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A Strategic Roadmap to Improve the Maturity Level of Maintenance Information Management Systems

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Abstract
Maintenance involves a large amount of data management. Although many tools, strategies, and systems, have been developed to organize the maintenance information resources, SMEs have not found the same benefits as large companies due to their inherent characteristics and, above all, the maturity level of the maintenance department. Maturity models are useful tools for assessing the maturity of maintenance information practices; however, existing models are not suitable for any type of business context, as they required companies to have a clear organizational structure and definite informative infrastructure. Moreover, they do not assist in identifying and defining actions to reach the highest level. This paper proposes a model for assessing and improving maintenance management information practices. It allows a clear measure of the maturity of the maintenance information management practices in industrial contexts and provides improvement actions identifying the information and data needed to enhance maintenance management information practices.

Keywords
Industrial maintenance; Maintenance management information systems; MMIS; Small and Medium Enterprises; SME; Maintenance maturity models.

Introduction

In the current industrial context, companies are pushed to continuously improve their processes to be competitive. The maintenance function has suffered many transformations over the years, nowadays it is recognized as a key manufacturing function that contributes to gain high business performance, guarantee system availability, reliability, safety, and sustainability (Franciosi et al., 2018). Moreover, due to the evolution of technologies and consequently more complex machines and business processes, the amount of information that is created, stored, and accessed within an organisation has risen exponentially (Tortora et al., 2022). The maintenance management process of an industrial plant involves handling a large amount of information and data. To guarantee high machines' reliability, availability, and integrity, adequate maintenance and repair actions must be performed (Leoni et al., 2021). Hence, the development of more effective strategies for information management assumes a central role in the academic and industry context. In this scenario, the Maintenance Management Information Systems (MMIS) are considered important tools for companies allowing fast and efficient analysis of maintenance data. Despite the huge benefits associated with MMIS, the success rate in its implementation has been rather poor (Wisniewski et al., 2020; Fumagalli et al., 2009) even more in the small and medium enterprise (SME) context. Several conditions and barriers limit MMIS implementation in SMEs. The maturity level of the maintenance department seems to be the most common issue (Wisniewski et al., 2020). Most companies are still unaware of what maintenance data classes must be collected and managed for introducing an appropriate informative infrastructure coherent with their needs; in other words, they do not achieve the proper level of maturity or readiness to introduce an MMIS. In this frame, maintenance maturity models are useful tools. Maturity models have been generally designed to assess the maturity (i.e., the capability and level of sophistication) of a selected domain based on a more or less comprehensive set of criteria (de Bruin et al., 2005). The application of this concept is not limited to any particular domain. The definition proposed by Becker (2009) is: "A maturity model consists of a sequence of maturity levels for a class of objects. It represents an anticipated, de-

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sired, or typical evolution path of these objects shaped as discrete stages. Typically, these objects are organizations or processes." Therefore, maturity models can also be used for assessing the maturity of the information maintenance management practices and suggest actions for introducing the right informative infrastructure in SMEs. However, a previous literature analysis highlighted the lack of such a maturity model (Tortora et al., 2022). In particular, the existing maintenance maturity models (Wendler et al., 2012; Macchi & Fumaglli, 2013) focus on generic assessment areas formulated from the literature as maintenance management processes key measures that do not vary in importance depending on the business context; the information management assessment area is also not always deeply and properly considered. The application of these models to different organisations may not be straightforward due to differences in several aspects, including the organisational structure and business context (Chemweno et al., 2015). Moreover, all these models allow for assessing the maturity level but do not indicate or assist in the identification and definition of the actions/activities that must be pursued to reach the highest level. Thus, this study was conducted to contribute to this research field by developing a maturity and improvement model that measures the maturity of maintenance management information practices and defines an improvement programme that supports SMEs to reach the highest maturity level as well as to introduce an appropriate maintenance informative infrastructure.

This paper is organized as follows. Section 2 reports a literature review on the relationship between maintenance management, information technologies (IT), and SMEs and also an overview of maintenance maturity models. Section 3 shows the steps performed to develop the proposed model. Finally, the main conclusions and future developments are presented in Section 4.

Literature review

IT and maintenance management in SMEs

Recent technological advancements and the rapid growth of IT and computer networks are changing the way companies handle information. Studies on the role of IT in competitiveness have been primarily focused on large organisations (Beheshti, 2004). Few works have attempted to investigate the role of IT in SMEs, even more, the role of IT in the maintenance management of SMEs context (Tortora et al., 2022). SMEs rarely view maintenance as a strategic issue contributing to the company's profit margins (Baglee & Knowles, 2010). Nevertheless, the large amount of information to manage has created the need to introduce systems better able to manage the maintenance data. Therefore, MMIS, e.g. CMMS (Computer Maintenance Management System), has been used (Jasiulewicz et al., 2020). MMISs became necessary systems able to analyse maintenance data quickly and efficiently to make better decisions (Hemmati et al., 2018, 2019). Despite the relevant benefits associated with MMIS as a support tool in maintenance management, different factors affect its implementation. Several surveys showed the existence of various conditions and barriers to MMIS implementation (Fumagalli et al., 2009). The most frequently indicated reasons are the maturity level of the maintenance department, high implementation costs, lack of knowledge of the system, unskilled and scarce workforces, and difficulties in changing organisational culture (Wisniewski et al., 2020). Indeed, SMEs are constrained in terms of their financial and human resources; the decision process is more intuitive and, based on experience, most of the activities are governed by informal rules and procedures, with a low degree of standardization and formalisation. At the information systems level, other relevant features, identified in a literature review by Zach et al. (2014), were pointed out: SMEs often lack the managerial expertise to plan, organise and direct the use of information resources, and many SMEs hold insufficient in-house expertise for successful information system adoption. Small organisations seldom have a defined IT budget or an explicit IT plan or strategy. The owner often drives investments in technology, rather than by any formal cost–benefit or strategic analysis. Thus, MMIS yields low success due to the readiness level of the smaller industrial contexts that are still unaware of the key role played by maintenance data in improving overall performances Most SMEs rely on outdated technology and labor-intensive and traditional management practices. This, in many cases, has led to a lack of information and inadequate in-house expertise (Hemmati et al., 2018). Most SMEs have simple systems and procedures that allow flexibility, immediate feedback, a short decision-making chain, better understanding, and a quicker response to customer needs than larger organisations. Despite these supporting features, SMEs are under great pressure to sustain their competitiveness in domestic and global markets (Singh et al., 2008). Therefore, SMEs should be ready to adopt an MMIS. This requires a change in the maintenance management practices. Furthermore, this trend highlights the importance of introducing an appropriate MMIS that reflects the readiness level of the specific industrial context.

Maintenance maturity models

Maturity models can be seen as a simple method that allows organizations to effectively measure the quality of their processes. Maturity models allow an organization to have its methods and processes evaluated by good management practices and with a set of external parameters. During the last two decades, the application fields of maturity models have widened. However, not much-published literature is reported on the development and application of maturity models in asset maintenance (Olivera et al., 2020; Chemweno et al., 2013; Macchi & Fumagalli, 2013). Many Capability Maturity Models, developed for asset maintenance, are reported in grey literature sources, developed largely by consultants or individual companies as in-house maturity assessment tools. These models are mainly proprietary and contain rather limited information, especially regarding their development and use. To highlight the novelty of the proposed model, the existing maintenance maturity models reported in Franciosi et al., 2018, providing technological aspects among the dimensions, were analysed. In particular, the main characteristics and limits of these models are reported in Table 1. The technological area is only a measurement dimension, the existing models focus on the maturity of the entire maintenance process (Macchi & Fumagalli, 2013; Oliveira et al., 2020; Mehairjan et al., 2015; Schuh et al., 2010), therefore this area is not well detailed. Some models (Nemeth et al., 2019; Oliveira et al., 2012) proposed approaches very difficult to implement in SMEs as they require companies to have a credible maintenance performance measurement framework and sys-

Table 1
Analysis of existing maintenance maturity models

Authors (year)	Objective	Dimensions considered in the maturity model	Weakness points
Kans M. (2008)	A conceptual model for identifying maintenance management IT	Key factors in each three dimensions: Operational; Tactical; Strategic	It focuses on the identification of IT functionality requirements for maintenance management, as well as how the demands of computerized maintenance management support can be determined. It doesn't give a measure of maturity
Schuh et al. (2010)	An assessment tool that identifies shortcomings in maintenance performance & potentials for improvement	(1) Information & knowledge management; (2) maintenance object; (3) materials management; (4) partnerships; (5) maintenance control; (6) maintenance organisation; (7) maintenance policy & strategy; (8) customer; and (9) maintenance staff	Information and knowledge management is only a measurement area and it focuses on the measure of the maturity of the maintenance process.
Kans et al. (2012)	Assessment of maturity in maintenance management information technology	(1) Maintenance Management Information technology (MMIT) utilisation level; (2) decision-making using MMIT; (3) MMIT integration; (4) Key Performance Indicator monitoring/control via MMIT; and (5) data quality in MMIT	Addresses issues specific for maintenance management information technology. Focused on IT maturity level. It defines the criteria for selecting an MMIT application suitable for specific enterprises' needs. No improvement is provided
Oliveira et al. (2012)	A maturity model that allows an understanding of the most appropriate strategy; maintenance tools, techniques & indicators; and potential improvements for the successful evolution of maintenance processes	(1) Maintenance strategy; (2) KPIs; (3) maintenance data systems (Computerized maintenance management system – CMMS); (4) technical competencies (culture); and (5) management models	It focuses on the maturity of the maintenance process. Only qualitative assessment methods, such as self-assessment of maintenance managers based on the reading of some tables, were provided. The dimension CMMS assumes the use of MMIS. No improvement is provided.

Table 1 continued

Authors (year)	Objective	Dimensions considered in the maturity model	Weakness points
Macchi & Fumagalli (2013)	A maturity assessment method for measuring the state of maintenance practices in a company	Several key process areas in each of these dimensions: (1) organisational; (2) managerial; and (3) technological	It focuses on the maturity of the maintenance process. Require a very clear maintenance structure. Processes well managed and standardized. The technological dimension is not specific on maintenance information management. No improvement is provided.
Mehairjan et al. (2016)	Measuring and monitoring the integral corporate vision of a set of multidimensional domains needed for maintenance management professionalisation	(1) Organisation & processes; (2) policy & criteria; (3) information & systems; (4) data quality; and (5) performance & portfolio	Focused on Professionalising maintenance. It is specific to a maintenance strategy
Nemeth et al. (2019)	Assessment of the maturity level of knowledge-based maintenance in smart manufacturing enterprises	(1) Data; (2) information; and (3) knowledge	Focused on specific maintenance strategy. The approach they presented was difficult to implement, as it required companies to have a credible maintenance performance measurement framework, and systematized and well-defined maintenance data and information.
Oliveira et al. (2020)	A maturity model identifying the current state of maintenance in organisations and driving actions to increase its efficiency & effectiveness towards becoming world-class	(1) Organisational culture; (2) maintenance policy; (3) performance management; (4) failure analysis; (5) planning & programming of preventive maintenance activities; (6) CMMS; (7) spare parts inventory management; (8) standardisation & document control; (9) human resource management; and (10) results management (maintenance costs & quality)	CMMS is only a measurement class. It analyses the use of the implemented CMMS.

tematized and well-defined maintenance data and information. This aspect is not linked with SMEs characteristics (the main domain of this work), since they are governed by informal rules and procedures and have very fragmented information resources. Almost all models do not give an idea of the practices that could be implemented to increase the maturity level. The two studies of (Kans, 2008, Kans et al., 2012) address issues specific for maintenance management information technology. For example, Kans (2008) proposes an interesting and well-structured procedure for the identification of IT functionality requirements for maintenance management, but the aim is to provide guidelines for investments in information technology and not on the creation of informative maintenance infrastructure. Based on the literature, no maturity model provided an assessment and improvement focused on maintenance management information practices. Therefore, this study attempted to fill this gap by proposing a maintenance maturity and improvement model of information management practices for SMEs, supporting maintenance operations in manufacturing systems.

The approach for model development

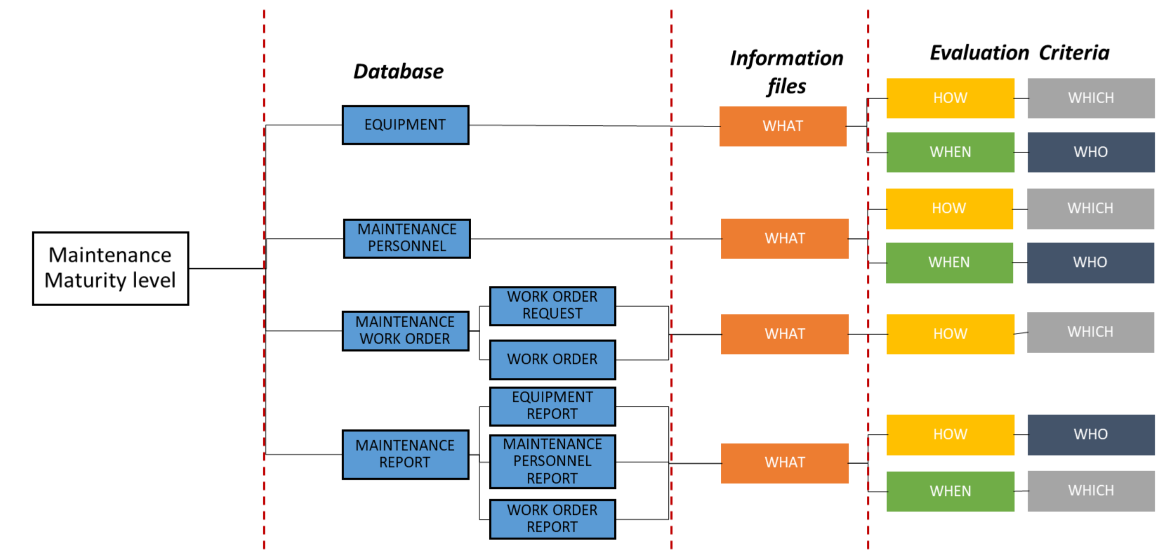
To develop the model a systematic approach, composed of three steps, has been followed (Fig. 1). Step 1 consists of the development of maturity model architecture; the assessment of the maintenance management information practices, performed through a sur-

Fig. 1. Steps for model development

vey, allows the identification of ML and, consequently, the weakness points where improvements can be made (step 2); starting from the ML calculated an improvement programme, based on the selection of the maintenance management best practices, is defined (step 3).

Step 1: Maturity model architecture

The approach proposed by Becker (2009) was applied to develop the maturity model on Maintenance management information practices in SMEs, as presented for the first time by Tortora et al. (2022). The model architecture design was carried out through the analysis and decomposition of the maintenance execution process to identify all relevant information and data, as well as, all the information repositories, to rightly perform maintenance activities (Tortora et al., 2022). The model architecture and the main concepts are shown in Figure 2, which reports the databases forming the maintenance information infrastructure and the criteria for measuring the maturity. The defined databases aim to provide all those concerned, at the place of use, with all the up-to-date and usable files and documents they need to prepare for



Maintenance Maturity Level	Database	Information files	Evaluation Criteria
Maturity level of maintenance information management practices (mainly based on maintenance informative infrastructure available). They can be calculated at different levels: the aggregated level, databases, information files and evaluation criteria.	Some of typical information repositories included in an maintenance application. Four databases are considered: Equipment, maintenance personnel, maintenance, work order and maintenance report.	List of information contents linked to each DB (WHAT).	The level of accessibility by users and the quality of each document (HOW); the upgrade period (WHEN); the support tool used for maintenance information management (WHICH); who takes care of information files correct management (WHO).

Fig. 2. M3AIN4SME structure and main concept

and perform the tasks for which they are responsible while optimizing costs and times as well as the different maintenance processes and sub-process (EN 15341:2019). In the next section, a broad description of the databases is provided.

Equipment database

The Equipment database must contain, store, and arrange all the information files needed to prepare, perform and close out a maintenance task safely for restoring the machine to a functional state. It includes five information file classes: 1) Physical data; 2) Technical data; 3) Failure data; 4) Maintenance data; 5) Improvement data.

Physical data consists of machines registry, drawings, files from manufacturers and engineering, and Structural bonds. The definition and structuring of the machines' registry are necessary to analyse and aggregate the information regarding the maintenance activity and the machine's performance. The classification is relevant to allow the analysis of homogeneous machine family groups that have similar features. The coding system must be simple and allow only univocal identification of all the machines. Drawings, and files from the manufacturer and engineering must be available and consulted to support the detection of any faults, locate them and identify the primary cause(s) (diagnostic phase). Structural bonds (Bill of materials) define all the maintenance spare parts of which the machine is made up to visualize all the hierarchical links.

Technical data aims to provide all the operating parameters inherent to the machine components to simplify the replacement of components and/or repairing of components; and/or regulatory interventions. The operating condition helps both to detect a failure and to test and boot the system after a maintenance intervention or to adjust the component to the required conditions.

Failure data consists of the formalisation of a diagnostic system (e.g. FMECA) and the structuration of an equipment history file continuously updated. A diagnostic system involves a quantitative failure analysis to create a series of linkages between potential failures, the impact on the mission, and the causes of the failure. The system supports to detection, characterize and prioritization the events (failures, breakdowns due to latent or hidden faults) based on standard maintenance procedure provided by the manufacturer. The equipment history file not only helps to create and enrich the diagnostic system but also supports collecting data and information related to failure and inspection performed on the machine. The purpose is to collect a list of undesirable events, causes, effects, the criticality of events, the occurrence of events to look for a possible recurrence of the failure, look for the primary causes of the failures (establish the causal chain), analyse the failure events to deal with and rank them by priority and establish a better schedule of maintenance interventions. The records in the equipment history file include the time and nature of failure, the undertaken repairs, total downtime, and machines and spares used. A monthly maintenance report (involved in the report Database) should include downtime of critical and major equipment and their availability.

Maintenance data includes maintenance best practices (Repair Methods, safety needs, Maintenance Standard Procedure) and documents of daily inspections for the auditing of basic functioning conditions (checklists of cleaning, inspection, and lubrication). Thanks to the maintenance record contained in the failure history file, the maintenance best practices are continuously updated to define the operative instructions to conduct a maintenance task safely and according to the various constraints (operating, environment, resources). The document of daily inspections contains all the procedures to conduct inspection operations; cleaning operations; Lubrification operations; and other treatments to prevent failure events (to introduce the autonomous maintenance practice).

Improvement data consists of a program of improvement defined by the data collected. The purpose is to define, monitor or realize and validate improvements of the machine when it is a better solution than preventive or corrective actions to manage failures or penalties. The machine can be improved in terms of reliability and/or maintainability and/or safety at a convenient cost.

Maintenance personnel database

The maintenance personnel database must contain all the information documents and files needed for providing promptly the internal maintenance personnel who have the necessary skill levels and certification to perform the maintenance activities. All the information files can be classified as: 1) Basic education and training; 2) Advanced education and training; 3) Basic reward and recognition; 4) Advanced reward and recognition.

Basic education and training class consists of a maintenance personnel system and job profiles and responsibilities system. Having a maintenance personnel system helps to create a structured and unified maintenance personnel coding system to collect in a standardized way all the information related to maintenance personnel. The job and responsibilities system instead, aims to manage jobs and skills. Through the collection and updating of skills levels, certifications, and qualifications, the more competent and appropriate internal individuals to perform maintenance activities can be identified.

Advanced education and training class consists of a maintenance personnel training program (self-education, on-job, off-job) for each maintenance personnel. Ensuring training, qualification, and certification of internal staff allows the company's internal staff to update their knowledge and achieve higher qualification and certification levels. The training should not be limited to transferring technical skills, and knowledge needed for optimal task performance. It should also cover generic matters like so-called soft skills: problem-solving techniques, team dynamics, and facilitation skills. These training courses shall address also risks related to Health, Safety, and the Environment.

Basic reward and recognition class consists of a maintenance personnel performance monitoring system (quality performance indicators, key factors).

Managers are advised to recognize and reward employees through status recognition. Therefore fluid forms of recognition need to be adopted including bonus, performance awards, and certificate of appreciation. This system must be based on the assessment of the level of skills, based on the definition of indicators obtained through the performance measuring of each employee.

Advanced reward and recognition class consists of training and competence needs system analysis. Taking into account the monitoring system and job profiles, it establishes the competence to reach future skills requirements for each employee. The system support qualifying in a continuous optimization cycle of internal and/or external individuals to assign the right (in terms of competence) employee related to each task. Based on future skills requirements, foreseeable staff movements, and the time it takes to make qualified staff available, recruit as necessary to satisfy needs promptly. Moreover, the system must define training objectives, identify training programmes, and then evaluates them. It provides the qualified internal staff needed to perform the tasks specified in the maintenance policy.

Work order database

The work order DB is the vehicle for planning, scheduling, performing, and controlling maintenance work. It also provides the needed information for monitoring and reporting maintenance work. A clear goal and effective procedures are essential for the implementation of the work order system and control of maintenance activities. Simply, a work order system can be seen as a form in which written instructions are detailed for planning and scheduling any type of maintenance intervention and also for work to be carried out. For this reason, we can distinguish two significant phases: 1) Maintenance work order request; 2) Maintenance work order. They must be filled for all jobs.

Maintenance work order request means the fulfillment (paper, telephone, or computer) of a "form" that contains all the information useful to the planner or the maintenance coordinator to schedule the maintenance operation. The requests can be established by any person in the organization and for whatever type.

Maintenance work order means the fulfillment (paper, telephone, or computer) of a "form" containing all the information useful to the maintenance and/or production operator in order to carry out the maintenance work (whether it is an inspection, a preventive or replacement intervention or an emergency). It is therefore the request that, once planned and scheduled, becomes operational. Hence, the work order system must be designed with care and take into consideration two points. The first one is the request that has to include all necessary information needed to facilitate effective planning and scheduling, the second one is the instructions provided to perform the work that has to emphasize clarity and simplicity for use. It is right to point out that in maintenance systems, there are two types of maintenance work orders. The first type is the "blanket" work orders (sometimes referred to as standing work orders) used for the small routine repetitive job, inspections preplanned, and required of interventions after a particular condition verified. . .) For these repetitive and/or preplanned jobs, the maintenance planning and scheduling unit needs a specific work request containing all the necessary information (related to the work to be formed and also related to the specific assets and maintenance personnel) to define clearly the procedures, the instructions, the time, the costs, the personnel to be handled, using a well-defined work order to dispatch for the performing. The second type is the emergency work order for which reporting all facts about the job is necessary after the work is performed (in this case sometimes it is not time to compile a specific work request, the intervention is immediately required). Moreover, related to the variation in the maintenance load (if the current resources meet the maintenance demand), variability in maintenance tasks, availability and constraints of material, manpower, and production system, there are work orders that are done by external companies to perform the tasks as externally contracting. Analysing a maintenance work order flow the information contents to include in the work order database have been defined, in particular in the maintenance work order request and in the work order realised for the execution. In the report database instead, all the data about the work done are collected.

The maintenance work order request for planning work has to include: the unit description and site requiring the intervention, maintenance personnel required (type/job), priority/critical code, time standard of execution, and failure effect (visible or verified).

The maintenance work order for performing the jobs has to include: the date of work, safety procedures, spare part and material required, job specification (work description), priority code, maintenance personnel required/planned, time standard of execution, frequency of execution and type of task (in case of a recurrent job e.g. cleaning, lubrification, inspection, and refastening operations). The maintenance work execution aims to restore the item to the required state. This restoration may be carried out either as a preventive measure or after a fault is detected.

Report database

The Report DB aims to collect, analyse, store all data needed to document and improve the maintenance process. All the raw data internal to the process (corrective and preventive maintenance reports, item-related data, tools used, risk monitoring and management, time spent, costs, etc.) or external to the maintenance process (production data) shall be validated and saved in an easy-to-use library and/or database. To be usable, this data shall be validated and classified according to its type and characteristics. The collected reports are analysed periodically to compile indicators and usually compared to the expected values/objectives defined in order to show the area where improvement can be made and also to monitor and evaluate the effectiveness of maintenance actions in a continuous optimization cycle. Therefore, a report database has to include the collection of data and feedback information derived from the equipment to be maintained, the maintenance personnel ,and the work order executed. For this reason, in the model proposed, it is structured and spitted out in 3 parts: 1) Equipment reports; 2) Maintenance personnel reports; 3) Work order reports.

The equipment reports include the collection of maintenance hours (per equipment), equipment maintenance cost (weekly or monthly), equipment downtime, in hours (weekly or monthly), equipment downtime, loss of production hours (weekly or monthly), % maintenance cost compared to asset value, Mean Time To Repair (MTTR), Mean Time Between Failure (MTBF) and maintenance activities not carried out on the scheduled date (delays) (per equipment). All these reports reflect some sort of efficiency measures that have to be periodically analyzed and monitored in order to detect the area of improvement. The improvements can relate the modification of items by changing only their reliability, maintainability, and safety characteristics (e.g. by improving maintenance techniques, methods, and existing maintenance practices) or by changing equipment functions or performances.

The maintenance personnel reports include the collection of time Report showing the hours worked by the employee per work order, time Report showing the hours worked by the employee in each department/area, time Report showing the hours by the employee to each type of work order (emergency, preventive, professional), overtime compared to normal shift work. These time reports ensure to monitor and measure the maintenance personnel performance in order to manage the jobs and skills of each one with the aim train on time the internal human resources who must have the necessary skill levels and certification to perform the maintenance activities. The analysis of reports helps also to identify and eventually define the maintenance services carried out by external companies who have the necessary skill levels and certification to perform the maintenance activities.

The work order reports include the collection of work order start, work order completion time, Maintenance technician arrives time (in case of emergency work order), diagnostic time (in case of emergency work order), spare part(s) order time, spare part(s) receive time. As previously illustrated, the maintenance work order is the core of a maintenance process and often captures the problem, the solution, at what machine the problem occurred, who solved the problem, when the problem occurred, and much other significant information. In the SMEs, these work orders are often manually written by maintenance technicians, entered into a database, or recorded directly into maintenance management software. Technicians often describe or record information informally – or do not record it at all – leading to inconsistencies and/or inaccuracies in the data. It is clear that some of these data can be difficult to calculate, e.g. diagnostic time, since it is hard to calculate when diagnosing stops and fixing a problem begins, but this decomposition supports to highlight the wastes in the execution of maintenance intervention. All these data have to be collected and analyzed in order to identify the real problems and to formulate an appropriate set of corrective actions aimed at improving firstly the entire maintenance process and in particular the work order system, the work execution, system availability, work backlog, and quality of work performed.

Step 2: Assessment of maintenance information management practices: Survey administration

A survey is carried out using a well-designed questionnaire to assess the maturity level of the information management practices adopted. The survey is structured in different question sections. There are questions groups to collect information related to the company (size, sector, operational headquarters, and role of interviews); a set of questions concerning the general maintenance practices adopted by companies; questions section for each DB and evaluation criteria and a final section for collecting feedback. Related to the section of each DB, questions are associated with a set of closed answers: in particular, each question contains a set of practices related to the management, keeping up and organization of the file/document (listed in the description of each DB) and the answers are ranked according to a description ranging from the initial/basic practice to the good/best one. The highest ML is assigned if the adopted practices are the best ones, instead the lowest ML is assigned when the used practices are ineffective. For example, related to equipment DB the first question asks to indicate among a list of documents ("information files") to be maintained, which are currently available and ready to be consulted. Then for each one handled, questions linked to each evaluation criteria are formulated. A practical example of "WHICH" criteria is provided in Figure 3. A simple algorithm implemented in excel, returns the aggregate maturity index, the specific ML for each DB, and evaluation criteria to identify the strength and weakness points of each one.

Regard to the documents claimed available:	
WHICH support tool is used to record information flows?	
Answer possibilities	**Maturity level**
Papery	1
An autonomous asset management system	2
Electronic (CMMS, ERP O EAM) and interfaceable with other company systems	3
Electronic (CMMS, ERP or EAM) and completely integrated	4

Fig. 3. Example of a question type

Assessment procedure

To quantify the level of maturity for each database a weighted average of the level of maturity of the single information files of that specific database is performed. Similarly, the level of maturity of the single information content is calculated as a weighted average of the levels of the four evaluation criteria (HOW, WHICH, WHEN, and WHO). Hence, the score for WHAT depends on how many information files in each DB is maintained by an organisation; for each information content available, the value assigned is 1 either is equal to 0. The normalized sum of the values assigned to information files gives the maturity level of WHAT that varies from 1 to 4. The score of each information file depends on the score of each evaluation criteria that ranges from 1 (initial practice) to 4 (best practice). Moreover, both the evaluation criteria and each information files are not equally important, so a relative weight is assigned to calculate the ML of each DB. The different ML can be expressed according to the mathematical formulation reported in Table 2. The assessment model provides

Table 2
Calculation of different ML

Equation	Range	Notation
$\mathrm{ML}_i = \sum_j b_j S_{ij}$	$\sum b_j = 1;\ \forall\, j = 1, \dots, 4;\ 1 \le S_{ij} \le 4$	ML_i: Maturity level i-th information content b_j: relative weight of j-th evaluation criteria S_{ij}: Level of practice used by i-th information content in the j-th domain ($S_{ij} = 1$ initial practice; $S_{ij} = 4$ best practice)
$\mathrm{MLDB}_k = \sum_i w_j \mathrm{ML}_i$	$\sum w_i = 1;\ \{1 \le \mathrm{ML}_i \le 4;\ \forall\, z \neq 0\};$ $\{\mathrm{ML} = 0\ \forall z = 0\};\ \forall\, i = 1, \dots, n$	MLDB_k: Maturity level k-iesimo DB w_i: relative weight of i-th information file
$\mathrm{MLD}_j = \frac{1}{n} \sum_i S_{ij}$	$\forall\, j = 1, \dots, 4;\ \forall\, i = 1, \dots, n$	MLD_j: Maturity level j-th evaluation criteria n = total information files

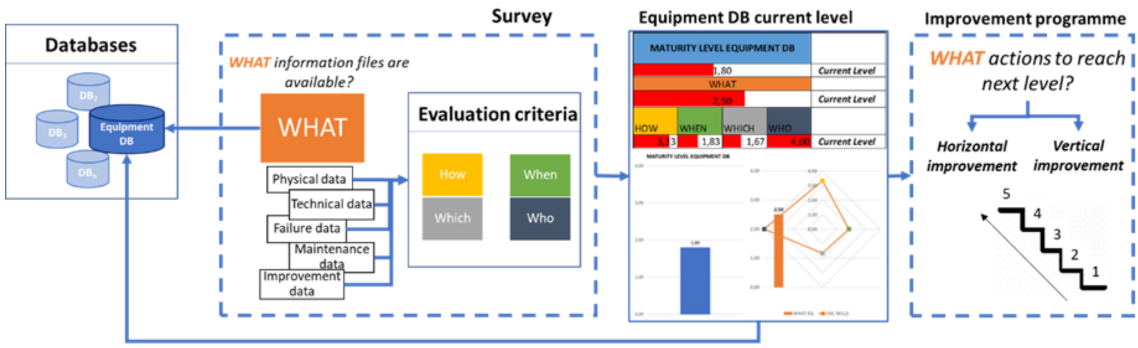


Fig. 4. Example of a question type

in output a description, as well as the meaning, of the maturity level reached for each DB and criteria, detailed in Tortora et al. (2022). The maturity level highlights the strengths and weaknesses of the current maintenance information management practices Different graphics (e.g., bar and radar chart) with the ML for each database and of each evaluation criteria are displayed as the result of the assessment process. In Figure 4 an example for the Equipment DB is showed.

Step 3: Improvement programme

The roadmap development consists of the development of an improvement path, highlighting what is already achieved and what is missing to complete the level reached. The completeness of each level is gained only if all other evaluation criteria (HOW, WHEN, WHICH, and WHO) have reached the highest level. Starting from the current maturity level the improvement programme is built. The improvements can be pursued along horizontal (by increasing the information contents/systems to the actual information infrastructure) or vertical dimensions (by improving the method for handling information infrastructure).

The Horizontal improvement is set starting from the maturity level of WHAT criteria (calculated as the mean of the WHAT level of all databases). It is the most important since it defines the information infrastructure of each database, for each result the orientation of the company and the actions for reaching progressive maturity levels or completing the achieved level one is defined. Moreover, the effort required to create each informative flow, as well as, the benefit obtainable is defined to make aware the management of the expected commitment and the improvement reachable. The defined scales for estimating effort and benefits are qualitative from a range 1 to 5. The criteria used for defining effort scale is data processing for its creation (1 no processing – 5 complex processing: crossing of more data). In particular, the scale is so defined (Table 3). Concerning the benefit scale, the criteria used are distinguished for each database:

- Quality/support for equipment and maintenance personnel DB in the execution of the maintenance intervention (in terms of easiness, timeless, goodness) (1 (no quality)–5 (high quality)).
- Quality/support in scheduling and performing maintenance intervention for work order DB (in terms of easiness, timeless, goodness) (1 (no quality)–5 (high quality)).
- Quality/support in identifying weakness points in the maintenance management process (for report DB in terms of easiness, timeless, goodness) (1 (no quality)–5 (high quality)).
- Support in the decision-making process for all DB (in terms of planning improvements) (1 (no support)–5 (valid support)).

Table 3
Effort scale

Effort	Value
The effort required is null since the flow is usually already present in the company, it only needs to be recovered, arranged, ordered, and standardised. No data processing required	1
The flow requires simple records of easily retrievable/extractable data	2
The flow requires a record of information obtainable from a simple data processing	3
The flow requires more complex recording and processing of data	4
The flow requires a lot of effort. A crossing of data and information from multiple databases is required. The information is also more difficult to read and analyse for extracting knowledge	5

The scale is so defined (Table 4). It is obvious that the efforts, as well as, the benefits achievable increase along with the increase of the maturity levels.

Table 4
Benefit scale

Benefit	Value
Having available this information flow allows for poor quality. It does not provide valuable support for the decision-making process	1
Having available this information flow allows to obtain a modest quality. It also provides little support for the decision-making process	2
Having available this information flow allows a good quality. It also provides initial support for planning improvement actions	3
Having available this information flow allows excellent quality and good support for the decision-making process	4
Having available this information flow allows an excellent quality. It also provides excellent support for the decision-making process, helping in the definition of improvement actions	5

As illustrated in the model, the maturity levels are four, but there is also a starting level, defined as level 0 (Fig. 5), that cannot be measured but it identifies a preliminary situation, for some companies that would like to start an initial improvement process and they are completely not aware of their status of maintenance information infrastructure. For each maturity level (Fig. 5) a description of the condition is provided and the actions to reach the next maturity level are suggested. The actions can be used for different purposes: for an organisation pursuing the transfer of information management best practices to its maintenance department or for other organisations beginning the adoption of a maintenance management information infrastructure for the maintenance department. Below the meaning of each level and the actions to follow to reach the next level are provided.

Level 0

***Chaos/Improvisation*:** This level is characterized by a chaotic condition in which the problem of what information and data, for all the most relevant databases, to be collected is evident. The stakeholders are not aware of the importance and relevance to have a structured DB. No consistent understanding of maintenance information needed to improve maintenance management practices exists in the company. Not all files regarding the physical and technical condition of the machines are available within the organization. Very few documents and/or systems interested with the management of "maintenance personnel" are managed. The company does not have an efficient and effective maintenance work order management system, in fact, it uses a work order system in which provides little useful information both to the planner for schedule an intervention and to the maintenance technician to perform the maintenance intervention at the best. The company does not have an efficient and effective reporting management system. It creates very few reports related to the equipment, to the maintenance personnel, to the maintenance work or-

Fig. 5. Horizontal Improvements steps

der whose records and monitors little data. This does not allow for the creation of meaningful statistics that can support the decision-making process.

***Call for actions to reach next level*:** The starting point identifies a critical condition for the information infrastructure. The first actions to do, along horizontal direction, are to add informative space for Equipment DB and Maintenance personnel DB which are the first most important databases whose data and informative flows are relevant and necessary for the creation of all other databases. Need to keep and sort the most relevant documentations, that often are already owned by the company. The recommended actions related to the documents ("information files") linked to the "machines/equipment" to be maintained and with regard to the documents and/or systems interested with the management of "maintenance personnel" are showed in the figure 6. Moreover, the red and green stamps, on the Figure 6, represents respectively the value of the effort and benefit according the scale defined above.

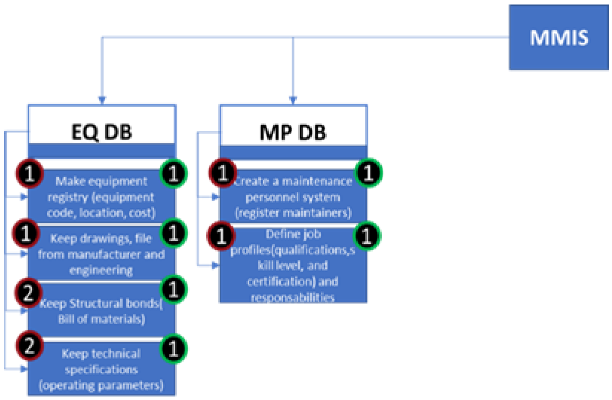


Fig. 6. Actions to reach level 1

Level 1

***Orientation*:**This level is characterized by an awareness of the importance of maintenance data as an improvement source of the company's operational performance.The company recognize the added value of information, but data are collected in a fragmented and irregular way.In particular, some files regarding the physical and technical condition of the machines and some machine failure data are available within the organization. Not many documents and/or systems interested with the management of "maintenance personnel" are available within the organization. The company does not have an efficient and effective maintenance work order management system, in fact it does not provide all the useful information to the planner and to the maintenance technician to perform the maintenance intervention at the best. The company does not have an efficient and effective reporting management system. It creates not all reports related to the equipment, to the maintenance personnel, to the maintenance work order whose records and monitors little data. This does not allow for the creation of meaningful statistics that can support the decision-making process.

***Call for action to reach next level*:** The actions to do are to expand with other data and files Equipment DB and Maintenance personnel DB. Over to keep and sort others relevant documentations, there is a need to establish priority measures essential for measuring maintenance performance. In this stage the company have to collect data and information related to maintenance activities and maintenance personnel and store them in the respective DB. Moreover, in this phase the company have to create a simple work order including the promptest information, that are simpler to detail. In the Figure 7, the equipment and maintenance personnel DB keep filling up, while the work order DB start to appear with the first data to include.

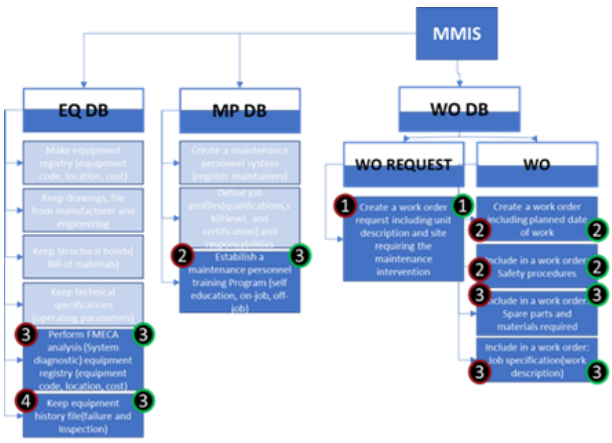


Fig. 7. Actions to reach level 2

Level 2

***Definition*:** In this level, most data and information are collected but not systematized and well-defined at all. In particular, some files regarding the physical and technical condition of the machines and some machine failure and maintenance data are available within the organization. Most documents and/or systems interested with the management of "maintenance personnel" are managed.

The company has a simple maintenance work order management system in fact it provides the earliest information to the planner and to the maintenance technician to perform the maintenance intervention at the best. The company has an initial reporting management system. It creates some reports related to the equipment, to the maintenance personnel, to the maintenance work order ,whose records and monitors some data. This allows for the creation of initial statistics that can support the decision-making process.

***Call for action to reach next level*:** The actions to do are to expand with other data and files of Equipment DB and Maintenance personnel DB. At this stage, the files and documents of maintenance equipment and personnel have to be well documented, evaluated, stored and proper filled with all the data collected in the time ,the measures to improve maintenance performance, based on the information gathered have to be laid down in the form of operating instructions for the equipment and maintenance personnel. Instead, concerning the work order DB information more difficult to identify and establish have to be included, since they must be obtained from preliminary analysis of equipment failure date and maintenance personnel performance (thanks to data included in the equipment and maintenance personnel DB). Moreover, in this phase the company have to create a reporting system for equipment, maintenance personnel and work order, including the promptest data and information simpler to take over, as presented in Figure 8.

Level 3

***Mantain*:** This level may be the stage in which the aim of information and data, as well as the way for collecting, are understood. At this stage, a high level has already been attained. In particular almost all files regarding the physical and technical condition of the machines and all machine failure and maintenance data are available within the organization. Almost all the documents and/or systems interested with the management of "maintenance personnel" are available within the organization. The company has an efficient and effective maintenance work order management system. The company uses a work order request in which provides almost all useful information to the planner. Moreover, it uses a work order in which provides almost all useful information to the maintenance technician to perform the maintenance intervention at the best The company has an efficient and effective reporting management system. It creates almost all reports related to the equipment, to the maintenance personnel and to the maintenance work order whose records and monitors, and analyse all data. This allows for the creation of meaningful statistics that can support the decision-making process.

***Call for action to reach next level*:** At this stage, a complete level for equipment and maintenance personnel have to be attained. In this sense, improvements can only occur in small steps, demanding large inputs of effort. Instead, concerning the work order and report DB all necessary information have to be included also that require some analysis about maintenance activities, as well as more time and efforts for collecting. Furthermore, most significant analysis of maintenance performance has to be performed and shared with all the employees in order to plan improvement programmes. As showed in Figure 9, in this way all DB are completed.

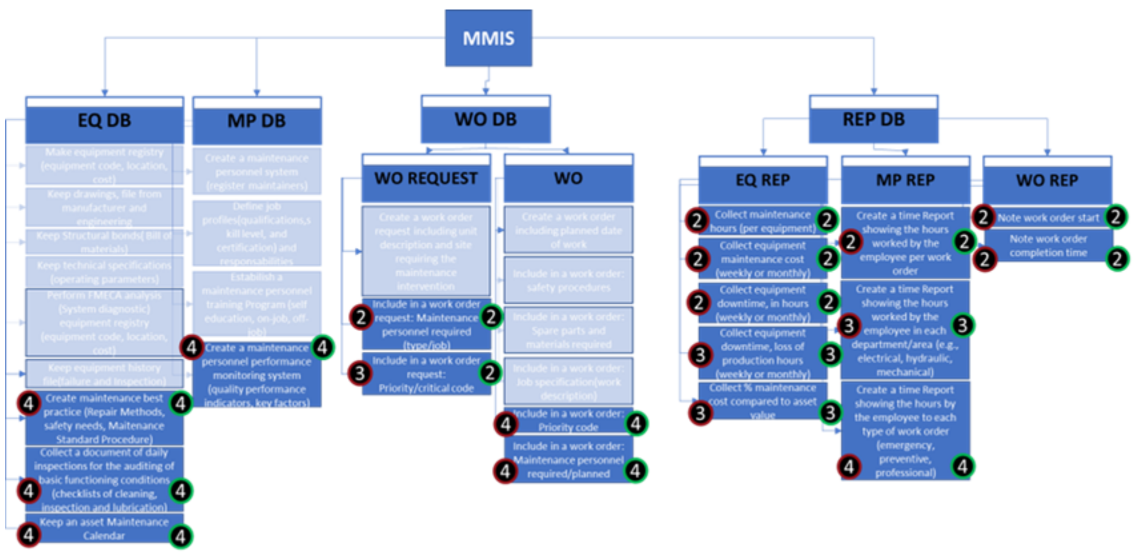


Fig. 8. Actions to reach level 3

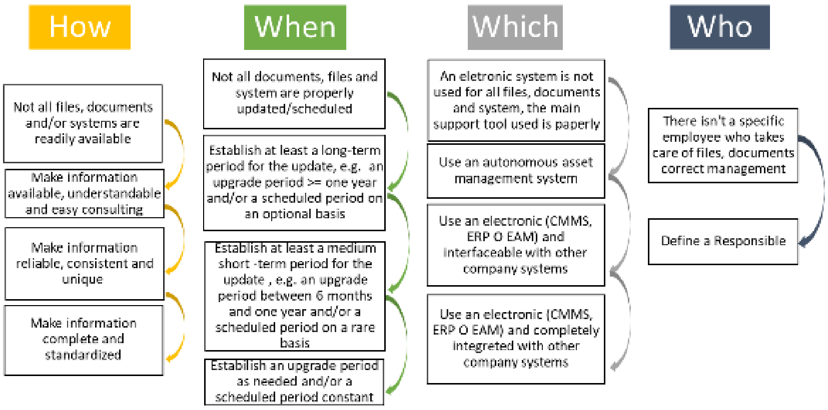


Fig. 9. Actions to reach level 4

Level 4

***Best in class*:** The last level is the highest one. The company has a well-managed and organized database, its information infrastructure is strong and effective. It is ready to introduce a suitable maintenance management information system completely integrated to guarantee interoperability between inter-/intra-enterprise information systems for seamless integration of internal departments and along the supply chain.

***Call for action*:** The highest level denotes a stage of high efficiency and effectiveness of informative maintenance infrastructure. At this stage, the most relevant databases have been organised using effectively coordinated steps. The actions to do are to improve them continuously and create the others that support the maintenance management.

Vertical improvement

The actions regard HOW manage them, WHEN update, WHICH system use to hand and WHO have the responsibility to control and analyse them (Vertical Improvement) can be defined by stakeholders related the step already reached and/or want to achieve and mainly linked to their objectives and plans. The different solutions are represented in the Figure 10 and these actions make use for all DB.

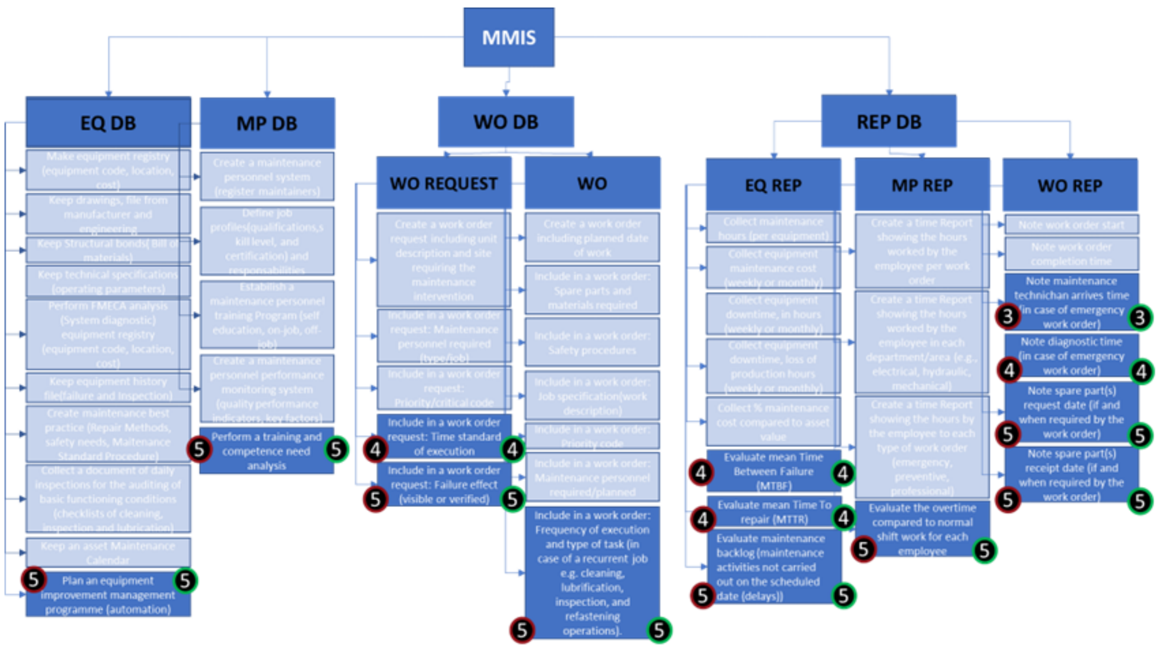


Fig. 10. Vertical Improvement steps

Tools, techniques and instruments supported DB creation

To provide a complete support in the creation of DB and especially in the collection of data and information flows concerning equipment and maintenance personnel database, the most relevant and useful Total Production Maintenance (TPM) tools (Ahuja et al., 2008) methods and instruments are suggested. In Figures 11 and 12 are showed a variety of tools that can be traditionally used in a TPM implementation program, sorted for Equipment and maintenance personnel. The TPM tools employed for affecting equipment DB creation include for example the Ishikawa diagram or Fish-bone Analysis technique, that can be used to identify the root causes of the problems; Pareto and ABC analysis instead help to identify the top portion of causes that need to be addressed as they are more critically; to create standard documents on maintenance activity a maintenance standard operating procedure (SOP) should be used, it is a detailed document that describes all the steps maintenance workers need to follow while performing a maintenance routine task.

It explicitly defines all the steps with image supporting without any misunderstanding. In particular, the SOP is a standard for maintenance activities carried out directly by production operators reducing errors and waste since the sequency of tasks is simple and clear. The TPM tools employed for affecting maintenance personnel DB creation, instead, include for example One-point lessons and lessons learned to transfer knowledge in a quickly and effective way; the skill matrix is a tool that allows to better keep control, manage and organize the skills of the members of a work team by assigning a value that represents the current level of skills. Any difference between the expected value and the current value is called the gap. Keeping control employee skills, experience and performance, the skill matrix helps to monitor worker development and assign the right jobs to the right people. When gaps arise, training activities must be planned for each type of gap in order to fill them.

Related to Work order and report DB, no support techniques have been suggested since they include informative category that have to be included in for optimized their management. Equipment and maintenance personnel contain documents that need to be retrieved or created. Instead, WO and report are themselves documentsfor which the contents to be write in (categories of information) have been highlighted. The sequence (the priority order) of contents has been defined in the roadmap in order to initially obtain documents with the most immediate and easy to obtain information until to fill and complete them with more elaborate content. The defined improve-

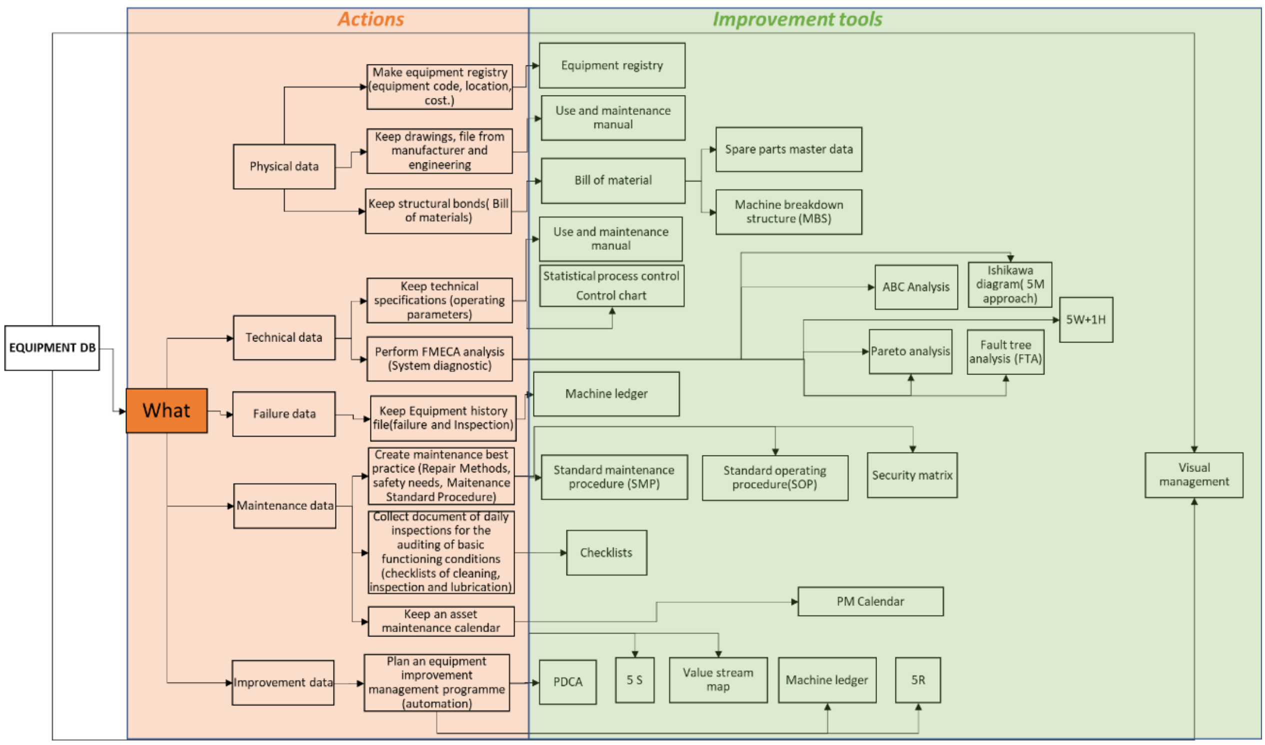


Fig. 11. Tools support Equipment DB creation Figure resolution is too low

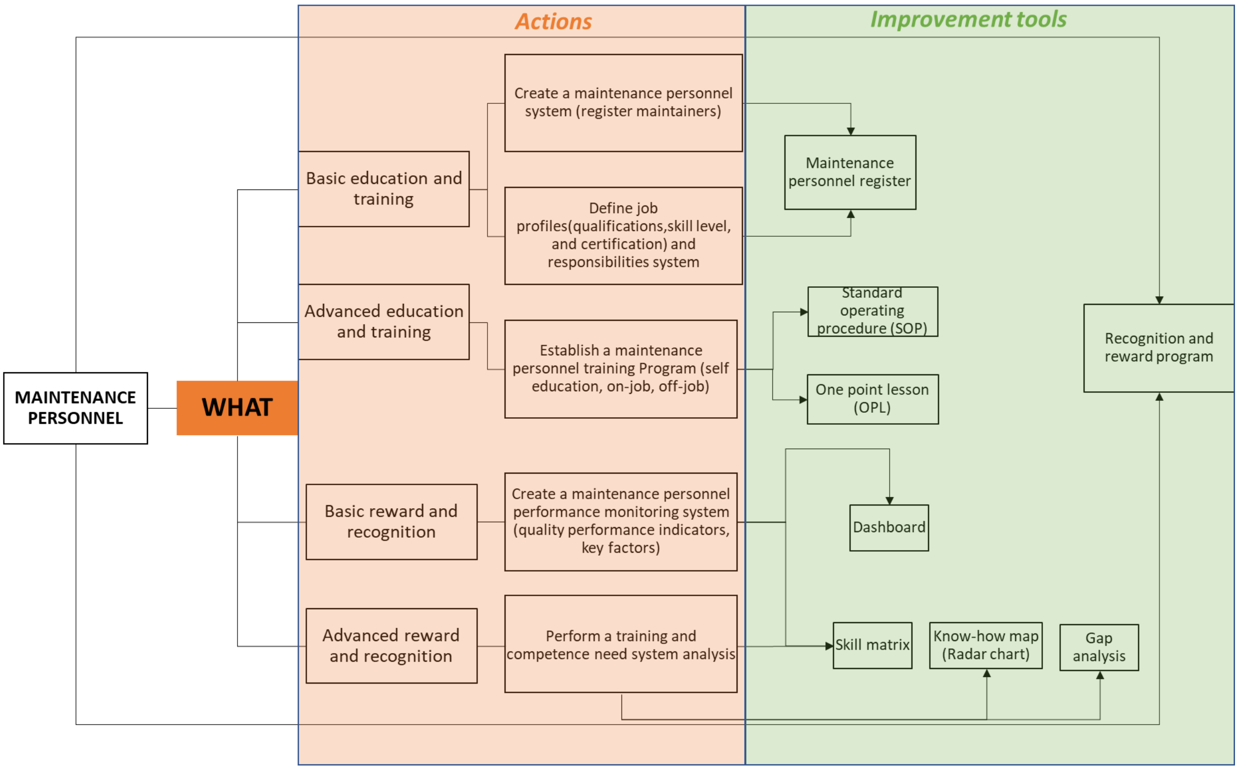


Fig. 12. Tools supported Maintenance Personnel DB creation

ment is based on how fill in these documents, what contents have to be included for companies do not use these documents and for those companies who already use these documents, what others contents and details can be included. Furthermore, IT solutions and/or technologies that can help to create a work order and reports in a simple and at the same time innovative way can be suggested. Solutions such as tablets, or mobile solutions with a hoc designed web applications, sensor systems applied to the machines, wearable devices on maintenance operators, can be used to fill work order document and report with data in real time.

Numerical example

In this section a numerical example is provided to show the functionality of the model. For compiling the survey it is assumed that the company is not aware of the relevance to monitor maintenance resources performance and the usefulness in the creation of reports; more over the company needs to adopt an information system for managing data and information as application standalone are still deployed. For the evaluation of the maturity levels, the weights assigned in the mathematical formulation (Step 2) were equally distributed to information files and evaluation criteria. The assessment results are illustrated and explained. Then the improvement programme is presented.

Assessment procedure results

The global ML result is 1,45/4. Below for each database the MLs and its meaning are reported.

Equipment database

The ML of Equipment DB is 1,86/4. The results (Fig. 13) show that some files regarding the physical and technical condition of the machines and some machine failure and maintenance data are available within the organization. Most equipment maintenance files are complete, standardized, well organized for access and retrieval. The information available is significant and correctly managed. The support used for the collection of most files is an autonomous system for maintenance management that is not integrated with other systems. It is a standalone application for the management of only maintenance interventions. Most machine maintenance files and documents are updated as needed. There is a specific employee who takes care of equipment maintenance files correct management.

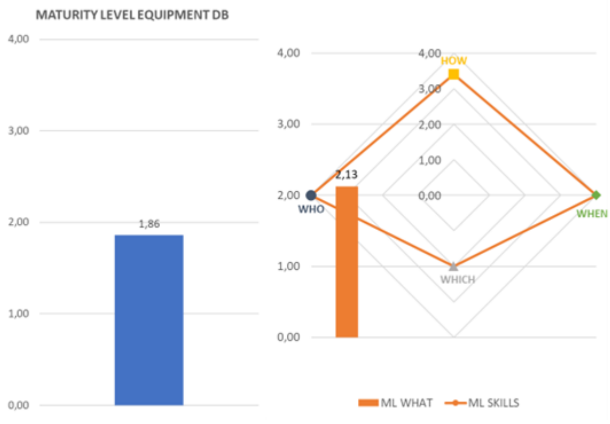


Fig. 13. Equipment DB ML

Maintenance Personnel Database

The ML of Maintenance Personnel DB is 1,40/4. The results (Fig. 14) show that not many documents and/or systems interested with the management of "maintenance personnel" are available within the organization. Most of maintenance personnel documents and/or most of systems managed are complete, standardized, well organized for access and retrieval. Also, for maintenance personnel files the support used for the collection of most of maintenance personnel documents is an autonomous system. Most of maintenance personnel documents and systems are updated and scheduled as needed. There is a specific employee who takes care of some/all maintenance personnel files correct management.

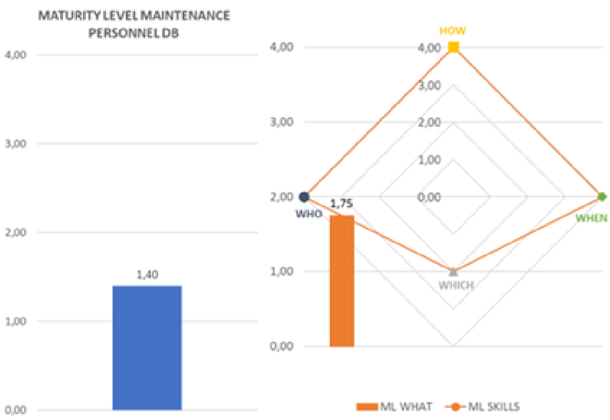


Fig. 14. Maintenance personnel DB ML

Work order database

The ML of Work Order DB is 2,13/4. The results (Fig. 15) show that the company has an efficient and effective maintenance work order management system. The company uses a work order request in which provides almost all useful information to the planner.

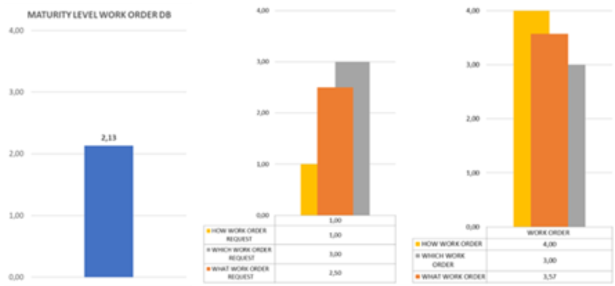


Fig. 15. Work order DB ML

Moreover, it uses a work order in which provides little all useful information to the maintenance technician to perform the maintenance intervention at the best. The support used for the collection of work orders and/or work request data is mainly an electronic software that can be interfaced with other company systems (for example Enterprise Asset Management (EAM) or CMMS or ERP). The software includes more features than an autonomous management system and this demonstrates a reduction in waste and inefficiencies towards an integration, albeit.

Report database

The ML of Report DB is 0,41/4.

The results (Figure 16) show that the company does not have an efficient and effective reporting management system. Infect, no equipment and maintenance personnel report are managed. Regards work order report, it records and monitors little data. This does not allow for the creation of meaningful statistics that can improve the work order management process.

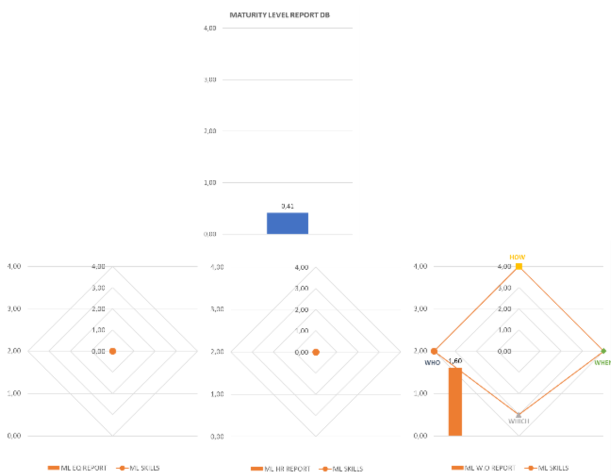


Fig. 16. Report DB ML

A standard has been established for the management of maintenance WO reports. The support used for the collection of work order report is an electronic software interfaceable with other systems. The maintenance reports are analysed as needed.

There is a specific employee who takes care of maintenance reports correct management.

Horizontal improvement

The ML resulting from the mean of "WHAT" criteria of all DB (value used to design the horizontal improvement) is in the range 1–2 (1,86/4), hence the improvement programme ensures to evaluate what is missing for completing the level 2 and what actions to reach the level 3. Therefore, in the Figure 17 the suggested improvement actions, matched with the effort and benefit required for each one (green and red points) are showed. The actions to do are to expand and enrich the Equipment DB and Maintenance personnel DB with the essential files and documents not yet managed. The maintenance Work order system is already well-defined and managed. The improvement actions are focused on the report database, which represents the weakness point. The actions ask to include the promptest data and information simpler to take over.

Vertical improvement

In Figure 18 vertical improvement actions are reported for each DBs. As described above, the model suggests all the possible next steps that can be pursued according to objectives and plans' company. No improvement actions are suggested for the skills that have already reached the highest standard, therefore they are marked with an X.

Conclusions

Information management is the most critical issue in the maintenance management activities of a manufacturing organisation. The research outcomes show that SMEs take an unsuccessful approach to maintenance information management because of their inherent characteristics and several barriers as the maturity of the maintenance department. Thus, there

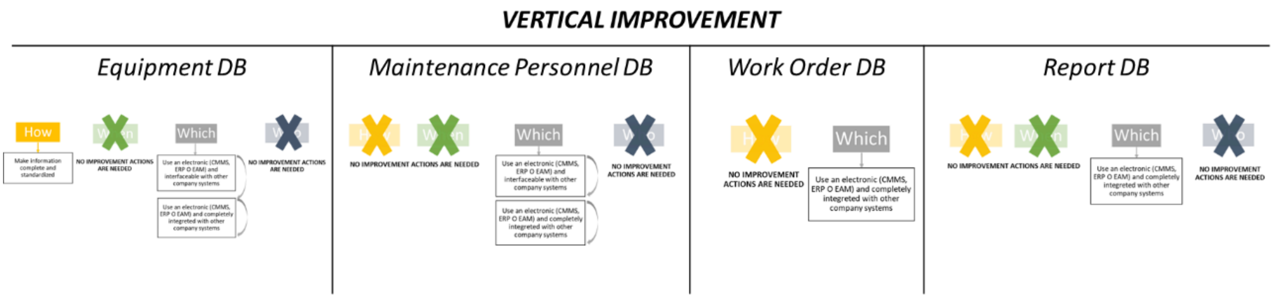


Fig. 17. Horizontal improvement

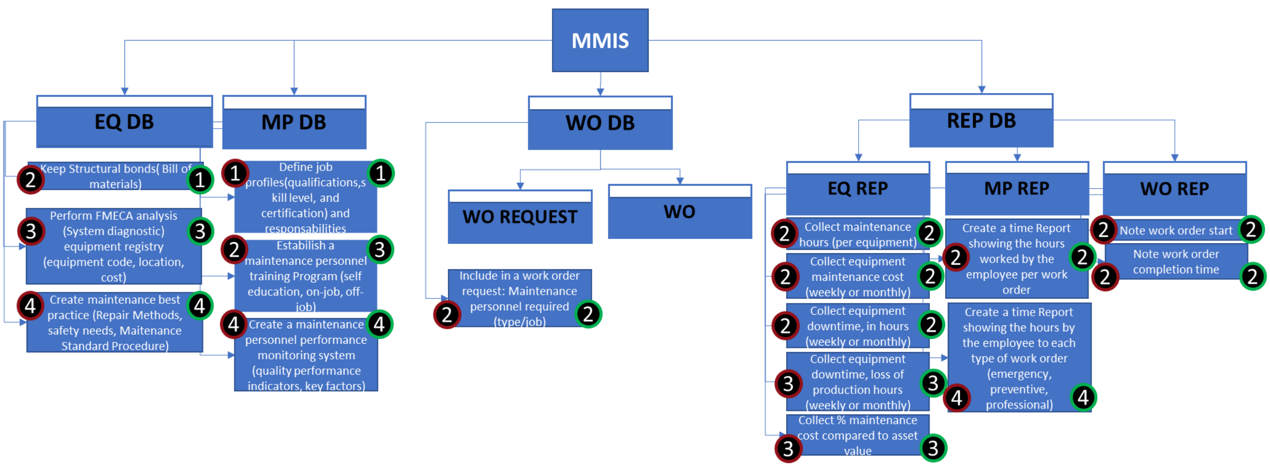


Fig. 18. Vertical improvement

is a general need for small manufacturing companies to be supported in the identification of their maturity level to enable them to improve their maintenance processes. Maturity models are useful in assessing maintenance management information practices and identifying a company's most significant weaknesses in its maintenance organisation so that it could identify and implement needed improvements. To the best of the authors knowledge, no maturity method or model provides a measure of the maturity in this field. Therefore, an innovative maturity and improvement model was proposed for assessing maintenance information management maturity and suggesting improvement actions, that could be adopted to achieve an effective and efficient maintenance management informative infrastructure. The main characteristics of the developed model are as follows.

First, as Polenghi et al. (2022) stated, a maintenance data/repositories map is required to support information and data management improvement. Hence, the model proposed identifies the kind of information and data needed to enhance maintenance management information practices. Moreover, the model provides a sort of maintenance data mapping to identify what maintenance data and information are relevant for the decision making process and where they should be stored (in which databases) to support small-medium companies to data standardization by defining a clear structure of maintenance data. Second, the model quantitatively and qualitatively measures the maturity of existing maintenance. information management practices focusing on shop floor level, through the assignment of a numerical level and a related explanation of the attained level. Therefore, the model can make maintenance and production stakeholders more aware of the maturity of their maintenance information infrastructure and their management practices. Finally, the model proposed, in addition to being an assessment tool, it provides and supports the knowledge on the behaviours and practices for achieving world-class results.

The improvement programme supports small companies in introducing a well-organised and managed maintenance information infrastructure, to adopt a maintenance system suitable to their maturity and organisation. Starting from the strengths and weaknesses points highlighted by the model, the actions and strategies companies to follow are identified. For example, the most crucial priorities for improvement may be identified as DBs with high importance for a company as well as low levels of maturity. A numerical example is provided to show the applicability of the model. The model has some limitations that are the natural evolution of the research:

- the model is general and not customised to specific industrial sectors; this would require additional evaluation criteria and, above all, different weights for the identified criteria. Furthermore, the current weights are equally distributed; an Analytic Hierarchy Process (AHP) approach, based on expert opinions, will be used to set the weights expressed in the mathematical formulation of the method.
- the application of the model will be performed as soon as the dataset of responses becomes consistent, this will allow statistical analysis in the specific sectors, the selection of the best-in-class companies, and the identification of the best practices frequently adopted. In conclusion, when talking about information and data, the connection with currently available technologies is advisable. The advent of new technologies of Industry 4.0 (such as the Internet of Things and cloud computing), has significantly increased/improved the possibility of collecting and storing data as well as their processing and analysis to recognize the potential hidden value in data collected. Due to implementation costs and IT competencies, many manufacturing companies (especially SMEs) still found it difficult. For this reason, the possible technologies to use as intelligent sources of data, as well as the identification of advanced techniques to extract useful information and/or knowledge from data will be identified for each DB.

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