Learner Centric Advanced Manufacturing Platform

PREDICTIVE MAINTENANCE

WPN° 3 Observatory

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LCAMP partners:

TKNIKA – Basque VET Applied Research Centre, CIFP Miguel Altuna LHII, DHBW Heilbronn – Duale Hochschule, Baden-Württemberg, Curt Nicolin High School, AFM – Spanish Association of Machine Tool Industries, EARLALL – European Association of Regional & Local Authorities for Lifelong Learning, FORCAM, CMQE: Association campus des métiers et des qualifications industrie du future, MV: Mecanic Vallée, KIC: Knowledge Innovation Centre, MADE Competence Centre Industria 4.0; AFIL: Associazione Fabbrica Intelligente Lombardia, SIMUMATIK AB; Association HVC Association of Slovene Higher Vocational Colleges; TSCMB:Tehniški šolski center Maribor, KPDoNE: Kocaeli Directorate Of National Education; GEBKİM OIZ and CAMOSUN college.

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GLOSSARY AND/OR ACRONYMS

AI - Artificial Intelligence

AM - Advanced Manufacturing

Cedefop - European Centre for the Development of Vocational Training

CoVE - Centres of Vocational Excellence

EAfA - European Alliance for Apprenticeships

EC - European Commission

ECVET - European Credit System for Vocational Education and Training

EntreComp - The Entrepreneurship Competence Framework

EQAVET - European Quality Assurance in Vocational Education and Training

EQF - European Qualifications Framework

ESCO - European Skills, Competences and Occupations

ETF - European Training Foundation

EU - European Union

HE - Higher Education

HVET - Higher Vocational Education and Training

I4.0 - Industry 4.0

KET - Key Enabling Technology

OECD - Organisation for Economic Cooperation and Development

SME - Small and Medium Enterprises

SWOT - Strengths, Weaknesses, Opportunities, Threats

TVET - Technical and Vocational Education and Training

VET - Vocational Education and Training

WBL - Work Based Learning

CONTENT TABLE

EXECUTIVE SUMMARY

Advanced Manufacturing (AM) and Higher Vocational Education and Training (HVET) need to update training, implement new technologies, and get quick access to data.

The causes behind these needs are technological factors (Industry 4.0), factors conditioned by education systems and education methodologies, social factors and environmental factors (the European Green Deal with its emphasis on the greening industry).

Under the CoVE initiative, the LCAMP project aims to support regional skill ecosystems and various stakeholders in providing new skills and implementing new or updated technologies in VET centres. LCAMP will tackle this by incorporating a permanent European Platform of Vocational Excellence for Advanced Manufacturing.

By collaborating across borders, LCAMP's goal is to support and empower regional Advanced Manufacturing CoVEs to become more resilient, innovative, and better equipped to train, upskill, and reskill young and adult students, to successfully face the digital and green transitions. We will help European regions and countries grow and be more competitive through their VET systems.

Therefore, the LCAMP OBSERVATORY is one of the services in the LCAMP platform. The observatory is led by the French cluster *Mecanic Vallée* and the French VET provider *Campus des Métiers et des Qualifications d'Excellence Industrie du Futur*.

This present document details the first results of the LCAMP Observatory, through the methodology that the LCAMP consortium used to set up and run the Observatory. We had set up a process cycle for the observation consisting of 5 stages:

- Stage 1: Diagnosis and priority
- Stage 2: Search and information gathering
- Stage 3: Information Analysis
- Stage 4: Creating value. Elaboration of LCAMP reports
- Stage 5: Dissemination and communication.

1. INTRODUCTION

The LCAMP observatory is one of the services of the LCAMP platform.

The LCAMP Observatory must be a reliable and easily accessible source of information and data for trainers, VET teachers, and professionals, updated on Digital / Advanced Manufacturing / Smart Industry, delivered through a multimedia and interactive platform -LCAMP platform-, that can be customized according to individual interests (Work in progress in WP8).

This observatory must feed other Work packages (WP), for instance, WP 5 on Learner Centric Training, or Open innovation Community in the WP4.

In a first document about methodology, are set up a process cycle for the observation consisting in 5 stages:

- Stage 1: Diagnosis and priority
- Stage 2: Search and information gathering
- Stage 3: Information Analysis
- Stage 4: Create value. Elaboration of LCAMP reports
- Stage 5: Disseminate-communicate.

Following this process cycle, are detailed the main aspects of the observation methodology:

- Identify reliable sources that we can find in Europe about Advanced Manufacturing.
- Classify and filter data gathered from different sources.
- Present several ways to collect data and to analyse them.
- Define the methods for the creation of annual reports.
- Validate process for those reports.

The observatory will publish periodical reports for VET and HVET target audiences about technology trends, labour market changes, skill needs, and occupations in Advanced Manufacturing. It is expected that SMEs, industry clusters and other associations will also find valuable information in the observatory.

The publication of a yearly report is planned.

- Report 1: June 2023,
- Report 2: June 2024,
- Report 3: June 2025.

This first annual report is gathering sub-reports written by around twenty different writers, from the main partners involved in the LCAMP project. 39 Topics were determined, and 22 TOPICS were analysed and worked on during this first period.

2. PREDICTIVE MAINTENANCE

The purpose of this chapter is to present some of the development areas related to AM.

These are topics that concern all or some of the stakeholders

- CoVEs and VETs: teachers, trainers and heads of VET schools;
- Learners: students, active workers, job seekers;
- Companies;
- Policy makers and other stakeholders

2.1 INTRODUCTION

In the age of advanced manufacturing, there is not just one but several maintenances. Historically, the correct operation of equipment was first carried out in a corrective manner (triggered by the malfunctioning or, worse, the breakdown of the machine) and then evolved, thanks to the use of statistics, towards preventive maintenance.

Among other indicators, the history of average times between breakdowns made it possible to "anticipate the occurrence" of a breakdown and to plan the replacement of parts before the machine was forced to stop during the production phase. However, there was no guarantee that the timing of the "repair" was always ideal and that the equipment would not have been able to carry out other production cycles without problems before a degraded operating mode or a breakdown.

The analysis of profitability, increased competition, but also the awareness of environmental costs and many other aspects, gradually forced a new questioning and pushed the decision-makers to find a solution more adapted to the context of the 2000s. Predictive maintenance then appeared, with the main objective of not suffering a breakdown, but also of not changing a part too soon while guaranteeing the optimal functioning of an equipment and extending its useful life under the best conditions.

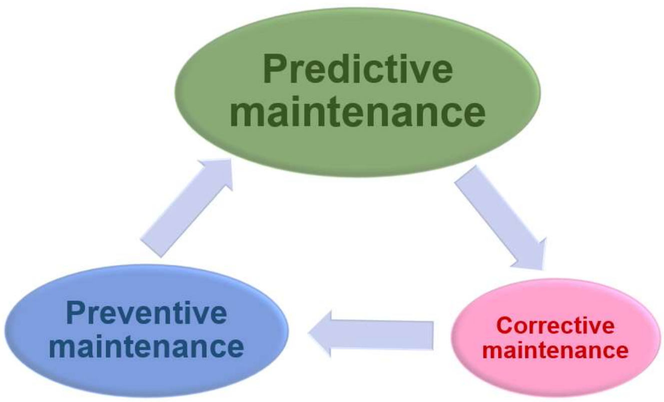

Figure 1 Predictive maintenance: Different types of maintenance

If it has already been favoured for more than 20 years, in the last few years, the technological evolutions linked to digitalisation have made it possible to improve its efficiency with the combined use of several technological trends such as IoT, big data, CPS (M2M & MES) etc.

Another positive point is that thanks to the pooling of infrastructure, tools and specialised human resources (such as IT development), SMEs have been able to use this technique which was previously difficult to implement.

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Already in 2019, the use of IoT was seen as a solution for the future. Even today, although its use is already widespread, the outlook for the next six years is still upwards, all over the world.

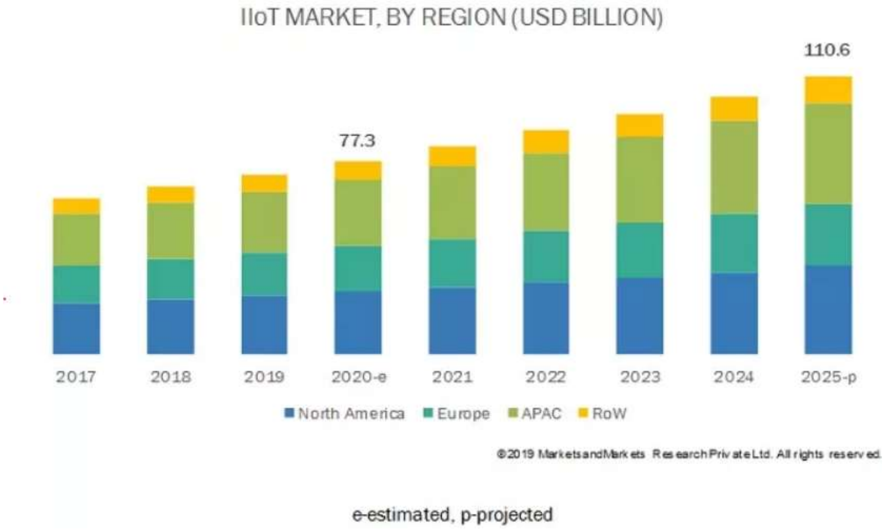

Figure 2 Predictive maintenance: The global IoT market[1]

2.1.1 CONTEXTUALISATION

What is predictive maintenance and what are its benefits?
The first obvious answer is that it allows the condition of assets to be monitored and their malfunction or failure to be prevented.
The other effect, which is less obvious to predict, is that it encourages exchanges[2] between departments that previously communicated little, or nothing.

Industrial IoT study case:

- **Shell uses the IoT for pipeline monitoring**[3]**:**

« Oil company Shell is taking advantage of an internet of things (IoT) connectivity solution to improve the company's monitoring capabilities for its operations in Nigeria. Last year, U.S. IoT connectivity provider Ingenu and Croatian producer of industrial electronics and power electronics devices Koncar Inem delivered an IoT connectivity solution to provide digital oilfield capabilities to the Shell Nigeria pipeline facility.

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[1] Future Market Insights, « Market Research & Business Intelligence | Future Market Insights », Market Research & Business Intelligence | Future Market Insights, 2019, https://www.futuremarketinsights.com/.
[2] GL EVENTS, « Maintenance industrielle : arme de compétitivité pour la productivité », Industrie online, 15 septembre 2021, https://www.industrie-online.com/p/actualite-2/actualites/maintenance-industrielle-arme-de-competitivite-pour-la-productivite.
[3] Juan Pedro Tomás, « Industrial IoT Case Study: Shell Uses the IoT for Pipeline Monitoring », *RCR Wireless News* (blog), 26 avril 2017, https://www.rcrwireless.com/20170426/fundamentals/industrial-iot-case-study-shell-pipeline-monitoring-tag23-tag99.

The Digital Oilfield (DOF) solution provides pipeline surveillance and wellhead monitoring capabilities to remote infrastructure in the Niger Delta. »

- **Lockheed Martin uses Big Data to maintain the F-35[4]**

« Lockheed Martin turned to 3D technology and big data to streamline the diagnostics and maintenance processes for its F-35 and F-22 fighter planes, according to a case study provided by the Industrial Internet Consortium. »

- **SIMAP: Intelligent System for Predictive Maintenance[5]: Application to the health condition monitoring of a wind turbine gearbox**

« SIMAP is the abbreviated name for the Intelligent System for Predictive Maintenance. It is a software application addressed to the diagnosis in real-time of industrial processes. It considers the information coming in real-time from different sensors and other information sources and tries to detect possible anomalies in the normal behaviour expected of the industrial components. The incipient detection of anomalies allows for an early diagnosis and the possibility to plan effective maintenance actions. Also, the continuous monitoring performed allows for an estimation in a qualitative form of the health condition of the components. SIMAP is a general tool oriented to the diagnosis and maintenance of industrial processes, however the first experience of its application has been at a windfarm. In this real case, SIMAP is able to optimize and to dynamically adapt a maintenance calendar for a monitored wind turbine according to the real needs and operating life of it as well as other technical and economic criteria. In particular this paper presents the application of SIMAP to the health condition monitoring of a wind turbine gearbox as an example of its capabilities and main features. »

- **Predictive analysis with ODiN[6] - Bosch**

« ODiN is a cloud-based service, which includes analysis via the ODiN platform, operation of the user interface (account), monitoring, support with reporting and provision of advice and recommendations.
This system was set up, within the framework of a PhD student's thesis, to ensure the maintenance of a hydraulic press for a company based in Morocco.
The figures in 2019: 11 countries - 27 connected sites (about 100 new ones being equipped) - 11 million measurements per day on one site - Maintenance time divided by 2. »

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[4] Phillip Tracy, « Case Study: Lockheed Martin Uses Big Data for F-35 Maintenance », *RCR Wireless News* (blog), consulté le 19 avril 2023, https://www.rcrwireless.com/20160902/uncategorized/big-data-lockheed-martin-tag31-tag99.

[5] Mari Cruz Garcia, Miguel A. Sanz-Bobi, et Javier del Pico, « SIMAP: Intelligent System for Predictive Maintenance: Application to the Health Condition Monitoring of a Windturbine Gearbox », *Computers in Industry*, E-maintenance Special Issue, 57, nº 6 (1 août 2006): 552-68, https://doi.org/10.1016/j.compind.2006.02.011.

[6] Bosch Rexroth France, « Brochure - Maintenance prédictive ODin », calameo.com, s. d., https://www.calameo.com/bosch-rexroth-france/books/00410823653cf456c4521.

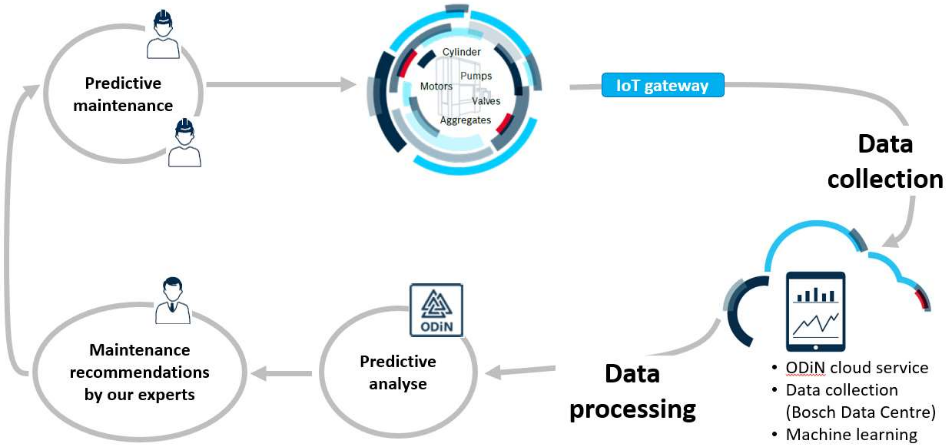

Figure 3 Predictive maintenance: Industrial solution Rexroth - Bosch

- **The technician on site before the lift breaks down[7]...**

« This is the case, for example, of the lift and escalator manufacturer KONE. To offer a predictive maintenance system, KONE has gone to great lengths. The artificial intelligence platform chosen by this manufacturer is IBM's Watson, which has proved its effectiveness, for example, with highly reliable medical diagnoses.
As for the connected sensors in its lifts, they record more than 200 critical parameters - opening and closing of doors, lights, automatic stop, distance and duration of trips, noise level, vibrations, temperature, air pressure, humidity, etc. - transmitted in real time! - transmitted in real time!
On this technical basis, KONE has developed its "24/7 Connected Services". As soon as the artificial intelligence anticipates a fault in a lift, the technicians receive a service order and a diagnosis. If a critical anomaly is detected, technicians can immediately order the necessary parts and schedule a rapid intervention. The repair will take place even before the failure and unavailability of the lift. But this intervention is scheduled wisely: the AI platform also assesses the degree of urgency of the intervention. The customer will not be disturbed by a minor fault, which will wait for the next maintenance operation on site! »

- **New Tools to Boost Automated Manufacturing[8]**

« Within the three-year research project IMPROVE[9] 13 leading players from academia, industry, and software development from all across Europe have joined forces to find innovative solutions for the manufacturing industry. Responding to the changing needs and challenges faced by manufacturers and production facilities in times of Industry 4.0, the project has developed novel tools in the field of simulation & optimization, condition monitoring, alarm management, and quality prediction.

The self-learning condition monitoring solution allows forecasting maintenance needs based on a data-driven machine learning approach. Up to now, only experienced operators were able to perform condition monitoring efficiently. The new IMPROVE solution is revolutionary for a

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[7] Usine Digitale, « Maintenance prédictive : comment peut-on réparer avant la panne ? », 25 juillet 2019, https://www.usine-digitale.fr/article/maintenance-predictive-comment-peut-on-reparer-avant-la-panne.N866955.
[8] Cordis, « New Tools to Boost Automated Manufacturing | News | CORDIS | European Commission », Cordis, 31 août 2018, https://cordis.europa.eu/article/id/123839-new-tools-to-boost-automated-manufacturing.
[9] IMPROVE, « Innovative Modelling Approaches for Production Systems to Raise Validatable Efficiency », IMPROVE, 31 août 2018, https://improve-vfof.eu/.

precise prediction. The tool protects producers from unexpected breakdowns or product degradation and can be translated into different software options.
The alarm management solution supports the machine operator in case of an alarm flood. The innovative algorithm is based on data-driven similarity learning as well as case-based reasoning and integrates expert knowledge. It particularly assists the operator in finding the root cause for the alarm and taking the right action.
With the decision support app for quality monitoring, IMPROVE helps the machine operator to predict the quality of the production by using data-driven models based on machine parameters. As the new app enables an exact quality prediction, it ensures the best possible quality for the whole production process. »

- **[L'instant tech] With Cetim, the SAB group goes to the end of the optimization of its foundry[10] - From automation to data analysis**

« After robotization and automation, it is time to analyse large quantities of data, to measure the carbon impact of the manufacturing of parts and to use additive manufacturing to optimize moulds. The SAB group joined the DeCISIFF[11] project, led by Cetim and CTIF (Technical Centre for Foundry Industries), alongside four other automotive foundry manufacturers. »

- **The industry of the future at the heart of Excellence Industry's innovation[12]**

« The Excellence Industrie consortium, a union of six regional economic players located in the Campus Région du Numérique in Charbonnières, is working on **decarbonation, digital transition, the factory of the future and the circular economy**.
The consortium includes EDF, Bosch Rexroth, Vicat, SNCF, Hef and the Serfim group. It operates on four major themes: the circular economy, decarbonisation, the factory of the future and the digital transition. One of the topics addressed by Excellence Industry is the connected ring. With this project, the consortium wants to create a solution to predict the maintenance of rings on construction equipment and infrastructures undergoing significant stress.
Thanks to the **PEL 4.0 connected ring**, the user is able to obtain traceability information, on the state of the ring thanks to numerous sensors and on the need to replace it... The ring benefits from a **technology adapted to all types of machines**. It is weather resistant. It can communicate via a wireless system and without batteries. According to Richard Brunet, president of Bosch Rexroth SAS, the project is aimed at companies wishing to benefit from support. »

2.1.2 OBJECTIVES / RESEARCH QUESTION / PROBLEM STATEMENT

Thanks to the analysis and exploitation of collected data, predictive maintenance makes it possible to identify warning signals in order to be able to intervene on the machines before the occurrence of operating anomalies or breakdowns.

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[10] Léna Corot, « [L'instant tech] Avec le Cetim, le groupe SAB va au bout de l'optimisation de sa fonderie », *L'usine Nouvelle*, 2 mars 2023, https://www.usinenouvelle.com/editorial/l-instant-tech-avec-le-cetim-le-groupe-sab-va-au-bout-de-l-optimisation-de-sa-fonderie.N2104391.
[11] Cetim, « DeCISIFF : un projet structurant pour la fonderie », Cetim, 27 avril 2022, https://www.cetim.fr/actualites/decisiff-un-projet-structurant-pour-la-fonderie/.
[12] FactoryFuture, « L'industrie du futur au cœur de l'innovation d'Excellence Industrie », *FactoryFuture* (blog), 26 janvier 2023, https://www.factoryfuture.fr/lindustrie-futur-coeur-innovation-excellence-industrie/.

*« **PdM[13] can reduce the time taken to schedule maintenance by 20-50%, increase equipment availability and uptime by 10-20% and reduce overall maintenance costs by 5-10%.** »*

Figure 4 Predictive maintenance: Benefits in figures[14]

OBJECTIVES

The major advantage of predictive maintenance is that it is carried out in real time, continuously and especially during the production phase of the equipment. The monitoring of parameters and the comparison of these with warning thresholds can allow intervention before the breakdown or malfunction.

The difficulty of such maintenance varies according to the sector of activity, but it also lies in the diversity and interweaving of the technologies used. Technologies directly correlated to the method: IoT, big data, MES/CSP and technologies linked to the cloud context: cybersecurity ....

RESEARCH QUESTION

Optimisation of the predictive model, thanks to learning: the more data the database contains, the better the performance of the analysis, which implies an infrastructure that some SMEs are not able to provide. Moreover, they do not necessarily have the technical and IT knowledge required to implement and maintain such a solution. These constraints, among others, explain why this technique is not always within the reach of SMEs.
Another line of research, in recent years, has been devoted to the automatic creation of models. At present, it can be said that although we are not yet in the pure domain of AI, we are getting closer.

In February 2023, the software publisher AVEVA presents the latest version of its AVEVA Predictive Analytics software[15], dedicated to the predictive monitoring of industrial assets involved in process management and manufacturing. The new version facilitates the deployment, validation, saving and interpretation of results.

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[13] Chris Coleman et al., « Making Maintenance Smarter », Deloitte Insights, 9 mai 2017, https://www2.deloitte.com/content/www/us/en/insights/focus/industry-4-0/using-predictive-technologies-for-asset-maintenance.html.

[14] « Deloitte_Predictive-Maintenance_PositionPaper.pdf », 10, s. d, https://www2.deloitte.com/content/dam/Deloitte/de/Documents/deloitte-analytics/Deloitte_Predictive-Maintenance_PositionPaper.pdf.

[15] Christian GLADIEUX, « L'IA au service de l'analyse prédictive », *Cad Magazine* (blog), 27 février 2023, https://cad-magazine.com/lia-au-service-de-lanalyse-predictive/.

The evolution of the software is characterised by a new feature that manages the automation of the construction and deployment of predictive models. Through the combined use of digital twin technologies and artificial intelligence, it has been possible to automate the creation of predictive models. These steps, which are carried out prior to implementation, have the double advantage of considerably reducing errors and the time required for deployment.

Unified predictive maintenance system:
UPTIME[16] is a predictive maintenance platform, created within the framework of the Horizon 2020 programme. A dozen partners from 5 European countries have participated in its development, in collaboration with 3 end-users from the steel, aeronautics and household appliance industries.
Real-time and historical data enables companies to manage all their connected assets. Maintenance scenarios assist and support users in their decision making to implement optimal and timely maintenance actions. Risk mitigation minimises maintenance costs and improves their Overall Equipment Effectiveness (OEE).

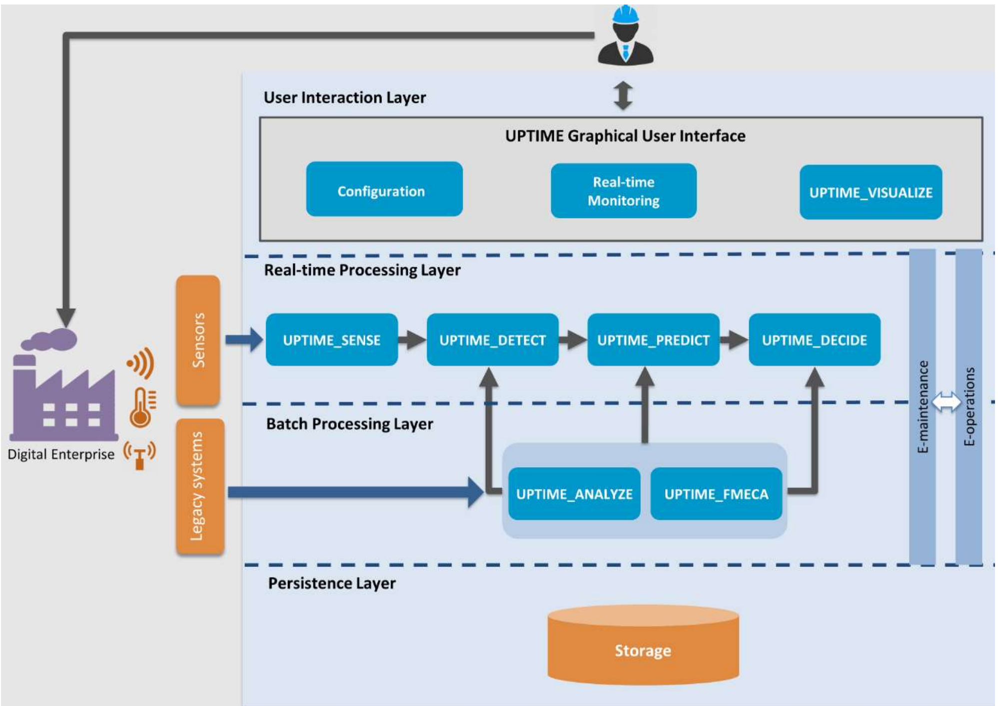

Figure 5 Predictive maintenance: UPTIME Platform[17]

UPTIME facilitates maintenance activity. Control screens allow managers to view real-time asset status, correlation analysis and actionable plans based on collected data analysis. Operators receive real-time alerts and notifications. Over time, they take responsibility for performing maintenance and those most involved can provide feedback to validate or improve the models in place.
The settings allow the tool to be adapted to the needs and data but also to the company's processes, with the aim of rendering the result of the analysis on different screens. The processing of the collected data returns actions and information to the different stakeholders in order to improve the maintenance of the assets.

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[16] https://www.uptime-predictive-maintenance.com/
[17] Cordis, « UNIFIED PREDICTIVE MAINTENANCE SYSTEM | UPTIME Project | Fact Sheet | H2020 | CORDIS | European Commission », 28 février 2021, https://cordis.europa.eu/project/id/768634.

Through six main modules, the architecture of the UPTIME platform offers all the functionalities allowing the interaction of the components as well as the integration and communication between all the functional elements of the system to ultimately provide a unified maintenance solution.
At the start of the project, most of the main modules of the UPTIME platform had already reached TRL5 with the final goal of TRL7, including the new ANALYZE module then under development. By 2022, with the main modules having reached TRL8, which is the right level of maturity before launching a product on the market, the whole UPTIME platform was "qualified".
The new clients, in addition to the financing, will make it possible to achieve a generalized TRL8 thanks to their specificities and their own challenges.
UPTIME differs from most of its competitors in that it has higher level intelligence functions, which requires strong vertical customisation and more complete integration with existing systems.

PROBLEM STATEMENT

Predictive analysis is only effective if it is based on a very large amount of data that must be stored, visualised and analysed. Based on this data, the development of predictive models or schemes allows for real-time monitoring of parameters and the reporting of any potential malfunctions.

Setting up models:
From this data, the preliminary work will be to determine the operational patterns, and the unusual patterns likely to indicate a malfunction.
This learning phase creates libraries that are then used to process the incoming data and define the diagnosis in real time.
The efficiency of the system lies in the large amount of data and its quality. It is in fact the machine equivalent of the experience and competence of the operators, with the advantage that it is and will remain accessible to all.

At the gateway to AI:
While the monitoring of patterns is automated, their creation today requires human intervention, so we are not yet in the domain of pure AI.

In March 2022 the DeCISIFF project proposed to use AI to automate the creation of these patterns[18], in March 2023 the SAB group wants to achieve this optimisation in the manufacturing process of aluminium parts in its foundry.
Despite several years of know-how and a very good knowledge of the production parameters, 3 to 4% of rejects (incomplete parts, porosity, broken cores) are due to "many hazards in the casting process". This project aims to take a new step towards increased performance and better quality.
During the production of a part, some fifty sensors collect information (aluminium temperature, cooling time, air flow, water flow, mould temperature, etc.). One of the challenges, piloted by Cetim[19], remains to cross this information with the quality data, to clean the data sets, to collect the missing parameters, in order to carry out descriptive statistics and to model the behaviour of the process, with an aim of predicting if the part will be good or bad. Good quality parts are compared to scrap in order to understand what went wrong and to take corrective action.
The company hopes to have an industrial demonstrator by the end of 2024.

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[18] Corot, « [L'instant tech] Avec le Cetim, le groupe SAB va au bout de l'optimisation de sa fonderie ».
[19] Cetim, « DeCISIFF ».

In 2023 AVEVA, introduces the new version[20] of its AVEVA Predictive Analytics tool that automates model building. This new functionality allows new predictive models to be deployed autonomously in a single action. While ensuring consistency in model development, this release facilitates large-scale deployment of the predictive maintenance solution.

Perhaps in the future, the automation of this first phase through the use of AI could be generalised throughout the industry, eventually reaching the SME.

Interconnection of highly specialised profiles:
From time immemorial, operators and managers have had to adapt, and this is even more true today where evolutions (or even revolutions) are constant during a career. Another important parameter of I4.0 is the interweaving of technologies that call on a variety of skills, the effectiveness of which is directly correlated to the ability of each individual to understand and integrate the general constraints and to know how to explain those of his or her field. In short, the greater the collaboration, the better the result.

Observation:
France is facing a lack of candidates, the cause of which is still unclear, is it due to a lack of training[21]?

Although the process of predictive maintenance is now well known and well established, the evolution of the technological means used and their interweaving require an adaptation of the people in charge of their implementation and follow-up as well as the training provided to them.

For example, the IoT calls on several professions such as mobile and embedded software development, server management, but also robotics and electronics. All these profiles must work together and their areas of expertise are increasingly complex and broad.
The needs must be clarified, and the positions[22] listed, because the generalisation of 5G will further enable the development of this field and the associated technologies.

Proof of this poor adaptation is the difficulty of recruiting suitable profiles[23] and the strength of these profiles which impose their will. Another factor that explains this observation is that even if there are training courses, they are less than 10 years old, and the people trained are just beginning to have the experience required (about 5 years) by employers for experienced profiles.
Normally this should improve in the coming years, but we will have to remain vigilant about the quality and adaptation of training.
Cybersecurity:

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[20] Communiqué de Aveva, « AVEVA fait progresser l'analyse prédictive grâce à l'IA », Decideo - Actualités sur le Big Data, Business Intelligence, Data Science, 23 février 2023, https://www.decideo.fr/AVEVA-fait-progresser-l-analyse-predictive-grace-a-l-IA_a12915.html.
[21] Raphaële Karayan et Usine Digitale, « La France manque de formations en IoT et en robotique », 31 janvier 2023, https://www.usine-digitale.fr/article/la-france-manque-de-formations-en-iot-et-en-robotique.N2095261.
[22] « GEN_RapportObsGENScan_A4_Light.pdf », s. d, https://www.grandeecolenumerique.fr/sites/default/files/GEN_RapportObsGENScan_A4_Light.pdf.
[23] Usine Digitale, « Métiers du numérique : “Les candidats sont devenus des rockstars” », 10 juin 2022, https://www.usine-digitale.fr/editorial/metiers-du-numerique-les-candidats-sont-devenus-des-rockstars.N2014017.

Of course, cybersecurity constraints must be integrated into the thinking and tested during each phase of the process and thus guarantee security and prevent malicious attacks.

2.2 FINDINGS

The first step, which is the collection of data, is done by different types of sensors depending on the piece of equipment to be monitored:

- **Infrared thermography analysis:**
  This non-invasive technology is widespread because it is versatile. It allows the monitoring of the temperature evolution of sensitive parts of an equipment and thus to anticipate malfunctions before they occur.
- **Fluid analysis:**
  Analysis of lubricants and coolants can determine the presence of contaminants (water, and other debris) that may indicate wear or part defects. Viscosity change is an alert to the change in lubricant required for the proper functioning of certain parts.
- **Sonic and ultrasonic acoustic analysis:**
  Acoustic monitoring can detect noises from gas emissions, liquids or surface leaks, the change in the sound pattern can be a warning signal. The cheaper sonic technology is more common, while the more expensive ultrasonic technology is dedicated to electrical equipment that emits more subtle sounds.
- **Vibration analysis:**
  Wear and tear on certain parts can cause slight changes in the vibration of the machine. With constant surveillance, and appropriate monitoring, a trained professional can be alerted and anticipate an imbalance, shift or failure by planning a re-setting of the machine or replacement of defective parts as soon as the alert threshold is exceeded.
- **Other technologies:**
  Some industries can also monitor laser alignment, electrical circuits, cracking or corrosion to complete the monitoring picture.

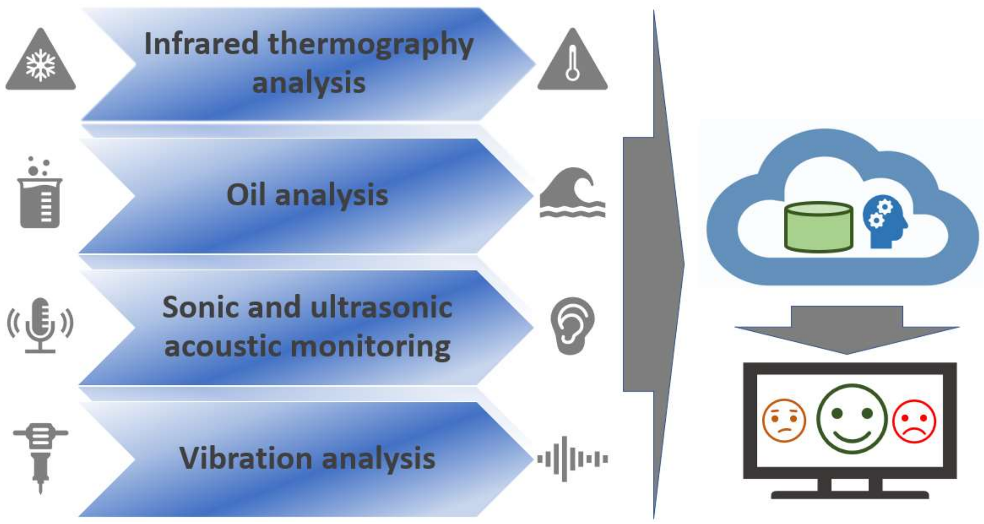

Figure 6 Predictive maintenance: Sensor types

The new generation of sensors, thanks to machine to machine (M2M) technologies, allow the transmission of data without human intervention. We can then talk about real-time transfers that are based on fully automated routines.

Once the data has been collected, the relevance of the data must be determined and the methods of analysis to be implemented in the MES must be defined.
The MES (Manufacturing Execution System) is a tool for steering and optimising the industry of the future. It is the software part, the brain of the predictive maintenance procedure which exploits and analyses the data in order to send the result of the analysis to the control centre or directly to the workstation.
The effectiveness of MES depends on the quality of the data collected, so key elements of the entire design chain must be scrutinised, from order to production to delivery. This very often involves interfacing with other company management systems such as ERP, CAPM ....

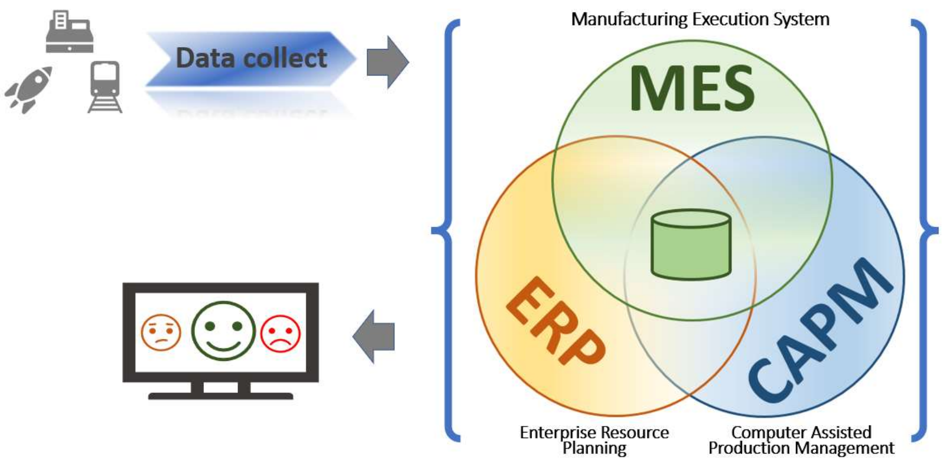

Figure 7 Predictive maintenance : MES interconnections

This is where the human factor comes into play, it is necessary to define the key elements to be traced and for this to be familiar with all the problems encountered by all the departments involved in the company's activity. The analysis phase prior to the definition of the model should not forget anyone and will guarantee the good integration of the MES in the manufacturing process.
Each problem reported will be an avenue of research. Answering the questions of how to detect it and what are the solutions to be implemented to solve it will be the elements on which it will be necessary to rely.
As seen above, current research focuses on the automation of this step through the use of artificial intelligence.

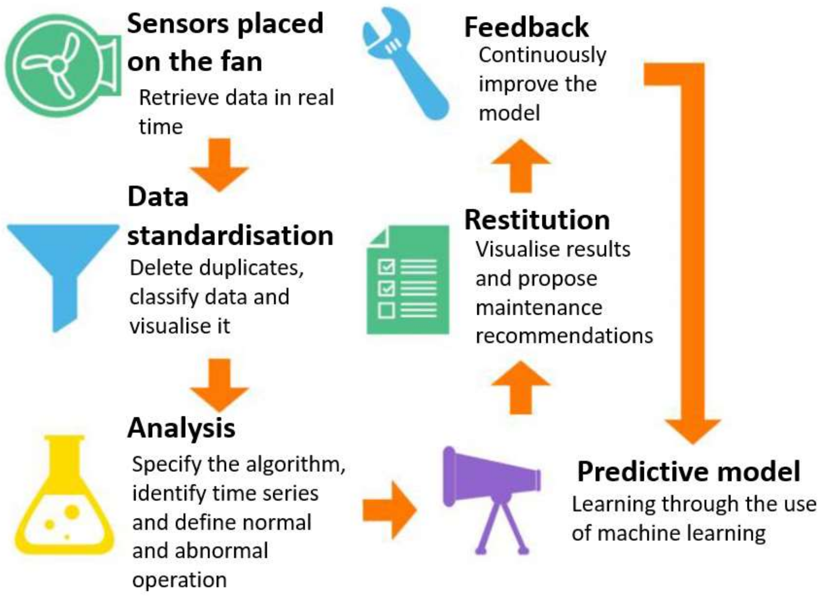

Figure 8 Predictive maintenance: Stages of the model[24]

Other benefits of MES[25]:
A complete MES, well integrated, collects and analyses all the sensitive phases of the process in order to advise and assist all the actors of all the departments. An alert generated by one department will very often find its solution through the intervention of another department.
It can improve overall communication within the company, by understanding the role of each person, it can encourage exchanges between departments that previously hardly communicated.

MES brings together all the links in the manufacturing chain around a common objective: the optimisation of quality production.
It is at the heart of what is known as Smart Manufacturing. It connects all the tools, equipment and trades for totally digitised processes, where the data ensures that the activity is maintained and adapted to new constraints.
Each company has its own needs and requirements, and the MES, in addition to controlling predictive maintenance, will aim to meet these specific needs. For example, in sectors (such as medical, food processing, biotechnology, etc.) subject to strict regulations, it will allow the control and recording of the elements necessary for quality assurance.
It will be used to manage all or part of the following elements:

- Optimised production monitoring
- Improved traceability
- Faultless quality control and regulatory compliance
- Management of preventive and corrective maintenance
- Optimisation of output

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[24] 3T Industry 4.0, « 3T Industry 4.0 & iET4.0 Training », Trainings, 3T Industry 4.0, c s. d, https://3tindustry40training.eu/.
[25] GL EVENTS, « Le MES : outil de pilotage et d'optimisation de l'industrie du futur », Industrie online, 23 novembre 2021, https://www.industrie-online.com/p/actualite-2/actualites/le-mes-outil-de-pilotage-et-d-optimisation-de-l-industrie-du-futur.

- Improved customer satisfaction
- Reduced manufacturing cycle and time to market
- Increased visibility into the supply chain
- Contribution to a paperless factory
- Etc.

Predictive maintenance technologies (the cloud)[26]:
This last section outlines the various storage and communication possibilities between equipment, MES and control screens.

Table 1 : Predictive maintenance: The cloud

	Public cloud	Private cloud	Hybrid cloud
Environment	Publicly shared computer resources	Private computer resources	Combining public and private resources
Self-evolution	High	Can be limited	High
Security	Good, but depends on provider security	Most secure: all data is stored in a private data centre	Very secure: sensitive data is stored in a private data centre
Reliability	Medium: depends on Internet connectivity and availability of service providers	High: all equipment is on site or hosted by a dedicated private cloud provider	Medium to high: partly dependent on the service provider
Cost	Low: pay-per-use model and does not require onsite storage or infrastructure	Medium to high: may require onsite resources such as a data centre, electricity and IT staff	Moderate: combination of pay-per-use model and on-site resources
Who is it for ?	Companies wanting to take advantage of the latest SaaS applications and the elasticity of IaaS while keeping costs low	Government agencies, healthcare providers, banks and any company handling large amounts of sensitive data	Companies that want to keep their critical applications and data confidential while still using public cloud services

Whichever mode is chosen, the centralised management system, to which the sensors and control screens are connected, is interfaced with the company's resource planning and production management tools (ERP, CAPM, etc.) in order to rely on a single database.
This complete system involves a whole chain of technologies, each of which plays a role that guarantees the cohesion of the whole and its ability to adapt automatically.

- **IoT network**: it transmits data between the sensors and the central management system, as well as feedback from the latter to the users.
- **IoT gateways**: on equipment prior to digital integration, IoT gateway terminals (cameras, microphones and thermometers, etc.) allow the collection and transfer of data.
- **Cloud connectivity**: is the internal or external network through which all elements are connected and the centralised management system based on a single database.

[26] SAP, « Qu'est-ce que la maintenance prédictive ? | SAP Insights », SAP, s. d., https://www.sap.com/suisse/insights/what-is-predictive-maintenance.html.

- **Modern database and ERP system**: The need to reduce response times as the volume of data increases has led to a rethinking of how information is stored. The modern ERP system relies on a fast, responsive, in-memory database with almost unlimited scalability.
- **AI and Machine Learning**: Machine Learning (a subset of AI), through algorithms, aims to analyse and understand the data in order to return real-time observations and, if necessary, recommendations when the data are close to dysfunctional patterns.
- **Advanced analytics**: Based on the data collected and the algorithms defined according to the initial schemes, it provides the desired analytical results. The particularity of advanced analytics lies in the desire to create programs that are capable of adapting to optimise their performance over time.
- **Digital twins**: they allow the simulation of real or supposed test cases, without risk or damage to the machine. These experiments reproducing proven or totally unknown cases contribute to the objective of self-learning.

Benefits of predictive maintenance:

The various business sectors have remarkably increased their efficiency through the implementation of the predictive maintenance system. Indeed, the integration of Industry 4.0 technologies has revolutionised the method, control and analysis of parameters in real time have not only improved the maintenance of assets, but have also had favourable effects such as:

- **Reduced maintenance costs** and **improved asset performance**: planning instead of reacting optimises maintenance actions, but also reduces stocks (of spare parts) and then maintains the life of assets, while reducing downtime.
- **Improved staff autonomy**: feedback from the maintenance system has transformed the work of operational staff who, instead of reacting to breakdowns and unforeseen events, can focus on developing and planning action strategies.
- **Better visibility**: the intervention of service providers and other equipment suppliers is facilitated by a better knowledge of the state of the assets.

3. CONCLUSION

4 main findings seem to emerge from this study:

1. The infrastructure (hardware, technical, software, etc.) and, to a lesser extent, the human resources provided by the platforms facilitate access to predictive maintenance for SMEs, which should make it even more accessible.
2. The creation phase of predictive models, which is about to be fully automated (thanks to AI and more particularly machine learning) could further encourage SMEs to engage in predictive maintenance.
3. Although the process of predictive maintenance is well known and established, the evolution of technological means that in France, the recruitment of qualified people with sufficient experience remains problematic.
4. This is why the effort to set up and adapt training courses must be maintained.

3 remarks to conclude this study.

If the predictive maintenance process is now well known and well established, the evolution of the technological means used and their interweaving require an adaptation of the people in charge of their implementation and of the training made available to them.

"In the environment of Industry 4.0, maintenance should do much more than merely preventing downtimes of individual assets. Predicting failures via advanced analytics can increase equipment uptime by up to 20%."

Figure 9 : Predictive maintenance: Key figure of the Deloitte report

But the implementation of MES can generate too much abrupt change which can lead to rejection by the operators but also by the management team. In this case, during the implementation, it is better to limit the model to critical issues and those where the return on investment will be visible and gradually integrate the remaining issues.

And finally, as for all technologies related to Industry 4.0, the major challenge is to guarantee training and certifications that integrate the evolution of techniques in order to facilitate the adaptation of people to new techniques and thus help companies to offer the right job to the right person, for the good and interest of all.

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5. INDEX OF IMAGES

6. INDEX OF TABLES

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