of the use of PoW algorithms, there are efforts to develop alternative solutions. Thus, a new consensus algorithm called Proof of Stake (PoS) has been suggested, which can be considered as a more energy efficient system (Kiayias et al., 2017).

Consequently, the blockchain applications for the area of interest should be developed taking into consideration issues that existent technology might have to be able to bypass them in the developing and implementing process. Before the technology becomes more mature and has gone through some standardisation processes, there is a need to find ad-hoc solutions, such as the PoS, in an effort to try to optimise the solutions of the blockchain technology that takes into consideration the energy efficacy without waste.

The blockchain technology has certain deficiencies in its scientific consistency, since it is at its nascent stage (Pilkington, 2016). However, many domains have started to understand its potential, and bitcoin is only one example of a blockchain solution. Therefore, blockchain applications have the potential to be implemented in many industries to solve different issues (Hwang et al. 2017; Chitchyan & Murkin, 2018; Larios-Hernández, 2017; Dori et al. 2017).

It is believed that the process of adoption of the blockchain technology will be gradual and balanced (Iansiti and Lakhani, 2017). However, it will take time before it can be introduced as a substitute for already existent technologies since it is important that it first gains an overall acceptance, which is expected to result in its increased acceptance and its further successful implementation with all what it concerns. Therefore, for the blockchain to become accepted as a standard technology, it is important that there is a shared understanding by different users and business in general in connection with the workings and impact of blockchain technology (de Kruijff & Weigand 2017).

III. MAINTENANCE 4.0

Maintenance activities are changing, as many other activities in the industry, by leveraging the support of CPS, and the data they collect, which is processed by means of big data techniques to support decisions in maintenance. In fact the current industrial revolution, called Industry 4.0, is focused on the data, and on how they can be used to enhance industrial activities, from the management of the supply chain, to augment the control of industrial processes, to maintenance. In this latter context, the term Maintenance 4.0 assumed the meaning of leveraging data for a stronger understanding of the condition of an asset, such as a manufacturing machine. This is strongly related to advanced maintenance concepts such as Condition Based Maintenance

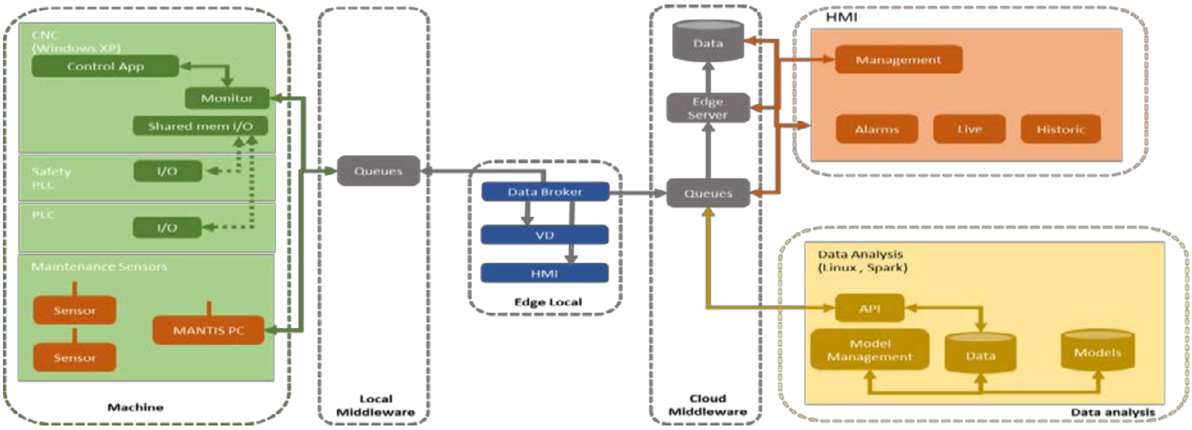

Figure 2 Reference Architecture of the MANTIS project (Ferreira et al., 2017)

(maintenance is performed when the condition of an asset requires it) and Predictive Maintenance (data is used to predict at which point in the future and which kinds of maintenance activities will be required), and how they can be supported by Maintenance 4.0's use of data.

The full benefit of the above described technologies is taken into use to support Maintenance 4.0. One of the emphasis is on the possibility of monitoring the machinery independent where in the world it is located, by means of CPS that have internetworking capabilities such as IIoT. As described earlier, a follow up of this is the possibility for manufacturing companies to provide services for the machinery they have produced at competitive price level assuming the need for maintenance can be reliably defined. Although the term Maintenance 4.0 might suggest that all of this is a straightforward application of techniques matured in the context of Industry 4.0, it might not be the case.

CPS provide the means to have the sensors and necessary processing power installed locally. There are a number service providers who can offer the needed connection capabilities and there are also numerous platform providers that enable the collection and processing of data in the cloud. The biggest challenge in practice is not related to the measurement of the data and access to it, but the meaningful and efficient use of the data. Since the amount of data that can be collected this way is enormous, the diagnosis of the developing failures will have to be automatic otherwise the solutions are not on sound financial basis. The automation of diagnosis can be very challenging assuming that there is now previous experience of that. Technically the final goal in this process is to be able to define the remaining n useful life of the components automatically so that maintenance actions can be carried out at optimal time.

Many pilots have appeared in the last few years, to both showcase different concepts in Maintenance 4.0, and to work on the Technological Readiness Level of each concept. For example, Figure 2 represents the architecture of a pilot built by the project MANTIS (Ferreira et al., 2017), which defined a three-tier distributed system where CPS (on the left) collect the data, edge computing (in the middle) is used to preprocess them and prepare them for the transport to the cloud, and the cloud applies machine learning techniques to enable Condition Based Maintenance, and provides advanced visualization mechanisms, with message-based middleware connecting the three tiers. Anyway, current advances are meant to be integrated in this vision to expand it and to cover novel use cases. For example, distributed ledgers can allow for non-centralized and secure management of collected data, and to support distributed decision making between different software agents in the cloud, edge computing, and human domain experts.

IV. Future of Maintenance Strategy

From maintenance strategy point of view the technologies described in the previous chapters will totally change the situation. The data that will become available will enable the genuine introduction of CBM with the capability to predict the remaining useful life of components of machinery although it is important to remember that a lot of work will be needed in understanding the wear of the monitored components. In addition to the introduction of CBM it will be possible to tune that strategy i.e. it will be possible to try out different strategies and risk levels with components using simulation. It is fair to assume that this kind of studies can take place fully automatically so that changes in the way the CMMS system handles maintenance work orders can take place totally without human intervention. Figure 3 presents a diagrammatic representation of the future maintenance architecture. IoT will enable the machine sensors to pass the information directly to the Central Server. The central server processes the machine health data and generate documents like job card, inventory status, and other reports. These will be used by the maintenance teams to carry out the requisite maintenance tasks. All these transactions will be based on the blockchain, thereby leading to an online distributed record of the interactions which are very beneficial for a green environment. All these facets form part of a viable Cyber Physical System for asset maintenance.

Related to the above the OEE value can be followed on-line all the time which will lead to dramatic growth of awareness of how well the machines are working. Nobody will in the future accept OEE values that are below 50%. Instead the goal will be set to high values in the order of more than 90%. This can then lead to dramatic reduction of the load the industry provides the nature globally. It should be remembered that in all cases when the OEE has been measured with some accuracy it has always been a surprise how low it is in these cases which can be considered to represent the front line of industry what are

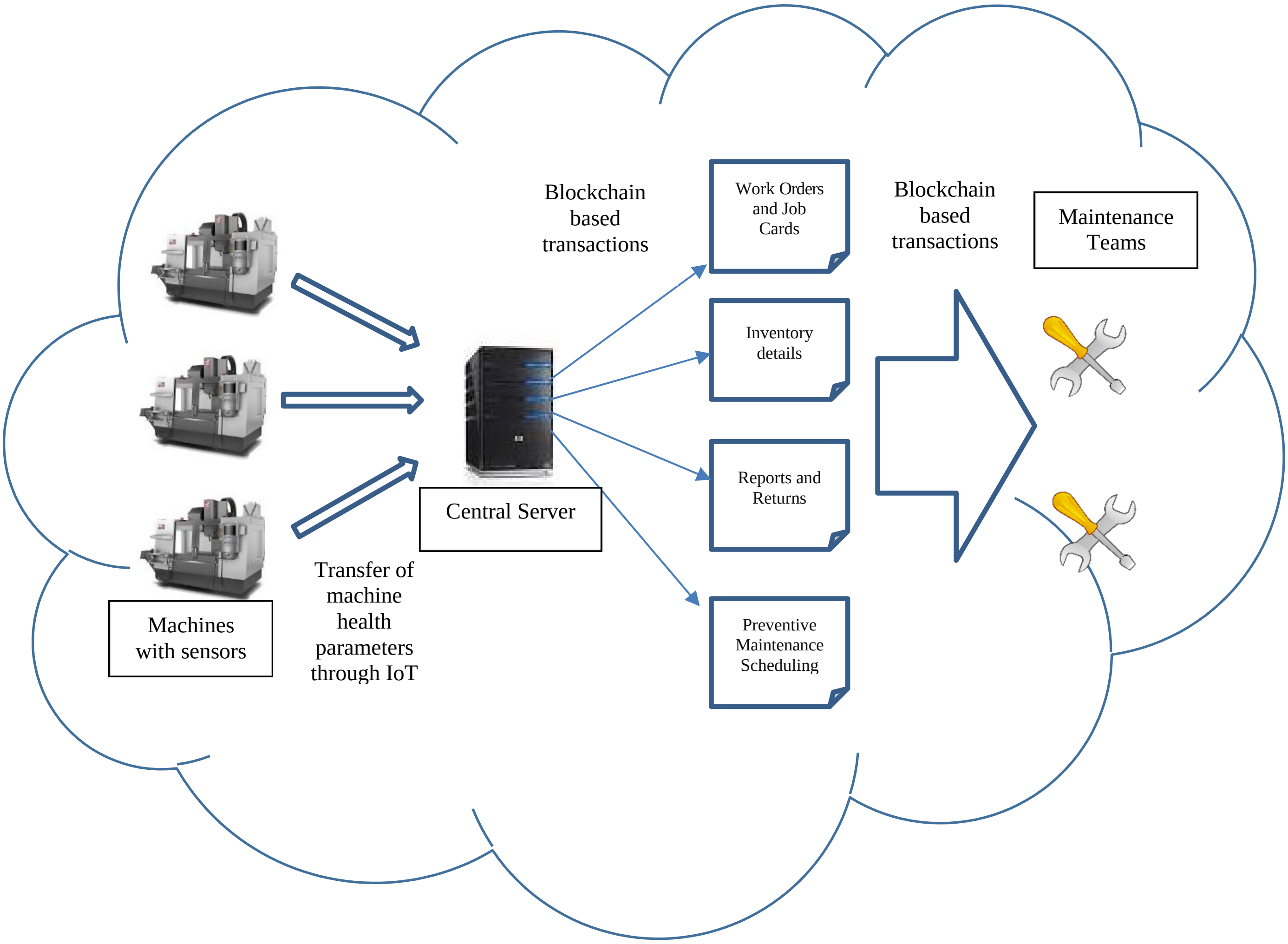

Figure 3 Advancing maintenance with CPS and blockchain

interested in this kind of monitoring. Consequently it is only possible to try to guess how low the real values are in majority of companies in the whole world. Could it be that the average of OEE in all industrial sectors in the whole world is below 50% today which could mean that load the industry creates to the nature today might be reduced to half with the same level of produced outcomes.

Naturally all of the above cannot come true overnight and without investments but reduction of the price of sensors and processing power and technologies like the blockchain and cloud technology will make it possible for companies that could not even dream about these technologies in the past. Consequently, the authors believe that the wheel has started to rotate and will rotate with increasing speed and that no other industrial improvement like e.g. improvements in energy production can have a similar size of influence to the stop the global warming.

V. Conclusion

The Blockchain technology provides several benefits, and it is, therefore, important to understand how to introduce it smoothly into the domain of interest. It is important to learn from the experience of the previous emergent technologies and how they have been introduced and accepted successfully. It has been shown that it is usually done by the standardisation of the technologies, which leads to their rapid acceptance as well as an increased use in the industry respectively. However, the standardization of the blockchain technology is somewhat important to avoid it becoming a technological hype.

The resulting vision is an extension of the current understanding of the potential of application of Cyber Physical Systems to collect data for Maintenance 4.0, since the distributed ledger allows for a decentralized trustable data management, and in this sense allows to reduce communication activities and third-party actions during data collection and processing. Thus, it allows for savings in terms of energy used in the communication, and time needed for the convergence of the data and mutual assurance on its validity.

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Ergonomics in Maintainability : System and Product Design Process

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***Abstract*— Maintainability is key part of RAMS estimation and prediction in complex assets. Indeed, availability calculation comprises accurate estimation of maintainability and many times, it is just a time stamp for MTTR estimations. However, maintainability is a human related figure where the skill, capabilities, tools and the design of the asset play key role in its performance. The aim of this article is to describe the effects of ergonomist contribution during maintainability process for system/products design. System designer thinking in system and its subsystem in a way of technical functionality. On the other hand, ergonomist are expertise in human capability and limitation. If human, become a part of system than their interface and interaction become crucial factors in a success of system performance and its sustainability. In this paper, it has discussed four main issues that help the process of maintainability design. These issues are safety (Safety I and Safety II), task analysis (Hierarchical Task Analysis (HTA) as tool) and risk analysis (using William Fine method). It has also touched reliability engineer's task in order to increase Overall Equipment Effectiveness (OEE).**

Keywords—maintainability, HTA, ergonomics. risk, safety.

I. Introduction

Usually designers think to technical functionality of intended or requested system/products. As it knows, system is a set of components that interact with each other in order to fulfill the required mission. One of the component of any system is human that have interact and interface with the system. On the other hand, ergonomists think to human abilities (both physical and mental) and their limitations when they become involved in the system or use of product. Ergonomist are saying, "fitting the task to the man not vice versa" as discussed in Teymourian et al. [1].

The fusion and emergence of these two way of thinking during design process will lead the concept of system thinking and human citizenship in the system. The more contemplated ergonomist in design process, the higher; Reliability (minimizing human error), Availability (human have thorough knowledge about the system functionalities), Maintainability (implementing of anthropometry, physiological and psychological), Safety and Safety Culture (RAMS) the system will have.

Peter Senge [2] indicated that Understanding system is a fundamental because larger system may drive in different way than our value. In another words by faulty design system may have some negative side effects on workers/maintenance operators; health, safety, performance and internal as well as external environment.

In maintainability management, safety engineers' involvement is one key issues as; O'Neill, [3], B. S. Dhillon, [4], B.S. Blanchard [5] pointed out. In this context, "Safety First" is the key issue of conceiving and perceiving human wellbeing in the sustainability of designed system/product. Designer together the maintainability engineers planning many issues for their system/product which among them is the procedures for maintenance and its frequencies. Performing maintenance required thorough task analysis both technically and their related risks to human and its environment.

The manuscript is arranged as follows. Section two describes the reliability engineering tasks and section three describes the safety. Section four explains the task analysis with a case study from the manufacturing industry. The related risk analysis is given in the section five. Finally, the conclusion for the study is presented.

II. Reliability Engineers Task

One of the reliability engineers task during design of system or product is identifying the possibility of failures that may occur for system or product functionality. By identifying failures, potential accidental event, causal and its consequences will be evaluate by using different risk analysis tools (Fault tree, FMECA, Event tree, etc.). Marvin and Arnljot, each failure and its frequency leads to breakdown, to which has an effect on system availability [6]. Vorne has classified six big losses on system performance [7]. Among them, is breakdown (others are; setup and adjustment, small stops reduce speed, startup rejects and production rejects). These losses in availability can be sporadic (well visible) and/or chronic (difficult to see). In order to minimized breakdown and other losses implementing of Total Productive Maintenance (TPM) or Productive Maintenance (PM) is key issue for increasing of Overall Equipment Effectiveness (OEE) of system/product. TPM or PM is based on involvement of all employees' activities for continuous improvement in maintenance performance [5].

List of failures and keeping system in function are a guideline for maintenance engineers in order to prepare different maintenance plans: preventive maintenance (all schedule

maintenance actions in order to keep system in its intended function), corrective maintenance (all unscheduled maintenance actions because of failures), predictive maintenance (it refers to condition monitoring of system in order to predicting the system degradation), maintenance prevention TPM (it refers to the concept of maintenance free design with the objective of minimizing maintenance down time and reducing life cycle cost) , adaptive maintenance (it is relating to the relevant software and changes in processing) adaptive maintenance(it refers to computer software so that increasing performance, maintainability) [5].

III. Safety

Identified technical failures and related maintenance activities need to discuss in another platform, in the context of human health and safety.

EUROCONTROL International Civil Aviation Organization (ICAO) defined safety as: "The state in which the possibility of harm to persons or of property damage is reduced to and maintained at or below, an acceptable level through a continuing process of hazard identification and safety risk management" [8].

Today and future technologies' require new way of thinking about risks that can reduce safety. Recently, safety consider as two categories; Safety I and Safety II.

Safety I defined as "Safety is defined as a state where as few things as possible go wrong".

Safety II, Ensuring that as many things as possible go right [8].

A White Paper that published by [8], describe, "Things go wrong due to technical, human and organizational causes – failures and malfunctions. Therefore humans are viewed predominantly as a liability or hazard". Therefore, accident investigation occur when it already had happened by identifying the sequence of events. In Safety I risk analysis carried out in order to clarify the degree of danger. In the area of safety I system is decomposable in parts and in order to find out the causes of accident but it cannot be used for: socio-technical system, human and organizational components. On the other hand safety II is concerning in: variability of every day performance and human as resources needed in the system for trying to understand how components functioning correctly in order to answer why part/process is not functioning as it planned. Safety II view is investing in safety not as a cost rather as investing in productivity. In a complex system workers performance occur base on working conditions rather than what they had told to do.

By knowing the differences between Safety I and Safety II characteristics, it can be concluded that safety I focuses on the two side of events normal distribution. In this part, improvement activities are more costly because of unexpected events. On the other hand Safety II concentrating in the middle of the same distribution (things go right) Figure 1. Improvement activities are smaller and more continuous. These two methods can be used together as complementary in order to enhancing and improving safety in the system/product performances. In another words moving from safety I concept to safety II will lead to make assured that system will function right.

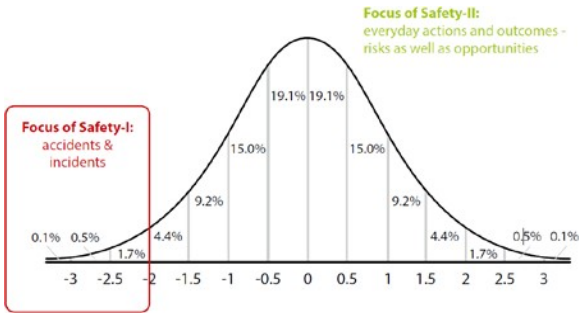

Fig. 1.Events distribution [8].

IV. Task Analysis

There are several methods that can be used for analyzing task: fault tree analysis (FTA), Event tree analysis (ETA) and so forth. Among them is Hierarchical Task Analysis (HTA) that is the focus for this paper.

This method was developed at University of Hull in order to analyze complex tasks [9]. HTA had been used for human factor and human computer interaction applications, including training by Shepher in 2002 [10], design by Lim and Long, 1994 [11], error and risk analysis by Baber and Stanton, 1994 [12] and team skills assessment by Annett et al., 2000 [13].

HTA method is top-down hierarchies and following walkthrough of the task. In the maintainability process, HTA is an appropriate tool for analyzing the performance of operation and maintenance. HTA is applicable at each stage of maintainability process that Blanchard [5] described as: conceptual design, preliminary system design, detail design and development, production and/or construction, system utilization and life-cycle support and system retirement and phase-out. It starts to describe the main goal as a set of sub operation [15]. These operations are broken-down or decomposed in hierarchy form in order to in what sequences sub performance should carried out. Operation or sub-operation can be break-down to such detail level that is necessary for starting task analysis. HTA is not actions per se rather it is a process for achieving planned of operational goals. Applying HTA as tool can show the root cause of existing failure or latent failure that can occur during performance it also proposing solution for modification or redesigning of: equipment, or work procedures, the type of required skill, training and support, risk analysis, and so forth.

Figure 4 shows HTA for the large tool maintainers at automotive chassis manufacturing company. The task is to separate tool, top from bottom in 17 or up to 20 sub tasks. Necessary information regarding, tool drawing and its documents, its work manual, checklist, work procedures, work instructions at the level of operators and instructor, training for being qualified, special skill requirement, type of equipment and facilities, work place design, risk analysis (W. Fine), working alone, ergonomic evaluation, personal protective equipment (PPE) had been prepared. Environmentally factors like temperature, working time, air quality, noise level, chemical

substances that are crucial factors to consider for task performance.

In some task or sub task it is required special skill as an example crane driver in production department is not qualified for separating tools apart in maintenance workplace. They are qualified for transporting objects while tools maintainers need to be specialized not only for transporting tools also how the heavy large tools should be turn.

Some of the practical examples of the process of the large tool maintenance are shown in Figure 2 and 3. In figure 2 separation of the upper part of the tool is shown (Task 8: lift upper tool slowly). In figure 3, is turning one part of the upper of the tool.

Fig. 2. Separating tools.

Fig. 3. Turn part of the tool.

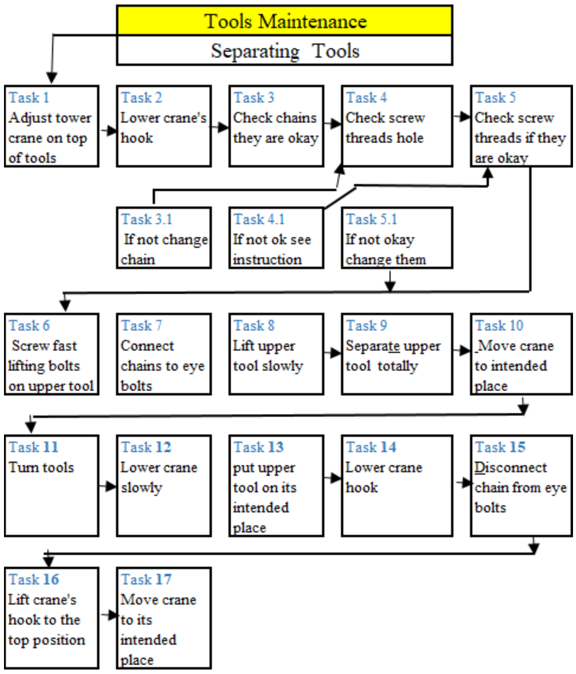

Fig. 4. Hierarchical Task Analysis.

V. RISK ANALYSIS

There are several risk assessments methods in ergonomics: Rapid Upper Lim Assessment (RULA) [15], Quick Exposure Checklist (QEC) [16], Rapid Entire Body Assessment (REBA) [17], etc.. Each of them has special quality and is strong in particular manner. All these method needs to an additional risk analysis regarding health and safety for preventing incident and accident.

William T. Fine [18] developed a mathematical evaluation for controlling hazard. His method gives a fast an overview of seriousness of hazards by calculating the score of risks which in turn calculated risk scores can be arranged in rank ordering in order to which one requiring most attention for corrective actions. Risk (R) calculation or risk score is a function of three factors: potential Consequences (C) of an accident, the frequency of Exposure (E) to the hazard event and Probability (P) that hazard event will lead to the accident and its consequences.

$$RR = CC \times EE \times PP$$

Each factor has descriptions and numerical ratings.

It is recommend during maintainability design phase, maintenance engineer and ergonomist start to simulate "work as-imagined" (idealistic view of formal task), ergonomic evaluation (relevant tools) and health and safety (William Fine method) risk assessment. These simulation give an over view of an idealistic work risks detection. By rank ordering risks list (descending number of product RR) start to think what should be done (correct action), who is responsible for measuring, due date and action taken. Many of risks can be reduced before real work starts. The next step will be re-evaluate risks in order to see the reduction of severities' degree.

Identified risks have three alternative: eliminating, reducing or accept as it is. In the case of last two alternatives, it is obligatory to protect exposed staffs from risks by personal protective equipment and/or education and information. When the real task start there is a possibility that new or latent risks discover. In this situation, the earlier analyzed risk should be updated.

Another advantage of W. Fine's method is the justification for recommended corrective action. Once the hazard identified and the cost of corrective action estimated it can calculate whether estimated cost is justified or not.

In this fraction numerator is R, the product of consequences (C), of exposure (E) and probability (P).

The formula is:

$$Justification = \frac{Consequences \times exposure \times probability}{Cost\ factor \times Degree\ of\ correction}$$

$$J = \frac{C \times E \times P}{CF \times DC}$$

Each element has description and numerical rating. The critical justification rating is 10 that is, if contemplated corrective action is:

$$Justified > 10 > Not\ Justified$$

For tool maintainer of the considered process, William Fine method used. Three factors contributed in the degree of hazard seriousness: Severity (S), Exposure (E) and Probability (P).

Severity description is from minor cuts, minor damage, to catastrophe for numerous fatalities and their ratings start from 1 to 100. Severity classified in five levels. See table 1:

TABLE I. SEVERITIES LEVELS

	Description	Lower rate	Highest rate
C 1	Minor damage, minor cut, headache, bruises, damage that can lead to less than 10 days sick absent,..	1	3
C 2	Burning damage, minor fractures, diseases with less disability, asthma, sick leave between 10-60 days,…	3	8
C 3	Fracture minor amputation, non-lethal poisoning, more than 60 days sick leave,..	8	15
C 4	Larger amputation (hands arm, legs, eyes) cancer, deadly damage,..	15	30
C 5	Very serious injuries affecting many people, fatalities	30	100

Exposure start from very rarely to continuously or many times per day, and its rating start from 0,5 to 10. It classified in seven categories and provided in Table 2.

TABLE II. EXPOSURE TIME TO THE HAZARD EVENT

	Description	Lower rate	Highest rate
E 1	Very unlikely. It is not known that it may happen	0,5	0,5
E 2	Possible. It is known that it may happen.	1	1
E 3	Irregular. This can happen from once a year to once a month.	2	3
E 4	Occasionally from once a month to once a week	3	4
E 5	Common from once a week to once a day (shift)	4	6
E 6	Often more than once a day (shift)	6	8
E 7	continuously or many times per day	8	10

Probability is classified in sex categories and it rating span is from 0,5 to 10 and shown in Table 3.

TABLE III. SEQUENCE OF ACCIDENT

	Description	Lower rate	Highest rate
P 1	Very unlikely, but possible	0,5	0,5
P 2	Unlikely, but possible	1	1
P 3	Rare	2	3
P 4	Often. It is likely that it occurs at 5-25% of exposure	3	4
P 5	Probably. It is likely that it occurs at 25-50% of the exposure times	4	6
P 6	Very probable. It is likely that it occurs at over 50% of exposure time	8	10

In this case, the health and safety group chose the degree of severity according Table 4.

TABLE IV. SEVERITY DEGREE

Degree of severity	$RR = CC \times EE \times PP$	
	Lower rate	Heights rate
No risk	0,5	10
Acceptable risk	11	30
Moderate risk	31	100
Serious risk	101	300 and above

TABLE V. IDENTIFIED RISKS FOR TOOL MAINTAINERS AT THEIR WORKPLACE ARE

No	Identified Risks	Degree of severity (R)	Recommended measure	Measured	Reassessment of (R)
1	Collision between cranes because of several cranes	360	Collision protection between all cranes	Done	3
2	Because of cramped between tools' table (tools working bench) there is a risk of collision with the other tool that stand on its bench.	360	Education, information about risk in order to keep himself away and make sure no one stays between tools	Done	180
3	Work under suspended load.	180	Prepare stands that tool can be put on for working under tool	Done	0,25
4	During turning tool, there will be strong fold on chain with wide angle.	120	Daily check of crane and its accessories continuous education and information	Done	4
5	Labeling tool weight there is a risk overloading the crane accessory	80	Marking clearly tool weights	Done	2
6	Lifting with magnetic device.	60	Information and education take a distance with load	Done	60
7	Other people who walk in the hall show very poor respect to those who drive crane.	40	information about the risks or forbid to go through the workshop	Done	0,25
8	Risk of hitting the head to chain	16	Information about risk	Done	16

VI. RESULTS &CONCLUSION

The concept of safety first is digested and accepted nowadays in everywhere. Understanding system is a key issue in order to up to what extend its performance fill system designers' expectaion and their value. Faulty design system may have negative side effects on health and safety for poeple invoved as well as internal and external environment. Designing well functioning system required multi-desiplinery uppdated knowledge. Maximizing system's perfomance is a function of knowledge and ability to the details analysis of hinders. That is, using relevant evaluating tools is key factors for system's safety (technical functioning), human's health and safety and how assimilating system to the environmetal requirement. In this paper two relevant tools HTA and Willam Fine intrudced for maintainability process. Application of them will lead better understanding of real work. According to the result of the study and based on table 4, it shows the degree of risks 1, 3, 4 have reduce from serious risk to no risk through corrective action. Risks 2 from 360 reduced to 180 due to minimazing probability but it is still in serious risk zone. Risk number 5 fron moderate risk level reduced to no risk. Risk number 6 has not changed and it is still in moderate level. Risk number 7 changed from moderate to no risk level and risk number 8 did not change and still in acceptable level.

TABLE VI. SUMMERY OF THE RESULTS

Risk No	Degree of severity (R)	Reassessment of (R)	Change in factors	Results
1	360	3	C, E and P	No risk
2	360	180	P	Serious risk
3	180	0,25	C, E and P	No risk
4	120	4	C and E	No risk
5	80	2	C and P	No risk
6	60	60	No changes	Moderate risk
7	40	0,25	C and E	No risk
8	16	16	No changes	Acceptable risk

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From networks to ecosystems: redefining inter-organizational transparency

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***Abstract* — Servitization and digitalization are two forces currently restructuring the industrial landscape. The next step for manufacturers becoming service providers is to take advantage of the servitization potential of big data that is generated by smart connected assets enabled by Internet of Things (IoT) technologies. As the concept of interdependency is now applied to the animate (i.e. organizations populated by individuals) and the inanimate (i.e. smart connected assets as industry's installed base), business networks are shading into complex business ecosystems. In order to guarantee effective service provision, organizations should be willing to share the above-mentioned big data, although such disclosure has been repeatedly proven as problematic in the past. The aims of the paper are twofold; (1) to map and categorize the reasons for failed transparency (i.e. issues and barriers) by conducting a literature review, and (2) to understand through multiple case studies how IoT is able to support information disclosure.**

Five types of issues and barriers are identified; (1) Asymmetrical power relations and opportunism, (2) Inter-personal relations and individuals' traits, (3) Poor commitment and inadequate relational support, (4) Insufficiency of data arising from methods/systems, and (5) Weak incentives and unresolved benefit sharing. The findings from the two case ecosystems indicate that IoT resolves each problem either directly or indirectly. As far as the theoretical implications are concerned, the paper provides a systematic listing of reasons for failed transparency and carries a suggestion that scientific discussion on inter-organizational relationships should focus on business ecosystems as the concept of business network is no longer congruent with the state-of-the-practice. The introduction of IoT plays a significant economic role in both case ecosystems, which should be of interest to managers and other practitioners.

Keywords* — *inter-organizational relationships; business ecosystems; Internet of Things (IoT); big data; transparency; information disclosure; issues and barriers

I. INTRODUCTION: NETWORKS AND ECOSYSTEMS

The role of services and service provision is rising across the industries. Machine and equipment manufacturers are becoming service providers by creating solutions and offerings to customers, which are comprised of conventional products and specialized services [1-5]. This kind of modus operandi where an organization transitions from selling products to providing advanced product-service hybrids is referred to as 'servitization' (see e.g. [6] for a recent literature review). Kowalkowski et al. [7] make a further distinction between servitization and 'service infusion' that are often applied interchangeably. According to them, service infusion is the process where the relative importance of services increases, while servitization is the revolutionary shift from a product- centric business model and logic to a service-centric one. Hence, servitization requires organizational and managerial philosophies that extend beyond the infusion approach.

Apart from the infusion of services, 'digitalization' is another factor that is changing industries and transforming competition by inducing another layer of complexity in the form of smart connected assets [8-9]. Smartness and connectivity are two qualities that are enabled by Internet of Things (IoT) technologies, e.g. Radio Frequency Identification (RFID), Near Field Communications (NFC), Wireless Sensor and Actuator Networks (WSAN), and data storage (e.g. cloud computing) and data analytics [10-12]. Recent bibliometric study of Mishra et al. [13] shows that the fascination towards the vision and applications of IoT is growing in the academia. Opresnik and Taisch [14] even suggest that services are slowly becoming a necessary, but insufficient condition for reaching lasting competitive advantage, i.e. services are commoditized. Based on this particular notion, they further argue that the next step in servitization is to capitalize on the big data that smart connected assets are generating. Novel information and communication technologies, including IoT, may therefore have a catalytic effect on industrial service provision [15].

According to Cenamor et al. [16], the creation of 'platforms' is a good way for manufacturers to leverage the value of digitalization and avoid the so-called servitization paradox, which means that increased revenues from service business do not translate to higher profits [17]. Gawer and Cusumano [18] define platforms as products, services or technologies that provide the foundation upon which outside organizations can develop their complementary products, services or technologies. In the IoT servitization context, platform is a combination of product-technology (i.e. smart connected asset) and services that are founded on the understanding of customer needs by collecting, storing and analyzing data from the assets on the field. In terms of Kowalkowski et al. [7], platforms are a move to a service- centric business model and logic that puts next generation, data-driven services in the center of the offering. It should be however acknowledged that original equipment manufacturers (OEM) do not have exclusivity on these kinds of services, as third-party providers may also tap into the potential.

Iansiti and Levien [19] argue that successful 'business ecosystems' are often founded on a platform strategy that not only enhances the performance of the keystone organization (e.g. OEM), but also that of ecosystem's other inhabitants. Moore [20-21] is the pioneer who first drew the parallel between natural and social systems by discussing about the new ecology of competition and introducing the metaphor known as business ecosystem. He then outlined it as "the organism of the business world", i.e. an economic community supported by a foundation of interacting organizations and individuals. As business ecosystems comprise a large number of stakeholders and even closest competitors, they can be perceived as forms of extended networks, a construct that is comparable with the understanding of business networks as extended enterprises. What is lacking from Moore's seminal characterization is the idea of installed base (i.e. smart connected assets) as the third interacting species alongside organizations and individuals in modern business ecosystems. By referring to this installed base as a fleet, we define (business) ecosystem in this paper as follows…

Ecosystem = ***Network*** *(of organizations / individuals)*

\+ ***Fleet*** *(of smart connected assets)*

The development of business ecosystems that revolve around the service-driven platforms causes unprecedented complexity to the industrial landscape. Instead of seeking to reduce complexity, Eloranta and Turunen [22] suggest that organizations should embrace the challenge of managing and orchestrating complex inter-organizational relationships either by connecting actors, sharing resources or integrating systems. Out of these logics, the most applicable to data-driven services is the sharing resources approach in which organizations are encouraged to establish deeper connections, build trust, and provide each other access to proprietary resources, including the vast amounts of data that originate from the fleet. This technical data dimension can be complemented with the exchange of economic big data that is available in the accounting and management information systems [23-24].

Simultaneously, it has to be also pointed out that such information disclosure has often been problematic in the context of traditional business networks [25]. Is it therefore possible that IoT – a new kind of mechanism forming interdependencies – has the capacity to foster transparency?

The aims of the paper are twofold; (1) to map and categorize the reasons (i.e. issues and barriers) for failed transparency, and (2) to understand how technological development (i.e. smart connected assets enabled by IoT) might resolve them. By building on the research aims, our research questions can be phrased as follows…

RQ1: *What are the issues and barriers that compromise inter-organizational information disclosure and thus the success of business networks?*

RQ2: *How IoT technologies support inter-organizational information disclosure and thus promote the transition to business ecosystems?*

In order to answer to the RQ1, a literature review was conducted by targeting two large scientific databases: ScienceDirect (Elsevier) and Emerald Insight. Authors' prior experience with the topic governed the selection of the databases. Keywords including, e.g. 'inter-organizational', 'inter-firm', 'relationship', 'partnership', 'network' and 'collaboration', were combined with 'information disclosure', 'information transparency', 'information sharing' and 'open-book accounting' in order to look for matching research agenda. The search resulted in a large number of publications that were then screened for indications of issues and/or barriers, which are causing problems in the inter-organizational interface. We tried to include both qualitative and quantitative research in the literature review so that the overall picture of the situation would be more complete and compelling.

As shown in **Table I**, five categories of issues and barriers that have been reported to either hinder or even prevent the success of business networks were identified while mapping the above-mentioned databases. They are:

- I/B:1 (Asymmetrical power relations and opportunism)
- I/B:2 (Inter-personal relations and individuals' traits)
- I/B:3 (Poor commitment and inadequate relational support)
- I/B:4 (Insufficiency of data arising from methods/systems)
- I/B:5 (Weak incentives and unresolved benefit sharing)

The five categories in the table are consequently also our definitive answer to the RQ1, i.e. "what are the issues and barriers that compromise inter-organizational information disclosure and thus the success of business networks?"

TABLE I. LITERATURE REVIEW: THE ISSUES AND BARRIERS

Author	Ref.	*I/B:1*	*I/B:2*	*I/B:3*	*I/B:4*	*I/B:5*
Seal et al. (1999)	[26]		X		X	X
McIvor (2001)	[27]	X	X	X	X	
Kulmala et al. (2002)	[28]				X	
Dekker (2003)	[29]	X				X
Kulmala (2004)	[30]				X	X
Seal et al. (2004)	[31]	X	X			
Kajüter & Kulmala (2005)	[32]	X	X	X	X	X
Free (2008)	[33]	X	X			
Paulraj et al. (2008)	[34]			X	X	
Agndal & Nilsson (2009)	[35]				X	
Suomala et al. (2010)	[36]	X	X		X	X
Agndal & Nilsson (2010)	[37]	X				X
Möller et al. (2011)	[38]			X		
Cheng (2011)	[39]	X				X
Kumra et al. (2012)	[40]	X		X		
Caglio & Ditillo (2012)	[41]			X		
Romano & Formentini (2012)	[42]	X				X
Fayard et al. (2012)	[43]				X	
Windolph & Möller (2012)	[44]	X				
Jakobsen (2012)	[45]		X			
Rajaguru & Matanda (2013)	[46]			X	X	
Alenius et al. (2015)	[47]	X				
In total		**12X**	**7X**	**7X**	**10X**	**8X**

In order to answer to the RQ2, case study method was chosen as the form of scientific inquiry. Two cases and thus ecosystems are discussed, i.e. Norwegian oil and gas and Finnish pulp and paper. The data collection relied on three sources of information: prior literature, two semi-structured interviews and organizational documents. As far as the interviews are concerned, the discussed topics retained the nature of inter-organizational relationships, the extent of data/ information disclosure, the implementation of ecosystem-level tools, methods and systems (incl. IoT), and the state of data quality and access. The following two chapters (II and III) provide full case descriptions of both ecosystems, while case comparison is presented in conclusions and discussion (IV).

II. ECOSYSTEM I: TECHNOLOGY AS AN INTEGRATOR

In the first case example, we take an industry-wide glance to IoT technologies. The benefits of IoT are discussed in the context of the ecosystem (i.e. the Norwegian oil and gas).

A. A transition from conventional to integrated operations

As a response to declining competitiveness, oil and gas producers supported by the Norwegian government decided to initiate the industry's third efficiency leap program in 2003-2004, where organizations would gradually switch to an Integrated Operations (IO) -model [48-50]. Whereas the two previous efficiency leaps had focused mainly on developing better drilling and production techniques, the ambition behind the third is to integrate onshore and offshore operations with novel information and communication technologies across traditional organizational boundaries. The concept of IO is comprised of eOperations [48-49] and eMaintenance [50] approaches combined with smart connected assets, the intelligence of which stems from IoT, e.g. sensor technologies and wireless data transfer. The first IO phase (2003 – 2011) focused on bridging the gap between onshore and offshore operations. Since then, more emphasis has been put towards improving inter-organizational collaboration, which is also the main objective of the second IO phase (2006 – 2018). [51] Because of the IO, the industry has undergone a major restructuring that has brought the producers, service providers, and support and supply organizations closer together [48].

B. The wide spectrum of technological solutions and benefits

So that the IO could be successful, the industry needed a neural network that is capable of integrating organizations' onshore and offshore operations. Since 1998, the oil and gas companies have had an industry-wide information system, Secure Oil Information Link (SOIL), at their disposal [48-49]. SOIL is a closed system that is not only reliable, but also extremely secure due to access control. Fiber-optic cables on the Norwegian seabed complemented with radio and satellite communication guarantee a large data bandwidth for its users. A variety of applications are run within the SOIL including RigCamp (i.e. a standardized way to transfer data, e.g. files and audio/video) and SOIL Directory (i.e. a database solution that facilitates the search of services and competencies among SOIL member organizations and their employees) [48].

The existence of SOIL enables the adoption of novel technologies, as there is an easy way to transfer data from offshore to onshore and vice versa. Technological solutions that are utilized to gather data from offshore platforms and other sites include sensors and actuators, automation and remote control, CCTV-monitoring, VisiWear-devices and wireless data transfer [48-50]. An important role in the industry's data-driven decision-making is played by onshore support centers (OSC) that control drilling activities and operations and maintenance. Decision-making in OSCs is supported by another set of technologies, including virtual conferencing facilities, SMART Boards, online diagnostics and prognostics, and 3D visualization/simulation tools [48-50]. OSCs are filled with expertise as engineers, geologists and analysts collaborate intra- and inter-organizationally. It is not unprecedented that personnel from two organizations (e.g. producer and service provider) are located in the same OSC.

As far as the benefits of the IO are concerned, OSC- prototype center introduced by one of the largest oil and gas producers in 2003 is a success story worth mentioning. Cumulative cost savings from its first two years of operation were up to USD 22 million that were realized by reducing direct man-hours and offshore-onshore transportations [48]. The payback period of the initial USD 5.5 million investment to the OSC-prototype was only seven months. In the larger scale, the savings potential of IO is even more substantial. Some have suggested that the operating costs are going to decrease by 30 percent, while the recovery efficiency of deposits increases by 10 percent [49]. In monetary terms, the industry-wide savings potential is around USD 30 billion [51].

C. Trusting culture as the foundation for transparency

We wanted to untangle the reasons behind Norway's success by interviewing the Integrated Operations Advisor (IOA) of an oil and gas exploration and production company that operates on the Norwegian continental shelf.

Would you state that you typically pursue closer and longer relationships, i.e. exchange beyond simple transactions, with key suppliers/customers?

IOA: *"Yes, definitely. It is an integral part of the Norwegian working culture. We pursue long-term relationships especially with the largest suppliers. Contracts are, at least, five years long with extensions of two or three years. We have even embedded offices with couple of our key suppliers."*

How are benefits shared between you and key suppliers/customers?

IOA: *"Everything depends on the contracts that we have. They are based on risk-reward considerations, which means that we pay for performance. These types of contracts have recently become very common in the industry."*

Do you disclose data/information with your key suppliers/customers?

IOA: *"Yes, we are very transparent. I think that the transparency stems from the working culture that I mentioned. Even so, we are still ahead of most Norwegian companies in this matter. Contractors, for example, have access to our IT-systems, but there are non-disclosure agreements (NDA) in place."*

What type of data (e.g. economic, technical etc.) do you usually disclose?

IOA: *"Well, I would say that mostly technical data that is available via SAP. We do not disclose cost information as such, but people are aware of these things as we work so closely together. However, macro-level economic data, such as budgets, are shown directly to partners in our meetings."*

What is the direction of exchange and the boundaries to openness?

IOA: *"We are very transparent as I said, but everything depends on the language in the contracts. We are often more open towards exchange of information than service companies that we work with. Contracts define the boundaries as well. We have certain three-way relationships."*

What are the actual tools, methods and/or systems that are used specifically to disclose information with your key suppliers/customers?

IOA: *"We have lots of them on several organizational levels. Microsoft toolbox is common, although we try to avoid Excel-spreadsheets. We arrange video conferences especially with our suppliers, and data is moved around using the industry standards, which are important. We also have custom-made tools that are specifically designed for inter-organizational collaboration."*

What are the most important and promising IoT technologies?

IOA: *"We are constantly working on sensor technologies and automation as we would like to reduce human impact in order to avoid mistakes. We also have on-going projects around artificial intelligence and robotics as well as new communication and collaboration systems. However, sensors are the main thing for us; we want new sensors, more sensors, wireless sensors, and smart sensors that can communicate. I would also like to see advanced analytics that looks for correlations in data and makes predictions."*

What is the role of fleet asset management, i.e. managing multiple assets instead of an individual asset?

IOA: *"Our approach is quite asset-centric, but there is variation depending on the organizational level. The big picture is not currently integrated, as the upper management does not have fleet-specific information in their decision-making views. Situation is getting better though."*

Do you think that data/information quality is adequate for decision-making, i.e. enough for utilizing those tools, methods and systems?

IOA: *"There are certain issues in quality, but significant improvements have been made. We have been working with a big name from another industry, where they have a lot more elaborate sensors than we do. Measure what you want to manage as they say, we are not entirely there yet."*

Do you always have full access to the data that your assets generate?

IOA: *"Unfortunately, we do not. There are multiple systems and databases, which are not entirely integrated to each other. We are constantly working on big data solutions to solve these problems. We have data coming from drilling sites that is pre-processed by our suppliers before we get our hands on it. We are now looking to re-process that data retrospectively."*

III. ECOSYSTEM II: REINVENTING MAINTENANCE

In the second case example, we take a relationship-specific glance to IoT technologies. The benefits of IoT are discussed in the context of the ecosystem (i.e. the Finnish pulp and paper).

A. The critical role of calender rolls in papermaking

Production process on a paper machine (incl. finishing treatments) is typically comprised of multiple phases, such as forming, pressing, drying, slitting and reeling. Depending on the paper type, finishing can also contain coating, surface sizing and calendering. [52] Due to its series-connected nature where production phases follow each other in a sequence, papermaking is very sensitive to unexpected malfunctions. Calendering, which improves paper surface properties (e.g. smoothness and gloss), adjusts paper thickness and levels the paper caliber profile [52], is maintenance-wise an interesting process phase as calender rolls wear out relatively quickly.

As paper web is led through a series of nips of rolls in the calendering, the total quantity of potentially malfunctioning rolls is considerable. There are also various roll positions, of which some are more prone to errors than others. To detach and replace a defective roll, production has to be stopped, which causes production losses. Our focus in this example is specifically on a case machine that produces SC-paper that is an uncoated and calendered grade of paper used widely in magazines, catalogues and brochures. Calender rolls are nowadays saturated with sensors that generate lots of data, which can be used to reduce unexpected stoppages and production losses by improving the uptimes of calender rolls.

B. Sensor-based roll maintenance: the savings potential

The entire Ecosystem II is naturally larger, but we have limited the scope to two case organizations in this study. Company A is a paper producer and the owner of the case machine, whereas Company B is a maintenance service provider and the OEM of the case machine. They have set recently in motion a joint big data project that focuses on utilizing sensor data in the maintenance of calender rolls. Within the limits of the project, Company B has an unlimited access to the production data of Company A in order to develop maintenance practices. On behalf of both companies, we have estimated the savings potential. This is illustrated in **Table II**, where the baseline situation is checked against a scenario that incorporates sensor-based improvements.

The calendering phase on the case machine is comprised of three coated rolls in difficult positions, five coated rolls in normal positions, and six thermorolls. The difference between a difficult position and a normal position lies in the uptime that can be five times longer in the latter. As the basis of the calculations in the scenario, we have estimated that – by analyzing patterns in the production data – uptimes can be increased by a week in difficult positions (i.e. from three to four weeks) and by four weeks in normal positions (i.e. from

sixteen to twenty weeks). As thermorolls are highly durable, their uptimes cannot be influenced with data analysis. Malfunctioning rolls are detached, serviced and eventually recoated after a few rounds of service (approx. five rounds to coated rolls and eight rounds to thermorolls). When the uptimes are improved (diff. / norm.), the number of calender rolls that have to be serviced and coated annually diminishes.

TABLE II. ROLL MAINTENANCE: BASELINE VS. SCENARIO

	Baseline	Scenario
Cost of downtime:		
Difficult roll positions	10 500 000 €/a	5 440 000 €/a
Normal roll positions	3 210 000 €/a	1 940 000 €/a
Thermoroll positions	1 170 000 €/a	1 170 000 €/a
Annual costs	14 880 00 €/a	8 550 000 €/a
Cost of roll service:		
Serviceable rolls (average)	63.2 pc/a	48.7 pc/a
Costs per service	30 000 €/pc	30 000 €/pc
Annual costs	1 900 000 €/a	1 460 000 €/a
Cost of roll coating:		
Coatable rolls (average)	8.1 pc/a	6.3 pc/a
Costs per coating	120 000 €/pc	120 000 €/pc
Annual costs	970 000 €/a	750 000 €/a
Total costs:	17 750 000 €/a	10 760 00 €/a
Change in €	-	- 6 990 000 €/a
Change in %	-	- 39,4 %

Minute adjustments in the uptimes of calender rolls have massive overall ramifications as the total costs plummet up to 39 percent from the baseline. The majority of this figure follows from the decreased cost of downtime especially in difficult roll positions. In monetary terms, the whole savings potential (~ EUR 7 million) is multiple percentages of the worth of annual production of Company A. It should be acknowledged that in reality the situation is never quite as drastic because there are complementary production units to the case machine and the paper demand fluctuates as well.

C. Towards improvements with a partnership arrangement

To be able to compare the two ecosystems, we decided to interview the Director of Operations (DOO) of Company A with an identical frame of questions than in Ecosystem I.

Would you state that you typically pursue closer and longer relationships, i.e. exchange beyond simple transactions, with key suppliers/customers?

DOO: *"Well, it really depends on the extent of our mutual business. With Company B, for example, we have a partnership agreement, which means that we are fully committed to joint business development. However, these kind of agreements are quite rare and lately in a decreasing manner."*

How are benefits shared between you and key suppliers/customers?

DOO: *"We set objectives, but benefit sharing has not been defined."*

Do you disclose data/information with your key suppliers/customers?

DOO: *"Not typically, no. We have sporadic relationships where small amounts of transparency take place. In this regard, the collaboration with Company B is currently rather unique in our relationship portfolio."*

What type of data (e.g. economic, technical etc.) do you usually disclose?

DOO: *"I would say that Company B is getting strictly technical data at this point of the project. Of course, there are things, such as spare part prices, which have to be openly discussed due to the fact that they provide basically all-inclusive maintenance at our plant."*

What is the direction of exchange and the boundaries to openness?

DOO: *"Within the limits of the on-going big data project, we send large amounts of process and sensor data to Company B, where it is analyzed and refined to models. Data is disclosed unilaterally, but in return, we receive models that are utilized to improve our operations and maintenance. Boundaries are always dyadic, as we do not have three-way relationships."*

What are the actual tools, methods and/or systems that are used specifically to disclose information with your key suppliers/customers?

DOO: *"As far as the relationship with Company B is concerned, we had a working committee discussing about this subject in the beginning of the big data project. I am not an expert on information systems, but I have understood that it is a crude set-up. Data goes from our sensors to a server, which is the location from where we sent updated data packages daily to Company B."*

What are the most important and promising IoT technologies?

DOO: *"As we have currently invested in the development of data-driven roll maintenance, sensor technologies are important to us. In this respect, we cannot forget control and automation systems either. Our laboratory instruments are also connected. If we think about the full potential, we should concentrate on the analyzers that are pre-processing the data in the field."*

What is the role of fleet asset management, i.e. managing multiple assets instead of an individual asset?

DOO: *"I would say that each paper machine is so unique that it is difficult to make reasonable comparisons. Nowadays technology also evolves fast and investments in new machines are made every ten years or so, which means that different machine generations are a factor. I think that a fleet approach makes more sense on the roll level, although we do not employ the terminology."*

Do you think that data/information quality is adequate for decision-making, i.e. enough for utilizing those tools, methods and systems?

DOO: *"It remains to be seen. As the big data project started only a few months ago, we are still in the beginning stages. Whether the quality is enough or not, we do not really know yet. I think that there is, however, a decent possibility that some new indicators on roll condition are still required."*

Do you always have full access to the data that your assets generate?

DOO: *"We have a pretty good access to the sensor data, but the difficulty lies in the variety of data forms. We have time-based data, event-based data and so on. It is challenging to combine different forms of data in order to be able to calculate cause-and-effect relationships for instance."*

IV. CONCLUSIONS AND DISCUSSION

Table III summarizes the discussion on the ecosystems. Although both cases are referred to as ecosystems, they are different relative to the ecosystem characteristics presented in the table. Ecosystem I is a well-established setting, where companies build long-term exchange relationships, disclose data/information based on benefit sharing agreements, have systematic tools, methods and systems as the means of disclosure, and utilize IoT on daily basis. In comparison, Ecosystem II is still emerging. Companies A and B are learning inter-organizational transparency and ways to take advantage of sensor technologies, which establishes a premise for a long-lasting relationship in the future. As far as the dimensions of disclosure (i.e. type, direction and boundaries) are concerned, the ecosystems are surprisingly similar as mostly technical data/information is disclosed bilaterally in a dyadic fashion. Only exception is found from Ecosystem I, where occasional three-way relationships take place as well.

TABLE III. A COMPARISON BETWEEN THE CASES

Ecosystem characteristics based on the interviews	Ecosystem I	Ecosystem II
Long-term relationships	Yes, esp. with key partners	No, the case is an exception
Benefit sharing arrangements	Risk-reward contracts	No sharing arrangements
Disclosure of data/information	Yes, but still NDA protected	Yes, roll data as a pilot case
Disclosure: the type (e.g. technical)	Technical data, also budgets	Mostly technical data at this point
Disclosure: the direction/boundaries	Bilateral/ even triadic	Bilateral/ strictly dyadic
Systematic disclosure tools etc.	A large variety, e.g. custom-made	Packages sent from a server
The utilization of IoT technologies	Yes, sensors and even robotics	Yes, currently piloting sensors
Fleet asset management perspective	No, but improving for upper mgmt.	No, but potential on the roll level
The quality of data/information	Getting better, but requires work	Pilot ongoing, still unknown
Access to asset data/information	Limited due to complexities	As it stands, good to roll data

In the beginning of this paper, we defined ecosystem as a combination of network and fleet. Based on the interviews however, fleet perspective is hardly recognized by the practitioners. We assume that this stems rather from a terminological disparity between academic and managerial outlooks than a sentiment that the collection of data is somehow irrelevant beyond the asset level. The access to data/information plays an important role in forwarding fleet- centric thinking in both ecosystems. The fixed nature of the IoT application in Ecosystem II provides a good access to required data, while the situation in Ecosystem I is more complex due to a large number of technological solutions. Good data/information quality should also ensure that a more integrated fleet asset management is a future possibility.

We should address the RQ2, i.e. "how IoT technologies support inter-organizational information disclosure and thus promote the transition to business ecosystems?" Based on the cases, IoT can outweigh the issues and barriers directly and/or indirectly depending on the category. Direct influence occurs in I/B:3 (Poor commitment and inadequate relational support) and I/B:4 (Insufficiency of data arising from methods/systems). Regarding the former, technological joint initiatives, i.e. SOIL (Ecosystem I) and the big data project (Ecosystem II), are signals of commitment. Customers in particular are often responsible for laying the foundations that promote trust in their suppliers. By establishing SOIL as an industry-wide system, oil and gas producers and other stakeholders have achieved a culture of trust that has transformed into commitment. IoT advances also relational support in Ecosystem I. OSCs, where experts work side by side, are the pinnacle of collaborative, data-driven decision-making. Feedback is another type of relational support, an example of which are the models that Company B devises based on the production data that it receives directly from Company A.

In the case of the latter category (i.e. I/B:4), the link between the problem (i.e. insufficient data), and IoT as the solution is even more evident. Smart connected assets in conjunction with information systems are able to overcome issues and barriers related to data quality/access. Even though the poor state of (cost) accounting systems is recognized as the predominant reason for data inadequacy in the literature, it did not emerge in this particular study, likely because the information exchanges were mostly technical. Joint IoT, however, improves shared technical compatibility between organizations. The informant from Ecosystem I brought up standardization as an enabler of information disclosure. The basis of standards are contracts that also determine the guidelines for benefit sharing. Therefore, IoT may have an indirect effect on I/B:5 (Weak incentives and unresolved benefit sharing). Some of the companies in Ecosystem I also pay for performance, the measurement of which has become easier with technology. The contractual extensions can be seen as incentives for suppliers to perform better.

IoT has indirect influences in the remaining categories: I/B:1 (Asymmetrical power relations and opportunism) and I/B:2 (Inter-personal relations and individuals' traits). As individuals may act as gatekeepers of data/information, organizations are able to dodge problems by removing the human variable from the equation with technology. Reducing the impact of humans is a central development theme in Ecosystem I, where organizations seek to automatize parts of their decision-making processes. As calender roll maintenance is a labor-intensive task, the big data project (Ecosystem II) is evidently built around similar objective. The scarcity of partnership agreements in the ecosystem is an indicator that calender rolls as the pilot case has facilitated the inter- organizational relationship between Companies A and B. The role that IoT plays in decreasing asymmetrical power and related opportunism (i.e. I/B:1) is more ambiguous. We can only speculate that the likelihood of opportunism should be decreased when organizations are fully committed to the development of joint technologies. The more powerful counterpart, often the customer, does not have to create a conflict that might have guaranteed disclosure in the past.

The paper carries two implications to the current theoretical knowledge; (1) a systematic listing of the reasons for failed transparency (i.e. issues and barriers) and (2) a suggestion that the concept "business ecosystem" should be increasingly emphasized in the scientific discussion as "business network" is no longer congruent with the state-of-the-practice. The managerial implications are twofold as well; (1) case-based evidence shows how IoT may support inter-organizational transparency, and (2) the economic significance of IoT applications is demonstrated from two complementary perspectives, i.e. industry and relationship. As the exploratory nature of the study imposes its limitations, the findings are preliminary. Further research could focus on the prerequisites that have to be reconciled (e.g. the role of fleet) before the transition from networks to ecosystems is absolute. Further case studies would also benefit from a longitudinal design.

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Implementation of Management System Maintenance in a Metal-mechanic Industry

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***Abstract*— This paper describes a simple and cheap computer solution for the organization and work in the Maintenance Department, developed in Microsoft Access® whose forms allow the management of requests for intervention in equipment or installations. Work Orders (WO) are generated which, in turn, are used to create general maintenance indicators, such as repair times and times between failures. These WOs record the individual labor costs, allowing the creation of indicators such as the occupation of the human resource or the overall cost in a given intervention. The list of items used in WOs is also updated in the database with the introduction of its price, image and supplier.**

In the way of the Industry 4.0, the data collection of an Automatic Saw, allow the visualization of the work done and collect some statistics of it. By following the machine's schedule, it is possible to establish maintenance plans focused on the use of it and not in the time elapsed from the last intervention or the working hours.

The Microsoft Access® application, that was created in this work, manages Corrective Maintenance, generates Preventive Maintenance documents, inventory items in Maintenance warehouses, manages machine list, human resources, and suppliers. The documents used in the maintenance, including the items and their suppliers and the time used by the Human Resources in the execution of the tasks, enable general indicators of the department functioning. The Automatic Saw machine form, shows the hourly statistics of its operation to facilitate the task of adjusting the maintenance plan to the reality of operation.

Keywords*— *Efficiency; Maintenance; database; Industry 4.0, Microsoft Access.

I. Introduction

According to data from the "Bank of Portugal", the metal-mechanical industry accounted for about one quarter of the number of companies, turnover and the number of people employed by the manufacturing industry [1]. This sector consists of 73% of micro-enterprises (<10 employees and <= 2 million euros of turnover) [2] [3] (Annex to Decree Law 372/2007 of 6 November, Article 2, point 3). Around 60% of turnover was originated in the external market [1]. In financial terms, the pressure on the sector is relatively small, individual information for 2013 shows that 25% of companies in the metalworking industry do not generate EBITDA, that is, profits from their operating activities, sufficient to support the interest resulting from their financial debt [1].

All companies want production systems and equipment to operate and be operated reliably. No organization wants production systems to stop, produce products that are of poor quality or that operate inefficiently. Unfortunately no physical asset works without fail for good. In many organizations, outages are the norm. Losses in quality and productivity are high. Delays in sending goods are frequent. Because most of these deficiencies are manifested as equipment-related problems, for example, faults or corrective maintenance actions, maintenance is too often blamed for all the problems that proliferate in this type of industrial facility. In fact, the reasons for these inherent problems are shared by all functional groups [4].

This work was performed after a need was identified in a metalworking company. Preventive Maintenance in the company is organized in two levels. In the "1st Level" maintenance is performed by the operator and at the "2nd Level", called "Preventive", is performed at greater time intervals by the Maintenance, due to the highest level of technical capacity required for its execution.

II. Arquitecture

A. *The motivation*

Microsoft Excel® has been used to manage and analyze large amounts of data in organizations. In the first phase, within the company, the author began to enter data using this tool. The objective was to keep track of time spent per intervention, so that over time the planned maintenance could be scheduled on a schedule.

Microsoft Access® is a database management tool that is the next step for the analyst who is faced with the steady increase in data volume. It does not have a predetermined number of columns and can manage relationships between different tables. In addition, Access® comes with the necessary tools that help us distribute the developed applications to users [5].

B. *System Arquitecture*

Before beginning the description of the architecture it is appropriate to clarify why this maintenance management

solution. Although there are many IT tools to manage maintenance, these have never been implemented in the company. The author thinks that the advantages of solution, maintenance management is the flexibility and the main disadvantage is that there is no to whom to appeal when it is intended to make a correction or improvement.

The requirements for the system to be developed were as follows:

• Customized Maintenance Management System (for professional use);

• Collection of machine data through MODBUSTCP;

• MySQL database for storing machine data;

• Access® application with dashboard of the main Maintenance and indicator of number of pending interventions and their classification;

• Possibility of generating various types of reports on the interventions carried out and on the types of outstanding interventions;

• List of Equipment with instantaneous listing of Work Orders executed;

• List of Materials / Products with the ability to add image for faster identification, datasheet, price and supplier;

• Possibility of sending an e-mail to the Logistics Department for the acquisition of materials and proposal to open new references;

• Management of the data associated with the traditional modules of a such as suppliers, human resources, intervention, work orders, etc ...

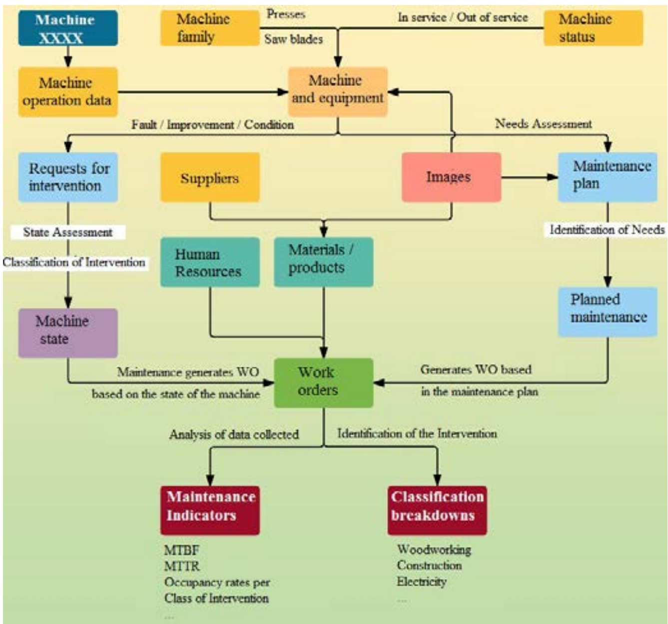

Fig. 1. General Flow Diagram of the information flow.

Based on the previous requirements, a general diagram of the Database Access is shown in Figure 1. The color of the diagram looks for identify levels of function to establish a relationship between Planned Corrective Maintenance and Unplanned and Planned Preventive Maintenance.

Figure 2 shows the block diagram of the whole system, namely, database, Raspberry PI®, and the PLC installed in the equipment chosen as a case study - automatic sawing.

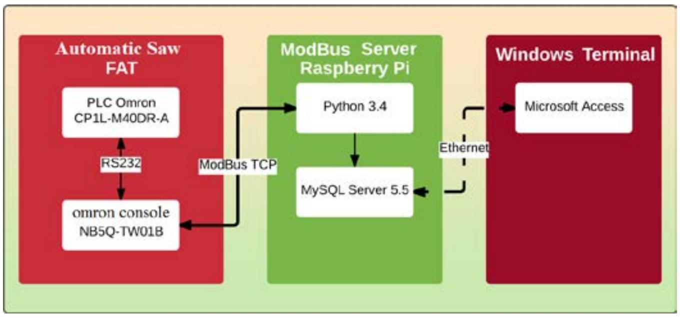

Fig. 2. Block diagram of the information system. FAT Automatic Saw (Machine XXXX).

The FAT automatic saw (Machine XXXX) allows cutting iron or steel pipes up to 100mm in side or 80mm in diameter with a maximum length of 6000mm. Allows perpendicular cuts, or at angles, with a maximum length of 3000mm.

Briefly, this saw operates as follows (ignoring the setup procedure):

- The tube is loaded manually into the saw loading tray;
- The machine loads a tube to start the cycle;
- When detected, the tube is pulled to the end of stroke that has been tuned in the setup;
- At this moment the tube is fixed by two pneumatic lathes driven by the machine;
- The cutting disc descends to the position defined in the setup by cutting the tube;
- The cut tube is then lowered into the receiving and draining casing of the cutting oil;
- After resuming the position of the unloading tray of the cut tube, the machine pulls the tube to be cut again, restarting the cycle;
- After the remaining tube passes a certain point, signed by a first inductive sensor, a new tube is loaded which pushes the tube being cut;
- In this way the length of the scrap tube is reduced by the maximum use of the length of the available tube.

Knowing that the console only allows to work in Master mode, it became necessary to implement a Slave solution to collect the information (Modbus Server). There are commercial solutions within Omron® but, in the sense of controlling costs, we chose to use Raspberry Pi® to make the MODBUS TCP server function using the Python language (Figure 3).

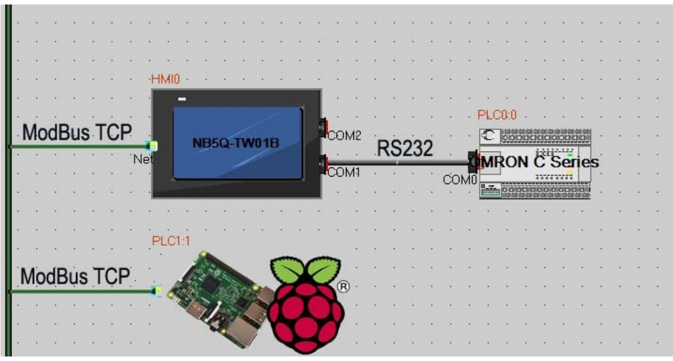

Fig. 3. Representation of the communication ports in the Saw NB5 console.

Data sent from the console, by MODBUS TCP, is handled by the Python application that handles and validates them. Hence the data is sent to the respective MySQL database table.

Table 1 indicates which data is received from the machine and the address that was used to receive each data type. In the example, in the memory of the PLC in word D502 the time in which the saw is connected is recorded. According to table information, each time the button connected to input 1.03 (Start) is pressed, the value of register D502 is sent to the server at address MODBUS 00.

TABLE I. ADDRESSING TABLE FOR DATA RECEIVED FROM THE SAW PLC MACHINE

Description	Trigger in PLC	Memory in PLC	Object in HMI	Address in the Console (HMI)	MODBUS Function	MODBUS Address
Start button pressed	200.04	1.03	DT0	0X - 1	00	00
Number of Loaded Bars	100.05	D610	DT1	4X - 7	06	06
Saw Time On	1.03	D502	DT2	4x - 1	06	00
Number of tubes discharged	200.05	D614	DT3	4X -9	06	08
Tubes Cut By Hour	200.05	D618	DT4	4X-11	06	10
Pipes loaded by Hour	200.05	D624	DT5	4X-13	06	12

The information presented in Table I allows, after inserted in the access database, to help carry out maintenance planning, depending on the variables listed.

III. MICROSOFT ACCESS® DATABASE MANAGEMENT

The maintenance management application in Access developed is shown schematically in Figure 5.

The organization of the tables focuses on the Machines, branching to the Intervention Requests (IR) that Generate Work Orders (WO). Figure 4 illustrates how all tables are related to each other. When the lines have an arrow it is considered that the ratio is from 1 to infinity (arrow) and when they do not have any arrow the ratio is from 1 to 1.

Turning to explain how the list of tables has been developed, it can be considered that all machines belong to a family (Presses, Millers, Lathes, ...) and that all have a current state (in service, out of service but in fixed assets, out of service and out of fixed assets). They also have at least one Maintenance Plan, a set of associated images and several materials that are part of it (valves, motors, inverters, oils, ...). On the other hand, they go through various locations within the plant, have several associated budgets, a list of components, which in turn are part of the bill of materials.

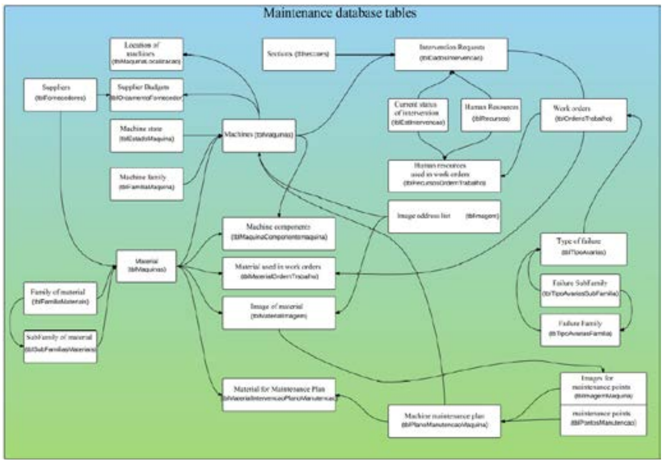

Fig. 4. Representation of the communication ports in the Saw NB5 console.

Each section (welding, presses, assembly, ...) can make several IRs and there can be several for a single machine. Each IR goes through a current state (In Scheduling, Awaits Material, ...) until the moment it is executed, and is requested by a company Human Resource.

For each WO there is an associated PI and is performed by various Human Resources normally belonging to the Maintenance Department. With the execution of the WO it is necessary to classify the type of damage identified for further analysis.

Figure 5 shows the relationship between the forms that allow the application user to enter data, update them and analyze all the information entered in the tables.

Section III.a will analyze in detail the forms created and some aspects that have been taken into account in their preparation. A brief presentation of these forms is given below in the main points.

The first form (Home), which appears when you run the application file, frames and links to all other forms directly or indirectly. When you open the form, the user can view the statistics associated with pending interventions and their distribution by the various states (In Scheduling, Waiting Material, ...). It is divided into several areas considered important during the work in the Department.

The Intervention Requests, where it is possible to add, then fill in the necessary data; search by number, text or machine, in order to obtain a list of cases that may fit the search and, from there, select the request that fulfills the requirements.

With the intervention requests created one can choose to create the associated WO. Again in the "Start" form you can search by number of WO and enter the data provided as material used, type of failure and time of execution. There is still the possibility of printing the clean WOs and some analysis of the occupancy of the human resources involved in WOs.

In the Material area it is possible to add a particular item that you want to buy, or supplier from where you want a quote or send an e-mail to the logistics to proceed with the order, which can later be consulted in another form and resent. In each of the material articles you can add an image, the budget for future reference or the respective technical information. The article search form, the material lists used per month as well as the inventory per warehouse are also accessible in the Material area.

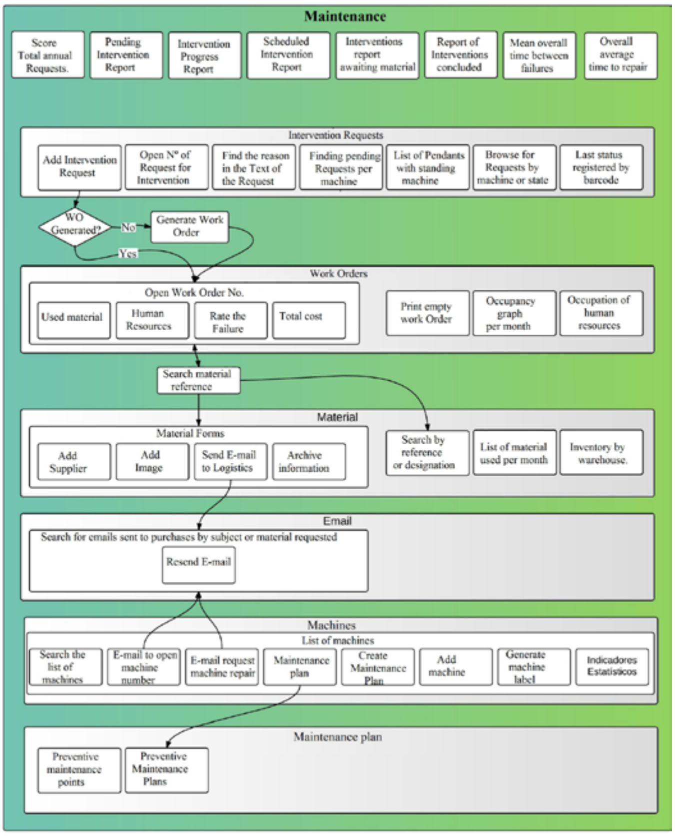

Fig. 5. Organization and distribution of forms.

As mentioned earlier, the list of machines is the basis of this application. It is dedicated to a form, accessed in the Machines area, which presents various information. If there are interventions previously performed and therefore with the respective WO completed, some indicators such as Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR) and Mean Waiting Time (MWT) of the machine appear. Of course there is the possibility of after machine search by number, send e-mail to open machine number by financial department, send e-mail to request transport guide for machine repair, add a machine or the Maintenance.

The area related to the Preventive Maintenance Plan comprises two forms. The creation of generic maintenance points, i.e., that can be applied to several machines (ex. Check Oil Level) and the creation of a maintenance plan for a particular machine (can be accessed directly on the machine form). In this plan, the pertinent information is added for a correct elaboration of the maintenance plan as, the periodicity of the execution, an image allusive to the action or location of the action and the material to be used if it is necessary. A field has also been added to place the planned time for action to check for variances.

A. Forms Organization

This section presents some of the forms built in Microsoft Access. The forms are in the Portuguese language.

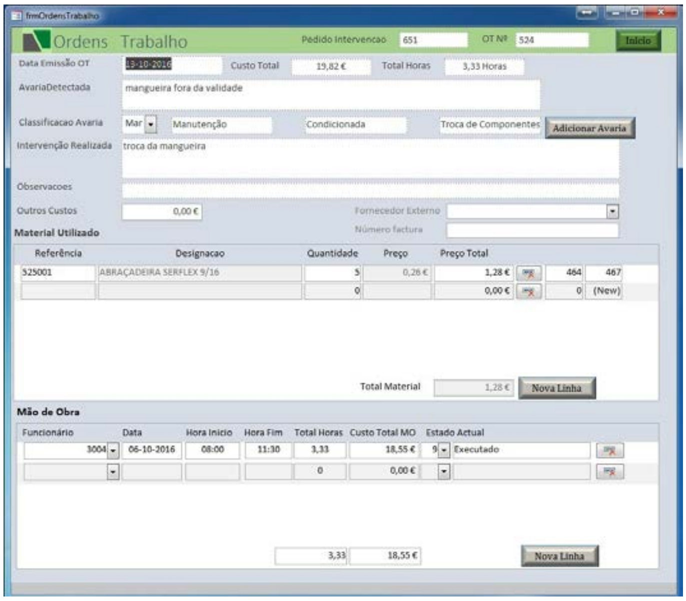

Fig. 6. Work Order Form.

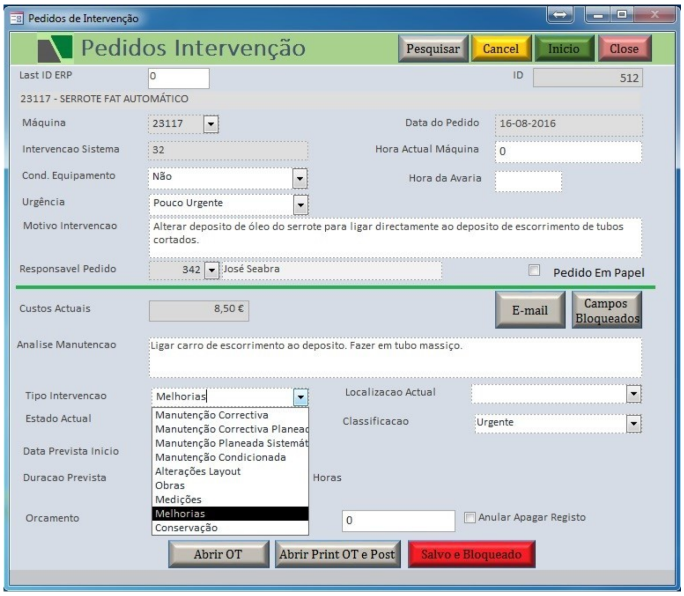

Fig. 7. Intervention Request Form.

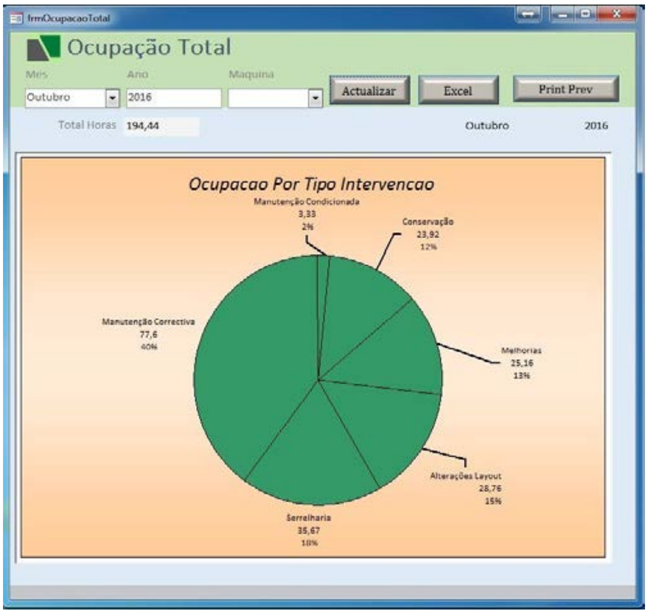

Fig. 8. Global Occupation.

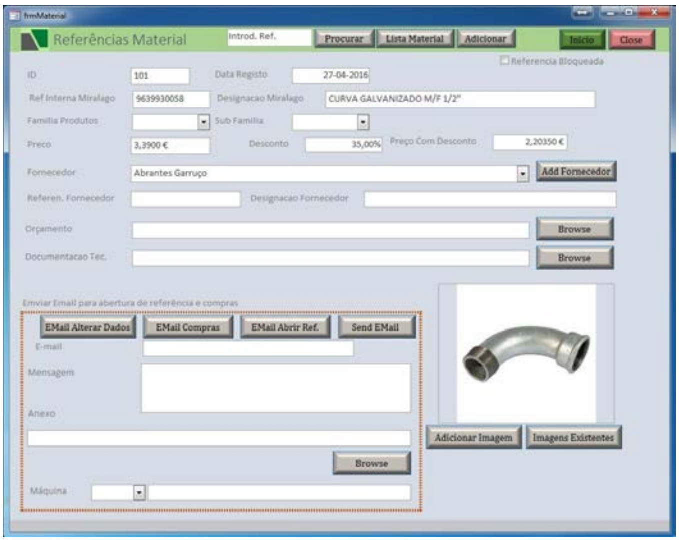

Fig. 9. Spare Parts Reference.

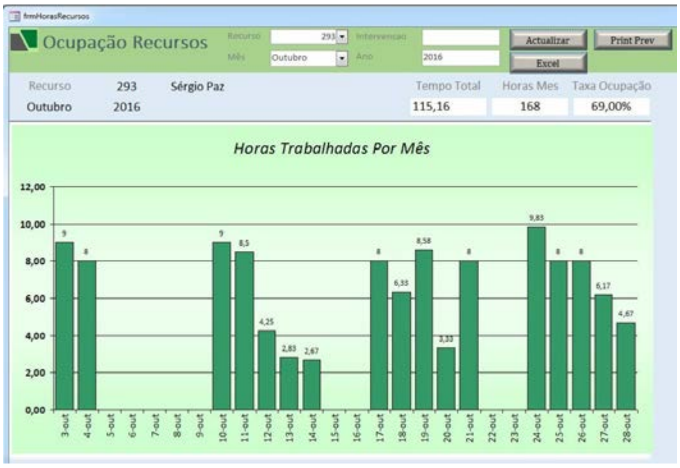

Fig. 10. Occupation resources.

Figures 6-10 present some forms of the developed Microsoft Access application. The implementation language was VBA.

IV. Conclusions and Future Work

This work had as fundamental objective the improvement, and the demonstration of the advantages, in the development of a database, of the activities within the Department of Maintenance of a company. Maintenance has always been seen as a solution to the problems of machines and equipment in general.

The use of existing hardware was one of the reasons for the success of this project. This is an inexpensive way to implement a machine data collection system without having to invest in processing systems.

There are other machine variables that could be collected, such as the consumption of the saw motor, the collection of vibration data from the disk, pressure variation on the pipe to be cut (tweezers) or the flow of cutting oil used.

With the impetus given by several multinationals like Intel, Google, Ericsson, etc., IoT (Internet of Things) and Industry 4.0, data collection on the machines can only improve. The distribution companies of electronic products dedicate pages with information and new products [6].

The collection of the above data could be carried out with some investment. The advantages of greater data collection will be better planning of interventions needed to keep the machine in perfect working order. Even corrective maintenance can be planned.

The use of Raspberry Pi was a logical choice for the price and ease of implementation. When you expand the network you will need a computer with greater capacity to manage the connections to your MySQL server. This computer can then be used on a machine, along with some sensors, to collect data.

Throughout the development process the author was noticing some limitations of Access software for database management. The use of links to images in the fields where they are used, instead of using the images within the database, limits the possibility of using the application by several users in places where access to a common network is more limited. Another possibility is the use of a remote server, with access to the users of the application, with the documents used (images, pdf, ...).

Maintenance documents generated, such as preventive maintenance, should be improved in their presentation. In addition, no solution has been implemented to produce Work Orders related to preventive maintenance, which are part of the annual maintenance plan.

Extending the collection of data to a greater number of machines will be an essential condition for a next step. From the survey conducted, there are good software solutions for maintenance in the industry. In some cases it is possible to collect data from the plant and the machines in real time, joining this data to the maintenance plan, it can be used to correct and / or change Maintenance Plans. With the

companies' cash flow limitations, they usually go to the end of the shopping list. The collection of a greater number of variables of operation of the machine will also be an aspect to implement. Using traditional sensors connected to existing PLCs or using a mini-PC with remote sensors, the assumptions are many and varied even using MODBUS TCP or Ethernet.

Acknowledgment

The author would like to thank the company involved, and all the people who contributed to this work.

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ISO 55001 - A strategic tool for the Circular Economy - Diagnosis of the Organization State's

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Abstract - Circular economics arises at a time when the needs for the reduction, reuse, recovery and recycling of materials and energy need to solidify, the current economy course, unsustainable in the short term; ISO 55001 defines a set of requirements that when implemented and maintained guarantee the good performance of an organization's asset management, responding to stakeholder needs and expectations and ensuring value creation and maintenance as well as a global vision of assets in a circular economy.
Organizations where physical asset management is of major importance include all those that involves: facilities, machinery, buildings, roads and bridges, utilities, transportation industries; oil and gas extraction and processing; mining and mining processing; chemicals, manufacturing, distribution, aviation and defense.
However, since ISO 55001 is a new standard in the global market, because it is intrinsically difficult to implement, a diagnostic model on the state of organizations can greatly help on the implementation.
Before beginning to implement the ISO 55001 standard, it is necessary to verify whether the organization is ready to begin this task. It is usually necessary to fine-tune many aspects before starting a great task like this. But where to start? What aspects do I need to correct before starting the default implementation?
This article proposes a diagnostic model to evaluate the state of organizations in relation to their potential to implement the ISO 55001. The diagnosis allows to identify the aspects of the organization that are ready to receive the new standard, the critical, the fragile and the weak points of the company that must be corrected.
The diagnostic model is based on surveys, with several questions and with five possible answers. Each possibility of response has a quantification and a critical classification.
The final result is a global positioning of the company with the identification of the various aspects to be corrected in order to be possible to implement ISO 55001. A radar chart provides a global "radiography" of the company diagnosis.
The diagnostic template has been validated and the results are presented in the document.

Key Words: Circular Economy; ISO 5500X; Sustainability; Industry 4.0

1. Introduction

The linear economy model that emerged with the industrial revolution has been applied up to the present day, based on the concepts of raw material extraction, processing and the end of life of products where they are discarded; this model uses exhausting materials and energy that makes it clearly unsustainable in the long run - basically everything in this model becomes garbage, which will cause environmental and also social problems and causing impact in the lives of others who are completely foreign to the process of which resulted this garbage.

Figure 1. Linear Economy [1]

In the current context, where increased consumerism and resource depletion introduces a new concept of circular economy, inspired by the natural ecosystems themselves, where everyone depends on products or by-products of others, and where resources regenerate and the cycle closes, the disposal of waste is small and all products and by-products are valued during the process, entering chains again within the same process or others, where nothing is lost and everything is transformed.

A circular economy is restorative and regenerative by project and aims to keep products, components and materials with the greatest utility and value at all time. A concept that distinguishes between technical and biological cycles, circular economy is a continuous and positive development cycle. It preserves and enhances natural capital, optimizes resource yields, and minimizes system risks through the management of limited stocks and renewable flows. A circular economy works effectively at all scales [2].

Circular economics offers multiple value creation mechanisms that are separate from the consumption of limited resources. In a true circular economy, consumption only occurs in effective biorhythms; on the other hand, replaces consumption. The resources are regenerated in the bio-cycle or recovered and restored in the technical cycle. In the biological cycle, life processes regenerate disordered materials, with or without human intervention. In the technical cycle, with sufficient

energy available, human intervention recovers materials and recreates order. Maintaining or increasing capital has different characteristics in the two cycles. The circular economy is based on three principles, each addressing the challenges of the resources and systems facing industrial economies.

1) Preserve and improve natural capital, controlling limited stocks and balancing flows of renewable resources. This starts by demystifying the utility by delivering them virtually, whenever possible. When resources are needed, the circular system selects them wisely and chooses technologies and processes that use renewable or better-performing resources whenever possible. A circular economy also increases natural capital by encouraging nutrient flows within the system and creating conditions for regeneration, such as soil.
2) Optimize the yield of resources, circulating products, components and materials with the highest utility in all technical and biological cycles. That means designing for remanufacturing, remodelling and recycling to keep components and materials flowing and contributing to the economy. Circular systems use tighter internal cycles as long as they preserve more energy and other values, such as work done. These systems also keep the product cycle down, extending product life and optimizing reuse. Sharing, in turn, increases the use of the product. Circular systems also maximize the use of end-use materials based on biological products, extracting valuable biochemical feedstocks and using them in different, lower and lower applications.
3) Promote the effectiveness of the system, revealing and removing negative externalities. This includes reducing the harm of human use, such as food, mobility, shelter, education, health and entertainment, and managing externalities such as land use, air, water and noise pollution, release of toxic substances and climate change.

While the principles of a circular economy act as principles of action, the following fundamental characteristics describe a pure circular economy:

- Waste does not exist when the biological and technical components (or "materials") of a product are designed to fit within a cycle of biological or technical materials. Biological materials are non-toxic and may simply undergo a composting process. Technical materials such as polymers, alloys and other artificial compounds are designed to be used again with minimal energy and high retention (while recycling, as often understood, results in a reduction in quality and is fed back into the process as matter - raw gross).
- Modularity, versatility and adaptability are valued features that need to be prioritized in a rapidly evolving world. Several systems with many connections and scales are more resilient in the face of external shocks than systems built simply for efficiency by maximizing production directed to extreme results in fragility.
- The ability to understand how the parties influence each other within a whole and the relationship of the whole to the parts is crucial. The elements are considered in relation to their environmental and social contexts. While a machine is also a system, it is strictly limited and assumed as deterministic. Thinking systems generally refers to the overwhelming majority of real-world systems: they are non-linear, high-interference, and interdependent. In such systems, inaccurate start conditions combined with interference lead to often surprising consequences, and results which are often not proportional to input. Such systems cannot be managed in the conventional, "linear" sense, requiring more flexibility and more frequent adaptation to the changing circumstances.
- For biological materials, the essence of value creation lies in the opportunity to extract additional value from products and materials by linking them through other applications. In biological decomposition, whether natural or in controlled fermentation processes, the material is divided into stages by microorganisms such as bacteria and fungi that extract energy and nutrients from the carbohydrates, fats and proteins found in the material. For example, going from a tree to the furnace loses the value that could be availed through state decomposition through successive uses like wood and wood products before deterioration and eventual incineration.

Figure 2. Circular Economy [1]

According to Douwe Jan Joustra (2017) there are ten key points in the implementation of a circular economy, one of which is

asset management [3]. Assets are physical, but they can also involve people, information or data. Assets are required to perform the services that are the basis of the contract with your customers. Although information and people are fundamental, in this context we talk primarily about physical assets, which can be of all kinds of scale: a drill is one and oil rig as well. Asset management is critical to creating good performance. Asset management and maintenance are often considered the same. From a circular perspective, asset management goes a step further. The challenge is to use the best possible performance of the assets within acceptable risks and at controlled costs over their useful life to deliver the services within the customers' expectations. The assets are the company's capital and will be part of the resources that can be used for quality production.

What is asset management? What are these assets? ISO 55000 defines asset management as "coordinated activity of an organization to realize value of assets" and assets, such as: "An asset is an item, thing or entity that has potential or real value to an organization." Asset management involves balancing costs, opportunities and risks against the desired performance of assets, to achieve organizational goals. This balance may have to be considered in different time frames. Asset management also enables an organization to examine the need and performance of assets and asset systems at different levels. In addition, it allows the application of analytical approaches to manage an asset at different stages of its life cycle (which can start from the conception of the asset's need until its disposal, and includes the management of any post-disposal obligation). Asset management is the art and science of making the right decisions and optimizing the delivery of value. A common goal is to minimize the cost of living of assets; but there may be other critical factors, such as risk or continuity of the business, to be considered objectively in this decision making [4].

2 – State of the Art

According to Jones et al. (2014) in the United Kingdom, the oil and gas sector identified the need for an asset management approach to physical asset management in the late 1980s. The main drivers of change were, as manage safety (risk) and achieve financial efficiency [5].

In 1988, a fire at the Piper Alpha oil rig in the North Sea, linked to the subsequent Cullen Report for maintenance problems at a pump and safety valve, killed 167 workers. This accident, combined with the dramatic drop in oil prices in 1986, focused on the oil and gas industry on the need to adopt holistic asset management based on a life cycle approach. This focus on asset life cycle management has resulted in improvements in efficiency, safety and productivity in the oil and gas industry. UK water and electricity also adopted an asset management approach when they were privatized a few years later. Privatized water companies in England and Wales have also developed asset management in response to pressure regulation to minimize rate increases, while simultaneously improving the level of service provided to customers and addressing the problem of aging infrastructures. The Office of Water Services, the economic regulator of the water and wastewater industry in England and Wales, was created in 1989. OFWAT initially focused on improving data quality, setting service level objectives, and monitoring compliance with service levels.

The Australian Government, which identified the need to address infrastructure management early, promoted the development of asset management during the 1980s. The Institute of Public Works Engineering of Australia developed and issued the Australian National Asset Management Manual in 1994: introduced asset management concepts and provided guidance on their implementation. In New Zealand, the National Asset Management Steering Group was established in 1995 to develop and promote asset management practices in infrastructure. In 1996, NAMS issued the New Zealand Infrastructure Asset Management Manual, which was used by municipalities and water services to develop asset management plans. The Institute of Public Works Engineering of Australia and NAMS then worked together to develop the International Infrastructure Management Manual, which was first published in the year 2000. This was built on previous manuals and case studies were included.

Asset management did not develop as fast in the United States compared to the UK, Australia and New Zealand, mainly due to the different structure of the industry. The US water industry has many more organizations and a mix of municipal entities. However, some US water utilities have implemented asset management programs in the early 2000s, such as Seattle Public Utilities (SPU) in Washington and Oregon's City of Portland Water Bureau, making them two good examples. On the wastewater side, the US Environmental Protection Agency (USEPA) recognized the benefits of an asset management approach with the introduction of the Competencies, Management, Operations and Maintenance program in 2001. This program was one of the first initiatives to require a form of asset management planning in the United States.

In 2004, the British Standards Institute (BSI), together with the Institute of Asset Management (IAM), published the Publicly Available Specification 55 (PAS 55). These specifications have been very successful, with wide use in the areas of energy, transportation, mining, process, and manufacturing industries. In 2008, 50 organizations from 15 industry sectors in 10 countries worked together to launch the latest update of PAS 55, known as PAS 55: 2008. These were made up of two parts: 1. PAS 55-1: Specification for Optimized Management of Physical Assets and 2. PAS 55-2: Guidelines for the Application of PAS 55-1 The new update provided clear definitions and a set of 28 specific requirements points to establish and verify alignment, optimization and the entire system of life management for all types of physical assets. At the end of July 2009, BSI, supported by IAM, submitted a proposal to form a "Project Committee" to develop an international standard. This ISO standard would be based on the good work already done at PAS 55 and which

included knowledge of other industries and scientific societies located around the world. Thus, in January 2014, under the cover of the International Organization for Standardization (ISO), the ISO 55000 family of standards for asset management was published, [7-9].

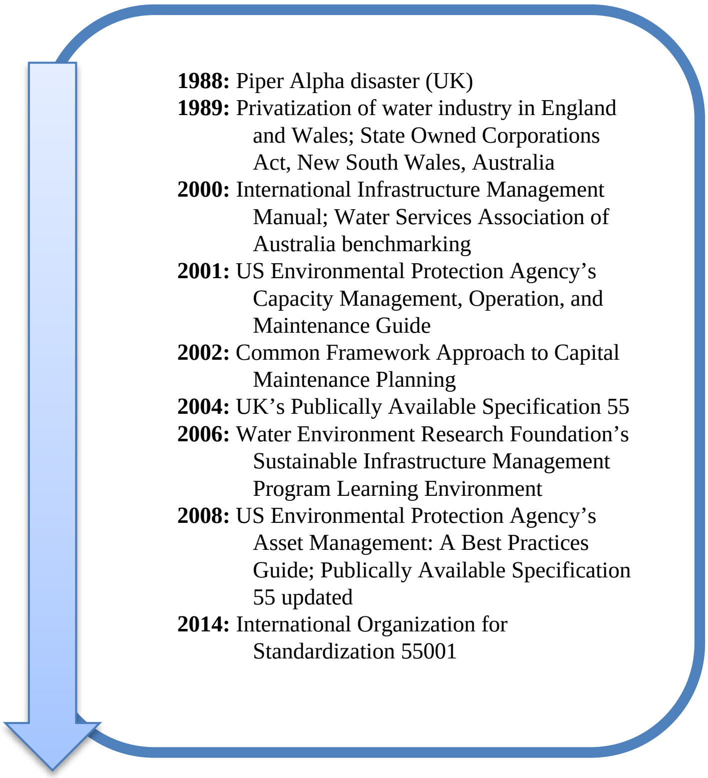


Figure 3. Evolution of Asset Management, adapted from " The Evolution of Asset Management in the Water Industry"

3 - Diagnostic Model of ISO 55001

3.1 – Diagnostic Model

The method of diagnosing the state of the organization for the implementation of ISO 55001 used is a set of surveys in which the evaluation of the responses indicates the position of the company in relation to the application of said standard. This audit method is designed to be used by members of the organization even if these little or no knowledge about ISO 55001; thus, it is a simple tool and easy to apply without great human resources requirements.

3.2 – The Surveys

The present methodology consists of 25 surveys, which are individual and can be filled either by company staff or external consultants. For this purpose, there is a fact sheet for each requirement of the standard, which must be answered by company managers or consultants outside the company. If there are doubts, each questionnaire is accompanied by a document explaining what is expected in each statement. The following table (Table 1) presents the 25 stages that make up the various questionnaires on which the diagnostic model is based, with the respective maximum and minimum scores.

Stage	Surveys	Maximum Score	Minimum Score
1	A. Understanding the organization and its context	3	2,4
2	B. Understanding the needs and expectations of stakeholders	4	3
3	C. Determining the scope of the asset management system	3	2
4	D. Asset management system	2	1,6
5	E. Leadership and commitment	17	13,6
6	F. Policy	12	9,6
7	G. Organizational roles, responsibilities and authorities	6	4,8
8	H. Actions to address risks and opportunities for the AMS	5	4
9	I. Asset management objectives	9	7,2
10	J. Planning to achieve asset management objectives	13	10,4
11	K. Resources	2	1,6
12	L. Competence	4	3,2
13	M. Awareness	4	3,2
14	N. Communication	4	3,2
15	O. Information requirements	12	9,6
16	P. Documented information	8	6,4
17	Q. Operational planning and control	4	3,2
18	R. Management of change	3	2,4
19	S. Outsourcing	3	2,4
20	T. Monitoring, measurement, analysis and evaluation	4	3,2
21	U. Internal audit	9	7,2
22	V. Management review	9	7,2
23	W. Nonconformity and corrective action	11	8,8
24	X. Preventive action	2	1,6
25	Y. Continual improvement	3	2,4

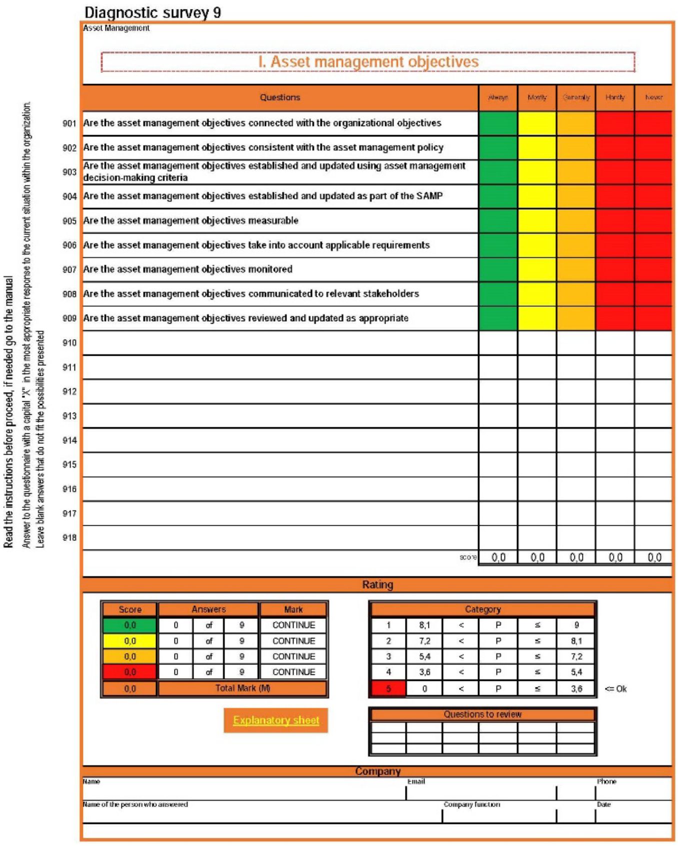
Table 1 – The 25 stages of the diagnostic model, with their respective maximum and minimum scores

For each of the items referred to, a diagnostic form, type survey, with several questions and five possibilities of response is elaborated, which are the following:

1. "Always" – always verified in the company;
2. "Mostly" - not always verified in the company;
3. "Generally" - sometimes verifies in the company;
4. "Hardly" - rarely occurs in the company;
5. "Never" - never verified in the company.

The following figure (Figure 4) presents an example of a Diagnostic survey 9 "I - Asset management objectives".

MPMM Maintenance Performance Measurement and Management



Diagnostic survey 9

Asset Management

I. Asset management objectives

Read the instructions before proceed, if needed go to the manual
Answer to the questionnaire with a capital "X" in the most appropriate response to the current situation within the organization.
Leave blank answers that do not fit the possibilities presented

	Questions	Always	Mostly	Generally	Hardly	Never
901	Are the asset management objectives connected with the organizational objectives					
902	Are the asset management objectives consistent with the asset management policy					
903	Are the asset management objectives established and updated using asset management decision-making criteria					
904	Are the asset management objectives established and updated as part of the SAMP					
905	Are the asset management objectives measurable					
906	Are the asset management objectives take into account applicable requirements					
907	Are the asset management objectives monitored					
908	Are the asset management objectives communicated to relevant stakeholders					
909	Are the asset management objectives reviewed and updated as appropriate					
910						
911						
912						
913						
914						
915						
916						
917						
918						
	score	0,0	0,0	0,0	0,0	0,0

Rating

Score	Answers			Mark
0,0	0	of	9	CONTINUE
0,0	0	of	9	CONTINUE
0,0	0	of	9	CONTINUE
0,0	0	of	9	CONTINUE
0,0	Total Mark (M)			

Category						
1	8,1	<	P	≤	9	
2	7,2	<	P	≤	8,1	
3	5,4	<	P	≤	7,2	
4	3,6	<	P	≤	5,4	
5	0	<	P	≤	3,6	<= Ok

Explanatory sheet

Questions to review

Company

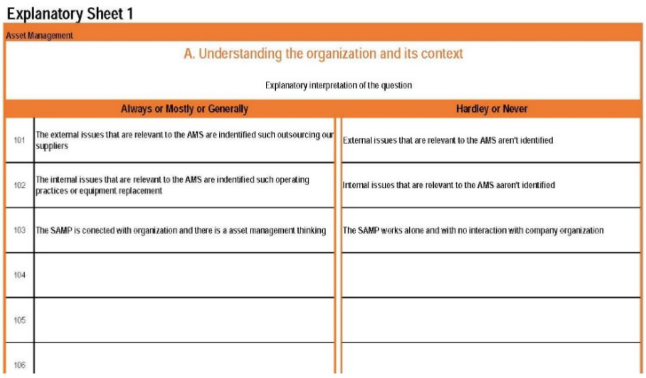
Name | Email | Phone

Name of the person who answered | Company function | Date

Figure 4. Diagnostic survey

3.3 – The Explanatory sheets

In order to minimize doubts about the content and comprehension of the questions formulated in the diagnostic sheets, these are accompanied by an explanatory card, individualized by questionnaire that allows, question by question, interpret the question and know which answer option to indicate.



Explanatory Sheet 1

Asset Management

A. Understanding the organization and its context

Explanatory interpretation of the question

	Always or Mostly or Generally	Hardley or Never
101	The external issues that are relevant to the AMS are indentified such outsourcing our suppliers	External issues that are relevant to the AMS aren't identified
102	The internal issues that are relevant to the AMS are indentified such operating practices or equipment replacement	Internal issues that are relevant to the AMS aaren't identified
103	The SAMP is conected with organization and there is a asset management thinking	The SAMP works alone and with no interaction with company organization
104		
105		
106		

Figure 5. Explanatory sheet

Diagnostic data sheets are identified at the top, through the number of the corresponding stage (1 to 25), by the name "Diagnostic survey" and identified by a heading designating the corresponding stage.

There follows an intermediate zone where the grid with the questions and columns reserved for the respective answer is located. Each of the lines begins by indicating a number associated with each statement consisting of three or four digits. The first one(s) represent(s) the number of the inquiry sheet and the other two identify the order of the statement. It is based on this numbering that you can search for help in "Explanatory sheets". The following five possible response possibilities appear in the following columns - "Always", "Mostly", "Generally", "Hardly" and "Never" - as already mentioned, one and only one option must be answered. If it is impossible to respond, then no option should be filled.

Finally, the lower part is reserved for determination:

- The score obtained;
- The consequent classification by categories;
- Elimination criteria achieved.

3.4 - Organization and analysis of information collected

Depending on the answers obtained in the surveys, interpretive of the current state of the organization in relation to the implementation of ISO 55001, each diagnostic record will have a certain score, which is divided into five categories: Category 1; Category 2; Category 3; Category 4; and Category 5. Within the positive situations we have category 1, synonymous with the very good positioning of the company, and category 2 that translates a good positioning. Next, a central or intermediate situation between positive and negative situations that translates a reasonable positioning. Within the negative situations, category 3 indicates that there are still aspects to be improved in the organization, while category 4 translates a bad positioning for the application of said norm, indicating that it will be necessary to carry out a broad and deep intervention of reorganization of this stage.

Thus, for each stage, category 1 is the category associated with the highest scores, synonymous with the good positioning of the company, while category 5 is relative to the lowest scores, associated with poor performance.

Each stage must achieve a minimum score in order to sustain the positioning of the next stage, viz, the company will not be able to adequately guarantee the implementation of the questions of a given stage without the previous stage having reached a position that is considered favourable. In practice, it is established that the company must reach the threshold of the third category as a guarantee of sustainability application of the next stage.

3.5 - Elimination criteria

Each possibility of answering the various questions is assigned a degree of importance, functioning as a criterion of elimination, according to four colours - green, yellow, orange and red - with the interpretation given in Table 2.

A disposal criterion is considered to have been achieved if the company has responded to a critically important question or exceeded the maximum number of allowable responses on matters of exceptional and inappropriate importance.

The evaluation of the questionnaires allows to determine the state of the company in the scope of the management of the physical assets of the organization.

It can be seen from the various questionnaires that the columns for "Always" or "Mostly" answers are the most desirable response possibilities and therefore the "green" colour of the elimination criterion is always attributed to them.

Green	Adequate answer This answer is always desirable.
Yelow	Inadequate answer Only some answers should be of this type and the company should improve them.
Orange	Exceptional answer Few answers should be of this type, although these responses are not eliminatory, the company should improve them as soon as possible.
Red	Critical answer The company should never have this type of answer, being the first to be reviewed.

Table 2. Criteria of importance of the responses in the positioning of the maintenance state [6]

For each questionnaire question answered in a negative or central form, viz, "Generally", "Hardly" or "Never", the template automatically produces a report of fragile points (responses obtained in orange zones) or critical point reports (responses obtained in red areas).

3.6 - Elimination grid

The elimination grids are no more than coloured cells in red, orange, yellow and green that are part of the questionnaire grid of each diagnostic sheet immediately, if a critical, exceptional, inadequate and adequate response has been given, respectively, allowing thus identifying whether the company in this matter has been eliminated or not, according to the process previously described.

The process of colour assignment in the criteria of elimination resulted from the importance with which each question contributes to the diagnosis of the maintenance and, consequently, its implications in the reorganization of the maintenance.

The score (A) obtained by the company results from the following formula:

$$A = \sum A_A + \sum A_M + \sum A_G + \sum A_H$$

Where,

A_A – Answer "Always"
A_M – Answer "Mostly"
A_G – Answer "Generally"
A_H – Answer "Hardly"

The score obtained gives origin to the category that the company achieved in each stage or questionnaire.

4 – Model Application

4.1 – Company Diagnosis

According to Table 3 it can be seen that the score achieved by the company clearly demonstrating that many changes will be necessary for the application of ISO 55001, this result was spectable since it is a public institute where few management, quality and maintenance tools are used and where the interaction between the various areas of the same is non-existent; in this way, the implementation of ISO 55001 will be easier where other management tools have already been implemented and consolidated in the organization.

Stage	Surveys	Company Score
1	A. Understanding the organization and its context	1,8
2	B. Understanding the needs and expectations of stakeholders	2,2
3	C. Determining the scope of the asset management system	1,7
4	D. Asset management system	0,0
5	E. Leadership and commitment	0,0
6	F. Policy	0,0
7	G. Organizational roles, responsibilities and authorities	0,0
8	H. Actions to address risks and opportunities for the AMS	0,0
9	I. Asset management objectives	0,0

10	J. Planning to achieve asset management objectives	0,0
11	K. Resources	0,0
12	L. Competence	0,0
13	M. Awareness	0,0
14	N. Communication	0,0
15	O. Information requirements	0,0
16	P. Documented information	0,0
17	Q. Operational planning and control	0,0
18	R. Management of change	0,0
19	S. Outsourcing	0,0
20	T. Monitoring, measurement, analysis and evaluation	0,0
21	U. Internal audit	0,0
22	V. Management review	0,0
23	W. Nonconformity and corrective action	0,0
24	X. Preventive action	0,0
25	Y. Continual improvement	0,0

Table 3. Scoreboard reached

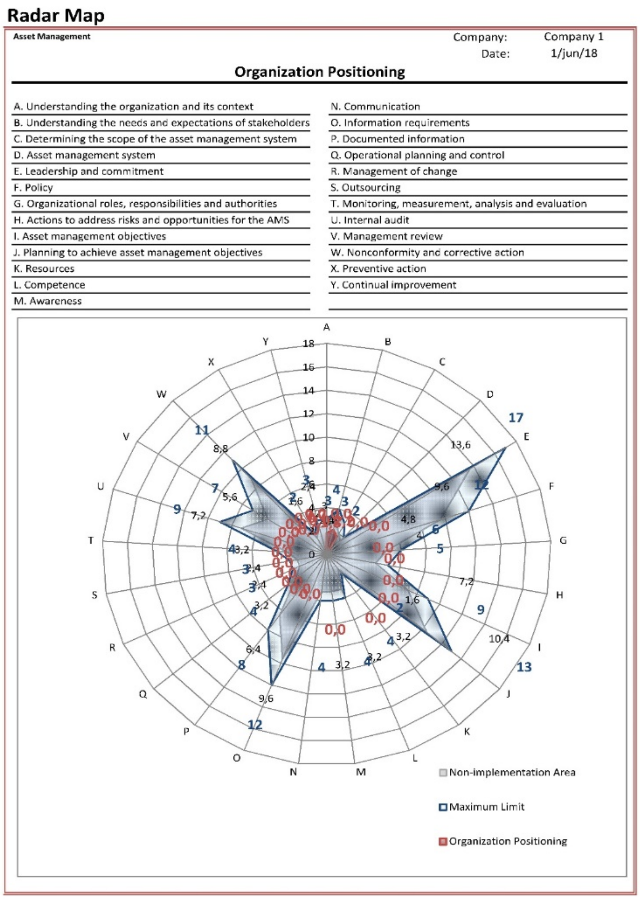


Figure 6. Radar Map

Figure 6 illustrates the company's positioning radar map. It can be said that the entity must improve its management culture in order to implement ISO 55001 and, at this stage, its application is completely inadequate.

5 - Conclusions

The diagnostic model developed to support the implementation of the ISO 55001 standard was easy to use and with concrete results to support organizations in identifying their strengths and weaknesses for their implementation.

The final result of the diagnostic model allows an "X-ray" of the entity through a radar map, as well as several supporting reports.

The model was validated in a public institute and resulted in a diagnosis that coincides with what was predicted empirically in relation to the primary state of the management culture in which it is found.

The model, in addition to the initial diagnosis, corresponds to a tool to support the implementation of ISO 55001.

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Maintenance Management Challenges for the region of Médio Tejo

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Abstract - For Legal and Regulatory reasons, namely those related with Indoor Air Quality, since the year 2000 buildings, their systems and equipment have evolved becoming increasingly complex. Simultaneously, users became more demanding and aware on issues related to Health, Safety and Comfort.

This situation led institutions to focus on their core business, choosing to subcontract Maintenance services. In today's competitive market environement, Facility Management supports institutions in the specialization inherent to Continuous Improvement, through tools such as PDCA, addressed at both National and International standards and guidance documents.

In Portugal there are still small and medium-sized buildings without maintenance plans and with limited human resources. In this context, it became urgent to realize the feasibility of a service that would meet such needs. The extended article shows how, through the study of existing supply and customer segmentation, it was possible to perceive which characteristics would make the service viable and to identify which features would make the service more valuable.

This whole process allowed to realize that in the scenario of Continuous Improvement and promotion of System Efficiency, Maintenance is also evolving along with the equipment and infrastructures. Today, decision makers have greater awareness of their needs and of the importance of Maintenance, increasingly seen as an essential tool for Health, Safety, and Comfort.

Keywords—Maintenance management, Physical Asset management, Facility management, Continuous improvement tools, Maintenance services, Markets.

I. INTRODUCTION

The design and construction of buildings integrate a growing number of infrastructure and systems, and complex equipment and technologies. The need to ensure the quality of life within buildings, in addition to the increasing technological complexity of systems and equipment, but also the European framework, have led to the publication of several legal and regulatory documents since the year 2000 [1].

While legal and regulatory requirements and other demands for the exploration and use of buildings and infrastructures increase, also users have shown a greater sensitivity and demand for issues related to safety, health and comfort. In Portugal, the number of small and medium size buildings and infrastructures, such as homes, hotels, cultural centers, swimming pools, etc., has grown very fast in recent years. It turns out that currently these facilities do not typically have a structured service for the organization and management of integrated maintenance for all their infrastructures, equipment and systems [1].

As a general rule, and particularly for small and medium-sized plants, both managers and those in charge of organizations have little sensitivity to technical issues related to the operation of the building and its systems. This is especially the case for small and medium-sized buildings without a maintenance team. In these cases, a significant difficulty is verified to ensuring the efficient management of the building, which naturally has negative financial, environmental and comfort implications, in addition to compromising indoor air quality [1].

It is in this context, and with the goal of technically supporting these organizations, that arises GM2E, a business idea in the Facility Management area.

II. ORGANIZATION AND MAINTENANCE MANAGEMENT

A. *Theoretical Fundamentals*

According to the Portuguese Standard NP EN 13306, Maintenance is [2]:

“All technical, administrative and management actions combined during the life cycle of an asset, intended to maintain or restore it in a state in which it can perform the required function”

Knowing that all physical assets, namely equipment, go over several phases during their life cycle (TABLE I), it can be stated that, in addition to complying with the standard, a good maintenance must also observe the condition of allowing the minimum overall cost over the life cycle. In order to be implemented in an ideal way, the maintenance should therefore be taken into account from the initial phase of any project or installation, taking part in the beginning of the operation of the equipment, being thus possible to study and analyze the assets previously, ensuring their proper functioning during the

operational phase. After this preparatory stage, it is sought that the maintenance function may be based mainly on permanent or periodic surveillance [3].

TABLE I. STAGES IN THE LIFE CYCLE OF AN ASSET [2][6][7]

Life cycle Stages	
Preparatory	Idea, Conception and Designing Manufacturing and Assembly Procurement and Installation Test Acceptamce and Commissioning
Operational	Service / Use Maintenance Promotion Planning Closure Disposal

In an organization, all actions that maximize the positive contribution of maintenance to overall profitability are considered, leading to the search of the most favorable solution for the organization. While seeking a balance between the various general maintenance objectives, the occupant's safety and assets security are considered as a primary objective for the organizations aforementioned.

Along with the definition of the maintenance general objectives and the choice of the most appropriate strategies to be implemented, nowadays, it is also essential to consider energy-saving needs, environmental conservation, the renewal of equipment and facilities, reliability, maintainability, efficiency, process optimization, its own quality and the technical enhancement of human resources. In this context, it becomes evident the importance of both Maintenance Audits and the Energy Audit and Certification for the good and efficient operation of the whole building.

The PDCA (Plan, Do, Check, Act) cycle, as shown in Fig. 1, is a continuous improvement tool common to these two major areas, Maintenance and Energy Efficiency, and it has as main merit the support to create routines that promote the incremental improvement of the quality, leading in the long run to excellent results [8].

Although sometimes a major improvement or advancement in some aspect of maintenance may also occur, continual Improvement is often achieved as a result of small, incremental improvements in processes, people, assets, strategy and relationships [9].

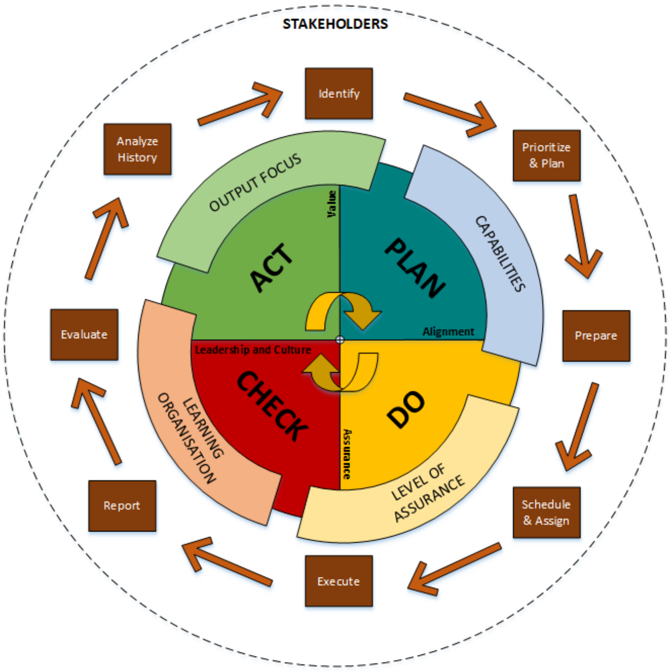

Fig. 1. Continual improvement based on PDCA Cycle [4][5][8].

B. Ennergy Efficiency

Generally, the concept of Energy Efficiency is based on the optimization of resources, enhancing how they are used to obtain the best results. Applying the concept to existing buildings, it can be said that it is the search for the best behavior of buildings through the lowest energy consumption.

Through a superior construction quality, based on the factors such as proper choice of materials; use of renewable energy sources; passive ventilation techniques and bioclimatic architecture techniques, improving the Energy Efficiency of buildings aims to bring maximum comfort to its users, spending the least possible resources.

In Portugal, it was found that in 2005, the energy consumption in buildings was approximately 30% of the primary energy and 62% of the consumption of electricity. Through these data, it can be seen that the implementation of energy efficiency retrofitting in buildings provides the prospect of great results. It is common knowledge that the unconcerned and predatory consumption over the years, considering natural resources inexhaustible and disregarding the consequences of this behavior (leading to global warming), led to an urgent need to reduce this consumption.

In practice, as previously mentioned, is extremely necessary an additional attention to the characteristics of the architecture. These technical features include the local characteristics of insolation and solar trajectory, climate and geography so we can take full advantage of local conditions, benefiting from solar energy. In interior comfort the choice of materials on front is very important, choosing materials which do not allow heat gain or loss, using passive techniques of ventilation and lighting. At another point, the active heating and cooling systems should only exist as a complement to the

interior comfort, since they are the ones responsible for the highest consumption in most cases. In order to work better they must be well designed and dimensioned besides being fundamental the correct isolation of the built structure.

C. Legislative and Normative Framework

According to Artur Rangel a standard is:

" (...) a document established by consensus and approved by a recognized organization, which provides rules, guidelines, or characteristics, for activities or their results, ensuring an optimal level of order in a given context."

Standards can also be used to describe a measurement or test method or to establish common terminology within a sector, such as NP EN 13306: 2007 - Maintenance Terminology [2].

In general, we can conclude that Standardization is an important and essential factor for maintenance and energy efficiency, as it enables companies to improve their maintenance management systems and service providers to organize and prepare better to meet the demands of their customers.

In order to boost and stimulate Energy Efficiency, as well as to clarify users, different decrees and documents have been created in Portugal over the years, such as:

- SCE (Building Energy Certification System);
- REH (Regulation of Energy Performance of Residential Buildings);
- RECS (Regulation of Energy Performance of Commercial Buildings and Services)

These decrees, together with their respective ordinances, regulate and determine the improvement of the conditions of thermal comfort and indoor air quality with reduced energy costs. Through tools such as energy certification for buildings, we can know exactly its behave, whether housing or services [10].

The evolution can be observed in Fig. 2, and be explained in D section

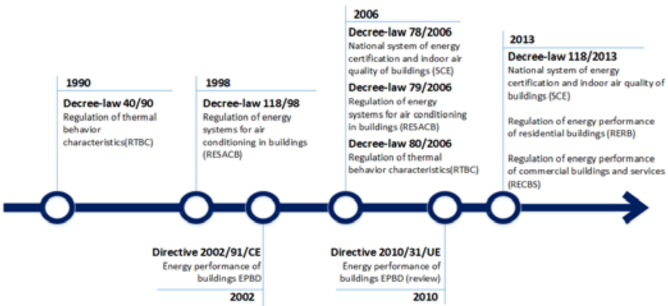

Fig. 2. Legislative developments in Portugal [10].

D. Evolution of Consulting Needs/Services in the OGM area

Some authors identify different stages in the evolution of the maintenance role, over time. of all, *Moubray [11]* is perhaps the one who brings the most consensus and affirms that maintenance has evolved since the 1930s over three distinct generations, as shown as a summary in Fig. 3.

The history of maintenance is much longer, but the main developments occurred in the second half of the 20th century.

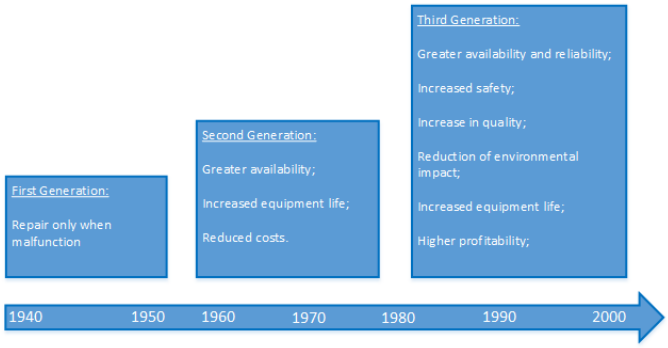

Fig. 3. Evolution of Maintenance [12].

There is no doubt that, by requiring maintenance, the energy efficiency legislation implemented since 2006 has been a major impetus for the preventive maintenance of buildings and their technical systems, in particular heating, hot water and lighting systems. Implemented since 2006, the legislation on Energy Efficiency, by requiring maintenance, was the main driver of preventive maintenance of buildings and their technical systems, in particular air conditioning systems, hot water and lighting systems.

This legislative evolution led the market to have an obligation of Continuous Improvement and centered on the “core business” and subcontracting of Maintenance services (subjects explores in Facility Management). It was notorious that the amount of energy used in buildings was growing, as well as the complexity of their systems and the traditional paradigm of installed power was compared to maintenance, which is assumed as the appropriate strategy to ensure comfort conditions, the effective energy performance and indoor air quality.

At the same time, both nationally and internationally (following PDCA approaches) through Standards and Guiding Documents, awareness-raising that maintenance is not harmful, but an investment that prevents overuse of energy [13]:

- National Level - NP 4483:2009 - "Guide to Implementation of the Management System"
- International Level - GFMAM - Global Forum on Maintenance & Asset Management
- International Level - EFNMS - European Federation of National Maintenance Societies;

This approach to the Continuous Improvement of the Maintenance Management System privileges the constant relationship with the customer (requirements and satisfaction), one of the most important objectives in the Facility Management, giving a special attention to quality, environmental, quality and safety requirements. This operational flow leads us to both plan and execute the Maintenance in more productive and efficient way.

However, as previously mentioned in the article, today in the interior of the country, there are still buildings (small and medium-sized) where there are no planned maintenance structures, which means that there is a lack of use of existing conditions and often their rapid deterioration. Most of the time, this neglect of the facilities is due to the existing limitation of human resources and those responsible not being specialized and not having an awareness of the importance of maintaining: not only the health of the building and of users but also in the control of energy costs and costs.

This reality led to the identification and structure of a Maintenance Service model that would support this type of building, which had been lacking technical and legislative support until then.

III. Estudy and Business Viability

The idealized maintenance service aims to enable managers of the institutions and companies, can focus on the core activities, delegating all the management activity of the facilities, improving efficiency in the operation of buildings and infrastructures, smartly monitoring the operations of the maintenance management and key performance indicators

Identified the business opportunity, as said before, will focus on the maintenance management of small and medium sized buildings that they need of maintenance structure, and statements the main goals, started by structuring the service to be presented to potential clients.

The identified main features for the service were:

- On-line platform, for business and relevant infrastructures operational management, with interface for all the stakeholders (clients, maintenance technicians and BackOffice);
- Maintenance plans and specialized execution of maintenance activity;
- Documentary organization;
- Support for compliance with legislation and standards;
- Reporting (editing reports and communication of relevant information);
- Maintenance audits and technical consultancy.

Parallel to the service structuring, a study was carried out of existent offer in the districts of Santarém, Leiria and Coimbra. Study that allowed us to understand and confirm the inexistence (only in big cities) of global and embracing services that pay attention to the required needs by small and medium sized infrastructures, at the level of organization and maintenance management. The information was collected through several processes, such as: on-line and off-line searches; sites and publicity; exhibitions and fairs; social networks; information provided by customers and suppliers.

A. *Costumers Study*

In way to ensure the viability of previously presented service, it was necessary to study potential customers. The study was carried out for three particular districts (as for the supply study): Santarém, Leiria e Coimbra. Starting from small and medium-sized buildings it was defined the types of potential future institutions and activities in which we can intervene:

- Homes;
- Hotels (up to 3 stars);
- Pools;
- Art Galleries;
- Museums;
- Libraries;
- Schools (Primary/Cycle/Secondary);
- Higher Education (Universities/Polytechics);
- Private Institutions of Social Solidarity (PISS).

The information gathering, through online research and database consulting, was treated and condensed in a spreadsheet, which allowed to support the first quantitative analyses in the built-up park in Portugal for these types of infrastructures. In Fig. 4 and TABLE II, it is presented the graphic and table resulting from the study for the three districts, where predominate Nursing Homes, Hotels and Schools. Naturally, this situation was evidenced for the three districts, when separately studied, thus leading to the identification of three types of costumers.

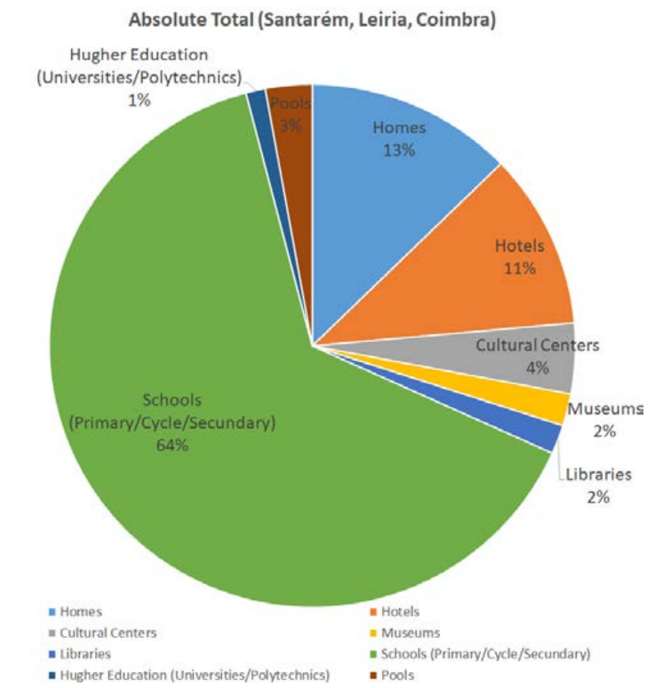

Fig. 4. Estudo dos Clientes, Total Absoluto.

TABLE II. ESTUDO DOS CLIENTES

Type	Quantity
Homes	404
Hotels	345
Cultural Centers	138
Museums	63
Libraries	57
Schools (Primary/Cycle/Secundary)	2038
Higher Education (Universities/Polytechincs)	38
Pools	91

Rather than the quantitative analyses, in the customers study, it is most import to segment them through their needs. To do so we established several characteristics:

- Customer/Service Provider Relationship;
- Carefree/Centralized Service;
- Possibility to evaluate the service/technician;
- Seasonality by season or type of building;
- Web Platform/Content Sharing;
- Preventive Technicians;
- Documental Organization;
- Response Time;
- Price;
- Empathy;
- Service Scope;
- Innovation;
- Training and Consulting.

In order to test the strength of all these characteristics we met with different type of clients and it was possible to understand what they really valued most. In Fig. 5, it is shown the result of these meetings, where we observe that, among others, the customer privileges the "Carefree/Centralized Service" and "Service Scope".

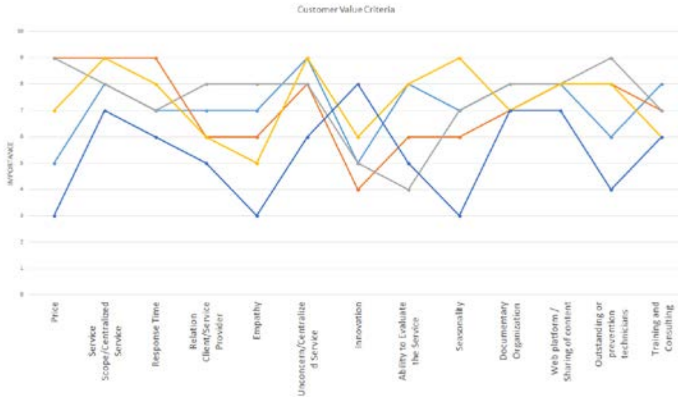

Fig. 5. Customer Value Criteria.

As it has been presented throughout the article, the greatest value of these characteristics is due to the fact that many of these infrastructures do not have specialized or certified Human Resources to support the Technical Systems constituent of the building, as is the case of Elevators, Warm Water Sanitary, Electrical Installations, Air Conditioning/AVAC, Gas Installation, etc. It is important to note that in the held meetings, we can see that of all indicated systems, the Air Conditioning has proved to be the most critical and where there is less technical capacity to act, either in case of failure or prevention.

All collected know how meet the initially idealized service, that is, the difficulty verified to act in technical systems, increasingly complex, can be filled with Specialized and Certified Human Resources, as is the case of the Qualified Expert (PQ) and the Installation and Maintenance Technician (TIM). Another important component to solving possible difficulties would be the possibility of a Global Service and a Single Interlocutor for all specialties, since it would thus be possible to guarantee both Legislative and Normative Compliance and Specialized Technical Support and Consultancy.

After completing the market study and testing the viability of the proposed service (presented in chapter III) together with maintenance documentation (B. Maintenance Support Documentation), it was possible to conclude that in a Continuous Improvement and System Efficiency scenario, Maintenance is becoming increasingly important.

B. Maintenance Support Documentation

In modern Organization and Management of Maintenance, this same management is usually done by a Management of Relevant Infrastructures Platform, however, in the majority of the times, due to financial difficulties felt by the small and medium-sized service buildings, its implementation is neither possible nor feasible. Being organization and reporting truly important factors in the GMOs field, it is essential to develop documentation that supports the work, collecting at the same time information that leads to the improvement and efficiency of the service.

Using NP EN 13460:2009 Standard – "Maintenance Support Documentation", it was possible to create documentation regarding the both Preparatory and Operational Phases.

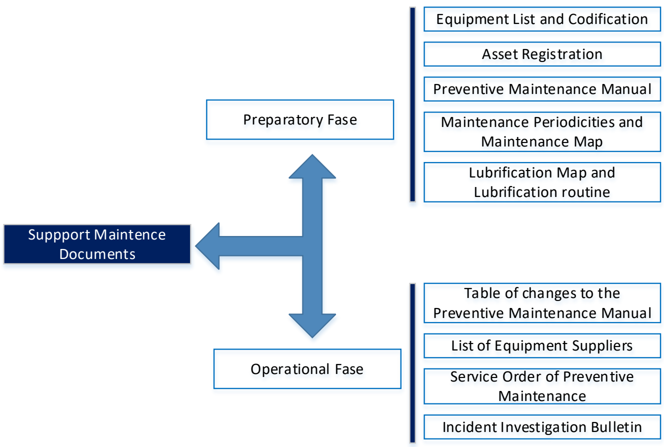

Fig. 6. Maintenance Support Documentation.

IV. CONCLUSION

The evolution of infrastructures, along with increasingly complex systems and customer demands for comfort and safety, have led to constant new presentations and developments of strategic and management models, aiming to improve and to optimize the organization and management maintenance service.

However, through the developed study, it was evident there is still room for improvement in the existing supply, especially concerned with maintenance provision services and smaller underserved buildings and structures. In these types of buildings, the difficulties they face focus on their human resources technical limitations, which often, together with decision-makers, do not raise awareness of a continuous improvement approach that contributes to a better asset management and a better buildings energy management.

By identifying the need felt by clients, it was possible to structure an effective and efficient maintenance service model. This service should have in its center the relationship with customer and have requirements stablished and intended by himself. The constant customer/service provider relationship contributes to a better planning and consequently to a better execution of maintenance works, which in it turns leads to a maintenance service maturation and to customer satisfaction.

Nowadays, knowing ahead that issues such as IOT, Circular Economy and Industry 4.0 (fourth generation), present themselves as essential themes for evolution, it is necessary to realize that are infrastructures in the interior of the country that do not have conditions to implement them being the great challenge: to structure a balanced service between the technological advance and innovation and the evidenced reality.

ACKNOWLEDGMENT

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Maintenance Optimization at EDP Produção through the application of RCM and RBM Methodologies

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***Abstract* — The recent energy market changes with the penetration of renewable technologies into the energy mix, without marginal cost, draws a significant share of production volumes to conventional producers. Nevertheless, conventional producers continue to be necessary to ensure the resilience of the electricity system, but with more volatile margins and high uncertainties regarding market opportunities.**

After some preliminary works, in 2015, EDPP created a Work Team to redefine an O&M Strategy for its generation assets, considering the new market context. Regarding to Maintenance of Generation Assets, it was defined a planning strategy supported on the RCM and RBM Analyzes and a focus on a predictive approach.

Keywords* — *Risk Based Maintenance; Reliability Centered Maintenance.

I. Introduction

During the last two decades changes have occurred in the energy generation market sector. From a market where the production mix was essentially formed by conventional thermal and hydraulic technologies it has evolved to a market with a high renewables technologies penetration. Without marginal cost, renewable technology draws a significant share of production volumes to conventional producers. Conventional producers nevertheless continue to play an important role ensuring the resilience of the electricity system, but with more volatile margins and high uncertainties regarding opportunities markets.

This has led EDP Gestão da Produção de Energia, S.A. (EDPP) to look with new eyes on its plants maintenance strategy. The focus has been to establish a holistic methodologic approach concerning plant maintenance optimization. As a result, EDPP in 2015 created a Work Team to define an O & M Strategy for its production assets. Regarding Maintenance, it was defined that it should be supported in the implementation of the RCM and RBM Analyzes.

This paper describes the process of implementation of RBM and RCM Methodologies and the expected results. First, some of the main strategic conceptual principles that drives the maintenance strategy redefinition are presented. Then the RBM and RCM methodologies and implementation processes are described and finally the full view of potential results is presented.

II. Background

A. Maintenance Strategic Basis

The development of a maintenance strategy is part of a broader context that is Asset Management. The "Effective control and governance of assets by organizations is essential to realize value through managing risk and opportunity, in order to achieve the desired balance of cost, risk and performance" [1]. This mind set where the aim is to balance asset costs, performance and risk during the life cycle of equipment's opposed to the blind and independent maximization of all three factors emerges as the main asset management concept in EDPP.

Increase competition but also aging of equipment create financial pressure on businesses and organizations to develop maintenance strategies that increase performance, reduce operational costs and increase life time of equipment's.

B. Maintenance Optimiziation

To achieve the goals discussed above proper maintenance of equipment's should be performed. There are two types of maintenance strategies: preventive and corrective maintenance. Preventive maintenance is divided in time based and condition based. The first one is performed after a fixed interval of time which is either the calendar time or operating hours of the unit. It is very conservative, typically costly, labor intensive, and often makes unneeded inspections and repairs in an effort to ensure that failures do not occur. Condition based maintenance is an on-demand maintenance strategy. It is performed based on the condition of the unit and is also costly because condition assessment or prediction requires costly techniques and sound historical data.

The well-known effect on cost of different maintenance approaches is shown in Figure 1. It can be seen that corrective maintenance approach has a relatively low maintenance cost but high operating costs associated with the high cost of unplanned shutdowns. In contrast, preventative maintenance generally has a low operating cost, but often results in high maintenance cost associated with the replacement/repair of components before they have reached the end of their useful

lives. The most efficient approach is to plan preventive maintenance with an efficient scope and just before the failure of the machine.

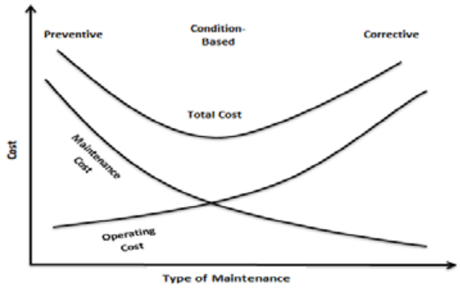

Fig. 1. Cost associated with Different Maintenance Approaches

C. Proposed Maintenance Optimiziation Methodologies

Reliability and Risk analysis provides a basis for effective decision on maintenance tasks, shutdown, repair, or replace.

A Reliability Centered Maintenance (RCM) methodology was proposed to define the equipment's maintenance plans or tasks. The goal is to remove less effective maintenance tasks from maintenance plans based on historical data and Operations and Maintenance personnel experience. Due to the relative low impact of failure of most systems, the type of systems and components maintained, and the amount of redundant systems in place a Streamlined or Abbreviated RCM method was considered. This method uses the same principles as the Rigorous RCM approach, but invests less time in the initial analysis when compared with a full Failure Mode and Effects Analysis (FMEA).

For an effective implementation of the Preventive Maintenance regarding the maintenance programing (Condition Based) the Risk Based Maintenance (RBM) methodology was proposed. RBM framework comprises two main phases: first the risk assessment and second the maintenance planning to mitigate the calculated risk.

III. RCM AND RBM IMPLEMENTATION

To capture efficiently all the benefits of both methodologies plants were prioritized regarding its economical position and technical characteristics. Each methodology was then implemented separately with a specific schedule and team.

A. RCM Implementation Process

The RCM implementation required a team for each plant constituted with plant personal. The first step was to intensively train all teams by internal RCM experts. Then an implementation plan was design regarding plant value position. During the implementation process and after the training period RCM experts were supporting all teams for rapid problem solving of methodologic aspects.

Regarding that EDPP has several assets with identical technologies some synergies benefits were obtained with the definition of a set of Functional Systems for each technology. For hydro power plants 8 Functional Systems were defined and for thermal power plants 28 Functional Systems.

RCM was implemented following three phases.

Plant/Unit Mapping - Set all Functional Systems (FS) and Functional Items (FI) (Function-Oriented and not equipment-oriented). Were the tasks performed were:

a) Identify the Functional Systems and Sub-Systems (FS) and related Functional Items (FI).

b) Confirm all systems and items with the existing P&Is and other documents, and compare with the existing physical system.

c) Colect all failure historic data for each Functional System.

d) Collect all information about preventive maintenance tasks for each Functional System.

Identify Critical Functional Items - Set a Criticality Checklist to identify critical Functional Items;

e) Define the criteria used to classify Functional Items as critical;

f) Analyze and classify all Functional Items as Critical or non Critical.

Definition of new maintenance tasks - Establish the necessary maintenance task for each Functional Item.

g) Define a Maintenance Plan for all Critical Functional Items based on its failure modes and failure history;

h) Aggregation of the plans of all Functional Positions into coherent maintenance plans for the whole plant, joining activities with similar schedules (for example, daily, weekly, monthly, etc.).

The criticality analysis of each Functional Item was based on seven fundamental questions:

- *what are the functions and associated performance standards of the asset in its present operating context?*
- *in what ways does it fail to fulfill its functions?*
- *what causes each functional failure?*
- *what happens when each failure occurs?*
- *in what way does each failure matter?*
- *what can be done to prevent each failure?*
- *what should be done if a suitable preventive task cannot be found?*

The implementation process took an average duration of 16 days for each system.

B. RBM Implementation Process

The RBM implementation required a team for each plant constituted with plant personal. The first step was to intensively train all teams by internal RCM experts. Then an implementation plan was design regarding plant value position. During the implementation process and after the training period RCM experts were supporting all teams for rapid problem solving of methodologic aspects.

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IV. Major Results

Major Results from the implementation of RCM methodology in the first 3 plants/units are present in Table 1. The relevant potential to achieve greater efficiency in systematic preventive maintenance can be summarized as:

- Less frequency of some activities – direct cost reduction.
- Incorporation of previously unforeseen activities into maintenance plans - avoiding corrective actions.

TABLE I. RCM Major Results

	Comparison between current and future plans			
	# FS	***# FI***	***# Critical FI***	***Preventive Maintenance man hours reduction.***
Plant A	9	1268	822	3%
Plant B	8	486	353	15%
Plant C	9	1309	774	13%

Note: Functional Systems (FS); Functional Items (FI).

Major Results from the implementation of RBM methodology in the first 3 plants/units can be summarized as:

- Longest time interval between maintenance outages, based on the failure statistics of analysed power plants/units
- Change of scope of outage to suit new operating ranges
- Reduction of outage costs from a life cycle cost perspective.

TABLE II. RBM Major Results

Table Head	Comparison between current and future plans		
	Time between planned outages	***Average Plant/Unit Outage Cost***	***Average Plant/Unit Annual Cost***
Plant A	+100%	+61%	-14,5%
Plant B	+50%	+8%	-16,6%
Plant C	+50%	+22%	-20,8%

Note: Functional Systems (FS); Functional Items (FI).

V. Concluding Remarks

This paper has presented the process of implementation and results of RCM and RBM methodologies as part of the Maintenance Optimization Strategy of EDPP. The main direct but also consequential and potential results of the implementation of the RCM and RBM methodologies were pointed out as follows:

1) Greater time interval between plant/unit overhauls, based on historic failure data of analyzed power plants, which didn´t result in higher risk levels because the outage scopes were revised.

2) Maintenance Overhauls Scope changed to suit new operating regimes.

3) Reduced maintenance costs, increased performance (availability and reliability) accounting the risk level to be considered acceptable for each type of installation.

4) Review of content maintenance routines to ensure that all critical functional positions are properly considered in a preventive maintenance perspective.

5) Greater commitment of the technicians with the new maintenance plan (they know it better and understand why each maintenance instruction is included).

6) Deepening of technological knowledge and process by technicians.

7) Unique opportunity for intergenerational transmission of knowledge.

ACKNOWLEDGMENT

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Metrological Assessment for Life-Cycle Optimization of Medical Devices and Facilities

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All of us trust our lives, and our loved one's lives to medical teams, supported by countless equipment. A modern hospital employs highly sophisticated equipment, with the prime objective of saving lives. Many of it are life-saving, and should be managed with risk assessment. Especially for these ones, Maintenance should be supported by other areas, such as Metrology and Asset Management. The combination of Maintenance and Metrology insures the safer operation of medical devices. Each one complements the other, and both should be planed side by side.

Keywords— Maintenance, Metrology, Maintainability; Medical Devices; Asset Management.

I. INTRODUCTION

Today´s hospitals employ several dozens of thousands of equipments, all serving the purpose of saving lives. Whether it´s a defibrillator, used to rescue acute cardiac patients, to a boiler that provides steam and hot water to day-to-day operations. The investment made by society in these infra- structures, and the numbers of highly skilled jobs involved, testifies to the importance that society places on the role of an hospital.

There is greater demand for reliable operation. According to EN 133306 [1], reliability can be defined has the ability to perform a mission, within determined conditions, on a limited time frame. That means that breakdowns, considered by many as normal, can't be tolerated by health professionals, especially treating acute patients.

For the past decades, there´s had been evidence that zero breakdowns are not realistic prospect, so there has been a cultural change, to regard maintenance of functions, and not of equipments [2]. Maintaining functions requires that management should look at an equipment population, serving that function, rather then managed each equipment. Asset Management standards provide sound organization background to achieve that goal, and are at the heart of the future of Maintenance.

New approaches, such as Metrological Assessment, can help Maintenance improve the maintainability of medical equipments. The focus is to deal effectively with the consequences of human error, rather then trying to eradicate it [3].

II. FUNDAMENTAL CONCEPTS

Maintenance can be defined has the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function [1]. This definition stresses the importance of the function, to perform Maintenance activities. It has been acknowledged that defining functions and the way they fail is the backbone of a sound maintenance program [2].

Metrology can be defined has the science of measurement and its application, including all theoretical and practical aspects of measurement, whatever the measurement uncertainty and field of application [5]. Metrology is a key aspect on healthcare facilities, because clinical decisions are made on measurements, such as temperature or pressure, among others. Metrology is also fundamental to the non clinical systems that support hospital operation, as water systems or heating facilities.

Metrology introduces to Maintenance two key concepts. The first one is the measurement uncertainty, which can be defined as the dispersion of quantity values being attributed to a measurand [5]. Broadly speaking, uncertainty can be compared to the standard deviation of an average. Average calculations without standard deviation don't necessarily express reality. If the author and the reader go out to dinner and had one roasted chicken, on average each one ate half chicken, even if the reader ate the whole chicken! Uncertainty expresses the risk associated with the measurement. The higher the uncertainty, less meaningful the measurement result is.

Another fundamental concept in Metrology is drift. Drift is the continuous or incremental change over time in indication, due to changes in metrological properties of a measuring instrument [5]. Drift can express the technical condition of the measurement device, with notable implications on its life cycle cost.

Maintenance's focus is on keeping the equipment's functions. Metrology focus is to insure that the measurements are made within an admissible error, with a given measurement procedure. Most, if not all, functions are measurable quantities. Metrology is, therefore, a key science to Maintenance. Metrology quantifies the risk associated with every measurement. It is essential to understand if a given

measurement is reliable, in other words, if it is an accurate representative of the quantity being evaluated.

Hospital and medical devices should be evaluated on risk assessment, due to health care's critical nature. Dealing with lives, the function performed by every hospital device should be carefully defined, monitored and maintained.

III. DEALING WITH HUMAN ERROR

Recently, it has become apparent that Maintenance, Calibration and Testing activities can be a major source of performance problems [3]. The idea that more Maintenance (in time and tasks) insures better, safer operation has been successfully challenged by Nowlan and Heap [6], on their ground breaking work on Reliability Centred Maintenance (RCM). Nowadays, it is considered good operational practice to only perform tasks that deal directly with failure modes and/or their consequences [2].

Increasingly higher demands for maintainability and risk assessment brought new approaches to the Maintenance work. Work validation, and error detection in teams are essential to detect mistakes and prevent accidents. But more people working around the same issue can, unsurprisingly, increase the number of human errors, due to invasive manipulating of equipments [2].

Even highly regulated areas are not immune to human error [3].

Trying to change human condition is futile [3]. Human errors are intrinsic to human nature, and should be expected. Managing human error requires changing the conditions under which work on equipments is carried out.

Several physiological factors that lead to human error have been identified [3]:

- attention is extremely limited, and can be disturdeb by small external factors;
- concentration is hard to achieve and lasts for very short time;
- stress and social interaction – especially in workspace;
- circadian cycles – especially working in shifts or at night;
- the effect of common sense, based on past experiences, which are not validated.

Several measures can be implemented to reduce the likehood of human error or its consequences [3]:

- training in error-provoking factors;
- implement measures to reduce deliberate violations;
- encourage mental rehearsal of tasks, before they are performed;
- ensure that personnel only performs tasks they are properly qualified for;
- manage fatigue;
- assigning tasks in enough frequency, so the like hood of error is less likely;
- write and use effective work instructions.

Besides all the measures, specific error detection and containment should be performed, asking several questions [3]:

- are functional tests and checks being omitted or abbreviated for any reason?
- after maintenance, is the equipment adequately tested before returning to service?

Metrology can enhance the efforts to overcome the effets of-human error, namely because it requires complete independence of measuring methods [4]. ISO 17025 requires a full array of procedures, measurement processes and external validations, to ensure the measurement results are comparable between laboratories worldwide.

What is essential is that the work of Metrology and Maintenance should validate each other. Increasingly complex equipments demand more sophisticated analysis and troubleshooting. Greater care is needed to prevent the effects of human error.

IV. HOSPITAL EQUIPMENT MANAGED USING LIFE-CYCLE COST

Life-cycle cost seeks to optimize the cost of acquiring, owning and operating physical assets over their useful lives, by attempting to identify and quantify all the significant costs involved in that life [7].

Nevertheless, there is evidence to suggest that many organizations make the acquisition of equipments simply on the basis of initial purchase cost [7]. Among the relevant costs, one should consider Maintenance as one of the most important. At the end of its useful life, an asset can spend 4 to 5 times more in Maintenance than the cost of initial purchase [8]. Deciding what type of maintenance should be applied to an asset can be made by the application of RCM. The RCM analysis reveals all types of failure modes, the risk associated to each and how they can be addressed.

It has been widely recognized that invasive maintenance procedures on assets increase the likelihood of failure [2]. Non-invasive testing should be the first option to determine asset condition. That means that Maintenance should rely on measurements to monitor assets and its functions.

The life-cycle cost is essential to ensured sustainability of asset exploration, and as a critical management toll to extend the useful economical life of assets.

V. CONCLUSIONS

Asset management using life-cycle cost is an essential tool for managing the ever increasing complex and expensive hospital equipments and facilities. Nowadays, performing Maintenance, with the sole objective of availability, is not enough to optimize asset's useful life.

Metrology is a partner to enhance the role of Maintenance on Asset Management. Metrology professionals are trained to perform measurements using precise procedures,

intercomparable testing and error-finding tasks. Maintenance personnel also measure, so Metrology places itself as anoption to put in place active measures destined to minimize the impact of human error. Key metrological concepts like uncertainty and drift, qualify the measurement as representative of reality and give strong input to evaluate measurement asset condition. Critical decisions on repairing or not equipment can be made with sustained data.

As hospital has typically several thousands of measuring equipments, from which fundamental healthcare options are being made. Ensuring that these readings are accurate is a key factor to successfully manage equipment hospital. Both Maintenance and Metrology can perform a leading role to success, by combining efforts and procedures.

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Motion Amplification Technology as a Tool to Support Maintenance Decisions

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***Abstract* — The present paper deals with Motion Amplification Technology (MAT-Iris M) as the basis to identify and characterize problems that affect most industrial equipment, helping maintenance professionals to make the correct decisions in a proactive way. The work describes MAT-Iris M as a disruptive technology and a revolutionary way to visualize vibration problems, linking it to condition monitoring, failure risk and maintenance decisions. The Motion Amplification Technology monitors critical manufacturing operations, processes, quality and structural components that affect plant reliability and productivity. Some real examples are presented to illustrate the capacity of such technology. Based on the characteristics of the technology presented in the work it can be stated that it could be an important tool to help who has responsibilities on physical assets and on the decision making process, based on risk perception and using a disruptive technology.**

Keywords—motion amplification technology, condition monitoring, maintenance.

INTRODUCTION

An adequate condition-based maintenance represents a good support to do the correct maintenance activities at the right moment. The impact of such decisions can be observed on business continuity, costs and people safety.

The continuous conditioning and monitoring technology significantly increases the life span of equipment, as well as reduces the maintenance cost. Some technologies can be used for such purpose. For example Mariprasath and Kirubakaran [1] refer the use of thermal images to monitor transformer's temperature based on hot spot indication technique. In fact, thermographic images are widely used for condition monitoring [2] [3] [4]. Other condition monitoring techniques are also used as oil analysis [5] [6] or vibration analysis [7] [8] [9].

It is observed that recently it is given great importance to condition monitoring and to emergent technologies making use of images, graphics and digitalization, applying concepts inherent to the Industrial Internet of Things (IIoT) and the 4th Industrial Revolution.

The present work shows how simple is to make a video capture and the ability to observe and list potential failure modes that could be present as the result of identified vibration problems. It is also possible to estimate the potential harm, impact or severity of each listed failure mode taking into account several dimensions (people safety, failure cost, production downtime and environment impact).

In the present work will be described and presented some demonstrative examples using MAT-Iris M, based on case studies.

The paper is structured into five sections. Section 1 presents an introduction to the issue under study and some risk problems derived from equipment vibrating mode. Section 2 describes the technology (Motion Amplification Technology) and its disruptive characteristics. Section 3 presents some demonstrative examples showing the potentialities of MAT-Iris M. Section 4 refer new developments under the scope of recent technological advances and present some limitations of MAT-Iris M. At last, in Section 5, are stated some conclusions about the work developed.

MOTION AMPLIFICATION TECHNOLOGY (MAT-IRIS M)

Operating Deflection Shape (ODS) analysis is a diagnostic technique that is used to obtain more data to reinforce diagnostic, in a way to determine the real root cause [10] [11]. ODS allows to visualize how a structure or equipment vibrate. The vibrating mode is the result of all operational (dynamic) forces that are present on the system under analysis. These dynamic forces are the result of defects or operational situations as unbalance, misalignment or looseness that are influenced by load, velocity, pressure, temperature, flow, etc. When referring structures the dynamic forces can result from environmental forces as the ones produced by waves or wind. To obtain an animation to demonstrate the way how equipment vibrates using ODS it is necessary to collect vibration data in several physical points, which means a great amount of time.

To overcome the ODS disadvantages recently appeared a new technology – Motion Amplification Technology (MAT-Iris M) that promotes a credible and accurate alternative, faster and economically more favorable than traditional ODS.

This technology detects subtle motion and amplifies that motion to a level visible by naked eye [12]. By turning every pixel in the camera into a sensor this technology takes millions of measurements in a fraction of a second with no physical connection to machinery or equipment.

MAT-Iris M refers to a revolutionary video processing that efficiently detects subtle and small movements and amplifies them with great accuracy. This solution, patented with the name

"Iris M" is the first amplification method that allows the user to see it as a simple video. It is also possible to measure the amplitude in displacement units in any coordinate inside the picture. The camera act as a data collector that record images from one can extract and analyze movements. Figure 1 shows all elements necessary for MAT-Iris M that include a high speed camera (1) mounted on a ridged tripod (3) linked by a USB3 cable to a tablet (4). According to distance there are four distinct objectives (2) with different focal distances.

Fig. 1. MAT Iris M elements

Although this technology is very recent (2016) it can make a revolution on the way how the analyst observes equipment or structure movements under a condition maintenance implemented strategy. Effectiveness relies on the sensitivity to measure displacements about 100 times more than other existent systems based on image. By other side the system allows to define a region of interest ROI to measure the absolute displacement directly on image and obtain a time waveform and respective frequency spectrum on two orthogonal directions, as represented in Figure 2.

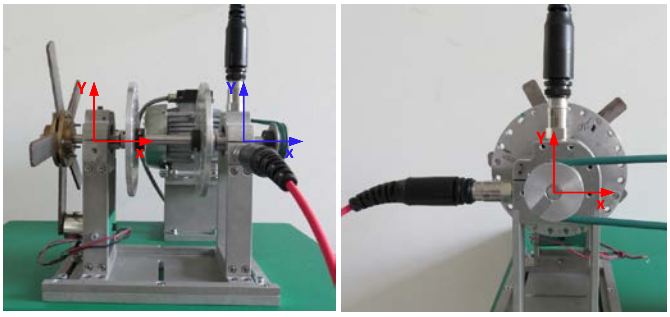


Fig. 2. Orthogonal Coordinates Referential X-Y

Figure 3 presents a time waveform extracted directly from the processed video where two Regions Of Interest (ROI) were selected to determine the dynamic response of the two supports of the didactic model on two directions (X-Y).

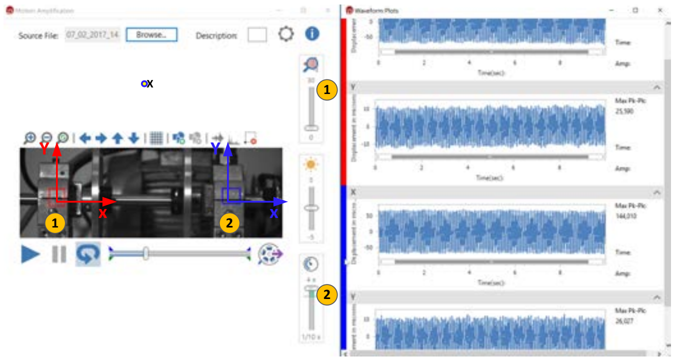


Fig. 3. Four time waveforms, on supports 1 and 2.

As signals were collected simultaneously it is possible to determine the "relative phase" between all signals. Figure 4 shows the signal of both supports (1 and 2) on direction X, being possible to observe that they are vibrating on phase (phase differential of 0°).

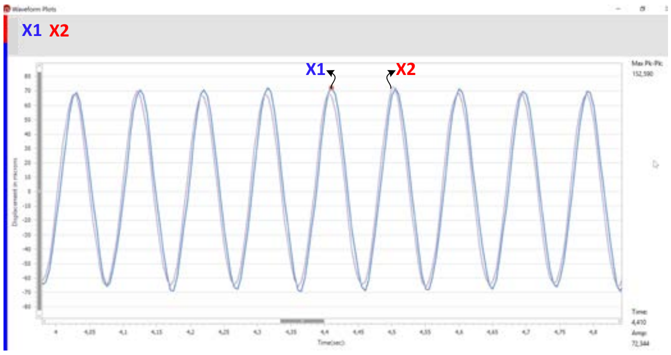


Fig. 4. Signals on direction X for support 1 and 2

This technology also allows obtaining frequency spectra on both directions for each ROI, as shown in Figure 5, representing displacement peak to peak on direction X for supports 1 and 2.

Iris M technology (MAT-Iris M) has also the advantage of being too fast on data acquisition (some seconds) and on the substantial quantity of information that is possible to extract from the video recorded representing high efficiency and less time. It is also very intuitive and easy to apply, use and analyze.

Fig. 5. FFT spectrum X1 and X2

To understand the complexity of structural movement of the equipment is usually installed sensors on several physical points of the equipment under analysis. Higher number of points means higher certainty on diagnostics, but with more time consuming (as ODS). Iris M is too simple, expanding video camera vision and representing the asset by millions of pixels. Data will be record on a single video file facilitating the management of data collected. It is possible to analyze a specific physical point even after the video recorded not being necessary to come back to equipment and make another video.

Traditionally the technician or analyst is able to identify the root cause of vibrations based on data analysis (Time waveform and frequency spectra). The amplification of the movement qualifies what is happening and its displacement measure can be used to quantify the movement itself.

MAT-Iris M is developed into six phases, as shown in Figure 6, representing few minutes in time, which is a great advantage of the referred technology, as mentioned before.

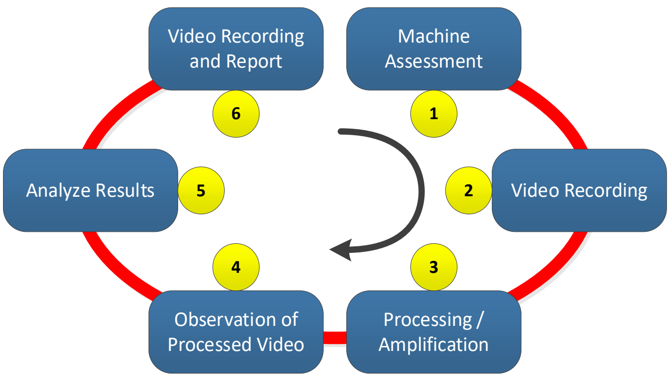


Fig. 6. Six phases of MAT-Iris M

Demonstrative Examples

3.1 – Dynamic balancing in one plane without phase (Four Run Method)

When dealing with corrective technologies dynamic balancing of rotors has wide applicability because unbalance is still being one of the most common root causes of vibration in rotary machines. Based on this it was performed a comparative test using the classic solution of one analyzer and an accelerometer by one side and MAT-Iris M using the video camera by the other hand. It was used the "Four Run Method" (without phase) to perform the balancing of the rotor.

A wide vision of the apparatus used on the referred comparative test is shown in Figures 7 and 8. The camera (3) was positioned 2 meters away from the targeted rotor (2). Iris M software installed in computer (1) gathered all the necessary data needed for a dynamic balancing. It was also used artificial light through the focus of light (4).

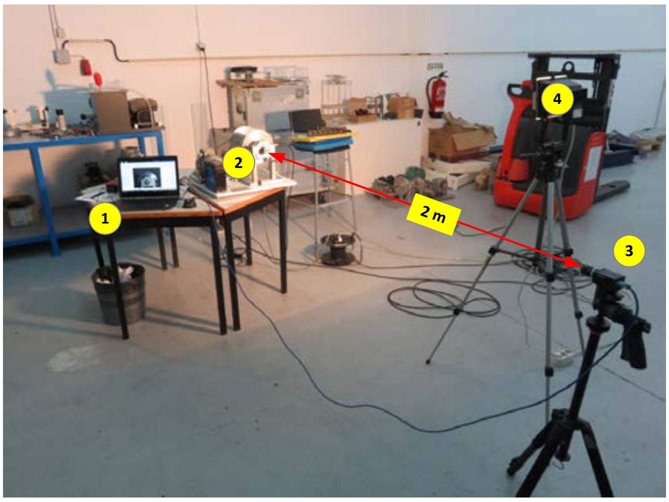


Fig. 7. Test elements

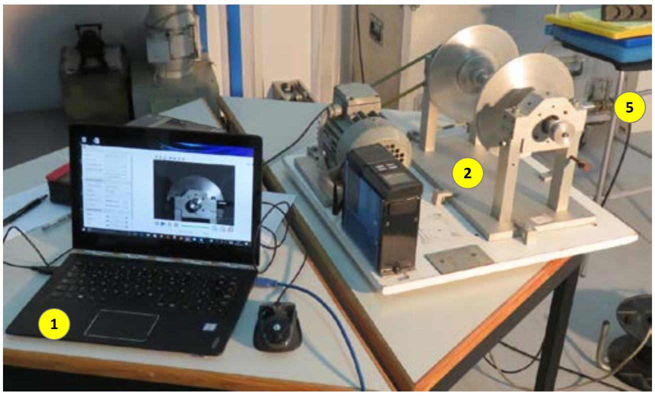


Fig. 8. Iris M system (1), didactic model (2) and accelerometer (5)

For comparison, it was mounted the traditional or classical equipment consisting of a data collector / analyzer and an accelerometer (5) on the horizontal position.

Figures 9 and 10 show the initial readings by Iris M and Figure 11 show the one obtained through the analyzer.

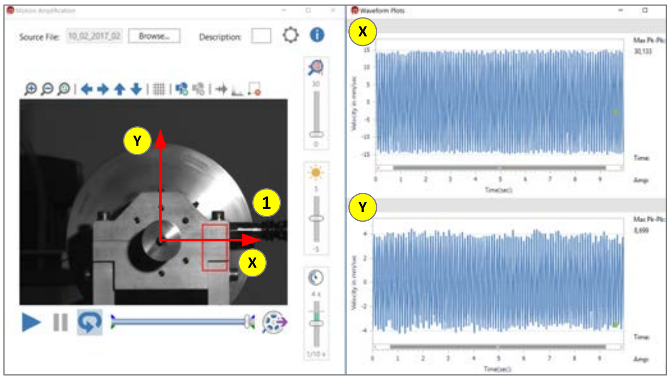


Fig. 9. Initial reading – Time waveform

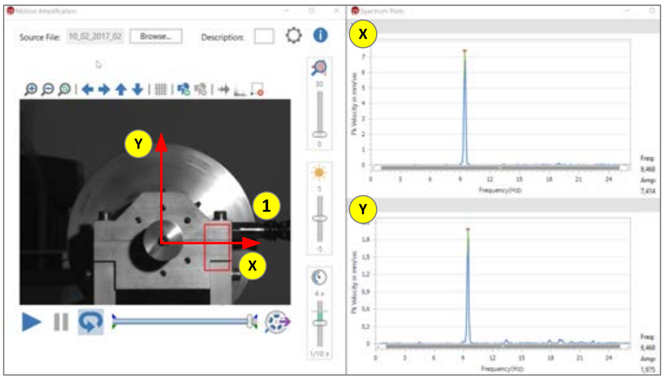


Fig. 10. Initial reading – FFT spectrum (1xRpm 7,414 mm/s Peak)

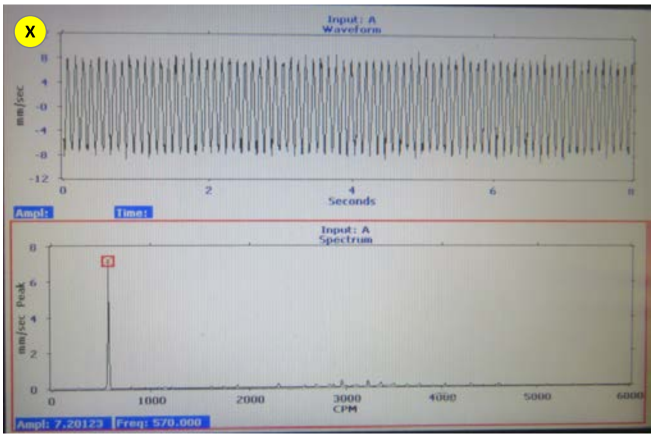
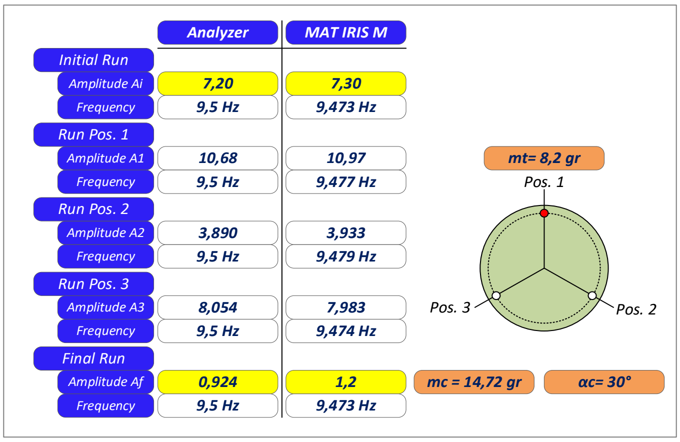


Fig. 11. Initial reading – Analyzer solution (1xRpm 7,201 mm/s Peak)

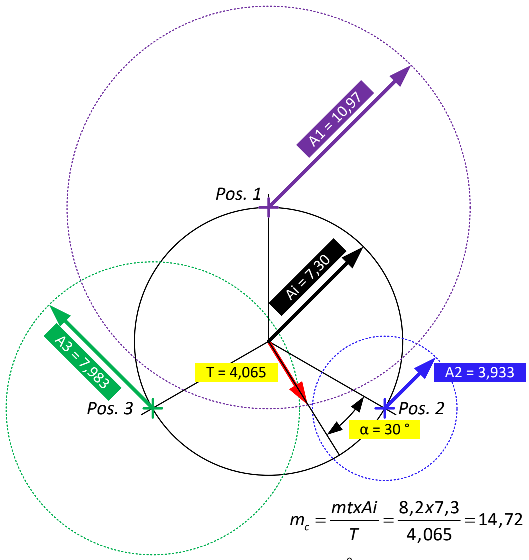
Figure 12 resumes the expressed amplitudes at 1XRpm obtained by the “Four Run Method”



		Analyzer	MAT IRIS M
Initial Run			
	Amplitude Ai	7,20	7,30
	Frequency	9,5 Hz	9,473 Hz
Run Pos. 1			
	Amplitude A1	10,68	10,97
	Frequency	9,5 Hz	9,477 Hz
Run Pos. 2			
	Amplitude A2	3,890	3,933
	Frequency	9,5 Hz	9,479 Hz
Run Pos. 3			
	Amplitude A3	8,054	7,983
	Frequency	9,5 Hz	9,474 Hz
Final Run			
	Amplitude Af	0,924	1,2
	Frequency	9,5 Hz	9,473 Hz

Fig. 12. Summary table with the readings obtained including the final reading

Based on the four readings (Ai, A1, A2 and A3) the graphical solution presented in Figure 13 allowed the determination of the corrective weight (mc=14.72 gr) and corrective angle (30°) measured from Pos. 2 to Pos. 3.



$$m_c = \frac{mtxAi}{T} = \frac{8{,}2x7{,}3}{4{,}065} = 14{,}72$$

$$\alpha_c = 30^0$$

Fig. 13. Graphical solution

Results show non-significant deviations between the classical solution and MAT (Iris M). After dynamic balancing new values were collected, as presented in Figures 14, 15 and 16.

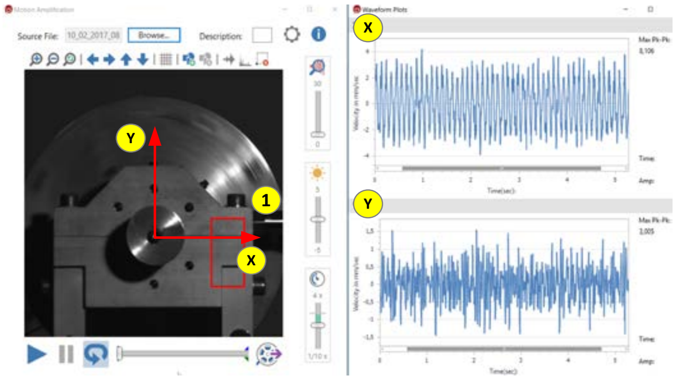


Fig. 14. Final reading – Time waveform

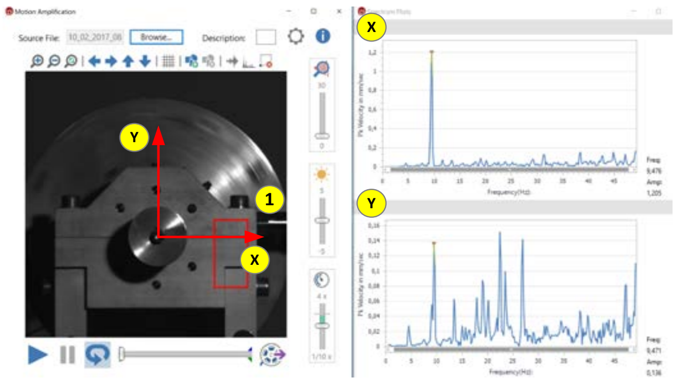


Fig. 15. Final reading – FFT spectrum (1xRpm 1,205 mm/s Peak)

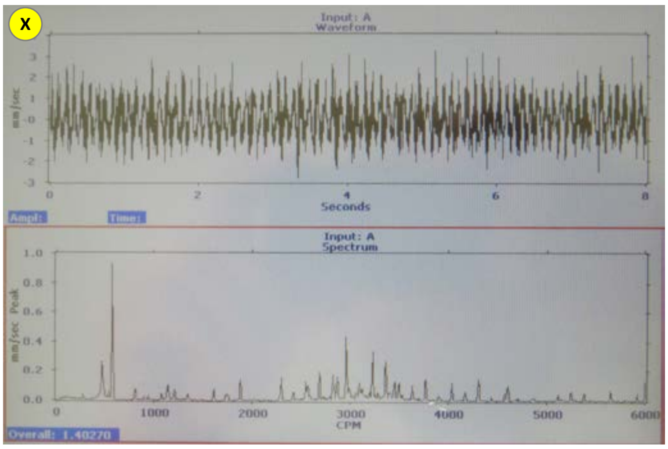


Fig. 16. Final reading – Analyzer solution (1xRpm 0,924 mm/s Peak)

3.2 – Pump and Motor assembly – Example 1

Next example refers to a pump and motor assembly (Figure 17) belonging to a water pump company. Data collected in a condition monitoring activity point out for a structural problem. Based on this assumption some images from the metallic structure were collected and was very simple to observe the soft foot problem.

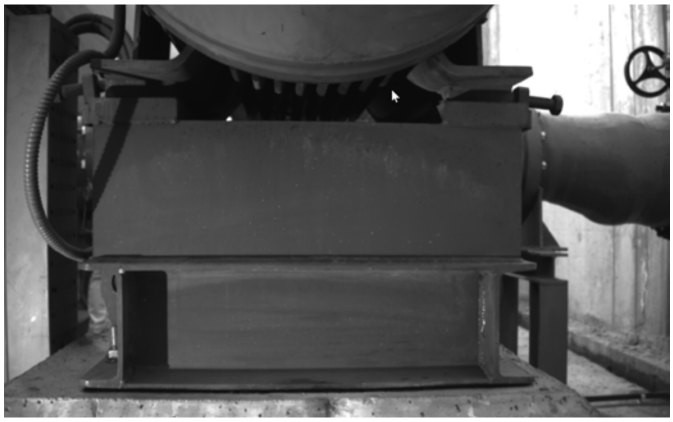


Fig. 17. Detail of the metallic support

3.3 – Pump and Motor assembly – Example 2

The present example also refers to a Pump and Motor assembly (Figure 18) but from an organization belonging to energy sector. It was diagnosed a misalignment problem and required the MAT-Iris M equipment to confirm that situation. Using this technology it was also verified the existence of loosened bolts. After corrective action it was proved the need for a group alignment process.

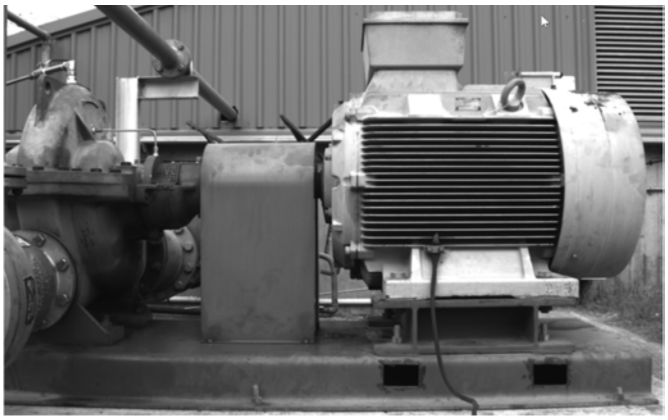


Fig. 18. Fixing detail on the metallic base

3.4 – Industrial structure

This example refers to a cement company situated on southern Spain which has a crusher on the top of a structure. The workers complained about excessive vibrations when they went up the stairs on their daily activities. MAT-Iris M was applied and it was verified that the structural vibrations were caused by the crusher itself.

Fig. 19. Structure subject to vibrating movement

NEW DEVELOPMENTS AND LIMITATIONS

New developments have been registered in the last months about MAT-Iris M and new tools and options appeared to reinforce and bring higher capabilities to this technology. The following paragraphs present some of these new features.

4.1 – Image stabilization

This option allows the elimination of shaking movement of the camera. As a rule, this device should be mounted in a place isolated from vibrations produced or transmitted by surrounding equipment. If this isolation is not efficient it is possible to process the video (post-processing) and digitally eliminate the rigid body movement of image.

4.2 – Filters

This tool allows to select the frequencies of interest and thus to visualize the corresponding movement of the equipment. For example, on Figure 20 it is possible to apply the filter (Bandpass) after acquiring the FFT spectrum on the selected equipment region and observe the movement at 1xRpm. Other filters than Bandpass are available as Lowpass, Highpass and Bandstop.

Fig. 20. Bandpass filter application

4.3 – Orbits – Absolut movements

Once the data acquisition is performed on two axes (x, y) this tool allows the calculation of the orbit associated to the two time waveforms, as represented in Figure 21.

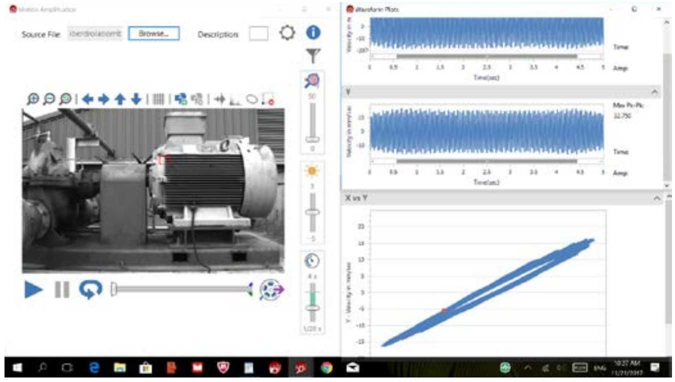


Fig. 21. Orbits

This orbit refers to the relationship between two absolute movements collected on machine structure.

4.4 – Technology limitations

The number of frames per second (fps) determines the frequency of sampling on time waveform digitalization that determines the maximum frequency of interest on FFT spectrum – Nyquist / Shannon Theorem.

Based on this, the present technology has an exceptional performance at low frequency band but it is not applicable for the high frequency band, as the example of bearing control. As MAT-Iris M uses time waveform in displacement, amplitudes tend to decrease as frequency increases.

CONCLUSIONS

Mat-Iris M is undoubtedly a revolutionary tool with a marked place on a condition-based maintenance strategy although its limited maximum frequency applicability.

Some of the advantages referred in this paper are proved and will be optimized in a near future, as new developments will be implemented, indicating a promising future.

It was demonstrated the ease of application of this technology as well as the high accuracy of time waveform and FFT spectrum. Recent developments as image stabilization, filters and orbit calculation reinforce the diagnostic capacity.

From the examples presented in this work it was possible to verify the existence of non-significant deviations between MAT-Iris M and classic solution (accelerometer and vibration analyzer).

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Overarching holistic maintenance approach for distributed linear assets

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Abstract

The distributed linear assets in infrastructure are not specific to a single location. They represent a network of assets which cross other networks and have non-linear assets included in them. Their maintenance requires new methods, including technology, business models, and organizational strategies.

An overarching holistic maintenance approach would consider both the common characteristics and the individual features of these interconnected systems. It would assess the condition of the infrastructure using advanced data acquisition methods and multiple data sources. Big Data analytics and advanced forecasting methodologies could be applied for decision support. The results could be integrated into financial and business models to provide intelligent decisions, considering operational and organizational contexts in order to connect the data from the field with company goals and customer satisfaction. Finally, to increase the efficiency and effectiveness of operation and maintenance, it is essential to have decision support tools that are fact-based, reliable, readily available, and easy to use while considering context.

This paper suggests the application of cross-disciplinary knowledge, competences, and transformative technologies characterized by artificial intelligence, machine learning, big data analytics, etc. to enable operational excellence in the maintenance of critical and distributed linear assets or infrastructure through augmented and intelligent decision-making in the operation and maintenance processes.

Keywords— linear assets, forecasting, nowcasting, segmentation.

I. INTRODUCTION. A HOLISTIC SYSTEM APPROACHES

A robust and reliable infrastructure is a requirement for a well-functioning society. One example is water and sewer systems (WS). They supply pure water for health and well-being, contribute to improved quality of water bodies, and protect urban areas from flooding. In addition, road and railway systems are key to financial prosperity; together, these infrastructure systems constitute enormous societal value.

Most of the existing infrastructure is old and requires maintenance and huge investments, but maintaining and improving it is difficult when public sector has a shortage of financial resources.

The paper proposes a holistic view of infrastructure that allows the inclusion and consideration of all relevant actors and systems and their complex interaction. This holistic approach is adaptable to change and can implement innovative designs and methods to meet the users' needs, providing stakeholders with safer, more reliable, and robust solutions. The approach is key to increased reliability, availability, maintainability, and safety at reduced economic and environmental costs.

II. COMPLEXITY AND DIFFICULTY OF MAINTENANCE MANAGEMENT OF LINEAR ASSETS

Infrastructure can be generally separated into two broad classes: it can be comprised of linear or non-linear assets. Non-linear assets are confined to a certain size and specific location, such as equipment, machine, fleet, etc. In contrast, linear assets are not specific to a single location. Examples are roads, runways, pipe lines, electrical transmission lines, railway tracks, telecommunication lines, etc. Many linear asset networks consist of several non-linear assets; e.g., one railway track can connect to other railway tracks and many non-linear assets, like railway stations, traffic control systems, power generating equipment, and, more importantly, other parallel linear asset like power cables, etc. Linear assets are more difficult to maintain than non-linear assets and require intensive management capability. Linear asset managers struggle to handle their infrastructure as it is complex and difficult to maintain. They need a unique solution to manage a network of assets. Currently, maintenance of linear assets relies largely on the maintenance of various stand-alone, loosely integrated systems requiring extensive manual operations. This makes it time consuming to track information, identify work locations, analyze data, collate cost information, make schedules, and track work status. The process is also dependent on independent operators.

With infrastructure constantly growing – and aging – the condition monitoring of assets is essential to drive savings (maintenance optimization) and to reduce the risk of infrastructure failure in the long term. As renewals and maintenance account for almost half of infrastructure managers' expenditure, smart maintenance planning and spending is of paramount interest, and organizations need to optimize the reliability, availability, maintainability, and safety of their networks and infrastructure. Most maintenance methodologies and technologies have been designed around discrete assets which fail to address these demands. We need a comprehensive, integrated solution that facilitates and connects

linear asset management activities with the complete range of enterprise processes and data.

The urban water system interacts with other infrastructure sectors, and the complex interactions are crucial to the management of water infrastructure assets. For example, the main water network is usually located along and under streets. Every pipe break and repair causes traffic disturbances and irritates residents. However, this has created new opportunities to consider how separately considered infrastructures can be brought together to deliver multiple benefits to humans and ecosystems, over and beyond the supply of water and the safe disposal of waste. New ways of operating and maintaining WS systems are required for safe, environmentally friendly operations. This can be achieved by a paradigm shift [1] from the present approach to an integrated approach using transformative technologies and integrating new digital technology with existing physical infrastructures [2].

III. TAXONOMIES OF LINEAR ASSETS

For asset-intensive and highly regulated industries with linear assets, using a top/down or hierarchical approach to manage linear assets is difficult. Linear assets have exclusive requirements that demand a unique asset management approach, called continuous or linear asset management [3]. Linear assets are also more challenging to model and implement than non-linear assets. The ability to model and execute the maintenance of these assets has enormous market potential.

Examples of linear infrastructure are:

- Roads: lanes, bridges, tunnels, variable message signs (VMS), traffic signals
- Railways: tracks, switches, frogs, crossovers, signals
- Utilities, Oil & Gas, Communications: pipes, valves, pumps, pipeline inspection gauges , electric transmission lines, distribution systems, substations, towers, and poles

IV. INCREASING THE EFFICIENCY AND EFFECTIVENESS OF OPERATION AND MAINTENANCE PROCESSES

Infrastructure owners and managers and service providers need better tools, including new ways of working, organizing and financing maintenance and investments, as well as new analytic methods that combine various knowledge fields and introduce digitized solutions. Organizations, both public and private, need to develop new ways of organizing the work and service provision for this to be accomplished, and to attract and retain competent staff. New business models and new ways of collaborating with other service providers or actors involved in maintenance or developers of new technical solutions are likely needed. Specialized and customized services need to be developed and service providers need user friendly ways to monitor their assets and predict and plan maintenance actions. Achieving excellence in infrastructure operation is high on the agenda of infrastructure owners and managers to provide disturbance free services to society. To achieve this, many are moving from corrective maintenance to preventive and predictive maintenance.

Fig. 1. Contribution to transformation of maintenance strategy.

However, to increase the efficiency and effectiveness of operation and maintenance processes, fact-based, reliable, readily available, and easy to use support tools are essential. Hence, the paper suggests the application of cross-disciplinary knowledge, competences, and transformative technologies characterized by artificial intelligence, machine learning, big data analytics, etc. to enable operational excellence in the maintenance of critical and distributed linear assets or infrastructure through augmented and intelligent decision-making, as shown in Figure 1. It considers aspects of the system – e.g. environmental, technological, business related, organizational, and practice related – in an intertwined and interrelated manner.

Decision-making in maintenance must be augmented and intelligible to understand instantly and act effectively. The new know-how in maintenance needs to focus on two aspects of knowledge: 1) what can be known and 2) what must be known. The maintenance decision-makers who know the answers to these question can take appropriate actions.

Our approach is driven by the concept of Maintenance Analytics (MA). MA focuses on knowledge discovery in maintenance by addressing the processes of discovery, understanding, and communication of maintenance data from four time-related perspectives:

1) Maintenance Descriptive Analytics (monitoring);

2) Maintenance Diagnostic Analytics;

3) Maintenance Predictive Analytics; and

4) Maintenance Prescriptive Analytics.

V. SMART MAINTENANCE: APPLICATION OF NEW AND EMERGING TECHNOLOGIES AND DIGITIZATION

We already have the technology to drive innovation in asset management. Globally, there is a focus on digitalization of infrastructure so that infrastructure owners and managers can embrace the benefits of digital solutions in the day to day operation and maintenance of infrastructure. The digitization of railway and road infrastructure has been a dominant theme during the last 5-7 years in OECD countries. The adoption of digital solutions for infrastructure maintenance has facilitated

the development and implementation of new transformative technologies in these sectors to make them robust and reliable. Even WS infrastructure managers have realized the power of such technologies and are gradually digitalizing WS networks and facilities. The digitalization of the WS network is a core issue in planning smart cities to facilitate easy and effective monitoring and maintenance.

If the trend is any indicator, the digital age has arrived in infrastructure management. State-of-the art sensor technology allows us to replace manual measurements and provides continuous monitoring to detect anomalies and prevent delay-causing failures. Coupled with the advanced analytical capability of machine learning, sensor systems provide infrastructure maintenance managers with valuable insights into the health of infrastructure, leading to effective and efficient planning of maintenance.

Extensive application of ICT and other emerging technologies facilitate easy and effective collection of data and information [4]. In maintenance, the enhanced use of ICT facilitates the development of artefacts (e.g. frameworks, tools, methodologies, technologies) to support maintenance decision-making [5]. These artefacts also enable the improvement of maintenance approaches, such as preventive and corrective maintenance. Furthermore, ICT provides additional capabilities which can be used in diagnostic and prognostic processes. ICT-based solutions to develop and establish an effective and efficient information logistics for prognostics and diagnostics of infrastructure state in an enterprise can be materialized through an eMaintenance solution [6]. At the moment, transformative maintenance technologies are built on AI, big data and machine learning.

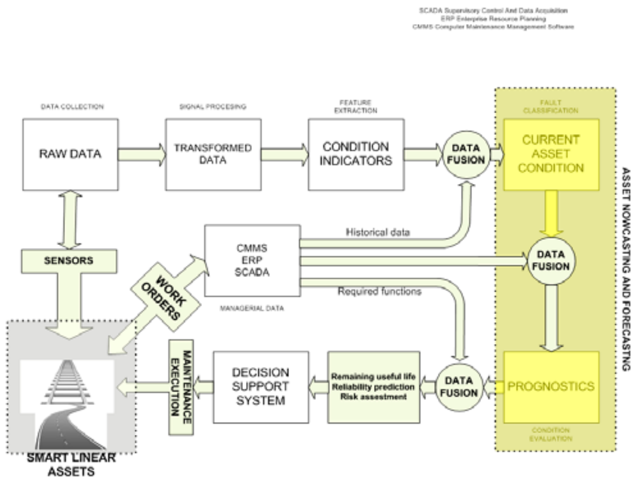

Fig. 2. Architecture for the assessment of asset condition.

A. *Nowcasting: Inspections and NDT (Non-Destructive Testing)*

A key barrier to the better maintenance of our linear assets, especially ones that are buried, like water pipes, is a fundamental lack of accurate, reliable, and timely data. It is more difficult to maintain the condition or serviceability of buried assets. Pump stations and treatment plants are more readily inspected and more easily maintained. There are many techniques for locating and assessing assets in the "underworld" [7]. For example, Rokstad and Ugarelli [8] explain how sewer condition deterioration can be modeled. There are also many techniques to assess condition and deterioration and to make good use of minimal data [9]. The causes of operational problems are not always structural defects or deterioration [10], demonstrating the need to take a holistic perspective to asset condition and the causes of what are often temporary problems. Responses may need to address unwanted behaviors by system users.

According to the World Meteorological Organization, "nowcasting" is the detailed description of the current weather, along with forecasts obtained by extrapolation for a period of 0 to 6 hours. In economics, it can be defined as "the economic discipline of determining a trend or a trend reversal objectively in real time. Nowcasting is fact-based, focusing on the known and knowable, and therefore avoiding forecasting. It is the basis of a robust decision-making process". A nowcaster does not try to predict the future, but focuses on what is known today, i.e., known "now" in real time. Forecasts are an integral part of orthodox asset allocation that is essentially guesswork. In other words, guessing is an integral part of how assets are allocated and risk is taken and subsequently managed. From the viewpoint of linear asset operation or infrastructure management, several inspection methods and systems used to assess the current condition of assets can be considered nowcasting.

B. *Forecasting: Predictive and Prescriptive Solutions*

The goal of any analytics solution is to provide an organization with actionable insights for smarter decisions and better business outcomes. Different types of analytics, however, provide different types of insights. So it is important for managers to understand what each type of analytics delivers and to match analytic functions to the organization's operational capabilities and needs across its real estate, facilities, and asset management functions. There are three main types of analytics solutions:

- Descriptive analytics uses business intelligence and data mining to ask: "What has happened?"
- Predictive analytics uses statistical models and forecasts to ask: "What could happen?"
- Prescriptive analytics uses optimization and simulation to ask: "What should we do?"

The three types build on one another, with descriptive analytics being the most common and prescriptive analytics the most advanced. Despite their inherent differences, they share goals for improving real estate, facilities, and asset operations with capabilities that provide an understanding of an event or action, uncover relationships in data, develop what-if scenarios, and simplify business decisions [11]. Some of the existing models, systems, and solutions address the three fundamental aspects of maintenance.

The area of forecasting and decision support is extensively researched in manufacturing and other sectors. New technology is able to support the assessment of the current health of assets

(nowcasting) and the prediction of their later health (prognosis or forecasting) based on all data sources available. However, information and communications technology (ICT) aspects related to maintenance are increasingly complex, and there is a real need for harmonized solutions. eMaintenance is an example; it combines disparate maintenance information sources (on and off line, with different granularity, locations and nature etc.).

Numerous decision models are available to determine optimal maintenance solutions – but not for infrastructure. There are even fewer models for road and WS systems. The research on forecasting and decision support and big data analysis is in its initial phase, and there are enormous possibilities for development.

Cohort survival models [12] are commonly used in the decision process to estimate future maintenance and replacement needs of infrastructure [13]. In WS, the asset survival curves are based on historical pipe decommissioning statistics and are usually highly path dependent [14]. They represent the depreciation of asset values because of physical deterioration and the impact of past coordination with other infrastructure and hydraulic capacity upgrades.

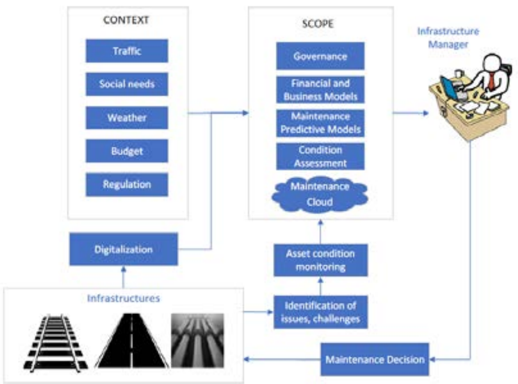

Fig. 3. Metadata for linear asset knowledge extraction.

VI. MAKING LINEAR ASSET MANAGEMENT MORE SUSTAINABLE

Traditionally, attempts have been made to manage assets sustainably, and various assessment frameworks have been employed [15]. However, sustainability assessment is not being done routinely [16], and "resilience" (s subset of sustainability) has become the main focus of many utilities [17]. A functioning system must be resilient and robust to adapt to future changes; i.e., it must be flexible and able to withstand impacts [18].

Ecosystems are increasingly considered assets. New areas of interest include natural capital and blue-green infrastructure management. These are part of a catchment metabolism approach [19] where ecosystems are understood to be vital in standard accounting procedures [20]. A transdisciplinary approach could be a way to ensure the sustainability of all assets, including ecosystems.

VII. CONCLUSIONS

Many different financing and business models are used for the maintenance of water, railway and road infrastructures. Whereas the latter two are generally the responsibility of national governmental agencies, the former involves more stakeholders – government, commercial enterprises, and private property owners.

There are clear maintenance rules for traditional assets like pipelines, treatment plants etc. However, when traditional infrastructure systems are integrated, the rules and arrangements no longer work. Management and maintenance become even more complicated when cities want blue-green infrastructures for their water instead of piped infrastructures.

For a shift in thinking to occur, there is a need to better understand organizational aspects, i.e., the daily operations and practices that constitute infrastructure maintenance. The technical processes for managing, rehabilitating, and enhancing the maintenance and operation of assets are generally clear, however, and many advances have been made in understanding the return on investment from various approaches.

ACKNOWLEDGMENTS

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Predictive Maintenance Support Tools for an On-Line Platform

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***Abstract*— Industrial activity has been increasing its levels of competitiveness in the current market. For this, the organizations have felt the need to guarantee an increasing reliability of their equipments and systems, aiming to increase the productive availability and the quality of the product and or the final service.**

Due to the rapid technological development, the degree of complexity of systems has increased, both in terms of their use and in their production and maintenance.

The production and maintenance management of today's industrial systems tends to be fully realized through digital platforms, including the logical applications that manipulate monitored data (BigData) that are sent to On-Line Platforms through Internet-connected sensory elements (IoT and IoP).

With the help of this type of tools, the organization's managers can carry out their production and maintenance planning through the data provided by the On-Line platforms that handles the data provided by the various systems in order to trigger the Work required to be performed, using tools that contain dynamic modeling algorithms and fault detection models, including prediction.

With this type of tools, it is possible to communicate with the other production and maintenance management software to more effectively trigger the Work Orders to be executed, to increase production times and to maximize the availability of the physical assets.

It is within this scope, including the basic aspects of maintenance management, planning and control, that the present article addresses electric motors, since they are fundamental elements in any industrial sector, aiming to maximize their availability for production.

***Keywords*— Production; Maintenance; Planning; Availability; On-Line Platforms; Big data; IoT.**

I. Introduction

Currently, with the use of sensory elements connected to the Internet of Things (IoT) [1] it is possible to monitor physical asset's data directly to independent systems and / or interconnected with other systems; is the case of the platforms that store the data and in which the Input data imply their Output values, consisting of the values treated to Generate the Work Orders (WO), as described in Figure 1.

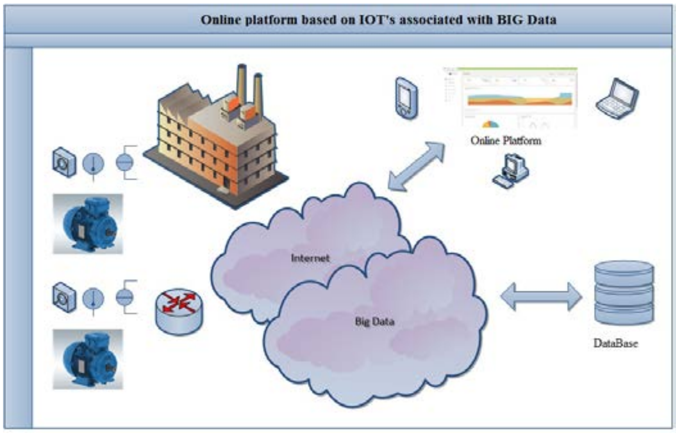

Fig. 1. On-Line Monitoring based on IoT supported on Big Data.

In the context of the IoT associated to Big Data platforms, the maintenance tends to develop Fault Detection Systems in Real Time, being integrated in the systems of control of the equipment or independent from them. Independent systems consist of On-Line Platforms that integrate information systems in the field of Predictive Maintenance to trigger the WO before the equipment fails.

According to the Big Data concept, the massive volume of data collected consists of monitoring the important quantities to be measured to predict the maintenance to be performed.

The case study discussed (Figure 2) in the following sections, corresponds to the monitoring of an electric motor [2] in which the main variables to be considered are the following: current; voltage; vibration; and temperature. If the parameter values do not fall within the ranges for which they are designed, this can affect the life of the electric motors and the deterioration of the materials and components that integrate them.

Through the monitoring tools, alarms are triggered to give rise to maintenance interventions, and the samplings of the variables can be performed, either through periodic or aperiodic cycles, as is the case of the operating variables: working time; operating cycles; etc. The use of this type of tools allows to supervise the operation of electric motors

through their most significant variables, so that their performance is the most appropriate.

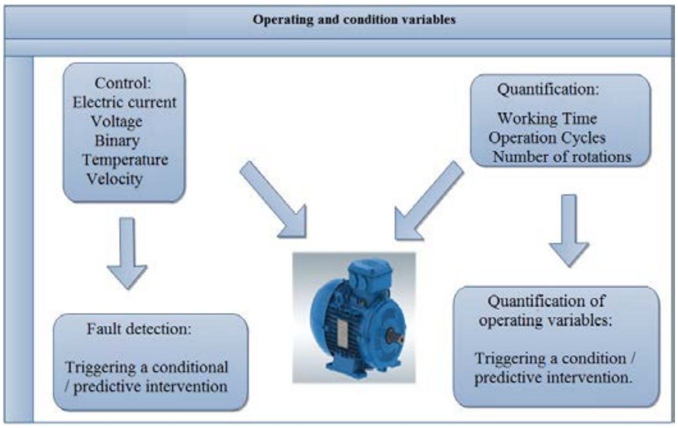

Fig. 2. Function and condition variables to be monitored.

The concept of Big Data includes the capture of raw data by devices (data acquisition), by monitoring data through devices that have logical applications to collect the data and send them to the Database using communication protocols [3] already pre-defined or developed specifically for this purpose. The use of Internet-connected devices, according to the IoT concept, facilitates the sending of data to the On-Line Platforms database, as is shown in Figure 3.

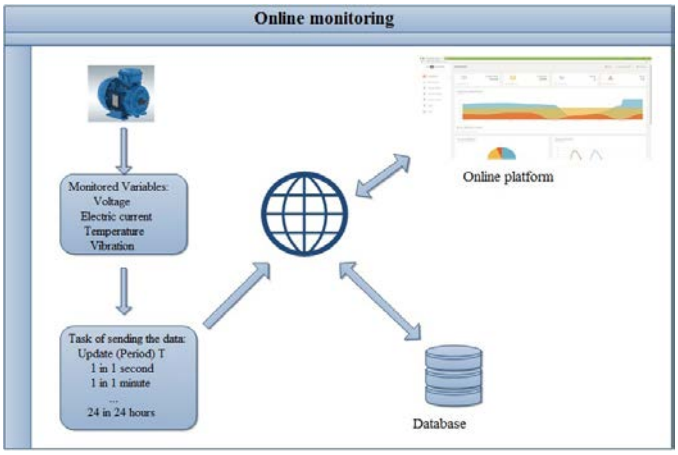

Fig. 3. Illustration of an On-Line Monitoring.

The data acquisition can be done by several ways, through SCADA systems, which corresponds to the Supervision and Data Acquisition of Industrial Management Control Systems, usually embedded in the logics of industrial process control, or through external and independent devices. Industrial process control systems capture the data and send it to platforms or databases that are allocated to logical applications / softwares.

Data processing is performed on the platforms and logical applications manipulate the data through the implemented logical algorithms. In this specific case, of a predictive system, having an associated error, whose tolerance must tend to a reduce the interval to allow a reliable treatment in accordance with the intended objective. In the case of Conditioning Predictive Maintenance, the interventions ought to happen before the equipment fails.

Maintenance planning [4] is based on a structuring of tasks that comprise the activities, procedures, resources and duration required to perform the combination of all technical, administrative and management actions during the life cycle of the physical assets.

All management activities that determine maintenance objectives, strategy and responsibilities and implement them by various means, such as planning, control and supervision of maintenance, as well as improvement of methods in the organization, including economic aspects, can be optimized with the help of software tools (CMMS / EAM / SCADA Systems / On-Line Platforms).

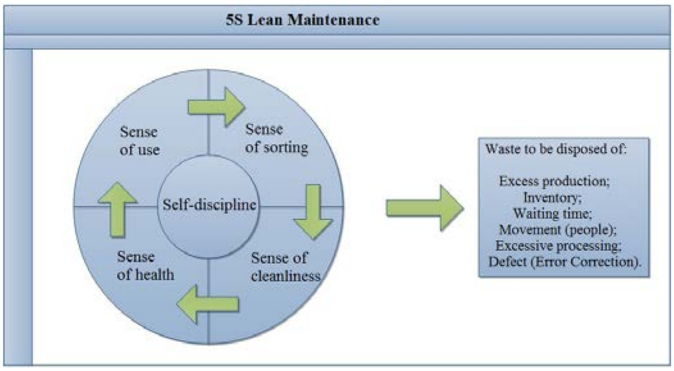

Fig. 4. New strands for asset management..

In this way, maintenance managers can readjust not only their parameterizations, but also their maintenance contracts, as well as improvement actions through FMECA or other analyzes, complemented by the new maintenance management tools, having always a perspective of a continuous improvement (Figure 4).

The Maintenance Planning can be done by scheduling the maintenance actions or by controlling and monitoring the operating variables and / or condition.

The foregoing aspects are discussed in the following sections, namely through the implementation of a case study based on an electric motor coupled to a load, in which perturbation situations are applied with respect to its normal operation.

The article is structured as follows:

- The following section presents the Hardware and Software used in the condition monitoring;
- The third section discusses the On-Line Platform;
- In the fourth section the case study is presented;
- Finally, the conclusions and future developments, as well as the references used, are presented.

II. Hardware And Software Used In Monitoring

In the implementation of the tool developed to aid predictive maintenance based on monitoring through an On-Line platform there was a need to use specific hardware and software. In the case of the hardware, a microcontroller was used to make the data acquisition through sensory devices

interconnected to each other. The microcontroller in question has a task that runs in a periodic interval that can be adjusted to capture the data to be sent to the On-Line Platform and at the same time keeping the memory of the microcontroller available for the next capture of the data to be monitored as illustrated in Figure 3. The data is sent to the database, because the microcontroller is an IoT device that allows to interconnect through Ethernet and / or Wi-Fi network, sending the data over the Internet to the On-Line Platform. Table 1 shows a small sample of data collected and sent to the On-Line Platform.

TABLE I. DATA MONITORED AND SENT TO THE DATABASE IN THE ON-LINE PLATFORM

Actions | Maintenance Plans | Tresholds | Sensors Data

Voltage (v)	AC Current (A)	Temperature (ºc)	Date
2,13	291	53,96	15/11/2017 10:00:00
2,07	296	53,22	15/11/2017 10:01:00
2,11	291	54,2	15/11/2017 10:02:00
2,07	300	53,22	15/11/2017 10:03:00
2,02	302	51,51	15/11/2017 10:04:00
2,06	299	52	15/11/2017 10:05:00
2,03	297	52,73	15/11/2017 10:06:00
2,11	291	53,96	15/11/2017 10:07:00
2,07	296	53,22	15/11/2017 10:08:00
2,03	302	51,76	15/11/2017 10:09:00
2,04	301	52,25	15/11/2017 10:10:00
2,13	296	53,71	15/11/2017 10:11:00
2,13	291	54,44	15/11/2017 10:12:00

III. ON-LINE PLATFORM

The On-Line platform was developed using the latest technologies and allows a simple and objective representation of the system to be monitored, also allowing access to a set of information about the different monitored devices [4].

For this purpose, a Web API (Application Programming Interface) was developed, that allows to collect and to manage the collected data, as well as to control the network of sensors and to interact with other systems.

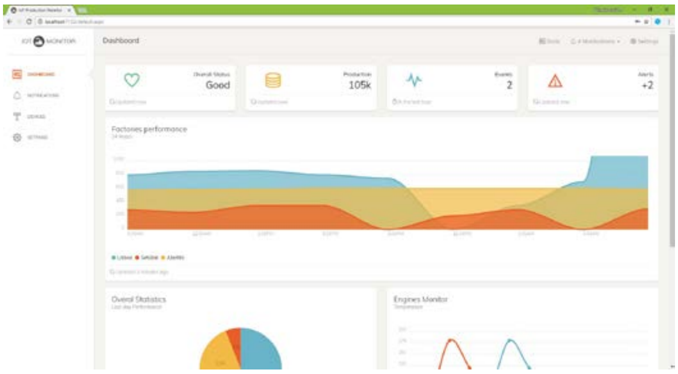

Fig. 5. Graphical On-Line Platform Interface - Monitoring panel.

The Web API [5] developed consists of a set of Web Services (web services - HTTP), which can be used by a wide range of clients, from browsers, mobile applications, etc.

This platform is made up of different modules that allow, among other functions, the data collection sent by the sensors / devices, the treatment of the collected information and the triggering of the actions according to the parameterizations previously defined.

The graphical interface was designed and implemented to be compatible with different types of devices, such as computers, tablets and mobile phones, thus allowing them to be used in different environments, facilitating their use (Figures 5-8).

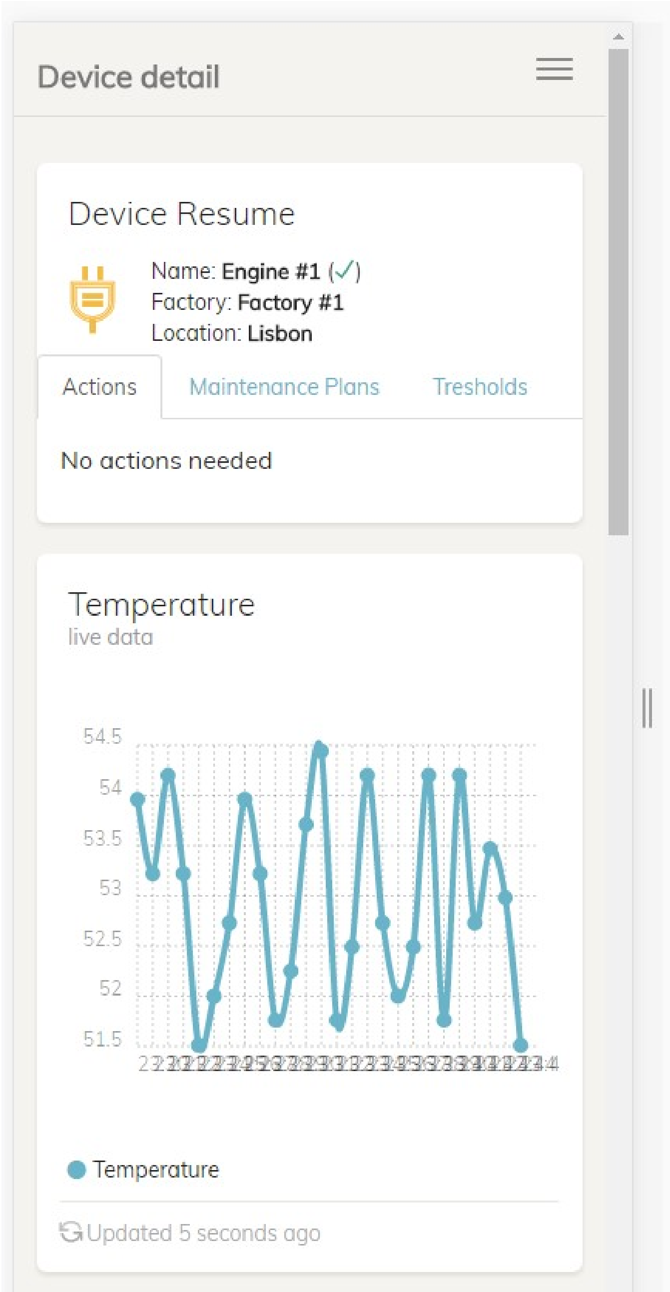

Fig. 6. On-Line Platform - Mobile Environment Simulation.

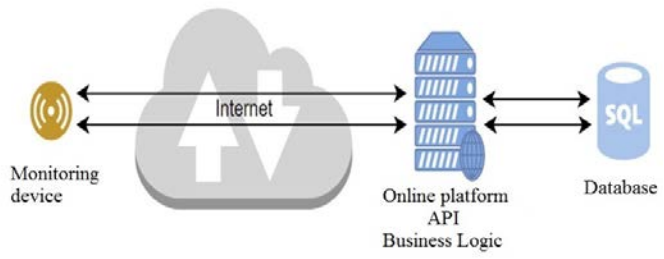

Fig. 7. API architecture.

Fig. 8. On-Line Platform - details of a monitoring device.

Figure 9 represents the overview of the developed system, consisting of a set of monitoring devices connected to the On-Line platform through the Internet.

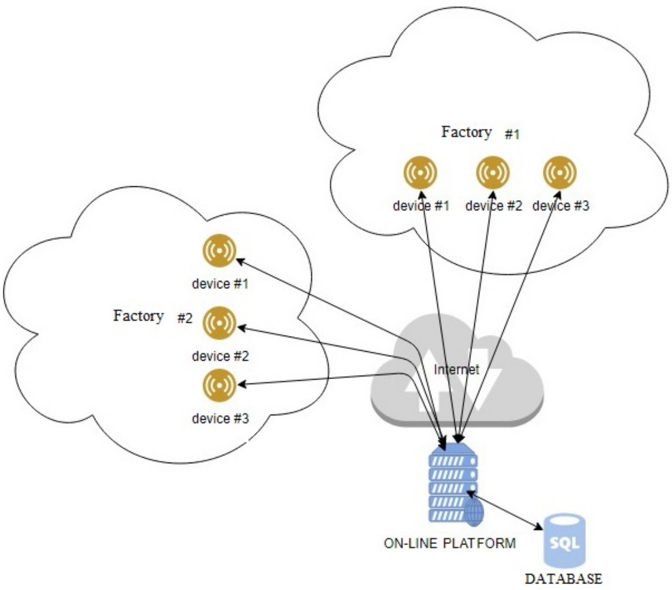

Fig. 9. Developed system overview.

IV. Case Study

As a case study, a single-phase electric motor was used, as shown by its sign plate (Figure 10).

Fig. 10. Characteristic plate of the monitored electric motor.

For test purposes, a test bench was built so that the initial tests could be performed. In the specific case of the test bench of the hardware, an engine control circuit has been implemented that allows the engine to start, start and stop, as well as turning it in different directions (clockwise and counterclockwise). The sensors connected to the microcontroller that monitors the electric motor are the temperature, voltage, current and vibration, as shown in Figure 11.

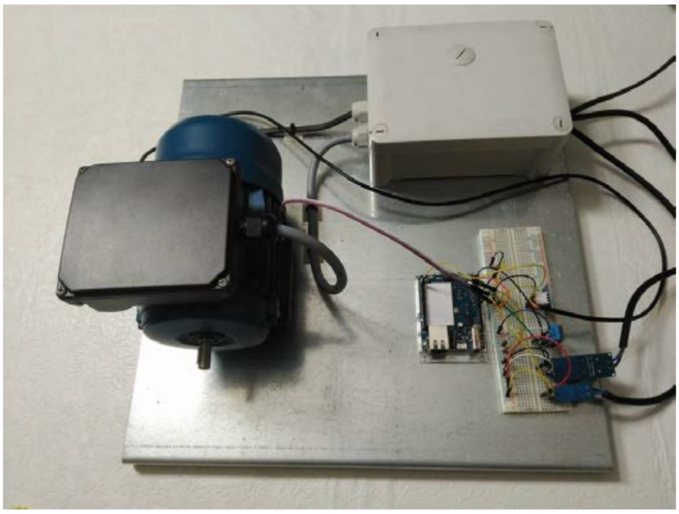

Fig. 11. Illustration of test bench.

Figure 12 illustrates the graphical representation of temperature monitoring (real value) and temperature prediction through a time series prediction algorithm as well as engine vibration.

Table 2 presents a small sample of the monitored data of the voltage and current consumed by the electric motor, in which the logic application calculates the power consumed by the electric motor through the Inputs of the voltage and current consumed by the motor and the angle of lag between the voltage and the theoretical current, as shown in Figure 10 of the electrical motor data plate.

TABLE II. MONITORED VOLTAGE AND CURRENT DATA AND PREDICTION OF ELECTRIC MOTOR POWER

Voltage V	Current A	Power W	P Predictive W	Sampling Interval
291	2,13	588,8385	588,8385	2017-08-26 23:50:27.030
296	2,07	582,084	587,4876	2017-08-26 23:50:35.523
291	2,11	583,3095	583,5184	2017-08-26 23:50:44.423
300	2,07	589,95	589,95	2017-08-26 23:50:53.317
302	2,02	579,538	579,538	2017-08-26 23:51:02.203
299	2,06	585,143	585,143	2017-08-26 23:51:11.103
297	2,03	572,7645	572,7645	2017-08-26 23:51:19.983
291	2,11	583,3095	583,3095	2017-08-26 23:51:28.897
296	2,07	582,084	583,3095	2017-08-26 23:52:56.710
302	2,03	582,407	583,3095	2017-08-26 23:53:05.800
301	2,04	583,338	583,338	2017-08-26 23:53:14.683
296	2,13	598,956	598,956	2017-08-26 23:53:23.570
291	2,13	588,8385	588,8385	2017-08-26 23:53:32.460
302	2,02	579,538	579,538	2017-08-26 23:53:41.350
301	2,05	586,1975	586,1975	2017-08-26 23:53:50.233
293	2,12	590,102	586,1975	2017-08-26 23:53:59.130
297	2,06	581,229	586,1975	2017-08-26 23:54:08.010
300	2,02	575,7	575,7	2017-08-26 23:54:16.907

According to the data shown in Table 2, the logic application calculates the power consumed by the motor using the theoretical power factor of the equipment.

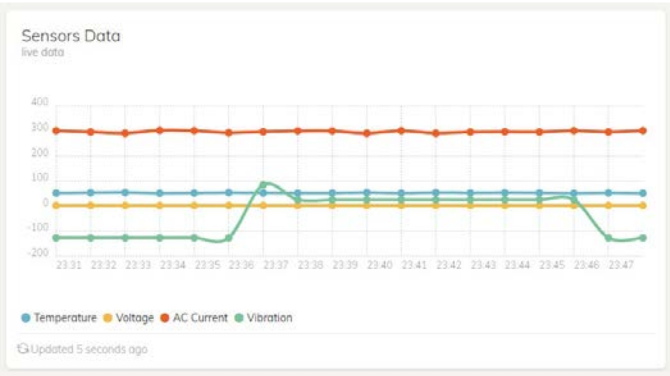

Fig. 12. On-line monitoring of the electric motor control variables.

The application thus performs the prediction of the absorbed power of the motor having as reference predefined values in the platform of the Permissible Consumed Power and identified as a Good Operation regime, doing a previous analysis of failure and thus alerting the Maintenance Manager to carry out a WO before failure occurs.

With the monitoring and prediction of the Motor Power Consumption, other types of controls can also be performed and also the detection of mechanical transmission failures, through algorithms that analyze the relation between the Power Consumed by the motor and the detection of the movement of the electromechanical drive, as will be presented in the section about Future Developments.

To perform a test of triggering of a maintenance intervention, through the temperature variable, the motor fan cover was removed, as shown in Figure 13. The cover of an electric motor has the function to protect the fan from being damaged and the physical integrity of the people surrounding the motor, as well as optimized routing of the air to perform the motor ventilation function, thus ensuring the quality of the properties of all components of the electric motor. The temperature is one of the most important control variables in such equipment, and the engine is responsible for whether or not it has a long life cycle.

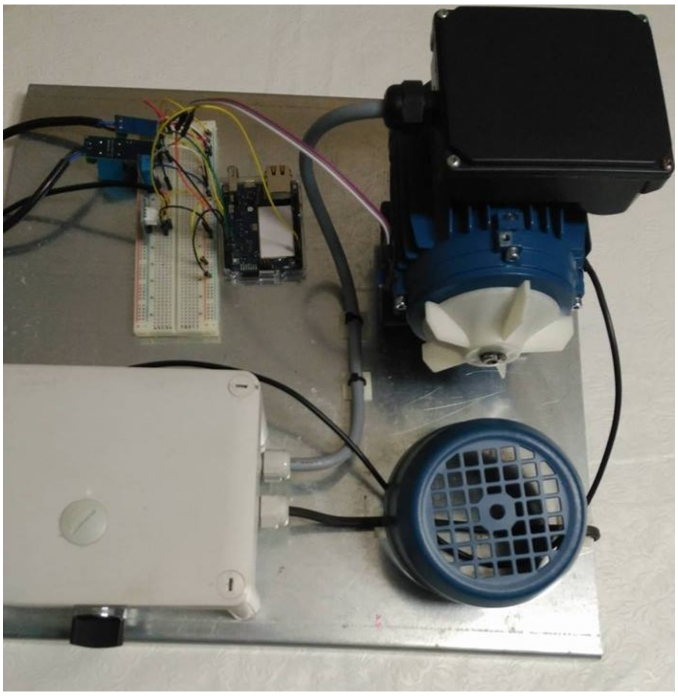

Fig. 13. Simulation of deficiency in the ventilation of the electric motor.

As shown in Figure 13, the motor cover is removed, and the microcontroller monitors the data and treats them through a prediction algorithm. When the value reached is equal to or greater than the default value for the operating mode temperature, the Platform launches a WO (Figure 14) because the temperature of the equipment has exceeded the default value.

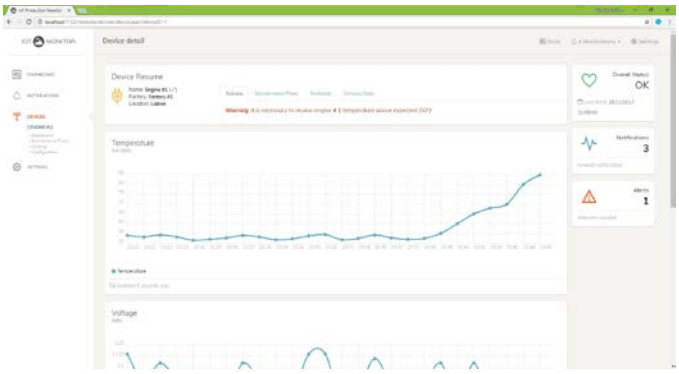

Fig. 14. Triggering an intervention through On-line temperature monitoring.

V. CONCLUSIONS AND FUTURE WORK

Predictive maintenance corresponds to an approach that aims to maximize the availability of equipment and, consequently, increases the levels of competitiveness of companies by decreasing production times.

For the implementation of the predictive maintenance we use tools to aid in the scheduling of predictive maintenance. In order to carry out and execute predictive maintenance management efficiently, the variables of operation and condition of the physical assets are controlled in periodic and aperiodic sampling cycles.

By using the IoT networks associated with Big Data platforms it is possible to interconnect the Physical Assets through the devices that allow the connection to the Internet and that can capture the data through sensorial elements and send them to a database where a logical application manage the data, making prediction for the next maintenance interventions.

The next step is the triggering of a WO to be performed before the failure event in the equipment, where this information is obtained through an On-Line Platform. The access of the user to the Platform is carried out through a device that allows access to the Internet.

Future developments will consist of the following:

- To interconnect with other information systems (EAM / CMMS) to trigger WO;
- To improve the prediction algorithms through new mathematical models;
- To combine several variables to improve fault detection;
- To implement fault detection systems using a second monitoring layer to ensure that the monitoring is performed in a way that the information is reliable.

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Predictive Maintenance using Ultrasound Technology as Condition Monitoring

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***Abstract* - Despite ultrasound technology has some decades upon its applicability on engineering, it remains nowadays as a technique that can be very useful on the condition monitoring of industrial equipment. The present paper is focused on the presentation of such technology and on the demonstration of several failure modes that can be present in most of the industrial facilities. It is shown where the technology can be applied as leak detection, valve inspection, steam traps inspection, electrical equipment inspection, hydraulic systems inspection, inspection of bearings and on lubrication based on condition. It is also presented some features that enable the use of ultrasound technology under the scope of Industry 4.0 through the use of web platforms to store data and access a huge variety of information.**

Keywords — ultrasound, condition monitoring, maintenance.

I. Introduction

Industry continuously faces the challenge of doing more with less. It means more production, less maintenance, more prediction, less manpower. This can be achieved through the use of proper methodologies, appropriate tools, skilled professionals, modern technology and taking part of recent developments under the industrial revolution in progress.

It is difficult to precise the right moment of the beginning of ultrasound technology. As other technologies ultrasound appeared as a necessity and suffered several improvements along the years. The first reference of ultrasound for engineering purposes can be found in 1957 [1]. Some years later a work about pinpointing industrial defects using ultrasound gave more detailed information referring the first application on the detection of air leakages through the use of ultrasonic transducers in telecommunication cables that were pressurized to avoid the entrance of humidity. Later it was also used to detect electrical defects, friction in rotating elements, leaks in valves and other applications. The great development of the technology was registered when the National Aeronautics and Space Administration (NASA) used ultrasound technology for space vehicles [2]. Today it is one of the technologies that are used for condition monitoring and

applied for operational reliability in industrial facilities.

Guillén et al [3] refer that the classical industrial view of

condition based maintenance is mainly focused on the use of condition monitoring techniques such as vibration analysis, thermography, acoustic emission or tribology. However, in modern times and using recent developments it is also notable that these techniques stay being used to control equipment health and as the support for maintenance decisions.

Monitoring can be processed online or in certain time intervals. The procurement of accurate data is critical to determine the occurrence of a problem and the solution to apply. Different techniques are available for condition monitoring as vibration analysis, acoustic emission, ultrasonic testing techniques, oil analysis, thermography and other methods [4].

The present paper is structured into six sections. The first gives a brief introduction to the theme and the second describes ultrasound principles that are in the basis of the referred technology. Section 3 refers to ultrasound data and some characteristics of it and section 4 shows how ultrasound is used on condition monitoring, with the description of some applications. Section 5 refers the implementation of a maintenance plan, including ultrasound technology as a condition monitoring technique, and Section 6 states some conclusions about the work developed.

II. Ultrasound Principles

Sound refers a phenomenon that involves the propagation of waves produced by a vibrating element. Audible sound consists on the conversion of air pressure oscillations into mechanical waves inside human ear and then perceived and decoded by human brain. These waves do not propagate in vacuum as electromagnetic waves do. Thus, propagation is usually referred on a solid, a liquid or a gaseous medium and wave propagation velocity depends on it, according to their elasticity and density as well as pressure, temperature, humidity, depth or salinity. For example, on air the velocity is usually around 343 m/s and on water it is around 1500 m/s. In metals there is a higher velocity, being around 5000 m/s on steel [5]. The sound velocity in air (v) can be determined as a function of temperature (T), using the expression (1):

$$v(t) = 331.45\sqrt{\frac{T}{273.15}} \qquad (1)$$

Where “T” is the temperature in °K. Figure 1 shows how sound velocity varies in function of temperature.

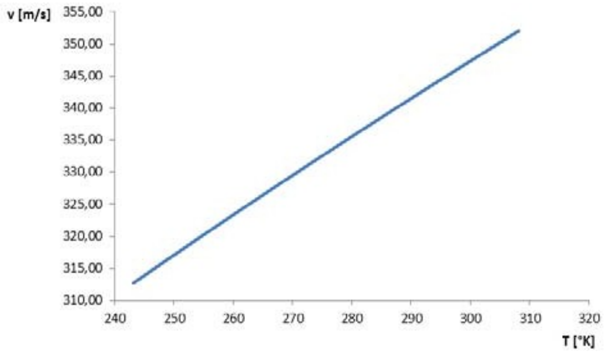

Fig. 1. Variation of velocity in function of temperature.

The sound, as a special form of energy, propagates through pressure fluctuations in elastic media. It can be classified as infrasound (f < 20 Hz), sound (audible) (20 Hz < f < 20 kHz), and ultrasound (f > 20 kHz) according to the frequency of pressure pulsation [6].

Thus, ultrasound refers to an acoustic wave with a frequency above 20 kHz that corresponds to the limit of human ears natural hearing capacity (20 Hz to 20 kHz).

The direction of ultrasound is another interesting characteristic. Low frequencies travel in multiple directions surrounding the receiver and thus being difficult the localization of the source or energy transmitter. This do not happen in high frequencies once sound travels in just one direction.

Acoustic impedance refers to the resistance that the medium offers to propagation, resulting in energy dissipation. Sound intensity (I) is inversely proportional on the squared distance to the source and can be expressed in decibels (dB) above the threshold of standard hearing level (I0). The logarithm involved, is exactly the ten-power intensity of the sound expressed as a multiple of the threshold of the listening intensity. Example: If I = 10000 times the threshold, then the ratio of the intensity to the threshold current is 104, the power of ten is 4, and the current is 40 dB.

The mitigation or loss of acoustic energy is also interesting and can also be measured in reference to the distance. For example, for 1000 meters the mitigation can achieve values about 60 dB.

There are three occurrences that are considered for ultrasound inspections once they are the basis for generating detectable high frequency noise, specifically turbulence, ionization and friction. Thus, any hydraulic, pneumatic, electric or mechanical element that generates or includes any one of these phenomena is candidate to be under an ultrasound inspection program. Basically, there are two types of ultrasound sensors, the ones that use piezoelectric crystals to detect high frequency travelling in air and those used to detect high frequency travelling in structures. The knowledge of ultrasound typology will also help to determine the frequency of inspection and the type of module to use in each case. It is very common to perform the following:

- For inspections where the ultrasound propagates in air, it is used a frequency of 40 kHz once it is the frequency with high natural sensitivity;
- For inspections where the ultrasound propagates in structures, it is used a frequency between 25 and 30 kHz, increasing the acoustic penetration without affecting sensor capacity;
- Ultrasound should not be used to detect sources that generated ultrasound in air passing to a structure once the acoustic impedance will eliminate a great part of original energy.

Another important factor to be taken into account is the ultrasound equipment sensitivity. Low sensitivity will not allow detecting all sources in vicinity but facilitates a specific detection at a short distance. High sensitivity allows detecting all high frequencies produced in the area but will difficult the localization and exact position of those sources. ASTM E 1002:2011 [7] refers to a standard practice for leaks using ultrasonics where the sensitivity validation is referred and the procedure is established.

III. Ultrasound Data

Data gathered by ultrasound technology is the most valorous element of an inspection. However, it is possible to capture other high frequency emissions in the area of inspection than the one that we seek. These emissions are called competitive ultrasounds. To minimize these competitive ultrasounds there are basically two options:

1) Control test environment – by eliminating the sources of the identified competitive ultrasounds, isolating the area of inspection through doors or curtains and performing inspections on lunch breaks or shift change (e.g. in soldering zones).
2) Use shield methods – Placing protective shields between the source of the competitive ultrasound and the zone where the asset under inspection is located (high frequency means low acoustic penetration on solid objects).

With the data gathered (in dB) it is possible to compare two or more pressurized gas leaks, monitor friction index in rotating elements (allowing to establish the basis for precision lubrication based on condition) or determine the hermetic level of a gate valve. Sometimes it is necessary to record the acoustic emission and perform a spectral analysis (e.g. 5 to 20 seconds). This is useful in electrical applications to observe the characteristics of each type of failure, in steam traps to clearly diagnose the opening or closing of a valve or its full open or close state or even in the inspection of rotating elements.

Data storage and data management are also important. A database will allow establishing routes and linking the data gathered to a specific asset, producing trend graphs, reports, alarms.

IV. Ultrasound in Condition Monitoring

Condition monitoring is used to estimate the moment in which the asset will probably fail based on its state and thus programming in a proactive way the maintenance intervention before the asset failure. Condition monitoring will help to avoid catastrophic failures, predict spares necessity or plan the work.

Condition monitoring can be supported by using some technologies as vibration analysis, infrared thermography, motor current analysis or oil analysis. All these technologies have pros and cons and can be used in complement of each other. Ultrasound technology can also be applied as a condition monitoring technology in detection of leaks in compressed gases, inspection of electric systems (low, medium and high voltage), inspection of power transformers, mechanical inspection (static), mechanical inspection (dynamic) and lubrication (precision).

Noise signs are used for condition monitoring in light of the fact that noise signals measured at areas in nearness to the outer surface of machines can contain imperative data about the inward procedures, and can give significant data about a machine's running condition. At the point when machines are in a decent condition, their noise frequencies have a particular shape. As faults begin to develop, the frequency spectra change. Every segment in the frequency range can be identified with a particular source within the machine. This is the essential reason for utilizing noise measurement and analysis as a part of condition monitoring. In some cases, the signal which is to be monitored is submerged within some other signal and it cannot be recognized by a straightforward time history or spectral analysis. For this situation, specific signal processing techniques have to be used [8].

Roy et al [9] refer a comparison of strengths of non-destructive evaluation (NDE) techniques for degradation assessment in metallic aerospace components. The suitability of techniques against various damage and defect types have been graded 1 (appropriate) to 4 (inappropriate) and it is possible to clearly observe that ultrasound, X-ray and pulsed thermography have the widest range of applications.

Ahn et al [10] present a work on artificial intelligence- based machine learning considering flow and temperature of a pipeline for leak early detection using acoustic emission. They refer that acoustic emission is widely used for detecting leaks and locating them on a pipeline. It is also said that the application of the ultrasound technique in the condition monitoring of rotating machinery has increased of late and is particularly true for bearing defect diagnosis and seal rubbing. However it is referred that the technique has a major drawback: the attenuation of the signal, and as such, the sensor has to be close to its source.

Li et al [11] also developed a work about pipelines presenting an experimental study on leak detection of a water distribution system subject to failure of socket joints. The acoustic characteristics of leak signals in the socket and spigot pipe segments were investigated and after feature extraction and selection, a classifier based on artificial neural network (ANN) was established.

The following sections describe some practical applications of ultrasound technology.

4.1. Leak detection

It can be assumed that a fluid in a pipeline follows a laminar flow in a certain direction, at the same velocity and with the same pressure. However, when there is a leak this change. There will be a way out of the fluid from a high pressure zone to a low pressure zone with an increasing velocity at leak point. There will be a turbulence generating vortices with several and distinct modules and directions that produce high frequency noise (ultrasound). In this case, the factors that affect turbulence are the difference of pressures, the size and shape of the hole and the fluid characteristics (viscosity). Thus ultrasound technology is mainly directed towards pressurized gases. Leaks have a huge impact on systems availability and reliability, producing high energy costs. More than 70% of the leaks are considered small but represent a higher volume of losses than those considered as critical ones [5]. ASTM E 1002:2011 [7] refers to the standard practice for leaks using ultrasonics.

Dudic et al [12] refer that with the leakage elimination in compressed air systems, it is possible to save up to 40% of energy, and thus leakage elimination should be a routine. This paper describes and compares two different noncontact methods for compressed air leakage quantification, ultrasound and infrared thermography presenting the potentials and limitations of these technologies. Results show that thermography offers good results for the leakage quantification from the orifices greater than 1.0 mm and ultrasound should be used for leakage detection for all the dimensions of orifices, but for the quantification purposes only for smaller leaks.

4.2. Valve inspection

Ultrasound technology can be used to detect the passage of the fluid into the valve, the blockage of the valve or the presence of cavitation. In this case it is necessary to measure on four distinct points, two before de valve and two after the valve. Then all levels must be compared and in accordance to them a conclusion can be formulated.

4.3. Steam traps inspection

Ultrasound technology can detect cyclic operations as the closing and opening of a steam trap. As saturated steam involves steam and water having the same temperature it is difficult in these cases to use thermography as the main diagnostic tool. Some steam traps fail in open position leading to steam leaks and generating high costs. About 15-20% of steam produced in a boiler is lost [13].

A correct diagnostic program based on ultrasound technology provides economic profit, increases safety and steam quality. Once again, the key word is turbulence increasing the friction between particles and providing different trajectories. Due to operation between the valve and the hole of steam trap turbulence is produced and thus being possible to detect it.

Inspections will point out if steam traps are operating in an adequate mode. These activities can be simply visual inspections, temperature measurements or acoustic inspections.

4.4. Electrical equipment inspection

Due to the criticality, when electric transformers are produced they are submitted to a lot of tests to assure their integrity. When in operation it is not common to observe their condition, unless some oil tests sometimes made annually. ISO 29821-1 [14] helps the decision making process in the maintenance of electrical assets, pointing out failures as the Corona effect, partial discharges and electric arc. Nowadays there are several types of ultrasound equipment able to record sounds on the field and then show it graphically. Technologies as thermography, ultraviolet chamber and ultrasound are used for electrical equipment. Table I shows a comparison between ultrasound and thermography applied for condition monitoring of electrical equipment.

TABLE I. TECHNOLOGIES COMPARISON FOR ELECTRICAL EQUIPMENT (ADAPTED FROM [5])

Ultrasound	Thermography
Detect Corona effect, partial discharge and electric arc	Detects hot points – No detection of Corona effect
Depends on voltage (not line charge)	Depends on current (requires high charge)
Verification at any time and any environment (humidity is advantageous)	Solar radiation and hot environment represent a problem
Detection occurs at any degradation stage	Detection usually happens at a mature degradation

For electrical cabinets, electrical substations and aerial equipment a major advantage of ultrasound technology is that is possible to acquire singular characteristics that can be used for identification in a spectral analysis and thus to distinguish Corona effect, tracking or electric arc. Data gathered can also be used to inform if electrical transformers are in a good state, at precaution or in an alarm state.

4.5. Inspection of hydraulic systems

Ultrasound can be used to inspect clogged valves and internal leaks in actuators and valves. All hydraulic circuit is inspected defining flow direction and recording leakages. In hydraulic cylinders there is a seal between the high pressure chamber and the low pressure chamber. When seal integrity is compromised there will be a lack or loss of the hydraulic force that is observable. Higher temperature and pump noise is also a signal of a leak in the cylinder.

Ultrasound technology is used to detect the leak when the fluid moves from the high pressure chamber to the low pressure one. The higher sound points out the place of seal violation.

4.6. Inspection of bearings and lubrication on condition

Usually the condition monitoring technologies applied to rotating elements are:

- Vibration analysis;
- Thermography;
- Oil analysis;
- Ultrasound.

Figure 2 shows the P-F curve comparing the development of a potential failure.

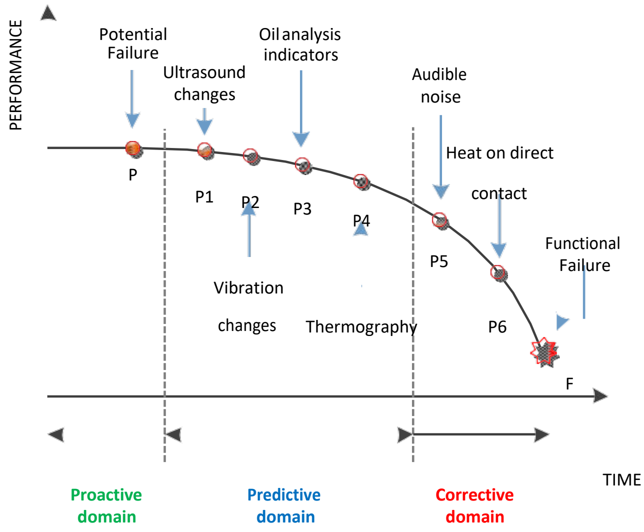

Fig. 2. Technologies comparison and domains on a P-F curve.

Ultrasound allows monitoring the friction index of a rotating element that is represented by a decibel (dB) number. These numbers are recorded creating an historical data and a tendency curve giving information about each individual element. Ultrasound equipment facilitates this job once it is possible to create inspection routes and databases in a systematic way linking every read at each point to a proper archive. It also provides an automatic diagnostic.

Precision lubrication based on condition is an important application for ultrasound technology once the correct amount of lubricant is not used. Usually technicians use an excessive quantity of oil in bearings which can have a negative impact on bearing life and operation. More than 50% of bearing damage is related to poor lubrication originating wear, grooves, stretch marks, fatigue damage and increasing temperature. This number can be reduced to 10% when ultrasound is used to assess lubrication needs. Table II shows the consequences of a poor lubrication.

TABLE II. DAMAGES RELATED TO BAD LUBRICATION PROCEDURE (ADAPTED FROM [5])

Damage or Deficiency	Cause	Comments
Noise	Poor lubrication	Metal to metal contact. Absence of oil film
Cage wear	Poor lubrication	Metal to metal contact. Absence of oil film
Wear of rolling elements or surfaces	Poor lubrication	Metal to metal contact. Absence of oil film. Tribological corrosion. gliding footprints
Fatigue	Poor lubrication	Metal to metal contact. High superficial tensions
Higher temperature	Poor lubrication	Metal to metal contact. Absence of oil film
Lubricant changes	High operating service period	Long period between oil changes

MPMM
Maintenance Performance Measurement and Management

The basis for precision lubrication based on condition using ultrasound technology rely on normal forces applied to bearings and elastic deformation of the elements on the area of contact as well as the lubricant effect. The right amount of lubricant influences bearing life. A well lubricated bearing will produce low acoustic energy and noise, establishing a baseline for bearing behavior. Lack or excess of lubricant will cause an increasing of acoustic intensity. With ultrasound technology it is possible to attend bearing condition overcoming common difficulties on lubrication process. ISO 29821-1 [14] establishes that the alarm level should be defined upon historical data that demonstrates an increasing value for acoustic energy on bearings. This modification will determine the right moment to proceed to bearing lubrication. The baseline must be defined taking into account five lectures on each bearing and be based on RMS value and wave form. When lubricant values are optimum the energy created is at its lowest. As frictional forces increase so does the acoustic energy.

With ultrasound technology it will be possible to understand the right amount of lubricant simply regarding the achievement of the baseline value (corresponding to a certain friction level) because zero friction is impossible to obtain.

V. Implementation of a Maintenance Plan

Reliability and availability of an industrial facility depend primarily on design and on the quality of the installation. Then, despite all developments related to the fourth industrial revolution, people will remain having an important role on industrial maintenance.

Thus, training and technical knowledge are very important when dealing with ultrasound. ISO 18436-8:2013 [15] specifies the requirements for qualification and assessment of personnel who perform machinery condition monitoring and diagnostics using ultrasound.

A certificate or declaration of conformity to ISO 18436-8:2013 provides recognition of the qualifications and competence of individuals to perform ultrasound measurements and analysis for machinery condition monitoring using ultrasound equipment. ISO 18436-8:2013 specifies a three-category classification programme that is based on the technical areas delineated herein, consistent with ISO 18436-1 and ISO 18436-3.

The perfect occasion to think about a good maintenance plan that enables a high reliability and availability starts in the design phase. After commissioning the maintenance plan should immediately be in action. The most critical failure modes must be known.

The first draft of a maintenance plan should be based on manufacturer instructions or generic guidelines accomplished by expert judgements and taking into account regulatory obligations. After this stage and a period of test, the maintenance plan must be revised and adapted creating new procedures for maintenance and even for operation.

The preventive maintenance program must include details for each inspection or action as what to do, if it corresponds to a running maintenance or shutdown maintenance, schematic drawings, lubrication, calibration, tests, recommendations, etc.

The steps to implement a maintenance plan are illustrated in Figure 3.

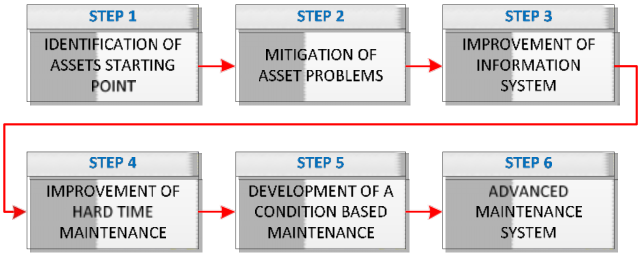

Fig. 3. Maintenance plan implementation steps.

Condition monitoring is very important once it allows preventing critical failures, reducing costs and act only if it is necessary. Ultrasound technology has proved to be one of the available technologies for performing a condition monitoring that can be very useful to detect some situations in an early stage. Recent developments simplify the use of such technology, being possible to use smartphones or tablets to connect to the system updating places, routines and inspection points. It is also possible to access organizational data and define the baseline for each point based on five initial records.

Inspection points are defined by the users, as well as the frequency of inspection or a specific re-inspection date (if necessary). It is also possible to take photos of inspection points and inherent equipment. If no hi-speed internet connection is available all data will be stored in the device and when web is available it will be placed in the cloud. When the defined thresholds are achieved then an alarm will be issued. It is also possible to select detailed reports and analysis about equipment health condition, routines, baselines and threshold levels.

VI. Conclusions

In the present work it was described how ultrasound technology can be used to diagnose equipment problems before catastrophic failure and thus minimize or eliminate production downtime by scheduling repairs. This technology also can play an important role on the reduction of energy consumption by detecting leakages, even in noisy environments.

The present paper describes the technology, gives a framework of its applicability in industrial facilities and the advantages of using it for predictive maintenance in the scope of Industry 4.0. The paper also shows how ultrasound technology can be used in a variety of equipment as bearings, gearboxes, valves and stream traps, electrical inspection and in testing leaks in pressurized systems (e.g. compressed air) and non-pressurized systems (when an ultrasound transmitter is placed inside a system).

The main objective of the present paper is to show a condition monitoring technique that sometimes is unknown for maintenance technicians and people responsible for the management of industrial physical assets and the potential number of applications in the scope of predictive maintenance, including the ability to use cloud services and access through mobile apps, being the first step to a successful ultrasound condition based monitoring program.

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The New Asset Management: Implications of Servitization in Circular Economy

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Abstract

The circular economy, or reduce, reuse, recycle, is gaining ground and is supported by many governments, with consequences for businesses. In asset management, the change in the economy paradigm must be driven by a new formula focusing on asset resilience, productivity rates, and asset integrity, while minimizing waste. In the circular economy, spares and broken components acquire an importance not considered in linear economies where disposal was common. The circular economy uses technologies such as IoT and understands the whole supply chain as connected. This implies information sharing that is not typical of production environments, and it offers new opportunities, such as: joint maintenance optimization of supply chain actors, maintenance as a service for all actors, and increased supply chain efficiency. In a circular economy, maintenance providers must consider environmental compatibility, energy efficiency, and human health and safety.

Keywords — circular economy, asset management, servitization.

I. Introduction

Asset manufacturers are faced with two major changes affecting their business: servitization and the circular economy. Servitization is the latest trend in business models; in servitization, manufacturing companies retain ownership of assets throughout their lifetime. Companies adapting these business models at an early stage have experienced a growth of 5 to 10 percent [1]. One well-recognized servitization model is pay-per-copy printers; other businesses have developed similar solutions, including for washing machines, clothing rental services, car sharing, and high-performance computing.

Servitization takes advantage of the digitalization of assets. Product digitalization offers valuable information and permits supervision over the lifecycle. Internet of Things (IoT) is the enabler of digitalization. IoT-related companies have grown in both number and size. According to Forbes, this growth shows, on average, a 23% CAGR (Compound Annual Growth Rate), which, in monetary terms, implies a growth from $157B in 2016 to an anticipated $457B in 2020. A more detailed analysis by GrowthEnabler [2] shows that Smart Cities have cornered 26% of the IoT market. Industrial IoT represents 24%, connected health 20%, and smart homes 14%; the rest of the markets are less significant. At this point, IoT-related technologies are a commodity and are affordable for most companies.

The second major change affecting asset manufacturers is the popularity of the circular economy, defined as efficient resource management, increased recycling, and reduced waste [1], more commonly seen under the popular rubric: reduce, reuse, recycle.

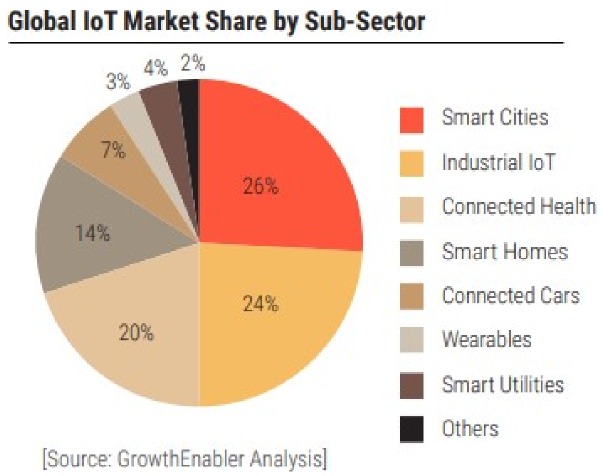

Fig. 1. Global IoT market share

II. Circular Economy

The circular economy considers the “integration of economic activity and environmental wellbeing in a sustainable

way” [3]. It is not a new concept; it was introduced in 1989 by Pearce and Turner, following studies on the ecological economy. In recent years, many governments have introduced circular economy principles and are promoting research on the topic. For example, the Danish government is working on the transformation to a circular economy as one of the pillars for the development of the country and its industry. The Netherlands and Italy signed manifestos in 2017; Finland defined a circular economy roadmap in 2016; Spain and the United Kingdom are working on the development of policies. But the example to follow seems to be China. The Chinese government defined its circular economy strategy in 2006 and enacted laws in 2008.

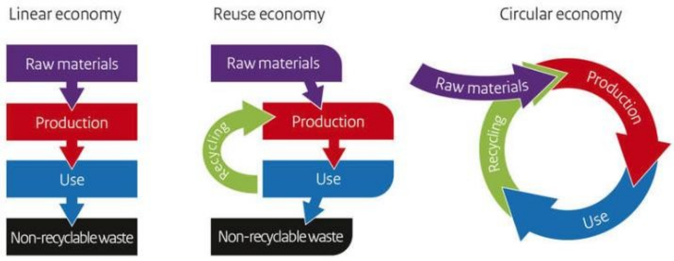

Fig. 2. From linear to circular economy

Research and the identification of best practices show that a transition to the circular economy can produce a more innovative, resilient, and productive economy. The following advantages are particular salient:

Substantial saving of net material. In the first two reports of the Ellen MacArthur Foundation [4], a detailed model at the product level is used to estimate the value of an "advanced" circular economy scenario. Taking into account only the sectors of complex goods of medium duration (for example, consumer electronics), the model finds estimated savings of up to 630,000 million US dollars per year in Europe after 2020. For fast-moving consumer goods (for example, food and drinks, clothes and packaging), the economic opportunity is estimated at more than 700,000 million US dollars a year worldwide, or material savings of approximately 20%.

Reduction of exposure to price volatility. A natural consequence of net material savings would be a downward shift in the cost curve of raw materials. In the case of steel, global net material savings could add up to more than 100 million tons of iron ore by 2025 if applied to a considerable part of the material flow (i.e. in the intensive steel sectors of the automotive industry and other transport sectors, which account for 40% of the demand). Furthermore, this shift would move the steel industry from the right side of the curve of costs of raw materials (increase), and this would probably reduce the volatility driven by demand increases.

Greater economic development. The study “Growth Within: A Circular Economy Vision for a Competitive Europe” [5] estimates that a change to the circular economy in three basic industrial sectors (mobility, food, environment) would allow Europe to increase productivity of resources by up to 3% per year. In addition, it would generate 1.2 trillion euros in benefits from non-resources and raise the total annual benefits for Europe to around 1.8 trillion euros. On a global scale, multiple studies have consistently shown the positive impacts of the circular economy using different methodologies and across sectors and geographies: they show a GDP growth of 0.8-7.0%, the creation of 0.2-3% more new jobs, and a 48% reduction of carbon emissions by 2030.

Greater potential for innovation and job creation. Circularity has proven to be powerful; it can generate creative solutions and stimulate innovation. An academic meta-study carried out for the “Growth Within” report finds a positive effect on employment when the circular economy is implemented.

Increased resilience in living systems and in the economy. Land degradation costs around 40 billion US dollars a year worldwide, without taking into account the hidden costs of increased fertilizer use, the loss of biodiversity, and the loss of unique landscapes. The application of the principles of circular economy, which promote greater productivity of the land, less waste in the food value chain, and the return of nutrients to the soil, will increase the value of land and soil as assets.

As mentioned, governments across the globe have considered or are considering a circular economy to prevent the waste of resources. However, as explained in the following section, the shift to servitization is forcing the producers of assets to be asset owners and to sell services instead of assets. This shift is complicated by the move to the circular economy.

III. ASSET MANAGEMENT IMPLICATIONS

As noted above, we are seeing a shift towards servitization. At the same time, governments and society are trying to persuade companies to achieve a more sustainable environment through circular economy policies.

Servitization is a challenge for industrial companies who are unaccustomed to designing services and who have traditionally relied on sales for their revenue. With servitizatation, assets are owned and maintained by asset manufacturers during the product’s lifecycle. This change must be accommodated by companies if they wish to remain competitive.

It would seem that accommodating this shift, as well as the move to a circular economy, might be difficult for asset manufacturers, but in fact, many principles of the circular economy are aligned with servitization in many areas. The following sections discuss circular economy principles and show their benefits for asset manufacturing and managing companies. Note that we do not consider all principles of the circular economy; some, such as energy production from renewable sources, have no direct application to the asset industry.

Reduce is a basic principle of sustainable manufacturing and the circular economy. Reduced material and energy consumption ensure more profitable assets, as well as long lasting assets that will be profitable for a longer period of time. If assets need to last longer, consume less power, and be built

using fewer materials, maintenance policies are crucial. Connected devices play a key role; they are the facilitators of data collection and asset management, and, as such, they enable the use of new maintenance techniques

Reuse is an important principle for parts. Proper application of this principle will lead to reduced manufacturing needs, as used machines or subsystems are reused after a first life-cycle. When reusing parts, a key aspect is determining their reliability and remaining useful life.

In *recover*, a concept very similar to reuse, assets are collected at the end of a lifecycle. Their parts are disassembled, sorted and cleaned for use in subsequent lifecycles [6].

Systems must be *redesigned* to be more efficient in material and energy use requirements. The redesign must also focus on reusing and recovering materials and subsystems from previous assets. The circular economy drives redesign. A better understanding of an asset's environment and working conditions can generate design feedback that can be integrated within a company's design process and create more efficient assets in the future.

Remanufacture refers to the reprocessing of worn assets in order to bring them back to their original state, reusing and recovering as many parts as possible. This particular principle of the circular economy includes most of the requirements of the preceding circular economy principles. Note that when an asset is remanufactured, and recovered parts are used to restore it, it is necessary to define how worn it is, i.e., to determine the remaining useful life of the whole asset.

In the ISO 55000 definition, asset management is the "coordinated activity of an organisation to realize value from assets". This definition involves activities in different fields, including identifying what assets are needed, setting funding requirements, acquiring assets, providing maintenance, and disposing of or renewing assets [7]. While this asset management vision is asset-user oriented, it can be applied to asset manufacturers as they adapt to the circular economy and servitization.

First, as service providers, asset manufacturers need to be aware of the total cost of ownership of their assets. In traditional cost structures, the cost of maintenance and repairs was the customer's concern, but service oriented businesses may face penalties if asset availability is not met. Therefore, the total cost of ownership should consider the risk of breakdowns and their influence on customers' business. This is a key point for service providers; all maintenance costs are supposed to be borne by providers. Thus, their risk management should consider issues and scenarios that would not otherwise be crucial to them. Asset availability is directly related to maintenance and design. If the asset is designed to have a long life expectancy, revenues are likely to be higher because there will be less need for maintenance and there may be a possibility of reusing reliable subsystems from old machines in new ones, or using the worn asset in a less demanding environment after a small retrofit.

Second, asset integrity needs to be guaranteed to ensure the availability of contracted machines in pay-per-use contracts. But applying the principles of the circular economy (reducing, reusing, and remanufacturing assets or parts of them) is risky when asset reliability is crucial for business outcomes. Therefore, remaining useful life calculations need to be precise to avoid machine breakdown and avoid penalties from users. Developing precise calculations is the basis for the optimization of maintenance actions. Even if some preventive maintenance actions will still be needed, these can be performed by asset users. Asset manufactures can center on offering predictive maintenance services which are perceived as value-added actions instead of costs. If predictive maintenance is a value-added service that customers are willing to pay for, achieving a prognostic system can be the key to achieving large incomes for asset manufacturers.

For purposes of prognosis, a current trend is to build digital twins for assets or their crucial parts. Digital twins can be personalised, taking into consideration specific conditions of a deployed asset, especially asset context and working requirements and conditions. Asset manufacturers should bear in mind that they are owners and managers of a fleet of machines that are exposed to diverse requirements in terms of working and environmental conditions. This presents an opportunity to gather valuable information about asset performance in a range of settings that would be impossible in a traditional business model.

Being aware of the context of operation of delivered assets and those that will be deployed in the future offers asset manufacturers/managers the following opportunities:

- In a market defined by servitization, context awareness, together with prognostic systems or digital twins, offer the possibility of creating new services that will create added value. As an example, machine parameters can be changed or personalized to achieve higher production rates or preserve a machine from breakdown.
- When achieving the circular economy principles of reuse and remanufacture, a good definition of the future working environment of the asset is crucial. Considering both past and future conditions, the most suitable asset could be defined in order to build an asset that meets those requirements. This may mean building a completely new asset.

Finally, companies should include asset management in their strategies. New business models that focus on fulfilling customer needs through servitization need to develop asset management strategies as part of a successful business model. Assets are the vehicle through which companies will deliver services, and their management cannot be avoided. One of the most important considerations is that the longer an asset can fulfil its mission, the higher its revenue will be until the point when the cost of maintaining that asset increases exponentially, leaving no room for earnings.

IV. Conclusions

Asset providers are turning to a new business model for two reasons. First, servitization is becoming a common practice

where customers pay for machine availability and reliability instead of buying assets. Second, governments and society are pushing for a circular economy in which manufacturing is environmentally sustainable. These two changes present opportunities for fast moving companies, but they also present problems that need to be solved if companies are to make a profit.

One of the biggest challenges is how to manage assets that are deployed in customer facilities. In a nutshell, asset management needs to take into consideration the total cost of the ownership of assets. It needs to determine with precision and confidence the remaining useful life of machines and their subsystems in order to reuse or rebuild them. Maintenance pays an important role, as it will make the difference between a profitable business and a non-profitable one. Prognostic systems and digital twins are the key to success, while context awareness is crucial for the redesign process. All these factors and challenges need to be considered to create a basic asset management system capable of dealing with servitization requirements and a circular economy. Fortunately, enabling technologies such as IoT are popular and accessible for most industries.

Acknowledgments

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