National High School of Technology
Department of Industrial Engineering & Maintenance

Maintenance KPIs, The State of the Art

Master's thesis in

Management and engineering of industrial maintenance

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Abstract: Maintenance plays a crucial role and has a significant impact on the results of industrial companies. Therefore, it is essential to manage maintenance, observe it, understand it, 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 gathering knowledge and exploring the best means to achieve the organization's goals. KPIs drive reliability growth while guiding decisions to improve maintenance efficiency and performance. A helpful maintenance KPIs help identify the problems causing the maintenance effect and helps to select the right strategy to support or correct the actions that produced the results.

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). On the other hand, industry and researchers develop and propose new KPIs according to the needs and within the performance improvement framework; these KPIs are developed following the lack of maintenance data, the absence of the decision support, 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.

Therefore, this work aims to inventory the most widely used maintenance KPIs and the most recent KPIs proposed by researchers. We study the evolution of these KPIs and for what purposes they are used to help in their understanding.

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1. Introduction

Maintenance is an essential function in the company to limit the industrial risks as much as possible (Blaise et al., 2017). 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 gaps between current and desired performance 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 (Meier et al., 2013). 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), 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 (Jones and Pimde, 2017). Maintenance KPIs are adopted by industry giants such as petrochemicals, the food industry, car manufacturers, the pharmaceutical industry, energy,transport, and logistics industry(Jones and Pimde, 2017).

This work aims, on the one hand, to identify the 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, 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 and to improve the maintenance policy. 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 situations.

This article is organized as follows: we define KPIs and essential maintenance KPIs in the second section. Section 3 presents the development of new maintenance KPIs. In the fourth section, we discuss themain findings of the current study. Finally, we conclude our paper by highlighting the key ideas to retain and our perspectives on this work.

2. Background

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(Parmenter, 2015). 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 them as a decision support tool (the choice of KPIs is an important step). The identification of 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 by 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 apowerful analysis tool.

Maintenance KPIs are generally classified into three categories (figure 1).

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

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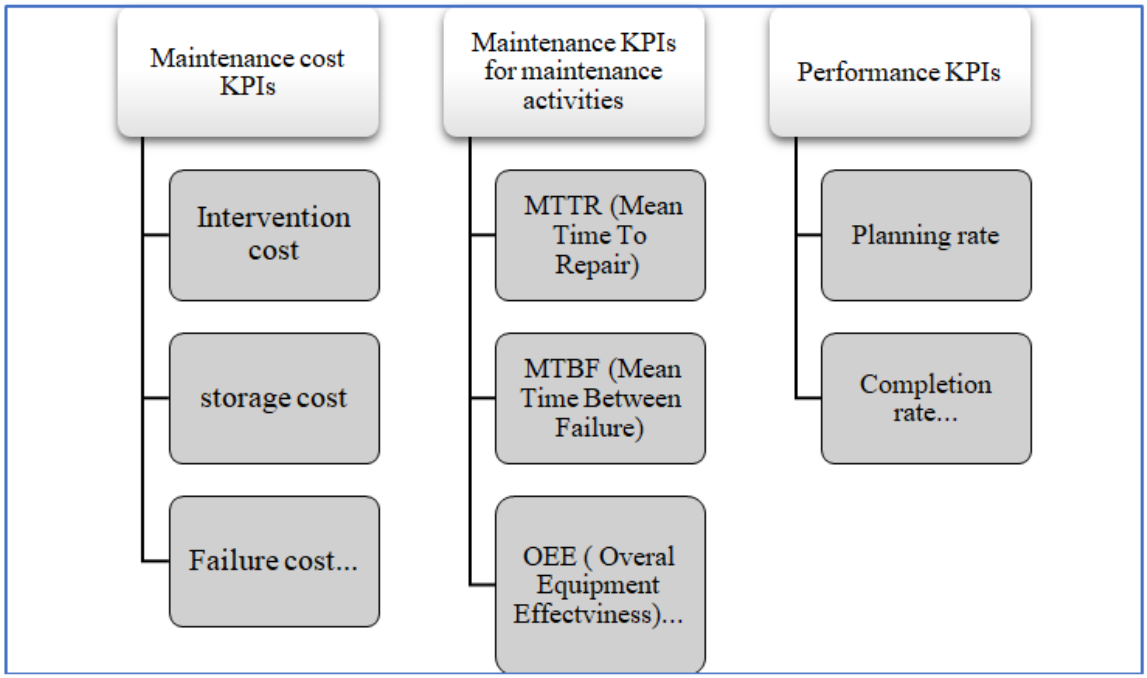


Figure 1: Categories of maintenance KPIs.

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

2.1. Maintenance cost KPIs.

according to AFNOR (1994), the KPIs linked to the cost of maintenance is

a. Intervention cost (Ci). Includes the expenses related to preventive and corrective maintenance. It does not include costs of investment, or those related directly to the production: adjustments of production parameters, cleaning, etc... The intervention cost can be decomposed in:

- Internal or external manpower.
- Stock spare parts or bought for an intervention.
- Required expendable equipment for the intervention.

b. Failure cost (Cf). These costs correspond to the losses of margin of operation due to a maintenance problem that has produced a reduction in 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 badly defined.
- Preventive maintenance badly executed.
- Corrective maintenance was badly executed.

c. storage cost (Ca). According to several authors (Diaz, A. & Fu, M.C. (1995)), 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 generally, that equipment is bought with initial investments bigger than fulfill the same requirements in terms of productivity.

2.2. Maintenance KPIs for maintenance activities.

a. Equipment Availability. According to (Gonzalezand al (2017)). 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 (BENABDOUALLAH.(2021)) shows 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) 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 apply-

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ing 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 instead 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, specific within the companycan be measured using the following formula:
MTTR =(the total duration of repairs over a given period)/(Number of breakdowns)
Moreover, (Rødseth et al., 2015) conducted a study on the key performance indicators to integrate them into the maintenance management and manufacturing planning and control, they arrived to select the OEE (Overal 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 to implement the improvement of the equipment 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:
OEE = availability rate * Performance rate * Quality rate

2.3. Performance KPIs.

(Gonzalez et al., 2017) 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. 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.

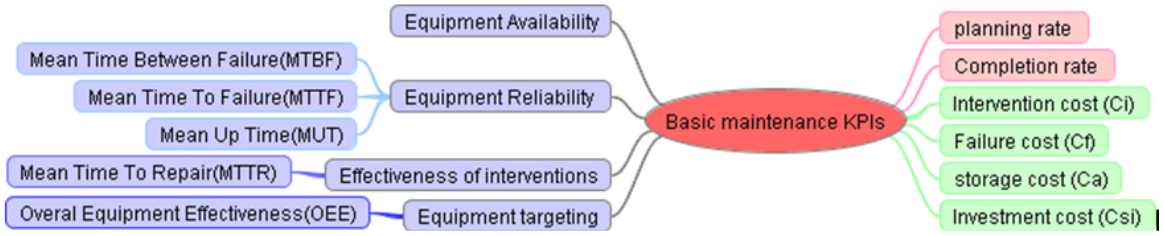


Figure 2: The basics maintenance KPIs

According to the need for maintenance, a structured approach must be followed to define the appropriate KPIs in a company, as illustrated in figure 3, this approach was chosen 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.

Work identification is the first step in establishing maintenance KPIs. During this phase, the failure modes and their impact on equipment capacity will be identified and controlled. Then the work planning process is then conducted to identify the needs and the necessary instructions. Next, the work schedule determines whether the resources required are available. Next, training for the execution phase will take place after the staff has been trained for development. Follow-up is the next phase, which keeps track of information during execution. The ultimate step is performance analysis intended to assess the maintenance program concerning the actual performance and performance required to extract the corresponding KPIs. Finally, after analyzing the previous steps and maintenance needs, maintenance KPIs are developed.

To successfully create new KPIs for industrial maintenance, it is crucial to analyze and understand the underlying cause and effect relationships and interdependencies between processes, equipment, and efficiency (Govindan and al. (2021)). Once these are fully understood, the concepts of monitoring and tracking strategies and effective measures can be developed. The measured variables must be defined as part of this step,representing the key parameters and resulting in the cause-and-effect ratios. At this stage, a

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close link with the process data source is essential because the availability of data and the measurability of these parameters are essential prerequisites for the next stage, which is the innovation of KPIs (Schmidt and al. (2016)).

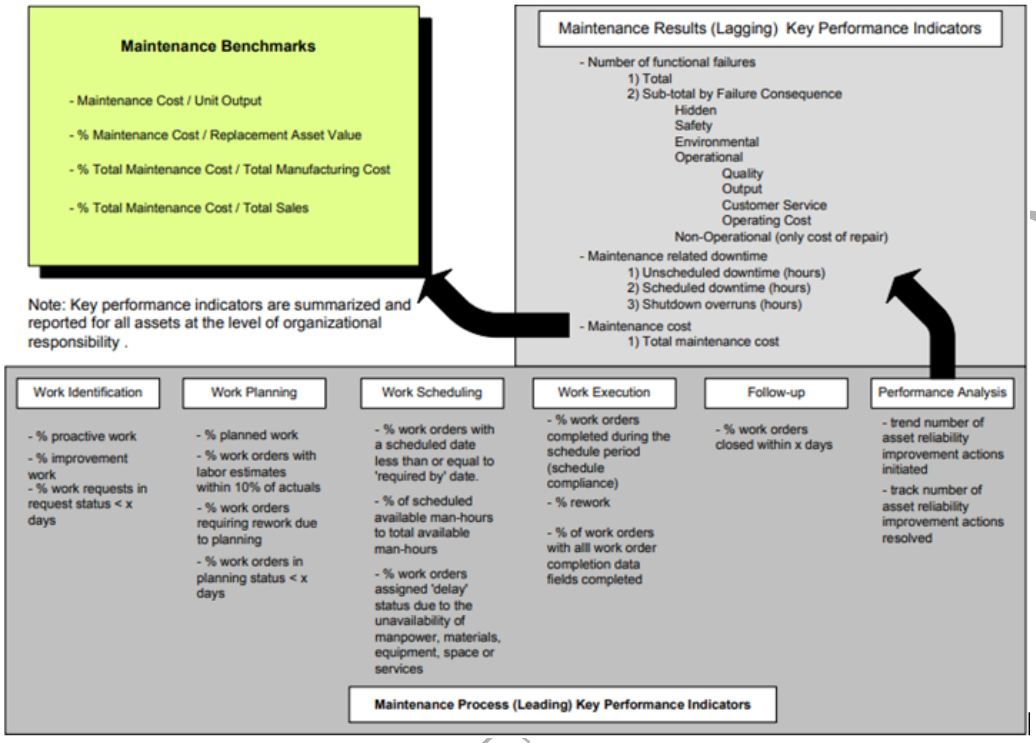


Figure 3: Maintenance Process Key Performance Indicators (Weber and Thomas, 2005).

The success factor in applying a new KPI depends on its continued measurability. In addition, the accuracy of data and its timely availability are also crucial for the standard calculation of indicators. Finally, to compare the current state and the target state, each KPI must be unambiguous in its expressiveness and must be assigned to a specific person or department responsible for reporting to higher management levels. Therefore, a generalized approach to categorizing KPIs and systematically developing KPIs is needed (Parmenter. (2015).

3. Research works for the development of new maintenance KPIs

This section aims to present some relevant works in developing new KPIs for maintenance to find out how maintenance KPIs have evolved within the industry since they are essential for good maintenance management. For this research, Google Scholar was primarily used as a search tool. The following keywords were used to find relevant articles: "maintenance KPIs," "maintenance management," "development of maintenance KPIs," "maintenance dashboard," and "maintenance 4.0". The papers selected include the newest, the most cited, and the papers based on the content relevant to the scope of our work.

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 (Ahmad &Dhafr, 2002). 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 (Chen and al., 2013).

In (Telford and al., 2011), the authors described the practical application of an optimized maintenance philosophy based on the development of 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; for early overhaul based on trend and characteristic monitoring and saved equipment from further damage.

Proceedings of MFPT, 2021/2

In (Xenosand al., 2014), the authors investigated a relevant effect of mechanical degradation leading to decreased efficiency overtime 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 through the development of 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 (Rødsethand al., 2015), the authors studied the critical performance indicators for the integration of maintenance management and manufacturing planning and control with a fixed objective which is through a study of the literature, they will identify relevant KPIs in both manufacturing and control disciplines (MP and C), and maintenance management, at the end of this article a KPI structure that integrates MP and C and maintenance management is developed illustrate in figure 4.

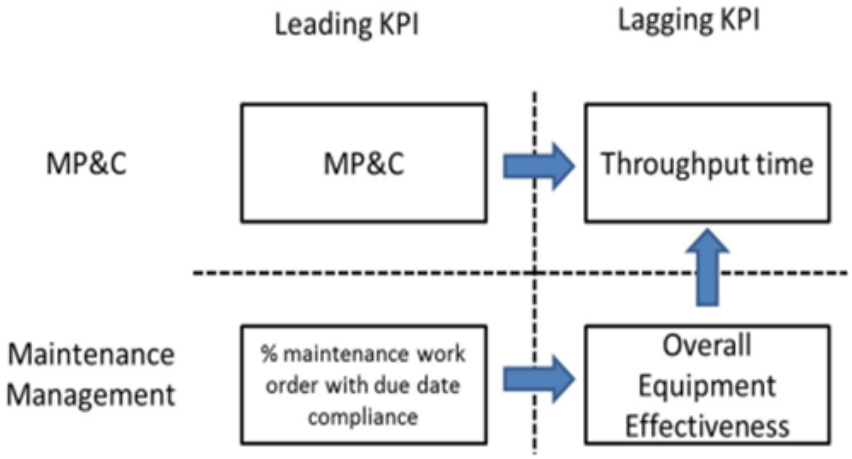


Figure 4: Structure of leading and lagging KPIs for MP&C and Maintenance Management

This structure is based on the interactions between the KPIs that are developed for maintenance management and MP&C, indeed the new KPI **maintenance work order rate** must be communicated to MP&C 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. They also used a basic KPI OEE as a coordinator between the two KPIs developed to improve the **maintenance time throughput** KPI and maintenance backlog.

In (Lindberg et al., 2015), 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 andemergency maintenance this involves too much maintenance, thus high maintenance costs and loss of production during each scheduled maintenance. The KPIs that are proposed in terms of maintenance are **Maintenance costs / Produced output over some time; Maintenance time / Produced output over some time; Number of alarms over some time.**

In (Gonzalez and al., 2017), the authors presented a review of the existing leading indicators used in the operation and maintenance of wind farms to be able to develop others based on what already exists. 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 then specific and measurable; **several interventions** and intervention is the fieldwork conducted to keep a WT in good condition; it implies a displacement of the maintenance crew. Monitoring the number of interventions, both scheduled and unplanned can show the

ceedings of M. F. - 2021/2

results after an optimization of the O&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 defined as 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 job** sare 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 followedby 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 (Hwang and al., 2018), 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 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, 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 (Brundageand al., 2018), 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 .

Proposed KPI	Signification
Common Problem Items	The number of issues at a facility for specific items.
Common Problem Items per Time Between Failure	The time between issues at a facility for specific items.
Common Problem Items by Machine Type	the number of issues at a certain machine type for specific items
Common Problem Item & Action per Time to Repair	The amount of time to solve an issue for a specific Item & 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 & Action per Time to Repair	The amount of time a maintenance technician spends repairing an issue.
Maintenance Technician Expertise per Problem Item & Action per Time to Diagnose	The amount of time a maintenance technician spends diagnosing an issue.
Maintenance Technician Expertise per Problem Item & Action per Time to Fix	The amount of time a maintenance technician spends solving an issue.

Table 1: KPIs derived from MWOs (Brundage et al., 2018)

In (Ferreira and al., 2019), 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.

In this article, the authors have developed KPIs for managing obsolescence in maintenance operations. 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 using artificial intelligence and then the creation of a decision support tool from these KPIs.

In (Wohlersand al., 2020), 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 and also the identification of the causes of malfunction and the correction of breakdowns is very difficult, especially in large industries or factories which operate in several interdependent units. For this, the author has developed a set of KPIs for the mechatronic system according to this procedure which is illustrated in figure 5.

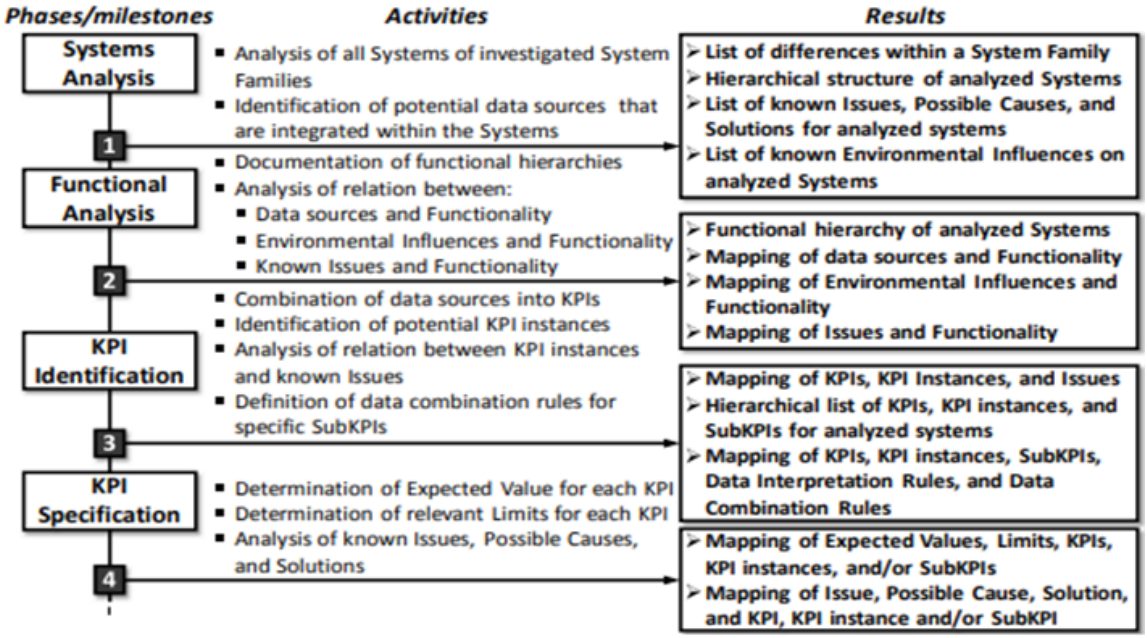


Figure 5: Procedure for identification and specification of KPIs for mechatronic systems.

The first phase consists of analyzing the mechatronic systems and understanding them in-depth, the second phase is the functional analysis of its systems, 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, define 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 for the manufacture of ATMs. He has defined these KPIs in two categories: KPI-based product control of automated teller machines which are mainly: **The KPI NoteTransportTime:** 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 ClutchTime** is for the monitoring and control of the clutch function it detects faults assembly or improper positioning of a rotating shaft. **The KPI IdleCurrent** controls the electrical consumption of the engine analyzed at system idle. These causes may be the incorrect mounting of a shaft or displacement of a belt in the transmission chain. **The DispenseSkewness** KPI provides information on the quality of the distribution, the alignment functionality, or rather the transport quality.**Finally, The NoteTransportCurrent** KPI is similar to the IdleCurrent 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 be able to detect future problems in the system before they cause damage, indeed whalers have found that the monitoring of each component of the system is not a trivial task therefore, these statistical KPIs make it possible to monitor any system at several hierarchical levels or which is devised by a family of component, these KPIs provide the monitoring of the current state and the forecast of the future state of any system component.

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: Summary of proposed KPIs in the literature

Article	KPI	Motivation
Telford and al., 2011	compressor valve temperature monitoring	Monitoring trends and characteristics and protecting equipment from further damage.
	stem positioning monitoring	
Xenosand al., 2014	electrical consumption of each compressor during the period of good operation	optimization of operation and maintenance of a network of compressors
	compressor condition monitoringand operational optimization of preventive maintenance strategy	reduce operating and maintenance costs of the air compressor network
Rødsethand al., 2015	maintenance work order rate	measures the rate of corrective maintenance work orders
	maintenance time throughput	measures maintenance time in production
Lindberg et al., 2015	Maintenance costs / Produced output over some time.	These KPIs are used to measure performance and identify the waste that maintenance causes in an industry.
	Maintenance time / Produced output over some time.	
	Number of alarms over some time.	
Gonzalez and al., 2017	Response time	it informs about the efficiency in maintenance planning,so it is a specific and measurable KPI.
	number of interventions	the field work 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),	inform 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.	can give insight into the quality of maintenance planning and is therefore relevant to stakeholders.
Hwang and al., 2018	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.
Brundageand al., 2018	Common Problem Items	the number of issues at a facility for specific items.
	Common Problem Items per Time Between Failure	the time between issues at a facility for specific items.
	Common Problem Items by Machine Type	the number of issues at a certain machine type for specific items
	Common Problem Item & Action per Time to Repair	the amount of time to solve an issue for a specific Item & Action.
	Machine per Time Between Failure	the amount of time between failures for a given machine.

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	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.
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	Maintenance Technician Expertise per Problem Item & Action per Time to Repair	the amount of time a maintenance technician spends repairing an issue.
	Maintenance Technician Expertise per Problem Item & Action per Time to Diagnose	the amount of time a maintenance technician spends diagnosing an issue.
	Maintenance Technician Expertise per Problem Item & Action per Time to Fix	the amount of time a maintenance technician spends solving an issue.
Ferreira et al., 2019	Indicators for obsolescence in maintenance operations	indicates which components are most at risk of becoming obsolete and evaluates the effects to reduce its obsolescence through maintenance operations
Wohlers and al., 2020	NoteTransportTime	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 the monitoring and control of the clutch function it detects faults in assembly or improper positioning of a rotating shaft.
	IdleCurrent monitors	the power consumption of the analyzed motor at system idle.
	Dispense Skewness	provides information about the quality of the distribution, the alignment functionality, or rather the quality of the transport.
	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 be able to detect future problems in the system before they cause damage.

4. Discussion and 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 their performance criteria. However, these defined KPIs cannot be set in stone. Continuous changes in the market or research methodologies require KPIs to be constantly redefined and updated to ensure that the KPIs are appropriate for the organization's current environment.

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 towards achieving its main 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.

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. These KPIs, however, are most often not open to use in other industries unless it is in the same sector or perhaps in those with similar activities and equipment because they are de-

Proceedings of M. F. E. G. I. M. - 2021/2

veloped based on the current state and situation and are not generalized. For example, the KPIs developed in (Xenos.2014) and (Telford 2011) 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 (Wohlers 2020) that are dedicated to the maintenance of mechatronic systems; they are not usable for a company that works with mechanical or electrical systems.

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.

Maintenance managers gain many benefits from KPIs because they facilitate the management. However, selecting them carefully is not trivial. Selecting simple, understandable, and easy to interpret information is crucial. Before selecting the relevant KPIs, it is necessary to identify the needs they respond to. Furthermore, they must be aligned with the maintenance strategy and the company objectives to avoid falling into the wrong selection of KPIs. Because this decision generates negative impacts such as the loss of time in exploitingnon-useful information, loss of money during the KPI implementation, and the significant risk is erroneous decision-making.

Key performance indicators should be aligned with the needs of maintenance managers. Indeed, the maintenance KPIs must be developed following the analysis of the needs of the maintenance managers and must measure what the managers must manage. For example, for a maintenance manager who struggles to manage preventive maintenance, we should select a KPI that provides information about preventive maintenance, facilitating its management.

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

Regarding the KPIs proposed in the literature, we cannot judge their usefulness because it changes from one organization to another, and sometimes it depends on the strategy and the maintenance policy, unlike the primary KPIs, which are helpful in all cases; for this, it is advisable before selecting new KPIs to analyze the needs of maintenance in the company properly.

Among the interesting KPIs that we encountered in this research is the KPI of obsolescence management in maintenance operations because it deals with a common and serious problem in companies; also, the KPIs which aim to link maintenance planning with production this is interesting because maintenance and production are two sides of the same coin and there is a strong dependency relationship between them.

KPIs should be calculated using advanced tools, such as 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; artificial intelligence is the heart of the new industrial era. 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. The contribution of Artificial Intelligence is to offer 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 come out with a reliable result that the manager can use directly.

As a proposition, we think it would be interesting to use a KPI Schedule compliance. 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 will provide an effective performance measurement tool because it is developed to the needs of managers. Therefore, the involvement of managers is essential in the development of new relevant KPIs.

From this work's perspective, we propose developing a dashboard plan to demonstrate the effectiveness of KPIs and how applicable they are in the organization.As known, maintenance dashboards are highly recommended for reporting, monitoring, and controlling KPIs.These state-of-the-art resultsare of great value to organizations, especially ones that do not know about newly developed KPIs and how to calculate them correctly.

Proceedings of M.F.E.G.I.M. 2021/2

With the advent of Industry 4.0, the acceleration of processes that accompany it, and the proliferation of data, the challenge of decision-making processes evolving in such a context is to ensure rapid and reliable decision-making. Key performance indicators (KPIs) for maintenance are closely linked to decision-making: they are both triggers and drivers. From these perspectives, we are interested in how to develop autonomous maintenance KPIs that measure performance, interpret the measures, and why not offer proactive solutions.

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ceedings of M. F. E.G. I. M. - 2021/2