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Essential and New Maintenance KPIs Explained

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Abstract: Maintenance in any manufacturing organization is critical, given its significant role in ensuring business continuity. Maintenance plays a crucial role and has a significant impact on the results of industrial companies. Therefore, it is essential to manage maintenance, observe, understand, and improve actions by adopting well-chosen performance indicators according to the company's needs. These indicators are known as Maintenance KPIs or Key Performance Indicators, which allow for gathering knowledge and exploring the best means to achieve the organization's goals. Maintenance KPIs are critical to keeping track of the function, monitoring performance, and ensuring fulfillment of business expectations. In addition, KPIs drive reliability growth while guiding decisions to improve maintenance efficiency and performance. A helpful maintenance KPIs help to identify the problems causing the maintenance effect and help to select the right strategy to support or correct the actions that produced the results. They also allow to identify the causes of equipment failures (measure the influence of life cycle factors), direct what maintenance does with its time and resources (measure the efficiency and effectiveness of the maintenance group) and identify if maintenance removes failure causes (measure the improved reliability and operational risk reduction results of maintenance effort) and help drive the business benefits provided by maintenance (measure the contribution to the business value of maintenance).

Essential maintenance KPIs are the most commonly used for maintenance management and are adopted by most industries; among these primary KPIs which are essential for maintenance management, we cite Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), and Overall Equipment (OEE). Nevertheless, it is crucial to continuously redefine and update KPIs to ensure they are appropriate for the organization's current environment, significantly when the constant market or research methodologies change. Hence, researchers and the industry propose several other maintenance KPIs outside the essential ones used in the industry according to the needs and within the performance improvement framework. These proposed KPIs aim to compensate for the lack of maintenance data, the absence of decision support, and the problems related to specific equipment, also in the context of improving the management strategy, the application of predictive maintenance, and the quality control of a maintenance process or the monitoring of systems reviews. Unfortunately, these indicators are not sufficiently known and are, therefore, not used by the industry. However, we believe that some of them should gain maturity and reach the status of widely used traditional indicators, such as the KPI of obsolescence management in maintenance operations and schedule compliance KPIs that aim to link maintenance planning with production. In addition, although not all proposed KPIs in the literature are generalizable, it has been identified that they can sometimes be specific to problematic situations, equipment categories, and even sectors of industry activity. Therefore, this work aims to inventory the most widely used maintenance KPIs and some of the KPIs proposed by researchers and the industry. In addition, we study the trends and challenges of selecting these KPIs and for what purposes they are used to help their understanding and usability. Indeed,

Maintenance managers need to select relevant KPIs aligned with the maintenance strategy and the company objectives.

Index Terms: Key Performance Indicators (KPIs), maintenance management, maintenance performance, decision support systems, predictive maintenance.

1. Introduction

Maintenance is an essential function in the company to limit industrial risks as much as possible [1]. For example, complex tools such as pressure equipment or industrial pumps must be closely monitored so that maintenance departments know when to intervene and the consequences of repair in terms of lost time and productivity. Since maintenance is a primary function in the company, it is necessary to manage it effectively to ensure its performance, effectiveness, and efficiency. Therefore, performance measurement is a fundamental instrument of maintenance management, so it is essential to have indicators to observe, understand, and implement maintenance performance actions. Furthermore, performance measurement is crucial because it identifies current and desired performance gaps and indicates progress. Hence, it is necessary to define the measures that will make it possible to monitor the performance of the maintenance processes by comparing calculated indicators with reference values and analyzing dashboards.

Indeed, key performance indicators or KPIs are crucial maintenance needs assessment measures for any industrial company [2]. They also allow to identify the causes of equipment failures (measure the influence of life cycle factors), direct what maintenance does with its time and resources (measure the efficiency and effectiveness of the maintenance group) and identify if maintenance removes failure causes (measure the improved reliability and operational risk reduction results of maintenance effort) and help drive the business benefits provided by maintenance (measure the contribution to the business value of maintenance).

KPIs support the company's strategy and constitute a decision-making tool that guarantees the transparency of strategic and operational decisions [3]. Maintenance KPIs are adopted by industry giants such as petrochemicals, the food industry, car manufacturers, the pharmaceutical industry, and energy, transport, and logistics [3].

Essential maintenance KPIs are the most commonly used for maintenance management and are adopted by most industries; among these primary KPIs which are essential for maintenance management, we cite Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), and Overall Equipment (OEE).

Beyond the essential maintenance KPIs used in the industry, many maintenance KPIs are proposed by researchers [4, 5, 6, 7, 8]. Unfortunately, these indicators are not sufficiently known and are not used in industry. However, we believe that some of them deserve to gain maturity and reach the rank of widely used traditional indicators. Therefore, we quote in a non-exhaustive way some of these indicators found in the literature, such as the KPI of obsolescence management in maintenance operations [9], and KPIs that aim to link maintenance planning with production, such as schedule compliance KPI that assesses the effectiveness of preventive maintenance or the accuracy of the maintenance schedule [6].

The use of KPIs by maintenance managers facilitates management in many ways. However, selecting them carefully is not trivial. Selecting simple, understandable, and easy-to-interpret information is crucial. A KPI must first be identified concerning the need to which it responds. In addition, they need to be aligned with the company's maintenance strategy and objectives to avoid incorrectly selecting KPIs. Among the negative impacts of this decision are loss of time when analyzing non-useful information, loss of money when implementing KPIs, and error in decision-making. Finally, maintenance managers should have access to key performance indicators aligned with their needs.

Additionally, most dashboards that monitor maintenance functions use KPIs such as MTTR, MTBF, and OEE, which focus on cost, time, and quality. Several other KPIs are worth exploring to assist managers in different situations, such as assessing the effectiveness of preventive maintenance through schedule compliance [9] or linking maintenance planning with production through some KPIs proposed in [6].

This work aims, on the one hand, to describe the leading essential maintenance KPIs that are used in all industries to manage the maintenance function, such as MTBF, which measures the time between the failures of a system, and MTTR, measures the repair time of the system, OEE measures time wasted in production, and failure cost. On the other hand, to identify KPIs developed by researchers and industries or under development to support the company's strategy in terms of maintenance to improve the maintenance policy and assist maintenance managers in their work. Furthermore, these KPIs are proposed to monitor and control the maintenance processes and results and provide indications for improvement according to the specifications related to the situation.

This article is organized as follows: we define essential maintenance KPIs in the second section. Then, section 3 presents the development of new maintenance KPIs. Finally, the fourth section discusses the current study's main findings.

2. Background

This section is dedicated to defining basic and essential maintenance KPIs, their objectives, their categories, and the most prominent ones used in the industry.

KPIs represent a set of measures focusing on those aspects of organizational performance that are the most critical

for the current and future success of the organization [10]. The main objectives of maintenance KPIs are (1) to report on the results obtained about the objectives set, (2) to assess the adequacy of the action to the strategic objective, (3) to provide essential, meaningful, and timely information, and (4) to facilitate decision-making by managers. In addition, they allow the manager to show the evolution of his process and monitor the equipment's state, allowing the design of a decision-making tool from the data they provide. Furthermore, allow system monitoring.

Key performance indicators should be easy to understand, measure, and represent so that they are used by everyone in the company and, in particular, the operators of the production sites. In addition, they should cover all maintenance activities following the overall company strategy. They must also be limited in Number to use as a decision support tool (the choice of KPIs is an important step). Identifying a KPI is made according to the company's needs). KPIs must be implemented and generalized quickly because all sectors of the company are concerned with these KPIs for the management and improvement of the current or future situation of the company. Maintenance KPIs enable monitoring, comparison, and improvement of equipment maintenance interventions. Thanks to the integration of a powerful analysis tool.

Maintenance KPIs are generally classified into three categories (fig1).

1. Maintenance cost KPIs.
2. KPIs of equipment maintenance activities (availability, reliability, interventions or repair, targeting).
3. Maintenance performance KPIs.

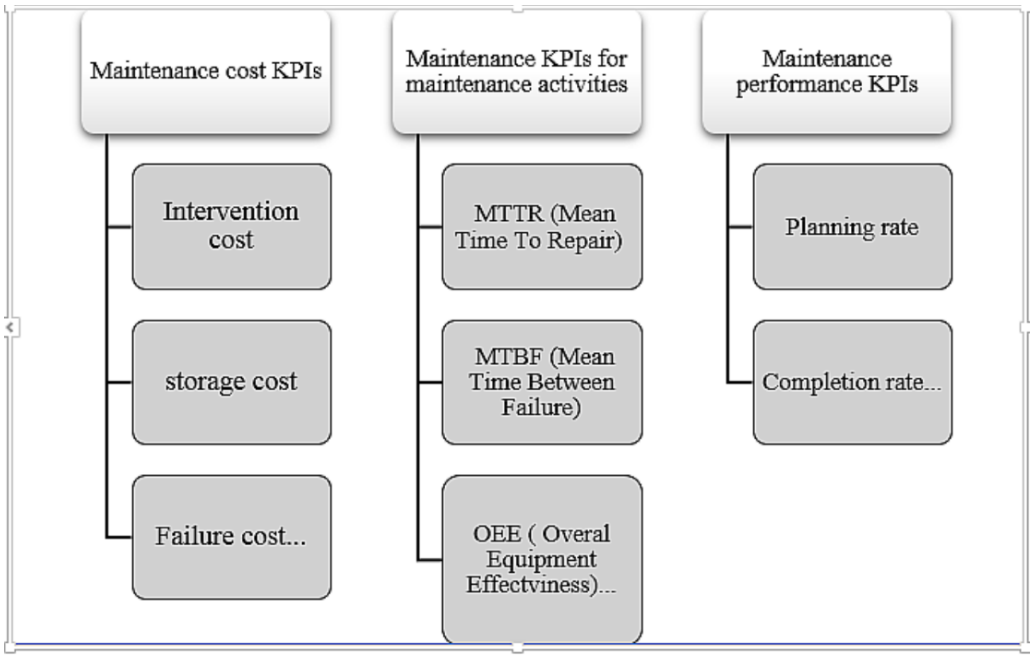

Fig. 1. Categories of maintenance KPIs

Each primary KPI covers an aspect of equipment performance or a maintenance system. These KPIs are:

1. **Maintenance cost KPIs.** according to [11], the KPIs linked to the cost of maintenance are:

   a. **Intervention cost (Ci).** Includes the expenses related to preventive and corrective maintenance. It does not include investment costs or those related directly to the production: adjustments of production parameters and cleaning. The intervention cost can be decomposed into the:
      - Internal or external workforce,
      - Stock spare parts or bought for an intervention;
      - Required expendable equipment for the intervention.

   b. **Failure cost (Cf).** These costs correspond to the losses in the operation margin due to a maintenance problem that has reduced the production rate of products in good condition. The loss of this margin can include an increase in the operating costs or a loss of business. The maintenance problems happen by:
      - Preventive maintenance is poorly defined;
      - Preventive maintenance is badly executed;
      - Corrective maintenance was severely executed.

   c. **Storage cost (Ca).** According to several authors [12], the storage cost represents the costs incurred in financing and manipulating the necessary inventory of spare parts and consumption for the maintenance function.

d. Investment cost (Csi). When designing the plant, the correct decision is the one that diminishes the global maintenance cost of the asset during its entire service life. It implies that equipment is bought more significantly than the exact productivity requirements with initial investments.

2. Maintenance KPIs for maintenance activities.

a. Equipment Availability. According to [6]. Availability is the operating probability of the equipment at time t. On which the availability rate depends: the Number of breakdowns (reliability), the repair speed (maintainability); the defined procedures (organization of maintenance); and the quality of the means (logistics).

b. Equipment Reliability. The main KPI for this category is the MTBF (Mean Time Between Failure): the average of proper functioning; this indicator, according to [13], is the probability that equipment will perform a required operation under given conditions and in a well-defined period. MTBF expresses the total Number of operating hours divided by the Number of failures for a specific component or equipment. MTBF is frequently used to describe reliability and its reciprocal value and failure rate. Other reliability indicators are: MTTF (Mean Time To Failure) indicates the system's average operating time before the first failure, and the MUT (Mean Up Time) is the average operating time after repair.

c. Effectiveness of interventions. In this category, we can cite the **MTTR** (Mean Time To Repair), Defined as the average time to repair or, in other words, bring equipment back to its functional state either by applying a repair or a complete replacement of the defective component. This indicator can be measured by dividing the total repair time by the Number of failures of equipment. This term should be referred to as mean time to repair due to its widespread use in the industry. The inverse of this indicator represents the repair rate. They meet all the properties, and their definitions are standardized and specific within the company and can be measured using the following formula:

$$\text{MTTR} = \frac{\text{the total duration of repairs over a given period}}{\text{Number of breakdowns}} \quad (1)$$

Moreover, [14] conducted a study on the key performance indicators to integrate them into maintenance management and manufacturing planning and control, and they arrived at selecting the OEE (Overall Equipment Effectiveness). This indicator is considered an essential KPI in asset management, dedicated to strategic, tactical, and operational purposes;

d. Equipment Targeting. This category's main KPI is the Overall Equipment Effectiveness (OEE) measures time wasted in production based on the six significant losses, including machine breakdowns, waiting, minor stops, reduced speed, scrap, and rework. It helps implement equipment improvement and preventive maintenance (the most central KPI in TPM). A measure is used to identify the percentage of planned production time. It is calculated from these three underlying factors: Availability, performance, and quality, each of these factors represents a different perspective according to which the manufacturing process is close to perfect production. We can measure this measure using this relationship between the factors:

$$\text{OEE} = \textit{availability}\ \text{rate} * \text{Performance rate} * \text{Quality rate} \quad (2)$$

3. Performance KPIs. [6] Mentioned other essential maintenance KPIs, such as:

a. The planning rate: is the ratio between the hours planned for the planned operations and the total Number of hours available.

b. The Completion rate (achievement rate): is the ratio between scheduled maintenance tasks completed on time and the total Number of tasks. It can be used to assess the effectiveness of maintenance execution or the accuracy of maintenance planning.

Figure 2 summarizes all the primary KPIs classified by categories.

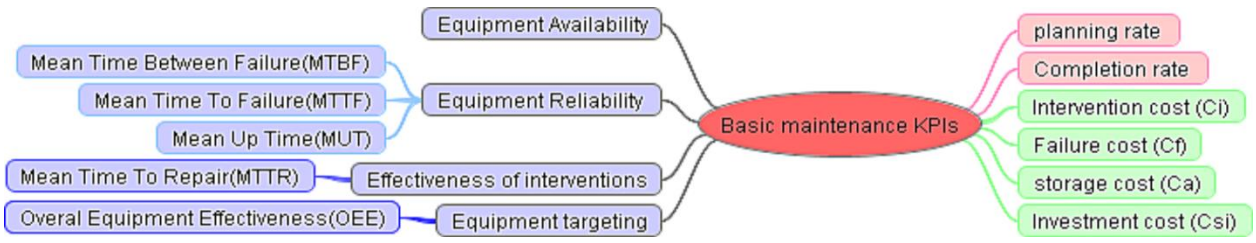

Fig. 2. The essential maintenance KPIs

According to the need for maintenance, a structured approach must be followed to define the appropriate KPIs in a company. This approach was selected among others because it provides a proactive process that is simple, understandable, and applicable in any industry; represented in this model aims to provide the performance required by the company to meet all of its corporate objectives and develop KPIs that meet maintenance requirements and specifications.

A maintenance KPI begins with the identification of work. This phase is concerned with identifying and controlling failure modes affecting equipment capacity. Following that, the work planning process is carried out to determine the needs and the accompanying instructions. The next step is determining whether the resources needed are available according to the work schedule. After the staff has been trained for development, they will be trained for the execution phase. During the execution phase, follow-up keeps track of information. Finally, the performance analysis is intended to assess the maintenance program based on the actual performance and the KPIs that need to be extracted. Following an analysis of the previous steps and maintenance needs, maintenance KPIs are developed.

Understanding the complex relationships between processes, equipment, and efficiency is essential to creating new KPIs for industrial maintenance [15]. Only after these concepts are fully understood can monitoring and tracking strategies be developed, as well as effective measures that can be implemented. First, a cause-and-effect ratio must be determined by defining the key parameters' measured variables. For the next step, which is the development of KPIs, it is essential to establish a close relationship with the data source since data availability and the measurability of these parameters are essential [16].

Measurability is an essential factor in the success of a new KPI. Furthermore, data accuracy and timely availability are vital for the standard calculation of indicators. A KPI must be descriptive and unambiguous in its expression to compare it with the current state. It must also be assigned to a specific person or department responsible for reporting to higher management levels. It is, therefore, necessary to categorize KPIs and develop them systematically [10].

3. Research works for the development of new maintenance KPIs

To determine how KPIs for maintenance have evolved within the industry, this section presents some relevant works on developing new KPIs essential to good maintenance management. ACM, Google Scholar, and ScienceDirect were the primary search tools for this research. The following keywords were used to find relevant articles: "maintenance KPIs," "maintenance management," "development of maintenance KPIs," "maintenance dashboard," and "maintenance 4.0". Based on the content relevant to the scope of our work, nine papers were selected from twenty-eight papers to explore new maintenance KPIs to assist managers in identifying the most appropriate KPIs for their individual needs. The trends and the challenges are discussed in section 4.

In [17], the authors described the practical application of an optimized maintenance philosophy based on developing new KPIs and conditions for the reciprocating compressors of an offshore oil and gas company (FPSO) in the North Sea. Intrusive maintenance of these compressors was required by analyzing system data provided and developing KPIs such as compressor valve temperature and stem positioning monitoring, which the operator performed via KPIs; early overall based on trend and characteristic monitoring and saved equipment from further damage.

In [4], the authors investigated a relevant effect of mechanical degradation leading to decreased efficiency over time to develop new KPIs. They used the general formulation of nonlinear mixed integer programming (MINLP) to optimize the operation and maintenance of a network of compressors connected in parallel by developing a KPI, which is the electrical consumption of each compressor during the period of good operation. In addition, another was developed for compressor condition monitoring, and operational optimization of preventive maintenance strategy was applied for compressor efficiency. The objective of the optimization was to reduce the operating and maintenance costs of the network of air compressors forming part of an air separation plant.

In [14], the authors studied the critical performance indicators for integrating maintenance management and manufacturing planning and control with a fixed objective through a literature study. They will identify relevant KPIs in both manufacturing and control disciplines (MP and C). Maintenance management: At the end of this article, a KPI structure that integrates MP and C and maintenance management are developed. This structure is based on the interactions between the KPIs developed for maintenance management and MP&C. The new KPI maintenance work order rate must be communicated to MPandC to update the MRP (Maintenance Reactive and Proactive) calculations. It should also be considered to reduce the current processing time to improve the maintenance backlog. Therefore, they also used a basic KPI OEE to coordinate between the two KPIs developed to improve the maintenance time throughput KPI and maintenance backlog.

In [5], the authors highlighted the importance of KPI benchmarking to monitor maintenance performance and infer improvement potentials. This article recommends identifying the most correlated process signals to develop and implement new appropriate KPIs to improve the performance of process and maintenance policies. The authors believe that the industry's poor performance is due to waste. For this, they have developed a set of KPIs, among which are maintenance KPIs to measure, monitor, and improve performance through actions that reduce waste; they say that too little maintenance leads to an excessive number of unscheduled shutdowns resulting in loss of production and emergency maintenance this involves too much maintenance, thus high maintenance costs and loss of production during each scheduled maintenance. The proposed KPIs are Maintenance costs/Produced output over some time, Maintenance

time / Produced output over some time, and the Number of alarms over some time.

In [6], the authors reviewed the leading indicators used in wind farms' operation and maintenance to develop others based on existing ones. They came up with a list of appropriate key performance indicators to help stakeholders gain insight into an operating asset and make informed decisions. These KPIs are Response time, defined as the time between failure occurrence and maintenance intervention. It informs about the efficiency of maintenance planning. Since it is often difficult to detect the failure starting time, it can be redefined as the time between failure detection and intervention. This new indicator is specific and measurable; several interventions in the fieldwork conducted to keep a WT in good condition imply a displacement of the maintenance crew. Monitoring the Number of scheduled and unplanned interventions can show the results after optimizing the O and M (Operation Maintenance) strategies; Corrective maintenance is the ratio of the purely corrective interventions over the total Number of interventions. This indicator meets all the properties, and defining a standard is possible; Schedule compliance is the ratio between the scheduled maintenance tasks completed on time and the total Number of tasks. Furthermore, it can be used to assess the efficiency of maintenance execution or accuracy in maintenance planning; Overtime jobs are defined as the ratio between the overtime working hours and the planned working hours (working hours per worker and size of the workforce), this metric can be measured on different time-scales; Backlog defined as the list of maintenance work that still needs to be completed; Labor costs versus total maintenance costs (TMC), the labor costs, expressed as a percentage of the total maintenance costs (TMC), inform about the effectiveness of maintenance execution; most operators agree on the importance of having qualified maintenance staff to ensure an ideal percentage of labor costs; Cost of spare parts versus total maintenance costs, the cost of spare parts, expressed as a percentage of the TMC, is directly related to the Number of failures followed by replacements; Total annual maintenance cost versus annual maintenance budget, setting the TMC concerning the annual maintenance budget (AMB) can give insight into the quality of maintenance planning and is therefore relevant to stakeholders.

In [7], the authors presented a case study on developing a condition monitoring system based on the newly developed KPIs for an offshore oil and gas plant on a floating liquefied natural gas (LNG) production storage and offloading vessel on a terrain that uses powerful compressors. This study aims to detect and solve the problems before the equipment is damaged by referring to the KPIs that provide information on the current state by defining the abnormal states of shaft vibration while monitoring sensor data, diagnosing abnormal types, and predicting the remaining states. Furthermore, he undertook proactive maintenance by building the system architecture, workflow, events, and testing algorithm and established the diagnostic and prognostic modules. Such intelligent diagnosis criterion by KPIs that provide relevant information was a more advanced technique than the conventional method widely used in condition monitoring and accurate and timely feedback.

In [18], the authors described maintenance Key Performance Indicators (KPIs), developed using MWO (historical data of Maintenance Work Orders) used when tracking and resolving any maintenance-related issues are manually written by service technicians, entered into a database, or recorded directly into service software, which shows why consistency and accurate data collection is vital for service decision-making. Maintenance data and its corresponding KPIs derived from MWOs are illustrated in table 1.

Table 1. KPIs derived from Maintenance Work Orders [18]

Proposed KPI	Role
Common Problem Items	The Number of issues at a facility for specific items.
Everyday Problem Items per Time Between Failure	The time between issues at a facility for specific items.
Everyday Problem Items by Machine Type	the Number of issues at a particular machine type for specific items
Standard Problem Item and Action per Time to Repair	The amount of time to solve an issue for a specific Item and Action.
Machine per Time Between Failure	The amount of time between failures for a given machine.
Machine by Problem Action per Time Between Failure	The amount of time between failures for a given machine for a given issue.
Machine Type per Time to Repair	The time to repair for a given machine type.
Machine Type per Problem Item per Time to Repair	The time to repair specific items for a given machine type.
Maintenance Technician Expertise per Problem Item	The Number of times a maintenance technician works on a specific item.
Maintenance Technician Expertise per Problem Action	The Number of times a maintenance technician spends on a specific action.
Maintenance Technician Expertise per Problem Item and Action per Time to Repair	The amount of time a maintenance technician spends repairing an issue.
Maintenance Technician Expertise per Problem Item and Action per Time to Diagnose	The amount of time a maintenance technician spends diagnosing an issue.
Maintenance Technician Expertise per Problem Item and Action per Time to Fix	The amount of time a maintenance technician spends solving an issue.

In [9], the authors stated that managing the obsolescence of expensive and critical components and equipment is a challenge for predictive maintenance, which is the choice of any new industry. Therefore, the authors have developed KPIs for managing obsolescence in maintenance operations in this article. This KPI is made up of two sub-KPIs that follow each other; the first to help see which components are more at risk of becoming obsolete and the second to assess the effects to reduce its obsolescence, the values obtained from this obsolescence management KPI are directly linked with a matrix to help the decision.). This obsolescence management KPI can be designed either by probabilistic calculation or by using Artificial Intelligence and creating a decision support tool from these KPIs.

Table 2. Summary of proposed KPIs in the literature

Article	KPI	Motivation
[17]	compressor valve temperature monitoring	Monitoring trends and characteristics and protecting equipment from further damage.
	stem positioning monitoring	
[4]	electrical consumption of each compressor during the period of good operation	optimization of operation and maintenance of a network of compressors
	compressor condition monitoring and operational optimization of preventive maintenance strategy	reduce operating and maintenance costs of the air compressor network
[14]	maintenance work order rate	measures the rate of corrective maintenance work orders
	maintenance time throughput	measures maintenance time in production
[5]	Maintenance costs / Produced output over some time.	These KPIs measure performance and identify the waste maintenance causes in an industry.
	Maintenance time / Produced output over some time.	
	Number of alarms over some time.	
[6]	Response time	Informs about the efficiency in maintenance planning, so it is a specific and measurable KPI.
	number of interventions	The fieldwork was conducted to keep a WT in good condition.
	Corrective maintenance	this indicator meets all the properties, and defining a standard is possible
	Schedule compliance	can be used to assess the efficiency of maintenance execution or accuracy in maintenance planning
	Overtime jobs	This metric can be measured on different time scales.
	Backlog	A list of maintenance work that still needs to be completed.
	Labor costs versus total maintenance costs (TMC),	informs about the effectiveness of maintenance execution;
	Cost of spare parts versus total maintenance costs	a rate directly linked to the Number of failures tracked by replacements
	Total annual maintenance cost versus annual maintenance budget.	It can give insight into the quality of maintenance planning and is therefore relevant to stakeholders.
[7]	shaft vibration	A KPI that provides current status information by defining abnormal shaft vibration states while monitoring sensor data, diagnosing abnormal types, and predicting remaining states.
[18]	Common Problem Items	The Number of issues at a facility for specific items.
	Everyday Problem Items per Time Between Failure	The time between issues at a facility for specific items.
	Everyday Problem Items by Machine Type	The Number of issues at a particular machine type for specific items
	Standard Problem Item and Action per Time to Repair	The amount of time to solve an issue for a specific Item and Action.
	Machine per Time Between Failure	The amount of time between failures for a given machine.
	Machine by Problem Action per Time Between Failure	The amount of time between failures for a given machine for a given issue.
	Machine Type per Time to Repair	The time to repair for a given machine type.
	Machine Type per Problem Item per Time to Repair	The time to repair specific items for a given machine type.
	Maintenance Technician Expertise per Problem Item	The Number of times a maintenance technician works on a specific item.
	Maintenance Technician Expertise per Problem Action	The Number of times a maintenance technician spends on a specific action.
	Maintenance Technician Expertise per Problem Item and Action per Time to Repair	The amount of time a maintenance technician spends repairing an issue.
	Maintenance Technician Expertise per Problem Item and Action per Time to Diagnose	The amount of time a maintenance technician spends diagnosing an issue.
	Maintenance Technician Expertise per Problem Item and Action per Time to Fix	The amount of time a maintenance technician spends solving an issue.
[9]	Indicators for obsolescence in maintenance operations	indicates which components are most at risk of becoming obsolete and evaluates the effects to reduce their obsolescence through maintenance operations
[8]	Note Transport Time	A KPI that indicates malfunctions at the note transport level, its indication reflects on an erroneous gear, defective clock, damaged system disk, or cut belt
	Clutch Time	The KPI Clutch Time is for monitoring and controlling the clutch function. It detects faults in assembly or improper positioning of a rotating shaft
	Idle Current	Monitors the power consumption of the analyzed motor at the system idle.
	Dispense Skewness	Provides information about the quality of the distribution, the alignment functionality, or the transport quality.
	Note Transport Current	this KPI is similar to the Idle Current KPI but describes the electrical consumption of the motor analyzed while the system is transporting notes
	statistical process control	Predict trends to detect future problems in the system before they cause damage.

In [8], the authors developed KPIs for maintenance in a manufacturing process in the field of mechatronic systems; the maintenance of the mechatronic system is not a trivial task, given their complexities. So the identification of the causes of malfunction and correcting breakdowns is challenging, especially in large industries or factories that operate in several interdependent units. Therefore, according to this procedure, the author has developed a set of KPIs for the mechatronic system. The first phase consists of analyzing the mechatronic systems and understanding them in depth, the second phase is the functional analysis of its systems, and the third phase consists of identifying the KPIs based on the results of the first two phases. Finally, the last phase is the specification of the KPIs, that is to say, defining the expected values and the limits for each KPI and the related causes and possible solutions.

The KPIs developed are KPIs for the Control Process of manufacturing ATMs. Authors have defined these KPIs in two categories: KPI-based product control of automated teller machines, which are mainly: The KPI Note Transport Time: it is a KPI which indicates malfunctions at the note transport level, its indication reflects on an erroneous gear, defective clock, damaged system disk or cut belt, The KPI Clutch Time is for the monitoring and control of the clutch function it detects faults assembly or improper positioning of a rotating shaft. The KPI Idle Current controls the electrical consumption of the engine analyzed at the system idle. These causes may be the incorrect mounting of a shaft or displacement of a belt in the transmission chain. The Dispense Skewness KPI provides information on the quality of the distribution, the alignment functionality, or the transport quality. Finally, the Note Transport Current KPI is similar to the Idle Current KPI but describes the electrical consumption of the analyzed engine while the system is transporting notes. The second category is KPI-based statistical process control. These KPIs are developed to predict trends to detect future problems in the system before they cause damage. Indeed, whalers have found that monitoring each system component is not trivial. Therefore, these statistical KPIs can monitor any system at several hierarchical levels or devised by a family of components. These KPIs monitor and forecast any system component's future state.

At the end of this section, we present a summary table (table 2) that includes all the KPIs proposed in the studied papers and their motivation.

Table 2 shows that some KPIs developed are specific to particular machines. In addition, many KPIs measure the frequency and time of maintenance operations, while others focus on the time of maintenance operations according to the type of human resource responsible for performing these operations. We have also noticed that very few proposed KPIs focus on predicting the subsequent breakdowns. Instead, the majority are limited to making an inventory of the equipment based on the history of maintenance operations.

4. Discussion

A maintenance KPI is a performance measure that helps the manager focus on the maintenance goals he wants to achieve. It is a quantifiable value that shows how effectively an organization is progressing toward achieving its maintenance goals over time. While goals may differ, they generally revolve around increasing equipment availability, reducing costs, and improving maintenance performance; these KPIs, some of which are basic and essential for good maintenance management, apply to all industries and all types of maintenance applied, they provide general information on the reliability, availability and maintenance costs of the system. In addition, researchers develop others with the same aim of guaranteeing the overall performance of maintenance.

We have noticed from the literature that traditional manufacturing and maintenance KPIs typically focus on cost, time, and quality criteria. Other authors have added dimensions such as delivery time, safety, and risk assessment [19]. With growing awareness of energy-related costs and environmental impacts, companies increasingly focus on indicators that measure their energy efficiency. The objectives are the reduction of the carbon footprint of products or plants and identifying improvement potentials at the company level to reduce energy losses and manufacturing and maintenance costs [20].

These KPIs are sometimes specific to problematic situations, equipment, categories of systems, or even sometimes to industry activity sectors. Indeed, KPIs are developing continuously in response to the needs and objectives of the companies. However, these KPIs are often not open to use in other industries unless in the same sector or perhaps in those with similar activities and equipment because they are developed based on the current state and situation and are not generalized. For example, the KPIs developed in [4] and [17] are used exclusively by industries equipped with large compressors, such as the petrochemical and liquefied gas industries. The food industry, for example, cannot use them. The same observation can be made for the KPIs proposed by [8] that are dedicated to the maintenance of mechatronic systems; they are not usable for a company that works with mechanical or electrical systems.

A KPI has drawn our attention from the literature, given its usefulness. It is the KPI of obsolescence management in maintenance operations [9] because it deals with companies' severe problems. In addition, we can highlight the importance of KPIs, which aim to link maintenance planning with production [6]. This is interesting because maintenance and production are two sides of the same coin and have a strong dependency relationship. From our point of view, a KPI that deserves to be used on a large scale, like traditional KPIs, is a schedule compliance KPI [6]. This KPI can be calculated by the ratio of scheduled maintenance tasks on time to the total Number of tasks. It assesses the effectiveness of preventive maintenance or the accuracy of the maintenance schedule; hence, we will have effective preventive maintenance because its planning becomes more organized thanks to this KPI's information. This key performance indicator will be helpful and provide an effective performance measurement tool because it is developed to

the needs of managers. Therefore, the involvement of managers is essential in developing new relevant KPIs.

To properly define maintenance KPIs, they should be approached as objectives. The ultimate goal is to improve maintenance performance at all levels; however, moving from the current position to the desired point requires well-defined steps specific to each KPI. Additionally, each KPI should be broken down into more detailed KPIs that outline the action plan and maintenance metrics it will use to measure progress.

In addition, KPIs should be calculated using advanced tools like artificial Intelligence to provide reliable, efficient, and effective performance management. This combination of KPIs and AI leads to good maintenance management and ensures optimal performance. Indeed the objective of AI in maintenance is to anticipate a hardware failure, plan a service interruption, detect a defect on a service part offered to companies, the ability to react and avoid incidents with sometimes dramatic consequences. For example, the calculation of the MTBF KPI has been achieved in a classic mean for many years and is historically based on statistical models; these traditional calculation methods can be replaced by a notion that is mainly based on the prognosis, which is the estimation of the operating time before failure of an equipment or system; which offers the advantage of being able to learn models based on empirical data and using artificial intelligence methods such as machine learning. Furthermore, artificial Intelligence's contribution offers more remarkable finesse to the KPIs measuring the performance by taking into account "real-time" factors, detecting weak signals, and discovering cases not listed. A concretization of AI in KPI development could be an autonomous KPI that collects information automatically via sensors, processes these collected data, and autonomously interprets them to generate a reliable result that the manager can use directly.

5. Conclusion

In this article, we highlighted the various maintenance KPIs (basic and advanced) that assess an organization's maintenance strategy and needs and help understand and improve its performance criteria. However, these defined KPIs cannot be set in stone. Continuous market or research methodologies changes require KPIs to be constantly redefined and updated to ensure that the KPIs are appropriate for the organization's current environment.

After studying the maintenance KPIs in the literature, we found that the primary KPIs are drivers of good maintenance management but are insufficient because they do not cover all the maintenance information. And this is what drives the development of the new KPIs.

The current overview of essential and new maintenance KPIs aims to assist maintenance managers and industrials in exploring and selecting the most relevant KPIs according to their fluctuant needs. However, even though some of them are specific to an industry sector, and many have not yet been tested widely; hence there is a risk in adopting them.

Despite this, we believe that maintenance KPIs will be based on AI algorithms based on historical data generated by maintenance operations and essential KPIs that ensure the regular monitoring of industrial equipment in the future.

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