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Ph.D. Course in Industrial Engineering
Curriculum in Mechanical Engineering - XXXV Cycle

A Maintenance Maturity Model for Assessing and Improving Information Management Practices for Small and Medium Enterprises.

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Pubblication List

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Tortora A.M.R., Franciosi C., Iannone R., Lambiase A., Miranda S.(2020). Towards effective maintenance of overhead conveyor systems: a case study in an automotive industry. Proceedings of the Summer School Francesco Turco.

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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 thesis 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.

The model was applied to a company's maintenance process. Improvement actions focusing on enhancing the informative infrastructure and improving information management practices have been designed based on the current maturity assessment. The findings and recommendations provide valuable insights for SMEs seeking to enhance their maintenance effectiveness and adopt appropriate IT solutions.

The proposed maturity and improvement model contribute to the field of research by addressing the specific needs of SMEs in assessing their maintenance management information practices.

The model supports SMEs to identify weaknesses, prioritize improvement actions, and enable continuous improvement. By leveraging the benefits of information systems, SMEs can enhance their maintenance processes, increase competitiveness, and achieve higher maturity levels in maintenance management.

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. 2017; 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 a 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 et al. (2009) is: ‘‘A maturity model consists of a sequence of maturity levels for a class of objects. It represents an anticipated, desired, 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, the 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 et al 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.2013). 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 PhD project 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 work is organized as follows. Chapter 1 provides a state-of-the-art shedding light on the literature results concerning the relationship between SMEs, IT and maintenance, and different aspects of MMISs in the industrial organization. Moreover, this section includes also a review of maintenance maturity models and methods for developing one, in order to highlight the difference between existing models and that proposed in this study. The section ends with the relevant research gaps and challenges. Chapter 2 shows the research proposal detailing all the steps followed for developing the Maintenance Maturity Model for Assessing Information Management Practices for Small and Medium Enterprises (M3AIN4SME). In the chapter 3 the applicability of the model is provided and finally, the notes for future developments and the main conclusions are presented respectively in the chapter IV e chapter V.

Hence, the project will try to achieve the research objectives through the following steps:

1. Literature analysis on different research topics: SMEs inherent characterises and their approach towards maintenance informative resources; the new trends of information technology in maintenance management systems; maturity models in the field of industrial maintenance. The main relevant features in these research field must be critically analysed in order to highlight the main literature outcome and research gaps and challenges.
2. Definition of structured and well-defined approach which includes all the steps that have to be developed to reach the objective. In particular, a maturity model is developed to assess the maturity level of small and medium enterprise related to maintenance management information practices.
3. Definition of a strategic roadmap that, starting from the measure of the current maturity level, provides actions for improving maintenance management information practices. The aim is to support small companies in introducing an appropriate maintenance management information infrastructure that reflect their current maturity level.

I Chapter: Literature review

Peer-reviewed papers were identified and examined. The search was conducted using the scientific database Scopus, covering the major journal publisher (e.g., Elsevier, Taylor and Francis, Wiley, Emerald) and conferences in the engineering and social science field, to review the studies developed in the literature.

I.1 IT and Maintenance Management in SMEs context

In today's industries and organizations, the management of information is an important and necessary activity (Hicks et al., 2010). The information management aims to support all business functions improving operating efficiency and organizational performance. For these reasons, information management was accepted by many organizations as an essential aspect that needs to be structured and better exploited. Moreover, recent technological advancement and the rapid growth of IT and computer networks are changing the way of companies handle information. A growing stream of research since 1980 has examined the concept of IT as a powerful competitive factor for organizations (Barney, 1999). Studies on the role of IT in competitiveness have been primarily focused on large organizations (Beheshti, 2004). Few works tried to investigate the role of IT in SMEs, especially the role of IT in the maintenance management of SMEs context. SMEs rarely view maintenance as a strategic issue, that will translate to a significant contribution to the company profit margins (Baglee et al., 2010). Nevertheless, the growing importance of the maintenance process within enterprises, as well as the great amount of information to manage, has arisen the need to introduce systems able to better manage the maintenance information flow. Furthermore, the literature outlined that SMEs generally have a poor approach to IT management, and consequently, fail in this field due to different factors. 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 formalization. At the information systems level, other relevant features identified in a literature review by Zach (2014) were pointed out: SMEs often lack the managerial expertise to plan, organize and direct the use of information resources, many SMEs hold insufficient in-house expertise for successful information system adoption. The information system is still perceived in its first stage of evolution, mainly used for support accounting function. Moreover, SMEs are reluctant to invest in IT supporting the industrial process, more especially in the IT supporting maintenance process.

Small organizations seldom have a defined IT budget or an explicit IT plan or strategy (Sadowski et al., 2002; Barry and Milner, 2002). Investments in technology are often driven by the owner, rather than by any formal cost-benefit or strategic analysis. These reasons could cause a low success rate of MMISs supporting the maintenance process. Most SMEs rely on outdated technology, labour-intensive and traditional management practices. This in many cases led to a lack of information and inadequate in-house expertise (Hashim and Wafa, 2002). Most SMEs have simple systems, and procedures, which allow flexibility, immediate feedback, a short decision-making chain, better understanding, and quick response to customer needs than larger organizations. Despite these supporting features, SMEs are under great pressure to sustain their competitiveness in domestic as well as global markets (Singh et a., 2008).

I.2 Systematic review on Maintenance Management Information Systems

To investigate the available literature on Maintenance Management Information Systems field, a systematic and structured approach was used. In the following sub-sections, first the method was described and then, quantitative, and qualitative results, were presented.

I.2.1 Method

The research method consists of a structured search aims to systematically analyse the scientific literature (Figure 1).

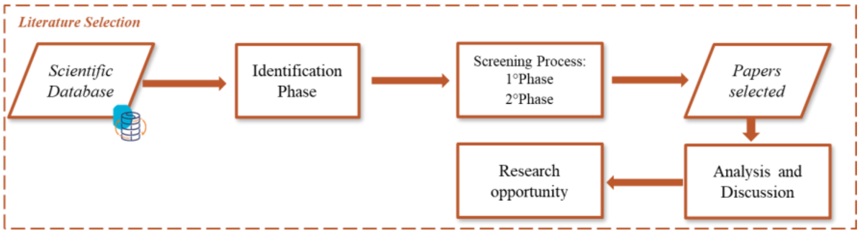


Figure 1: Research method

Peer-reviewed papers on the MMIS were identified and examined. The search was conducted using the scientific database Scopus, the largest scientific multidisciplinary database of peer-reviewed literature, covering the major journal publisher (e.g. Elsevier, Taylor and Francis, Wiley, Emerald) and conferences in the engineering and social science field.

A structured search was conducted using a set of keywords and a search string (Table 1). Groups A, B, and C list keywords related to maintenance management, information systems and production systems, respectively, representing the main keywords. The final keywords list used to search consists of all possible combinations of keywords from Groups A, B, and C using the Boolean "AND" operator to link each group (e.g. Maintenance management AND Informat* systems AND Industr*), with the "OR" operator used within each group. The keyword marked with an asterisk was searched through the truncation function, which allows searching from a significant root for all the variants for that term.

A	B	C
Maintenance management	Informat* systems	Industr*
	Informat* technology	Manufacturing
	Computerized maintenance management systems	Production

Table 1: Groups of keywords

The search took place in March 2020. Articles that had the searched keywords in its title or abstract and were published in the last 20 years, between 2000 and 2020, were screened. Moreover, only articles in English and published in peer-reviewed journals, conferences or books were considered.

In the identification phase, all papers were uploaded into a database manager (i.e., Mendeley). The screening process was divided into two stages. The first stage included the reading of all title, abstract, keywords of the identified papers with the aim of excluding the papers which are clearly out of research purpose.

In the second screening stage, instead, after the reading of the full text of the papers, they were classified as included or excluded according to the specific exclusion criteria (EX) described below:

- EX-1: Papers did not address any concept of interest (out of topic);
- EX-2: Text not available

The selected articles were analysed respect to the following features: publishing type; year of publication; paper contribution and adopted research method. Then, the selected papers analysed and reviewed in order to highlight the research opportunities.

I.2.2 Quantitative results

Figure 2 reports the results of the review process. The total number of papers resulted from the database search was 322. After the first screening phase, 65 papers were identified as relevant. Definitive assessment-based 1st and 2nd, exclusion criteria were performed, and 24 papers were selected in the second screening phase.

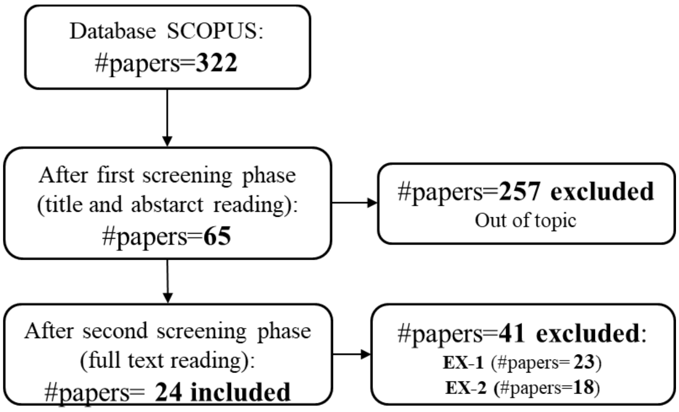


Figure 2: Review process

33% of the selected papers are published in journals and 67% in conference proceedings. The distribution of the selected papers showed a constant trend over the years (Figure 3), highlighting a constant research interest.

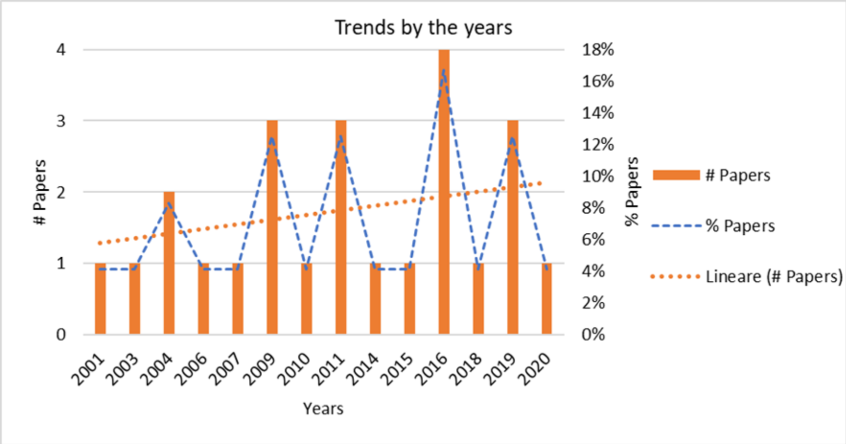


Figure 3: Publication trend by year

Contribution	#paper
C1. Framework	3
C2. Methodology/ model/method	6
C3. Other type of contribution	6
C4. State of art	3
C5. Tool	6
Total	24

Research Method	#paper
R1. Case Study	11
R2. Experimental Research	5
R3. Literature Review/ Theoretical research	4
R4. Other type of research method	4
Total	24

Table 2: Types of contribution and research method.

Concerning the type of contribution, 6 papers (25%) developed methodologies, methods or models; other 6 papers applied one or more existing methodologies or conduct empirical research to investigate the reasons behind the low success rate of MMIS other or presents the condition to implement these systems; 6 papers (25%) proposed a tool; 3 papers developed a qualitative or a quantitative framework (12,7%) and 3 papers proposed a state-of-the-art (12,5%). On another hand, the methods used to carry out the research were: 46% Case study; 21% Experimental Research or simulation; 16% Literature Review or Theoretical research; 17% surveys or other types of research methods (Table 2).

I.2.3 Qualitative results

The maintenance management information system is constituted by the data and information (such as an equipment tree, or a meter reading) input to or output from the maintenance activities, by the managerial practices (codified as norms and procedures) used for maintenance management, and by the tools and technologies (such as hardware, operating systems, mobile devices, etc.) used to collect, store, compute and distribute the above-mentioned information and documents (UNI 10584/97).

The maintenance management information system can be implemented manually by paper-based documents, as well as by unstructured information organized in general purpose software (such as a spreadsheet). Otherwise, the maintenance management information system can be implemented with specific application software, namely a Computerized Maintenance Management Systems (CMMS) (Wireman, 1994). A CMMS is an integrated set of computer programs and data files designed to provide its user with a cost-effective means of managing the massive amount of maintenance data in a standardized way (Cato and Mobley, 2002).

I.2.3.1 Trends of Information technology

Information technology has been applied in maintenance management for about 40 years. Maintenance management systems have been improved by information technology to facilitate the accessibility, storing, and retrieving information. The trends of information technologies in maintenance management can be divided in 3 phases: Introduction, coordination and integration (Kans, 2009) (Figure 4).

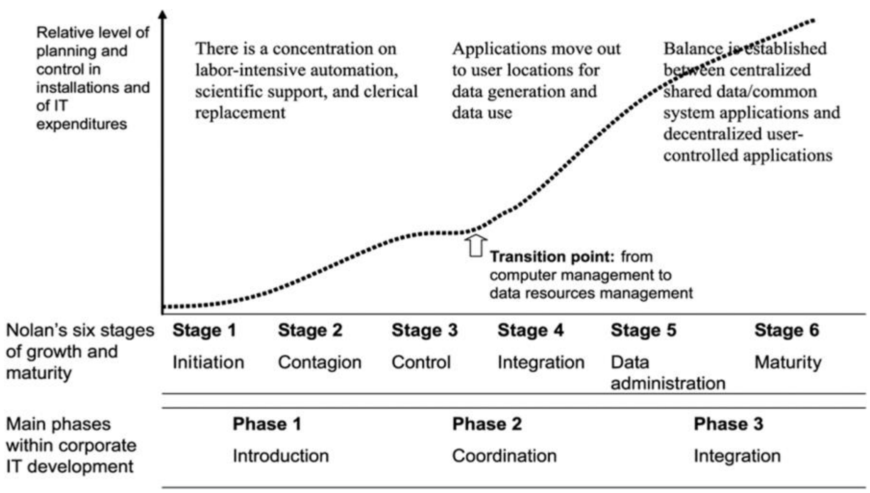


Figure 4: Advancement stages of information technology (Kans, 2009).

Introduction: According to Wilder and Cannon (1993) the first stage of computerized maintenance management systems can be seen from 1970s due to the full recognition of maintenance as an important business function, initially used for limited tasks to support scheduling for preventive activities. By minicomputers advent as new technology in 1980s, the number of computerized maintenance management systems increased. New functions were developed to manage the inventory, budget, stock control, and even expert systems to decrease the downtime and diagnosis of fault based on maintenance data (Shareghi et al., 2011).

Coordination: In this stage, cooperation and exchange of information were significantly employed in organizations to improve business processes. Data repository, relational model databases, central databases in this stage were used to facilitate interchange of data in organizations (Dahlbom, 1997; Kelly et al., 1997).

Integration: In late 1990s and after evolution of material resource planning (MRP), integrated solutions such as enterprise resource planning (ERP) received a lot of attention in companies (Leon, 2008). At this stage, information systems were applied to integrate the whole parts of organizations together in order to provide a better collaboration and cost-effective systems in maintenance management. Integration phase in information technology have been significantly improved over recent years and is growing too fast.

Common features of MMIS

The use of MMIS has attracted so much attention owning to the fact that enormous amount of maintenance data needs to be analysed fast and efficiently in order that decisions are reached. The literature analysed can be divided in different cluster related to the specific issues of MMIS addressed.

Some studies focused on describing and/or on improving the common features of a MMIS since it can be considered as a set of functions that process data to develop indicators supporting maintenance activities.

According to Cato and Mobley (2001), Donoghue and Prendergast (2004) and Zhang, Li, and Huo (2006), usually the MMIS have assigned a set of functions and applications, including:

1. Assets Management: that consists of recording all assets (or equipment) and a historical record of

repairs and equipment parts list;

2. Work Orders Management: that allows setting and releasing of work orders to the maintenance technicians.

3. Preventive Maintenance Management: that supports the planning, scheduling and control of activities.

4. Inventory control: giving access to spare parts availability.

5. Report Management: MMIS processes large amounts of data and produces performance indicators (KPI).

These functions allow a better efficiency and effectiveness for the maintenance function by taking advantage of Information and Communication Technologies (ICT) (Carnero et al., 2006).

Moreover, in literature the primary uses of MMIS appear to be as a storehouse of maintenance information and data. Nevertheless, companies consume a significant amount of management and supervisory time compiling, interpreting, and analysing the data captured within a MMIS.

Based on this issues authors considered the most existing off-the-shelf software packages, especially CMMS and enterprise resource planning (ERP) systems, as systems greedy for data input that seldom provide any output in terms of decision support.

However, taking into account the currently available systems, it is possible to identify several areas that need improvement (Labib 2004, Rastegari 2016):

– Analysis of data on device health monitoring;
– Diagnosis of resource failures;
– Support for decision-making.

MMIS Implementation rate

Despite the huge benefits associated with MMIS as a support tool in maintenance management, success rate in its implementation has been adjudged rather poor. Several surveys showed the existence of various conditions and barriers to MMIS implementation (Wisniewski et al.2020; Fumagalli et al., 2009).

In a survey conducted among enterprises that do not have CMMS at the moment (Wisniewski et. Al, 2020), respondents were asked about the reasons for not implementing a computerized maintenance management system.

The most frequently chosen reasons are:

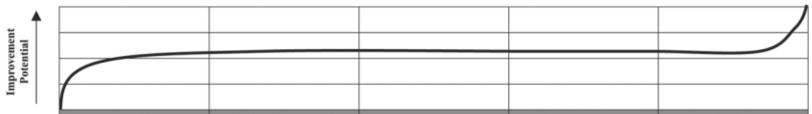
– **maturity level of the Maintenance Department (66.1%),**
– high implementation costs (59.6%),
– the specificity of technical infrastructure owned (49.5%),
– ignorance of the system (48.6%),
– unskilled workforce (47.7%),
– too few employees (44.0%),
– failure to determine the length of the computerized maintenance management system implementation process (43.1%),
– difficulties in changing organizational culture (41.3%),
– too much uncertainty (41.3%).

Other, less common reasons are:

– obsolete planning and management methods (28.4%),
– resistance of trade unions (22.9%).

Summarizing the research results conducted in this study, it should be emphasized that one of the most frequently indicated reasons for the lack of MMIS implementation was the maturity level of the Maintenance Department. Thus, if, on one hand, MMIS is declared as a suitable tool to enhance maintenance activities, on the other hand it finds low success, due to the readiness level of specific industrial contexts that require a simpler system respect to existents. The gap between systems proposed in literature and the needs of small realities causes difficult understand which solution are suitable for their specific industrial contexts.

Few studies tried to discuss and analyse the requirements and conditions for the implementation of MMIS. The maintenance concept has suffered many transformations over the years. In the figure 5, five stages (that reflect the culture of the maintenance function) can be identified.



	Stage 1. Uncertainty	Stage 2. Awakening	Stage 3. Enlightenment	Stage 4. Wisdom	Stage 5. Certainty
Management Understanding & Attitude	No comprehension of maintenance as a management tool	Recognition that maintenance management may be of value	Learn more about maintenance management; becomes supportive	Participative and recognises its role	Maintenance is an essential part of the company system
Problem Handling	Problems are fought as they occur	Still reactive but with spare parts available when failures occur	Problems solved by input from maintenance, operations, engineering and quality control	Predictive using monitoring techniques	Problems are prevented increasing availability and therefore productivity
Company maintenance posture	"We don't know why we have problems in maintenance"	"Is it necessary to have problems with maintenance?"	"We identify and solve problems"	"Quality products cannot be made with poorly maintained equipment, therefore quality maintenance is a routine"	"We don't expect breakdowns, on the contrary, we are surprised when they occur"
CMMS	No CMMS used	System contains asset and materials management modules	A condition monitoring event module is integrated into the system	Capable to generate PM schedules. A DSS is used to support the decision making process	Fully automated, from the detection of failure to the generating of work orders based on meaningful and reliable information

Performance Measures

Source: Adapted from Antil (1991)

Figure 5: Maintenance Organisational Maturity Grid

Maintenance evolves from a predominantly reactive state in the first stages to a preventive and eventually into a predictive state in the last stages.

This evolution requires a change in the awareness from management about the role playing by maintenance in the organization. According to the degree of maturity reached by maintenance function, the organization is ready to adopt a MMIS with different characteristics suitable for their specific needs.

The last maturity stage corresponds to the recognition of maintenance function as a key tool not only for saving money by reducing the frequency of failures but also for improving the availability of the plant (as equipment reliability increases) and the quality of the products being manufactured (Fernandez et al., 2013).

Furthermore, this trend highlights the importance of selecting an appropriate MMIS that can suit maintenance needs. This issue seems to be crucial for smaller industrial context which are still unaware about the key role played by maintenance function.

SMEs should be ready to adopt a MMIS. This requires a change in recognition of maintenance function as a powerful competitive factor for overall performance improvement. Furthermore, this trend highlights the importance of introducing an appropriate MMIS that reflects the readiness level of the specific industrial context. This satisfaction is dictated not by the features of the system, but by the culture of the maintenance department. One of the main issues in the development of MMIS is to understand the maturity stage of the maintenance function related to its information infrastructure.

I.3 Maintenance maturity models

The literature analysis demonstrated that the recognition of the current maturity state of the maintenance process in the organization is a mandatory step to determine the specific need of an industrial context and consequently a successful adoption of an MMIS; for this reason, an exploratory study on these systems was carried out.

The purpose of the Maintenance maturity models (MMM) analysis is to understand the state of the art on MMM and, above all, what the main aspects are for developing a maturity model for the maintenance information management domain.

I.3.1 Literature review: Objective, research questions and method

A systematic review of the literature was conducted. The search strategy is then reported in the following. First, the objective was set, i.e., identify all the tools, methods and models presented in literature for maintenance maturity assessment in manufacturing systems and determine if they also assess maintenance management information practices. Thus, the following research questions (RQs), to which the study aims to answer, were defined:

RQ1. What are the models/methods/tools provided in the literature that assess the maintenance maturity of manufacturing systems?

RQ2. In these models/methods/tools, are the maintenance management information practices also assessed?

The review was conducted in October 2021 in the Scopus database using the keywords “maintenance” and “maturity” in the title search field of the database. In the first screening step, the title and the abstract of each paper retrieved from the search were read; the paper was excluded if it was off-topic (e.g., if it was on software maintenance maturity models) or included if it was consistent with the objective and the RQs of this study. The included papers were then read fully in the second screening step to finalise the selection of papers for review. Finally, the references of the papers were checked to see if additional papers can be evaluated and included in the analysis according to the objective of study.

I.3.1.1 Literature review results

A total of 39 papers were initially selected from the database. After the full reading of the text, 8 articles were retained because they were fully coherent with the objective and the RQs of the study. The limited number of included papers was a result of the highly focused objective and RQs.

The main characteristics of the selected papers are reported in Table 3. It will be noticed that in the selected papers, the dimensions term is often interchangeable with other terms such as criteria, key process areas and classes. Therefore, we generalise with the term dimensions because it is the most frequently used in the papers. The column weakness point represents the lacks and gaps of the existing models compared to the scope of this project.

Table 3:Literature review results

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 computerised maintenance management support can be determined. It doesn't give a measure of maturity
Schuh, Lorenz, Winter & Gudergan (2010)	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 managment is only a measurement area and it focuses on the measure of the maturity of maintenance process.
Kans, Ehsanifard & Moniri (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	Adresses issues specific for maintenance management information technology. Focused on IT maturity level. It defines the criteria for selecting an MMIT application suitable for specific enterprise's needs. No improvement is provided
Oliveira, Lopes & Figueiredo (2012)	A maturity model that allows 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 competences (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, was provided. The dimension CMMS assumes the use of MMIS.No improvement is provided.
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, van Hattem, Djairam & Smit (2016)	Measuring and monitoring the integral corporate vision of a set of multidimensional domains needed for maintenance	(1) Organisation & processes; (2) policy & criteria; (3) information & systems; (4) data quality; and (5) performance & portfolio	Focused on Professionalising maintennace. It is specific for a maintenace strategy

Authors (year)	Objective	Dimensions considered in the maturity model	Weakness points
	management professionalisation		
Nemeth, Ansari & Sihn (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 & Lopes (2019)	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 measuremnt class. It analyses the use the implemented CMMS.

Not much published literature is reported on the development and application of maturity models in asset maintenance (Olivera et al., 2019, Chemweno et al., 2015, Macchi et al., 2013). Many Capability Maturity Models (CMM), developed for asset maintenance, are reported in unpublished 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.

However, the literature results showed that the IT aspects, was addressed by some authors only in terms of the deployment of IT in maintenance. For example, the model that Kans et al. (2012) proposed allow to evaluate Maintenance management information technology (MMIT) maturity of an enterprise for selecting MMIT application, the criteria used are not focused on the informative infrastructure. However, almost all models did not give an idea of the practices that could be implemented to increase the maturity level. In particular all models reviewed allow assessing the maturity level but do not indicate or assist in the identification and definition of actions/activities that must be pursued to reach the highest level. Moreover, the approach they presented was difficult to implement in manufacturing organisations, as it required companies to already have a MMIS, as well as a clear and structured maintenance organization. Furthermore, applying these models to different organizations may not be straightforward due to differences in several aspects that include organizational structure, or business context (Chemweno et al., 2015).

Considering the analysed literature, no maturity method or model provided an assessment and improvement of maintenance management information practices.

I.3.2 The main aspects for developing a maturity model.

Maturity models have proliferated across a multitude of domains since the concept of measuring maturity was introduced with the Capability Maturity Model (CMM) from the Software Engineering Institute (SEI) – Carnegie Mellon. Maturity models can be seen as simple method which allow organizations to effectively measure the quality of their processes.

When talking about maturity models, most people first think of Capability Maturity Model Integration (CMMI). It is a framework of the best practices to software development, systems engineering, and

product development.

During the last two decades the application fields of maturity models have widened.

In the study of Wendler who propose the first systematic summary of maturity model research, two points of view are underlined when developing a maturity model:

1) Life cycle perspective identifies models having a well-defined ‘‘final’’ stage of maturity, which will be reached while evolving over time. Therefore, they may serve as tools for management supporting the development of the examined objects. The idea is that an organization evolves over time and therefore automatically has to pass all stages due to improvements and learning effects. The user may decide if it is desirable to proceed to the next stage

2) Potential performance perspective is principally used with the same purpose of the previously one, but there is only a fine difference. These models show a development path, too, but the stages focus on the potential improvements which occur by moving along.

Maturity models, regardless the perspective view, describe and determine the state of perfection or completeness (maturity) of certain capabilities. The application of this concept is not limited to any particular domain. Therefore, maturity models define simplified maturity stages or levels which measure the completeness of the analysed objects via different sets of (multi-dimensional) criteria.

This explanation is well reflected in the definition by Becker et al.: ‘‘A maturity model consists of a sequence of maturity levels for a class of objects. It represents an anticipated, desired, or typical evolution path of these objects shaped as discrete stages. Typically, these objects are organizations or processes.’’ Summarizing, two relevant issues have to be considered during maturity models development: the definition of maturity levels along which the examined object evolves and the criteria for measurement.

However, maturity models allow an organization to have its methods and processes evaluated by good management practices and with a set of external parameters. Typically, a maturity model consists of the following components (Fraser, 2002): 1) the number of maturity levels (ML), 2) descriptor for each level, (e.g. uncertainty, certainty), 3) description of characteristics expected of an organization at each level, 4) the number of dimensions, 5) description of elements/activities at each dimension, 6) description of each activity as performed at each maturity level.

I.3.3 Methods for maturity assessment development

Whilst maturity models are high in number and broad in application, there is little documentation on how to develop a maturity model that is theoretically sound, rigorously tested, and widely accepted. In this section, the studies that proposed a method to develop a generic maturity model were analysed to apply the best practices of this field for the development of a model for the evaluation of information practices on maintenance management in SMEs context and provide a model more robust and rigorous from a methodological point of view. The models available in the literature (Seguel, Eshuis, and Grefen 2010; Becker, Knackstedt, and Pöppelbuß 2009; Salviano et al. 2009; Maier, Moultrie, and Clarkson 2012; García-Mireles, Moraga, and García 2012; De Bruin, T., Rosemann, M., Freeze, R., & Kaulkarni 2005) providing a generic method, are reported in Table 4.

Table 4: Studies available in the literature

Title	Year	Scope	Phases of the model
Understanding the Main Phases of Developing a Maturity Assessment Model (de Bruin et al. 2005)	2005	This paper proposes a methodology and outlines the main phases of generic model development. The paper applies the model proposed to two advanced maturity models in the domains of Business Process Management and Knowledge Management.	1) Scope 2) Design 3) Populate 4) Test 5) Deploy 6) Maintain
Developing Maturity Models for IT Management – A Procedure Model and its Application (Becker, Knackstedt, and Pöppelbuß 2009)	2009	This paper proposes a procedure model for the development of maturity models. A case study shows the applicability of the model. The results of this paper are used as a manual for methodically well-founded designs and evaluations of maturity models.	1) Problem definition 2) Comparison of existing maturity models 3) Determination of development strategy 4) Iterative maturity model development 5) Conception of transfer and evaluation

Title	Year	Scope	Phases of the model
A method framework for engineering process capability models (Salviano et al. 2009)	2009	This article introduces a Method Framework for Engineering Process Capability Models as an element of a methodology on a Process Capability Profile to drive Process Improvement	1) Initial decisions 2) Source analysis 3) Strategy for development 4) Model design 5) Draft model development 6) Draft model validation 7) Model consolidation
Assessing Organizational Capabilities: Reviewing and Guiding the Development of Maturity Grids (Maier, Moultrie, and Clarkson 2012)	2009	This paper presents both a reference point and guidance for developing maturity grids.	1) Planning 2) Developing 3) Evaluation 4) Maintenance
The Design of Focus Area Maturity Models (Seguel, Eshuis, and Grefen 2010)	2010	This paper presents a generic method to develop a particular kind of maturity model, the focus area maturity model. The focus area maturity model is particularly well-suited to support incremental development of functional domains as it departs from the concept of having a limited fixed number of generic maturity levels as used in CMM. Instead, it defines maturity levels, called capabilities, per focus area within the functional domain	1) Scoping 2) Design model 3) Instrument development 4) Implementation & exploitation
Development of Maturity Models: A Systematic Literature Review (García-Mireles, Moraga, and García 2012)	2012	In this paper, a systematic literature review was conducted to discover and analyse the existing methods and recommended practices for developing maturity models. The SLR results have served to propose a method for developing maturity models that are focused on product quality characteristics.	1) Stating the problem 2) Establishing the goals 3) Developing a plan to perform a new maturity model.

The general activities that these methods consider, at an early stage, are problem identification, identification of participants, as well as scoping and planning of goals. At a second stage, the activities establish the design strategy and architecture of the model. That is, they define the levels of capability, dimensions (some authors name these processes or focus areas), and establish best practices expected for each dimension according to their capability level. At the third stage, an instrument to measure the maturity of the object of interest is built, and the procedures for its deployment and management are defined. In the last stage of development, the maturity model and assessment tool are validated. If the model is accepted, it enters a maintenance stage, where changes are managed and, if necessary, the model or instrument is updated.

I.4 Literature discussion: gaps and challenges

The literature analysis showed significant relationships between the four mains aspects investigated: SMEs characteristics, information technology, maintenance management practices, and maturity models (Figure 6).

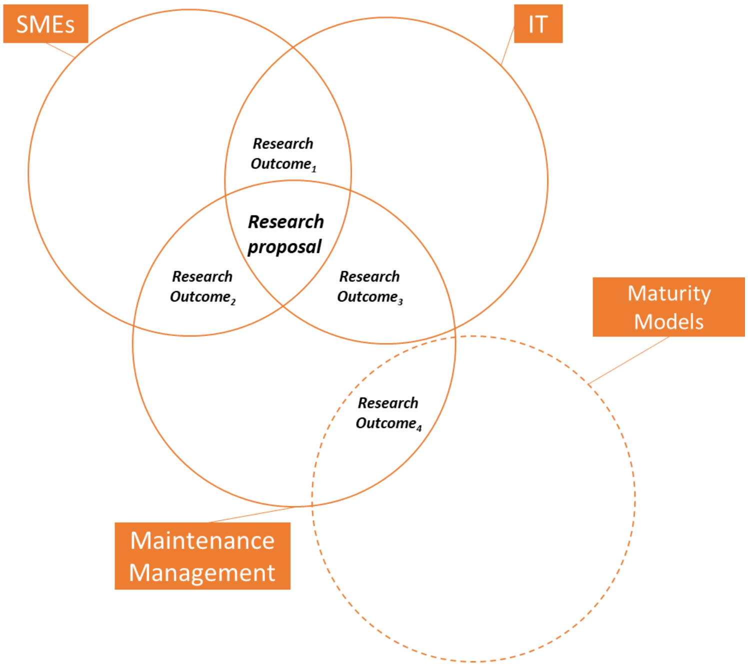


Figure 6: Venn Diagram of research outcomes

SMEs' characteristics and limited resources influence the implementation of MMISs. It is necessary to understand the maintenance department maturity level of these companies and to adapt the features of the systems to their

specific needs. Many MMISs fail since organizations are not ready and because the functions of these systems do not meet their needs.

To date, systems suitable for SMEs maturity are not readily available in the literature or the market. To better justify the research proposal described in the next section, the problems between these different issues were clarified.

SMEs & IT

The Research outcomes on the relationship between SMEs and IT highlighted that SMEs' characteristics put at risk the success of any IT project, in particular, due to the lack of managerial, economical, and technological competencies. In particular, these aspects were pointed out (Khadrouf et al., 2020; Baglee et al., 2010; Hicks et al., 2010; Singh et al., 2008; Beheshti, 2004):

1) SMEs rely on outdated technology.
2) SMEs have a poor approach to IT management.
3) SMEs have limited financial and human resources.
4) SMEs lack managerial expertise to plan, organize and direct the use of information technology.
5) SMEs are reluctant to make investments in IT.

The issues resulted from this correlation, reveal that SMEs should first have a standardized procedure to systematize information flow and then introduce IT in their processes.

SMEs & Maintenance Management

The Research outcomes on the relationship between SMEs and Maintenance Management highlighted that SMEs, due to their barriers in terms of expertise and resources, have difficultly adopting effective maintenance strategies because they are focused on operational aspects primarily geared towards day-to-day survival (Fumagalli et al., 2009; Kans et al., 2010; Wienker et al., 2016; Hipkin, I., 2001; Wisniewski et al., 2019).

1) SMEs adopt traditional management practices.
2) SMEs require simple systems and procedures.
3) SMEs have information resources gathered in a fragmented way.
4) SMEs have a low degree of standardization and formalization about maintenance information flow.
5) The maturity level of the maintenance department is one of the most critical key points.
6) SMEs need tools to collect, analyze and improve maintenance information flow.

These aspects showed that the development and application of more effective maintenance management strategies based on the maturity level of the maintenance department could be a good solution to improve the maintenance process and more. Moreover, an efficient maintenance management system must not only report on the performance of the maintenance department, but it must also provide an opportunity for in-depth analysis to drive improvement actions, without investing too much time. All of this requires consistent, up-to-date, and well-managed databases. In practice, very few of the existing maintenance management strategies meet these needs.

Maintenance Management & IT

In literature, the limits of existing systems for a specific type of organization were highlighted (Labib 2004; Pintelon et al., 1990; Van Horenbeek et al., 2011; Barberá et al., 2012; Tsang 2002; Lopes et al., 2016).

1) Most systems are geared to administrative and accounting control and are not management tools able to support decision-making.

2) Existing systems are often the only storehouse of information and data, lacked maintenance improvement suggestions.

3) These systems are not adequate to SMEs' requirements and maintenance department maturity.

4) The success rate in its implementation has been considered rather low due to the large investment, high resources, and enterprise organizational capacity required.

5) Currently, there is a large gap between academic models and practical applications.

6) Industrial companies have a huge difficulty adapting these systems to their specific business context.

7) Existing systems are difficult to integrate with all other business processes to obtain an enterprise completely integrated.

The development and implementation of these systems have been undertaken by many of the larger global manufacturing organizations supported by the latest hardware technologies and software architectures ensuring many benefits. These approaches require high investment and competencies. Many SMEs cannot implement and manage these solutions due to their limited resources.

Maturity Models & Maintenance Management

The studied MMMs propose the use of numerous subjective assessment criteria, and as such may present applicability challenges when used for maintenance maturity measurement (Chemweno 2013; Olivera 2019; Wendler, 2012). However, MMM discussed in the previous paragraph ignore several important aspects that include:

1) No clear method/framework for deriving the assessment items.

2) Absence of a clear linkage between the maintenance process (especially executive) and assessment items.

3) No improvement program that supports companies to reach a higher maturity level is included.

Moreover, in the models proposed, the assessment areas defined are quite generic (high level), formulated from the literature as maintenance management process key measures, and they do not vary in importance depending on the business context, this potentially could lead to ambiguous maturity results. Furthermore, SMEs seem not to have a structured maintenance organization, therefore the measurement classes identified could be incoherent with their specific business context.

II Chapter: Research Proposal: The M^{3}AIN4SME model

The discussion of literature outcomes pointed out several issues concerning the existing MMIS and the barriers meet by SMEs in their implementation. In particular, SMEs lack standardized procedures to systematize information flow, they need an up-to-date and well-managed database, they cannot manage solutions developed until now, the maturity of the maintenance department is a critical point.

The research proposal aims at addressing these deficiencies, offering a solution to these issues. The proposed approach (Figure 7), composed by 3 steps, aims to measure and improve the effectiveness of the maintenance information management practices in SMEs.

The step 1 consists of a proper allocation of information contents to maintenance process. The output is the identification of the maintenance information infrastructure including the most significant information databases, essential for the right maintenance process execution. The assessment of the maturity level (ML) of maintenance management information practices is performed through a well-organized and standardized approach (step 2). The measurement of ML allows identifying the areas where improvements can be made. To achieve an ML level highest, improvement programme (step 3) is defined, and the company is driven by a strategic roadmap based on the selection of maintenance management best practices.

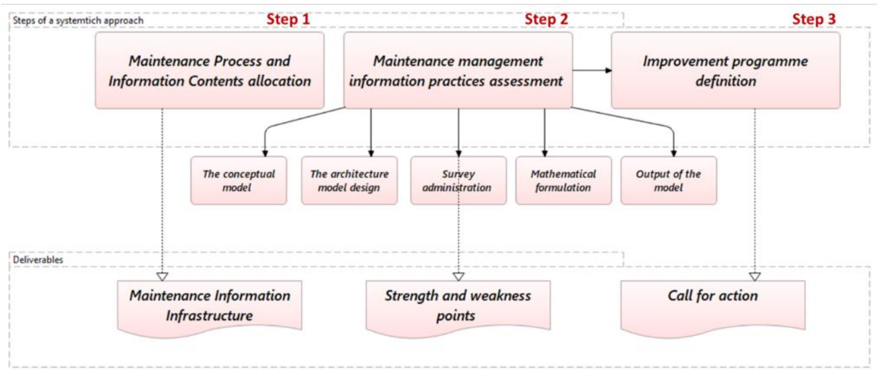


Figure 7: Research Proposal

II.1 Step1: Information contents allocation to a generic maintenance execution process

II.1.1 A language for enterprise modelling: an overview on Archimate

To create an overview of the structure of an organisation, its business processes, their application support, and the technical infrastructure, the different aspects and domains, and their relations need to be expressed. According to ISO/IEC/IEEE FDIS 42010:2011 standard (ISO/IEC/IEEE 2011) the architecture is described as a set of fundamental concepts or properties of a system in its environment, embodied in its elements, relationships, and in the principles of its design and evolution. An architecture provides an integrated view of the system to be designed or studied.

A language for modelling enterprise architectures should focus on inter-domain relations. A language should allow to model:

– Any global structure within each domain, showing the main elements and their dependencies, in a way that is easy to understand for non-experts of the domain.

– The relevant relations between the domains.

Another important property of an enterprise modelling language—and of any modelling language—is a formal foundation, which ensures that models can be interpreted in an unambiguous way and that they are amenable to automated analysis.

The role that the enterprise architecture modelling language plays is summarised in the figure 8. It provides a means for integration, by allowing the creation of models that show high-level structures within domains and the relations between domains.

In the enterprise modelling language, the service concept plays a central role. A service is defined as a unit of functionality that some entity (e.g., a system, organisation, or department) makes available to its environment, and which has some value for certain entities in the environment (typically the 'service users'). Service orientation may lead to a layered view of enterprise architecture models.

Service layers with services made available to higher layers are interleaved with implementation layers that realise the services. Within a layer, there may also be internal services, e.g., services of supporting applications that are used by the end-user applications.

The language uses service-orientation to distinguish and relate three different layers:

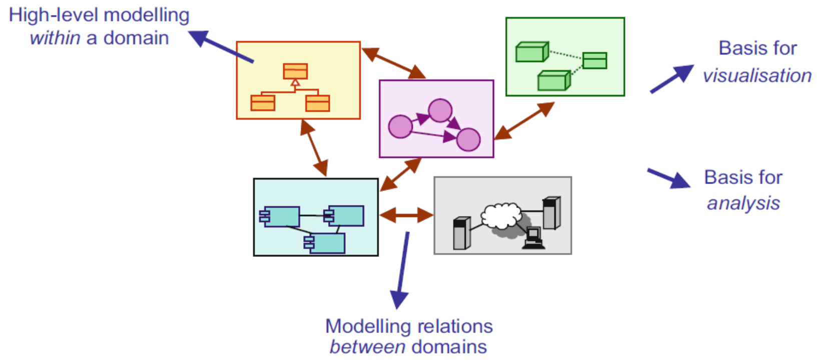


Figure 8: Enterprise architecture modelling language

1. The business layer offers products and services to external customers, which are realised in the organisation by business processes (performed by business actors or roles).

2. The application layer supports the business layer with application services which are realised by (software) application components.

3. The technology layer offers infrastructural services (e.g., processing, storage, and communication services) needed to run applications, realised by computer and communication devices and system software.

The core concepts presenting in each layer of the language are depicted in Figure 9. Behavioural concepts are assigned to structural concepts, to show who or what displays the behaviour.

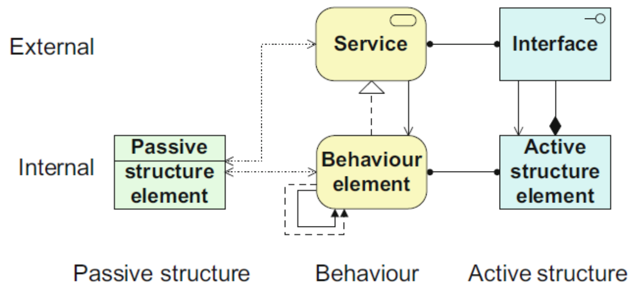
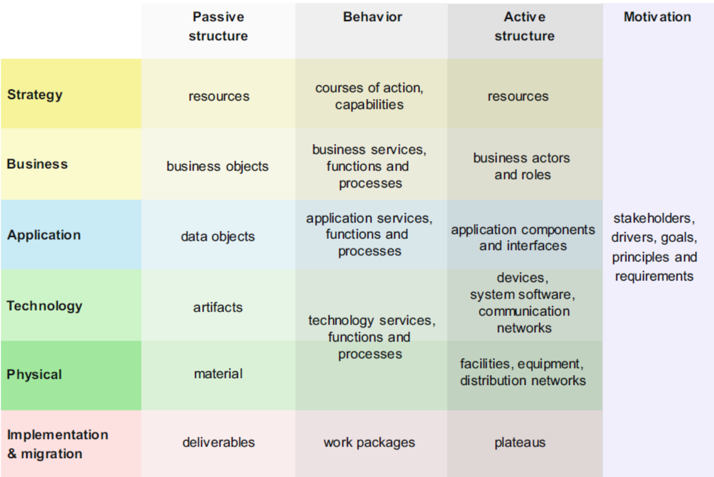


Figure 9: ArchiMate core concepts

In addition to active structural elements (the business actors, application components and devices that display actual behaviour, i.e. the ‘subjects’ of activity), also passive structural elements are used i.e. the objects on which behaviour is performed.

A distinction between an external view and an internal view of systems is made. When looking at the behavioural aspect, these views reflect the principles of service orientation as described previously. The service concept represents a unit of essential functionality that a system exposes to its environment. For the external users, only this external functionality, together with non-functional aspects such as the quality of service, costs, etc., are relevant. If required, these can be specified in a contract or service level agreement. Services are accessible through interfaces, which constitute the external view of the structural aspect.

For the internal realisation of services and interfaces, there is a difference between behaviour that is performed by an individual structural element (e.g., actor, role component, etc.), and collective behaviour (interaction) that is performed by a collaboration of multiple structural elements. The core of the ArchiMate language consists of these concepts, specialised for the three layers identified. The structure of the language and the most important concepts are summarised in Figure 10.



	Passive structure	Behavior	Active structure	Motivation
Strategy	resources	courses of action, capabilities	resources	
Business	business objects	business services, functions and processes	business actors and roles	
Application	data objects	application services, functions and processes	application components and interfaces	stakeholders, drivers, goals, principles and requirements
Technology	artifacts	technology services, functions and processes	devices, system software, communication networks	
Physical	material		facilities, equipment, distribution networks	
Implementation & migration	deliverables	work packages	plateaus	

Figure 10: The full ArchiMate framework

Services point of view provide a way to show the alignment between the different modelling layers and it is applicable at several layers: business services made available to internal or external customers, application services made available to 'the business' or to other applications, and infrastructure technology services made available to applications.

This service orientation put strong focuses on the relations between the different domains and aspects of the enterprise.

II.1.2 Maintenance Process Architecture

The generic maintenance process has been investigated to identify all possible information contents. In many studies, a representation of a maintenance process was presented (Lutchman, 2006; Hwang et al., 2007; Barberá et al., 2012) and by the analysis of European Standard (PR NF EN 17007) all the information contents moving into the maintenance process were identified. Regardless of the type of maintenance request (professional, autonomous or emergency) and of the item to be maintained, a generic maintenance process can be divided into four subprocesses: planning and scheduling, performing, work closeout, monitoring and continuous improvement. To rightly perform activities included in each subprocess, several information contents should be readily available. Each sub-process is based on access to a specific information repository to make proper decisions. Figure 11 describes the complex information infrastructure behind the maintenance process through the Archi modelling tool (Lankhorst, 2017; The Open Group, 2018).

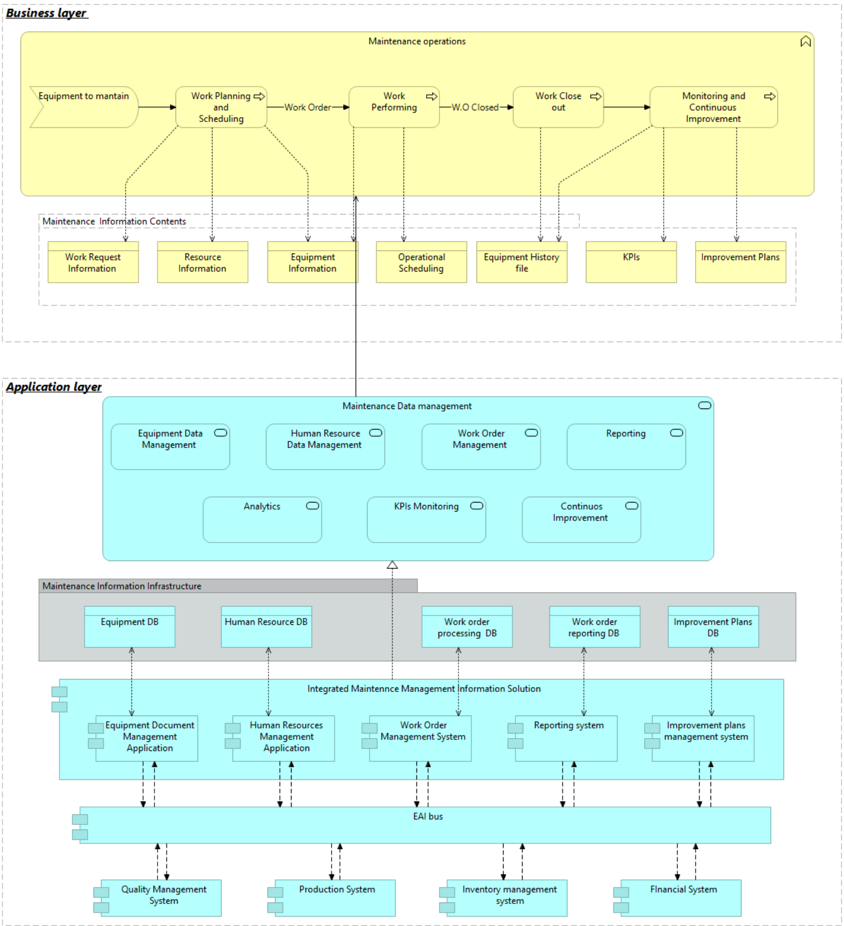


Figure 11: Maintenance process architecture

The high-level architecture modelling highlights the relevant interaction between the maintenance business process and application portfolio (can be seen as a set of databases) that any organization should have to be competitive.

Figure 12 illustrates the business (yellow boxes) and application (light-blue boxes) core layers to demonstrate how meaningful and valuable are data and information management to support decision making and improvement functions.

At the business layer, a wide variety of business objects (repository of information) were used to represent all data and information that are relevant to execute each subprocess. Considering the maintenance operations, the planner needs the details on the equipment to be worked, human and material resources and all relevant information enclosed in the equipment, resource and work request databases respectively. Maintenance scheduling needs information as maintenance technicians/maintainers, equipment, materials required and reasons for the work. This is the stage where the work request becomes a work order (W.O). All data recorded during the execution stage (concerning what happened on equipment and what was performed) are processed and organized in the equipment history file. The monitoring of KPI and trend analysis allows the definition of maintenance best practices and the identification of all improvement plans. Improvement programmes come back in the process thus reaching a continuous optimization cycle.

At the application layer, to support and automate the process, an integrated MMIS solution is proposed. The solution consists of different application component which one performs specific application functionalities (e.g Equipment data management, human resource data management, analytics, reporting) thanks to a well-organized and structured database (DB): equipment, human resource, Work Order, Work Order reporting and Improvements plans. To reach a complete integration, the maintenance information solution should communicate with all business functions through an enterprise application integration. Nevertheless, just maintain the quality, reliability and integrity of data and information is considered a critical point for SMEs. For this reason, SMEs need a procedure to create, organize and process databases properly.

II.2 Step 2: Maintenance management information practices assessment

Step 1 shown in Figure 1 allowed to define a typical maintenance information infrastructure. The output of step 1 was used in the development of the maturity model (step 2). The maintenance information file proved by the first analysis provided inspiration and support for the definition of maturity model architecture (section 3.2.2). In the following subsection, all the phases for the development of the maturity model were well detailed and described.

II.2.1 The conceptual model development

The approach proposed by Becker (Becker, Knackstedt, and Pöppelbuß 2009) has been applied to develop an assessment/readiness model on Maintenance management information practices in the SMEs context. In the following subsection, all the phases (figure 12) are detailed and described.

Figure 12: Phases for the development of maturity models proposed by Becker

II.2.1.1 Problem definition

"The prospective application domain of the maturity model, as well as the conditions for its application and the intended benefits, must be determined prior to design (Becker et al.2009)".

The use of information and consequently the development of more effective strategies for its management are widely accepted as being important issues for any organisation, especially for SMEs.

Information is central for strategic planning, management, control, tactical planning and daily operation.

The objective of more effective information management strategy is to efficiently support these activities to ensure that the value of the information is identified and exploited to its fullest extent.

Since the 1980s, considerable advances have been made in information communication and technology (ICT) and in particular handling electronic information. As a consequence, the development and application of techniques and tools computer based for a given process or activity were developed.

For maintenance process, many information systems have been developed. As widely said in the literature analysis, these systems are not successfully implemented by SMEs due to their inherent characteristics; the main cause is related to the maturity level of maintenance department. Maintenance management information practices measuring aims at providing a comprehensive representation of SMEs' information infrastructure state. The identification of present shortcomings and future fields for action by means of a maturity model was broadly justified by the available literature studies discussed in the first chapter.

In order to support smaller enterprise to adopt an appropriate maintenance information system, the assessment of existing situation is a mandatory step.

II.2.1.2 Comparison of existing maturity models

"The need for the development of a new maturity model must be sub satiated by a comparison with existing models. The new model may also just be an improvement of an already existing one (Zelewski 2007)".

Maturity models that explicitly address Information maintenance management practices could not be identified. Instead, different maturity models could be detected that view "Information maintenance management" as a sub domain in the maturity assessment of maintenance process. Among the maturity models that refers to Information maintenance management in a broader sense are: Olivera et al., 2019, Chemweno et al., 2015, Macchi et al., 2013.

These maturity models generally disregard the importance of data collection as well as the quality of information collected in order to have well managed databases. There are, however, separate maturity models for IT management, alignment of functionality information system but are not specifically related to maintenance field.

Moreover, it is argued that this fundamental understanding of the existing information infrastructure is critical for the effective specification and implementation of additional elements of the infrastructure to improve information management. It is also a prerequisite for the effective long-term management and development of the IS infrastructure. This issue in not well evaluated by existing maturity models since the scope is different.

II.2.1.3 Determination of development strategy

"The most important basic strategies that can be discerned are: the completely new model design, or the enhancement of an existing model (CMM); the combination of several models into a new one (CMMI); as well as the transfer of structures (DPMM, eMM) or contents (ACMM, IS/ICT CMF) from existing models to new application domains" (Becker at al.,2009).

The comparison of existing maturity models with the problem definition suggests a design strategy that brings a new model development. The identified maturity models are used as a starting point for the design process, since they covered some of the aspects of information maintenance management.

On one hand their tiered structure, the definition of maturity levels and the suggestion concerning the calculation of maturity level provided an inspiration for the structuring of maturity model, in fact all these parts were expediently transferred to our problem area. On the other hand, all the contents, the definition of evaluation criteria, the description and definition of maturity level are a new contribution.

II.2.1.4 Iterative maturity model development

"The central phase of the procedure model is the iterative maturity model development. The sub-steps of this phase, selecting the design level, selecting the approach, designing the model section, and testing the results will be iterated" (Becker et al.,2009).

The maturity model design was carried out through five stages. In the first iteration, a primary architecture was drafted, which included the identification of the main informative databases; based on an extensive literature research, the main contents of each one, their attributes and evaluation criteria were defined during the second iteration. At these stage five degrees of maturity, ranging from the identification of chaotic condition (0) to best in class (4), were included and described.

In the third stage a structural survey was set as well as a mathematical formulation of the model was developed in order to measure the maturity level. Furthermore, a consolidated spreadsheet-assisted maturity evaluation was created.

In the fourth stage, instead, a semi-structured interviews with Maintenance experts were conducted in order to confirm the completeness and feasibility of the model. The strong orientation towards the operative aspects of maintenance management information practices was largely approved as well as a great precision and details of contents whereas some technical aspect was criticized. Following improvement suggestion, the modified architecture, carried out in the fifth and last stage, led to a revised version of the maturity model which received good feedbacks by the domain experts.

II.2.1.5 Conception of transfer and evaluation

"The different forms of result transfer for the academic and the user communities need to be determined" (Becker et al.,2009).

Besides academic publications, the current conception of transfer and evaluation includes the administration of the survey to SMEs territorial in order to understand the current situation and also give to companies a measure of their maturity. This is meant to expand the empirical basis, creating a consistent dataset, as well as validate the model, so far consisting of evaluation from the expert interviews. The survey results should allow a statistical survey of the distribution of the degrees of maturity in individual companies in order to support the definition and creation of an evolution/improvement path.

II.2.2 The architecture model design

The architecture of the maintenance execution process, performed through the ArchiMate, allowed the definition of maintenance management information infrastructure composed of a set of databases (DB) (Figure 15):

(1) The equipment DB includes all documents and information files associated with the equipment, relevant for carrying out the right maintenance intervention. All the types of documents should be consulted both to plan a maintenance intervention and to perform the work order. The information files associated with the equipment regarding physical and technical documents, failure documents, maintenance documents, and improvement plans.

(2) The maintenance personnel DB includes all documents and systems associated with the maintenance personnel, relevant for planning and choosing the right operator for carrying out the intervention. The systems associated with maintenance personnel regard systems for education and training, and reward and recognition in order to monitor the performance and improve the competencies with a specific training program.

(3) The maintenance work order system is composed of two parts: a maintenance work order request and a maintenance work order. Maintenance work request means the fulfilment (paper, telephone, or computer) of a "form" that contains all the information useful to the planner or the maintenance coordinator in order to schedule the maintenance operation. The requests, so intense, can be established by any person in the organization. Maintenance work order means the fulfilment (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.

(4) The Maintenance reports system includes elements (data) collected for the previous objects: equipment, maintenance personnel, and work order.

The aim is to understand which information exists to define indicators and to monitor the progress of the maintenance process. The scope is to assess the maturity of each DB considering several criteria: WHAT and how many documents ("information files") linked each DB are currently available and ready to be consulted; the level of accessibility by users and the quality of each document (HOW); the upgrade period (WHEN); the support tool used for their maintaining and management(WHICH); if for each one there is a specific employee who takes care of their correct management (WHO).

As not all the criteria are significant for each DB, therefore for maintenance work order only the criteria HOW and WHEN are evaluated. Related to the aspects included in a work order request and work order, the other criteria (WHEN and WHO) are not significant.

However, the model developed until now covers four DB (Equipment, Maintenance personnel, Maintenance work Order, and Maintenance report) therefore to assess the maturity level of each one a systematic approach is used (Figure 13).

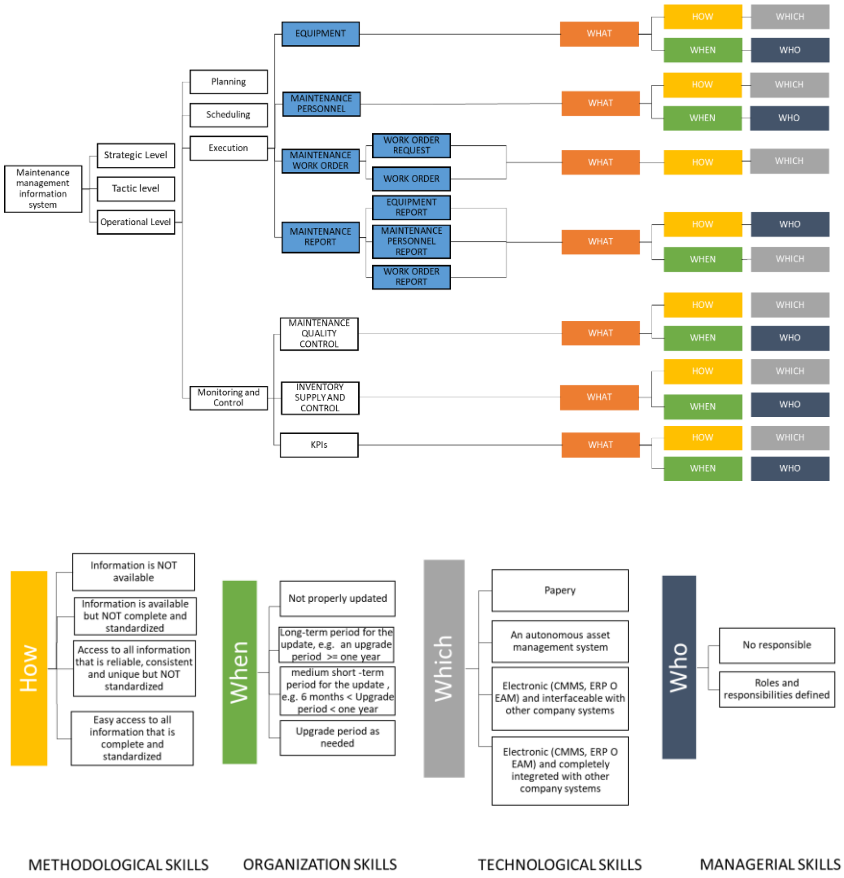


Figure 13:The fundamental structure of the maturity model

II.2.2.1 Description of Databases

The databases defined aim to provide all those concerned, at the place of use, with all the up-to-date and usable files and document they need to prepare for and perform the tasks for which they are responsible while optimizing costs and times as well as the different maintenance processes and sub process.

The Equipment Database

The Equipment/ machine database (Figure 14) must contain, store and arrange all the information files needed for prepare, perform, close out a maintenance task safely for restoring the machine in a functional state. It includes five information files classes classified as:

1) Physical data & Technical data
2) Failure data
3) Maintenance data
4) Improvement data

Physical & Technical data consists of machines registry, drawings, file from manufacturer and engineering, Structural bonds (Bill of materials).
The definition and structuring of the machines' registry is necessary in order to analyze and aggregate the information regarding the maintenance activity and the performance of the machines. The classification is relevant to allow the analysis for homogeneous machines family groups that have similar features/characteristics.

The coding system must be simple and allow only univocal identification of all the machines.

Drawings, file from 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 in order to visualize all the hierarchical links.

Technical specifications aim to provide all the operating parameters inherent 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 with the aim to create a series of linkages between potential failures, the impact on the mission and the causes of the failure. The system support to detect, characterize and prioritize the events (failures, malfunctions due to latent or hidden faults) based also on standard maintenance procedure provided by manufacturer.

The equipment history file instead not only helps to create and enrich the diagnostic system but also supports to collect data and information related to failure and inspection performed on the machine. The purpose is to collect a list of undesirable events, causes, effects, criticality of events, occurrence of events with the aim 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 also the time of failure, the nature of failure, the repairs undertaken, 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 practice (Repair Methods, safety needs, Maitenance Standard Procedure) and document 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 in order to define the operative instructions to conduct a maintenance task safely and according the various constraints (operating, environment, resources, etc.)).

The document of daily inspections contains all the procedure to conduct inspection operations; cleaning operations; Lubrication operations; and other treatments to prevent failure events (with the aim to introduce the autonomous maintenance practice).

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

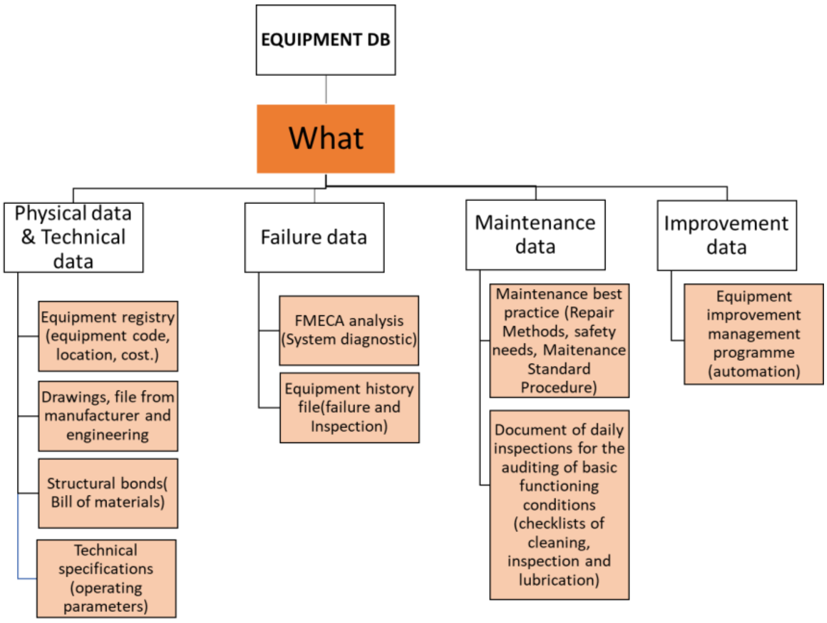


Figure 14: Equipment DB

The maintenance personnel database

The maintenance personnel database (Figure 15) must contain all the information document and files needed for providing in a timely manner the internal maintenance personnel who have the necessary skill levels and certification to perform the maintenance activities.

All the information files can be classified in two classes:

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 with the aim 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 level, certifications, and qualification, the more competent and appropriate internal individuals to perform the 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.

Ensure 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 transfer 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 maintenance personnel performance monitoring system (quality performance indicators, key factors).

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

Advanced reward and recognition class consists of training and competence need system analysis.

Taking into account the monitoring system and job profiles, it establishes the competence to reach and future skills requirements for each employee. The system support to qualify in a continuous optimization cycle internal and/or external individuals with the aim to assign right (in terms of competence) employee related to each maintenance activity.

Based on future skills requirements, foreseeable staff movements and the time it takes to make qualified staff available, recruit as necessary to satisfy needs in a timely manner.

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.

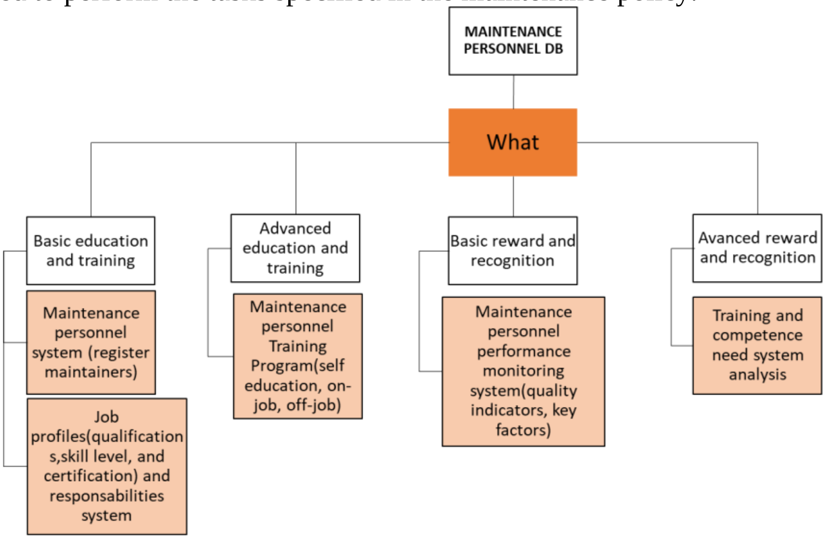


Figure 15: Maintenance personnel DB

Work order Database

The work order system 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.

In a simple way, a work order system can be seen as 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: a maintenance work request and the work order itself. They must be filled for all jobs.

1) Maintenance request means the fulfilment (paper, telephone or computer) of a "form" that contains all the information useful to the planner

or the maintenance coordinator in order to schedule the maintenance operation. The requests, so intense, can be established by any person in the organization and for whatever type .

2)Maintenance work order means the fulfilment (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 have to include all necessary information needed to facilitate an effective planning and scheduling, the second one is the instructions provided to perform the work that have to emphasize clarity and simplicity for use.

In industry, it is referred to by different names such as work request, work requisition, and request for service.

The purpose of an effective work order system is to provide means for the following:

1. Requesting in writing the work to be performed by maintenance.
2. Screening the work requested by operation.
3. Assigning the best method and the most qualified personnel for the job.
4. Reducing cost through the effective utilization of resources (manpower, material).
5. Improving planning and scheduling of maintenance work.
6. Maintaining and controlling the maintenance work.
7. Improving overall maintenance through data collected from the work order and used for control and continuous improvement programs.

It is right to point out in maintenance systems, there are two types of maintenance work order.

The first type is the “blanket” work orders (sometimes referred to as standing work orders) used for small routine repetitive job, inspections preplanned, 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 are necessary after the work 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, avaibility and constraints of material, manpower and production system, there are some work orders that are done by external companies to perform the tasks as externally contracting.

In order to explain better the information contents included in a work order system, a typical maintenance work order flow have to be illustrated. It refers to the dispatching procedures and the order in which the job is processed from its initiation till its completion.

1) Upon receipt of the work request by the planner (it can be initiated via telephone, computer terminal through an enterprise resource planning (ERP), or in hard written form), it is screened, and a work order is planned and completed, showing the needed information for planning, execution, and control.

2) The work order is registered in a register that lists pertinent data for each work order.

3) The work order is assigned taking into account all the constraints (availability resources, production system constraints, timeframes, maintenance constraints and uncertainties, …) and all the needed information are provided for a right execution.

4) The maintenance personnel designed for the execution receives all the information needed for the performance, and then fills the necessary information about actual work done (such as actual time and actual material used)

5) The information included by the maintenance personnel are verified and the quality of work is checked before forwarding information to the maintenance control

6) The planner returns the information to the originator.

7) The planner sends information also to accounting to fill in information about costs. After that, the information collected are sent to the department where the maintenance information system is maintained (it could be a unit by itself or within planning and scheduling, depending on the situation). The information in the work order is entered in equipment history file.

Figure 17 shows a flowchart showing these steps. If an automated system is used, the work order is routed via a local area network. In this case, the necessary information is automatically extracted from the work order to the equipment history file. In case an ERP or e-system is used, the work order is stored and utilized for generating reports and eventually archived.

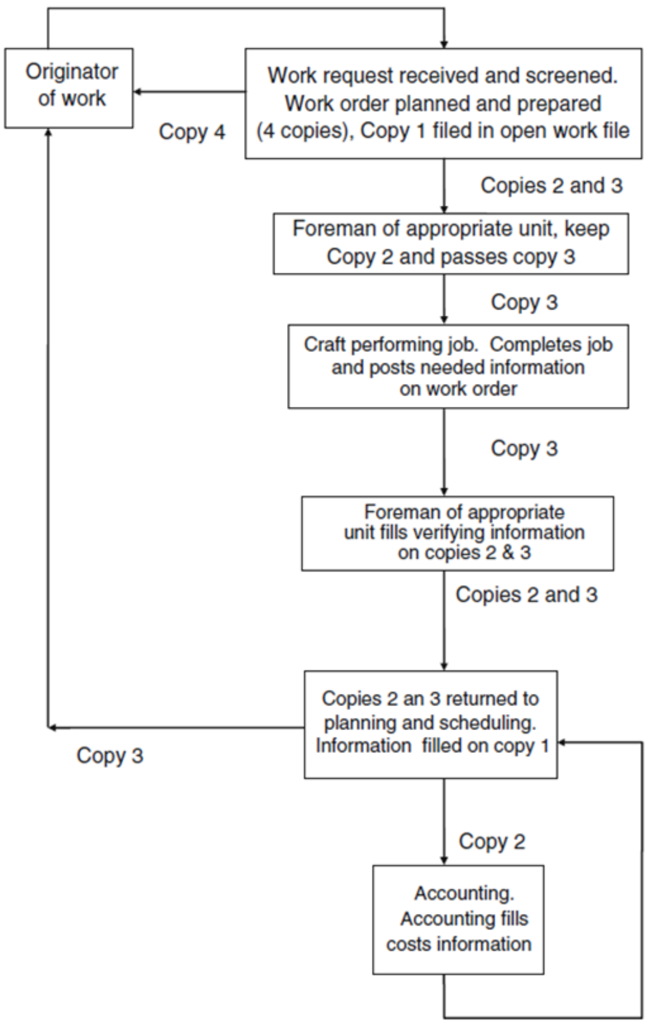


Figure 16:Logical flow of work order system

The maintenance work order flow allowed to define the information contents to include in the work order database, 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 request for planning work have to include (Figure 17): 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 work order for performing the jobs have to include (Figure 17): 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).

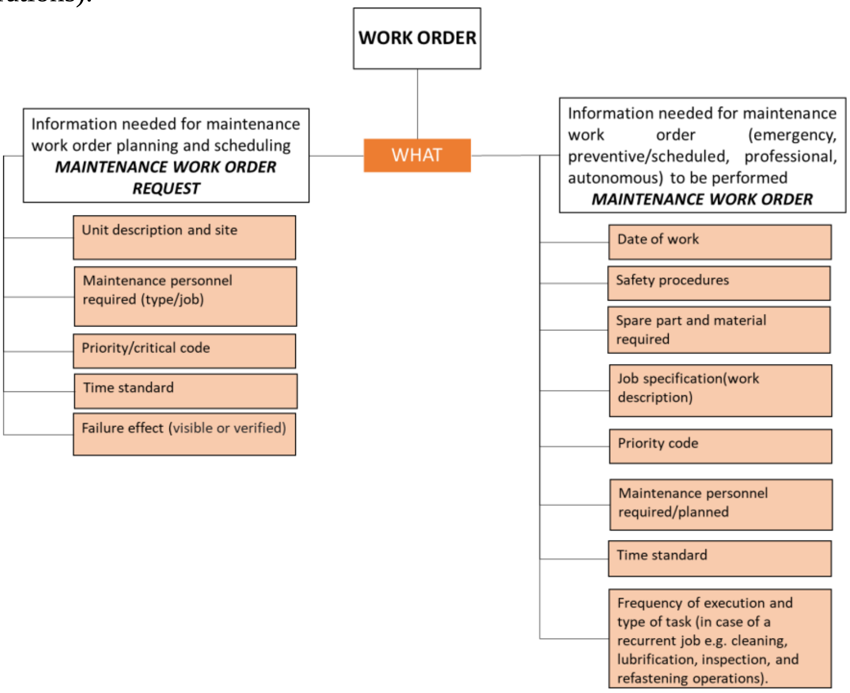


Figure 17:Work order DB

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.

Key activities / elementary processes are:

1. Ensure the safety of the items and individuals (restrict use of the items and access points, provide personal and collective protective devices).
2. Conduct a “safety” inspection.
3. Implement the means required to perform the task (site preparation).
4. Follow the predetermined maintenance procedures.
5. Check that the maintenance task has been completed and remove the restrictions related to the items and access points.
6. Check the proper operation of the item in its functional environment.
7. Determine the actions to be taken to handle deviations (in functioning, in procedure, supports, etc.)

Report database

The Report Database 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 reports collected 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: equipment reports, maintenance personnel and work order (Figure 18).

Related to the equipment the most relevant reports to collect are: 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 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.

Related to maintenance personnel the most relevant reports to collect are: 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 jobs and skills of each one with the aim train in a timely manner 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.

Related to work order the most records to collect are: 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 previous 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 many 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 action 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.

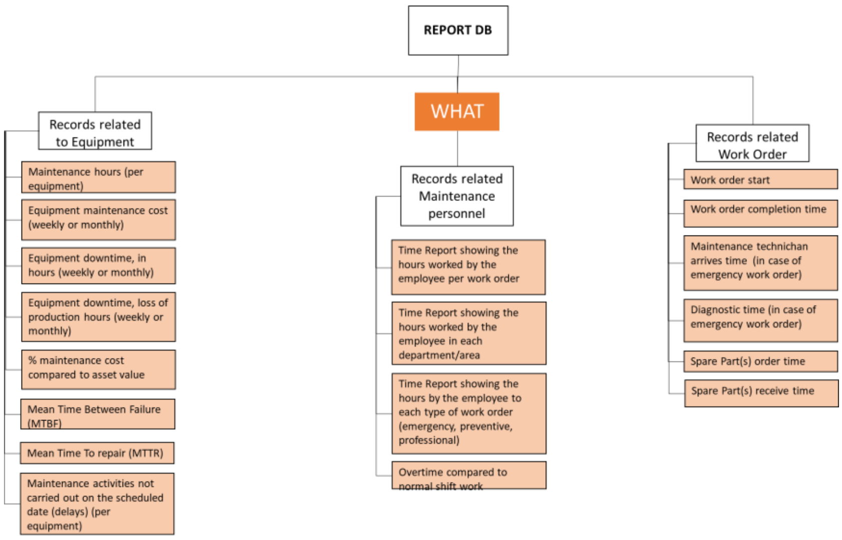


Figure 18: Report DB

II.2.3 Survey administration

A survey is carried out using a well-designed questionnaire to assess the maturity level of the information management practices adopted. The objective is to understand and have a quantitative measure of the maintenance information infrastructure adopted by small companies, as well as identify a maturity level.

The structured web-based survey was devised and deployed for data collection through an open-source platform called "lime survey". It is an open-source web application that allows the simple and effective creation of questionnaires and online surveys in which an unlimited number of users can participate. The sampling frame was collected from the lists of companies belonging to regional trade associations. Figure 19 shows the logical structure of the survey, including the main questions groups.

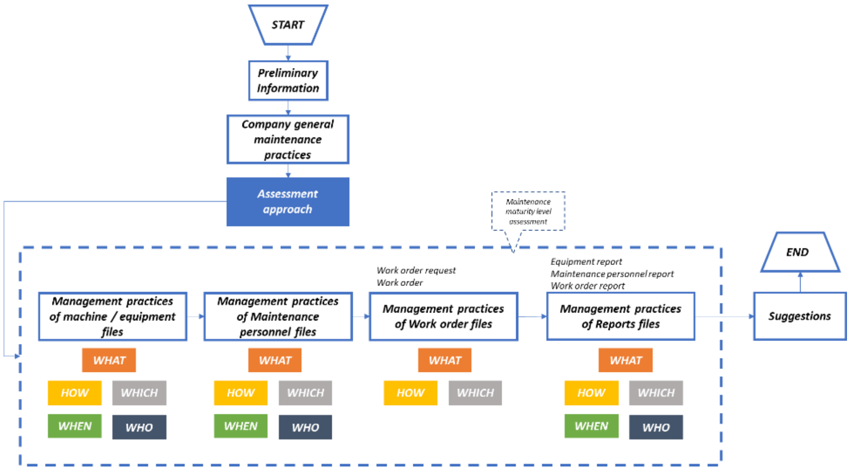


Figure 19: Survey structure

Preliminary information contains a set of questions related to the company (size, sector, and operational headquarters) and the interview (professional role). A set of questions concerning the general maintenance practices was included to understand the strategy and the approach adopted by the companies for maintenance operation. Based on the fundamental structure of the model, a section for each DB containing questions for every evaluation criterion was performed. The answers are ranked according to a description ranging from the initial/basic practice to the good/best practice. The highest ML is assigned if the management practices used run according to best practices; the lowest ML is assigned when the practices are either weakly available or not performed at all. For better understanding, a practical example is provided in figure 20.

The final section, suggestions, contains questions for collecting feedback and recommendations of the survey from the experts who compile the survey.

A simple algorithm implemented in excel, returns an aggregate maturity index as well as the specific maturity level for each DB and evaluation criteria to identify the strength and weakness points of each one. Until now the survey was submitted, and the responses are being collected.

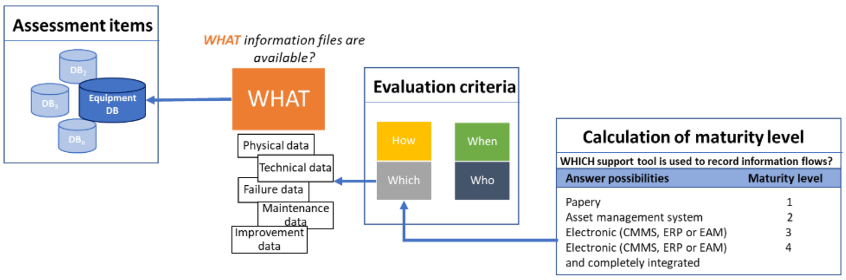


Figure 20: Example of a survey question

II.2.4 Mathematical formulation

The variable i=1,…n represents the detailed information contents (WHAT) related to each DB. For example, drawings, files from manufacturer and engineering, equipment registry (equipment code, location, cost...), bill of materials, technical specifications (operating parameters), failure mode and effect critically analysis, maintenance best practice (repair methods, maintenance standard procedure), equipment history file (failure and inspection), equipment improvement management program are the information contents concerning the equipment DB.

The score of "what" depends on how many information contents in each DB are maintained by an organization; if information content is available the variable z is equal to one, either z is equal to 0. Based on the value assigned for each information content, the maturity level of WHAT varies from one to four.

The variable j=1,…4 represents the different domains related to each information content (HOW, WHICH, WHEN, and WHO). These domains are standardized and not equally important. While b1, b2…b4 are the relative weight of these m domains.

The variable Sij is the level of practice used (initial practice=level 1, best practice= level 4) in the j-th domain for the flow i-th.

Then, the maturity level for i-th information content can be calculated as:

$$ML_i = \sum_j b_j S_{ij} \qquad a)\sum b_j = 1;\ \forall\ j=1,..4;\ 1 \leq S_{ij} \leq 4 \qquad (1)$$

Moreover, assuming that information flows are not equal importance, and wi is the relative weight reflecting its importance to the maintenance system, a measure of the MLDB of k-th DB (k=1,…4) can be obtained using the Composite Score principle:

$MLDB_k=\sum_i w_i*ML_i$	b)$\sum w_i=1;\{1\leq ML_i\leq 4\ \forall z\neq 0\};\ \{ML=0\ \ \forall z=0\};\ \forall i=1,...n$	(2)

The maturity level of each domain MLDj is measured as a mean of the levels of practice used for all information contents:

$MLDj=1/n*\sum i\ Sij$	$\forall$ j= 1, …4; $\forall$ i=1,..n	(3)

The maturity level highlights the strengths and weaknesses of the current maintenance information management practices. Different graphics (e.g., bar chart and radar chart) with the maturity level for each database and of each capability is shown as the result of the assessment process described above (figure 21). The areas with the lowest ML are candidates for improvement programs. Considering the weaknesses of each domain, a strategic roadmap will be drawn. The maintenance improvement programs will provide a growing path made by steps supporting the company to reach the highest maturity level. To reach the next step on the roadmap, the organization must complete the previous one. This will enable the company to achieve a higher maintenance effectiveness standard more than once and a continuous improvement process will be activated. The different ML can be expressed according to the mathematical formulation reported and summarized in the table 5.

Table 5: Calculation of different ML

Equation	**Range**	***Notation***
$\boldsymbol{ML_i = \sum_j b_j S_{ij}}$	$\sum b_j=1;\ \forall$ j=1,..4; $1\leq S_{ij}\leq 4$	**ML_i:**Maturity level i-esimo information content **b_j**:relative weight of j-esimo evaluation criteria **S_{ij}:** level of practice used by i-esimo information content in the j-esimo domain (Sij=1 initial practice; Sij=4 best practice)
$\boldsymbol{MLDB_k = \sum_i w_j ML_i}$	$\sum w_i=1;\{1\leq ML_i\leq 4\ \forall z\neq 0\};\ \{ML=0\ \forall z=0\};\ \forall$ i=1,...n	**$MLDB_k$:** Maturity level k iesimo DB **w_i**:relative weight of i-esimo information file
$\boldsymbol{MLD_j = 1/n \sum_i S_{ij}}$	$\forall$ j= 1, …4; $\forall$ i=1,..n	***MLD_j:*** *maturity level j-esimo evaluation criteria* **n=** total information files

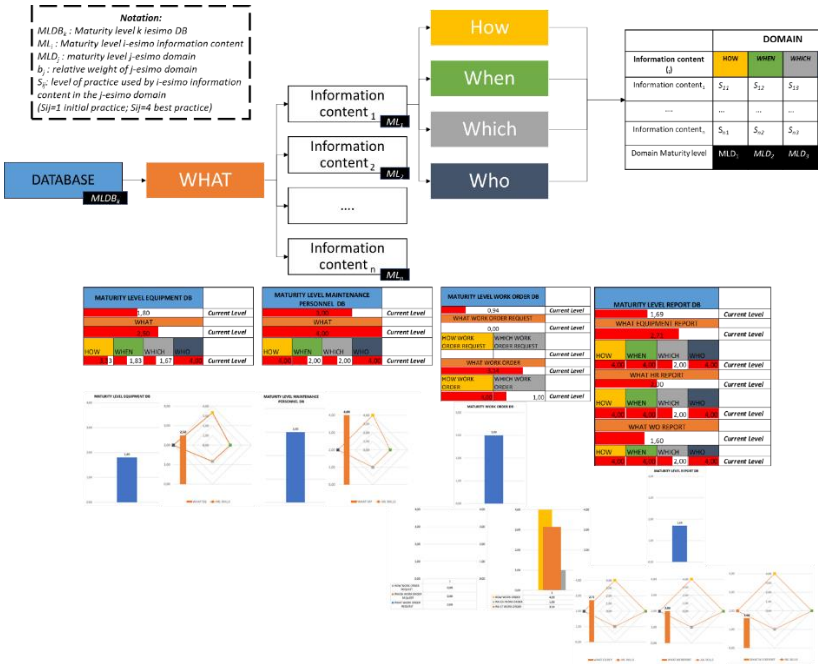


Figure 21: Mathematical formulation and results

II.2.5 Output of the model

The model proposed provides in output a description, as well as the meaning, of the maturity level reached for each criterion as showed in the tables included in appendix A.

II.3 Step 3: Improvement programme definition

In literature, very few studies developing a maturity model try to purpose an improvement program to reach the highest level. For this reason, contrariwise for the maturity model, methods for defining an improvement programme have not been present in literature yet. Therefore, we propose an innovative idea on how to build an improvement program, that will be detailed in next sections.

The improvement programme (STEP 3) will be designed based on the assessment model developed. It will be based on setting targets and related to the specific weak-ness measured during the assessment, a roadmap with the selection of what are the actions to follow for reaching the highest ML will be suggested. The roadmap could be considered as a beginning step for improving or for introducing maintenance management information practices with maintenance processes. It can be used for different purposes: for an organization pursuing to transfer information management best practices to its maintenance department or for other organizations starting the adoption of maintenance management information infrastructure from the maintenance department. The roadmap will be more flexible and can be adjusted according to any maintenance strategy. The improvement can be pursued along horizontal (by increasing the information contents/systems to the actual information infrastructure) or vertical (by improving the way to handle information infrastructure) dimension. This enables the company to achieve a high maintenance effectiveness standard more than once, and a continuous improvement process will be activated, keeping the goal to-wards a higher maturity level.

The aim is to define a growing path made of sequential steps, for improving the management of each DB by the definition of best practices for each one.

The Improvement program will be based on the principle of Total productive maintenance, identifying the best practices, techniques, and methodologies that can be introduced to improve maintenance management information practices. Nonetheless, when talking about information, the connection with currently available technologies is advisable. Therefore, the identification of the available technologies supporting maintenance management practices will be performed.

II.3.1 Total Productive Maintenance

Total productive maintenance (TPM) is a unique Japanese philosophy, which has been developed based on the Productive Maintenance concepts and methodologies. This concept was first introduced by M/s Nippon Denso Co. Ltd. of Japan, a supplier of M/s Toyota Motor Company, Japan in the year 1971. Total Productive Maintenance is an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns and promotes autonomous maintenance by operators through day-to-day activities involving total workforce (Bhadury, 2000).

McKone et al. (2001) identify training, early equipment design, early product design, focused improvement teams, support group activities, and autonomous and planned maintenance as the six major activities in TPM implementation. In measuring TPM implementation, Maier et al. (1998) consider preventive maintenance, teamwork shop floor employee competencies, measurement and information availability work environment, work documentation, and extent of operator involvement in maintenance activities as factors reflecting TPM implementation. The basic practices of TPM are often called the pillars or elements of TPM.

The entire edifice of TPM is built and stands on eight pillars (Sangameshwran and Jagannathan, 2002). TPM paves way for excellent planning, organizing, monitoring and controlling practices through its unique eight-pillar methodology. TPM initiatives, as suggested and promoted by Japan Institute of Plant Maintenance (JIPM), involve an eight pillar implementation plan (Figure 22) that results in substantial increase in labor productivity through controlled maintenance, reduction in maintenance costs, and reduced production stoppages and downtimes. The core TPM initiatives classified into eight TPM pillars or activities for accomplishing the manufacturing performance improvements include Autonomous Maintenance; Focused Maintenance; Planned Maintenance; Quality Maintenance; Education and Training; Office TPM; Development Management; and Safety, Health and Environment (Ireland and Dale, 2001; Shamsuddin et al., 2005; Rodrigues and Hatakeyama, 2006).

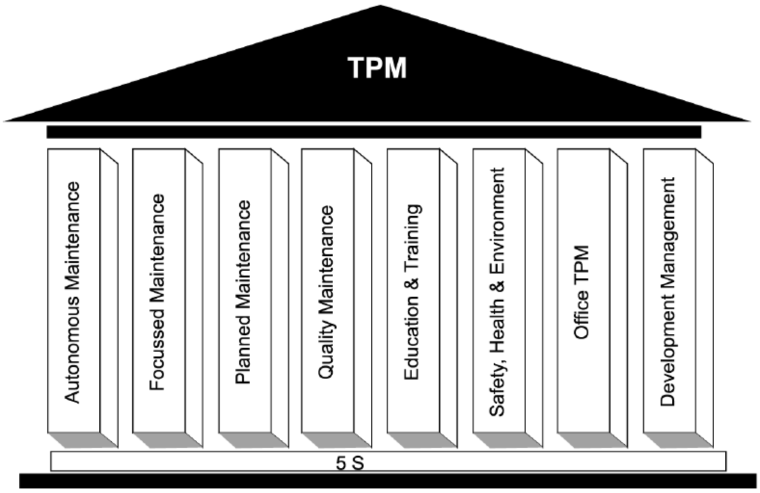


Figure 22: Eight pillars approach for TPM implementation (suggested by JIPM)

In order to introduce the principles and practice application of TPM, an implementation method is necessary. There have been many approaches suggested by different practitioners and researchers for implementing TPM in the different organizations having varying environments for garnering manufacturing competencies to accomplish the organizational goals and objectives. Thus it has been observed through the literature review that, although number of models and methodologies have been suggested by practitioners and researchers for the Western World, the organizations world-wide are faced with a stiff challenge of working out right sequence of initiatives for effectively deploying TPM practices successfully, in the most effective manner.

It has been reported in the literature that TPM implementation is not an easy task by any means. The number of companies successfully implemented TPM program is considered relatively small.

The failure of organizations to successfully institutionalize effective TPM implementation program is due to lack of a support system.

Thus, it becomes pertinent to develop TPM support practices in order to realize world class manufacturing attributes.

Furthermore, having a systematize and well-structured databases help to introduce some practices of TPM successfully.

II.3.2 Improvement programme

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 roadmap development consists of the definition of an improvement path, highlighting what is already achieved and what is missing for 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.

II.3.2.1 Horizontal Improvement

The Horizontal improvement is set starting from the maturity level of WHAT criteria (calculated as the mean of the WHAT level of all databases), which is the most important since it defines the information infrastructure of each database. For each level, the orientation of the company and the actions for reaching progressive maturity levels or complete the achieved level one will be defined. The completeness of each level is gained only if all other evaluation criteria (HOW, WHEN, WHICH, and WHO) have reached the highest level.

Moreover the effort required to create each informative flow, as well as, the benefit obtainable are defined in order to make aware the management about the expected commitment and the improvement reachable.

The defined scales for estimate effort and benefits are qualitative from 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 4):

Table 6: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
Flow requires more complex recording and processing of data	4
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

Concerning the benefit scale, the criteria used are distinguished for each database:

1a) Quality/support (in terms of easiness, timeless, goodness) in the execution of the maintenance intervention (1 no quality-5 high quality) for equipment and maintenance personnel DB

1b) Quality/support (in terms of easiness, timeless, goodness) in scheduling and performing maintenance intervention (1 no quality-5 high quality) for work order DB

1c) Quality/support (in terms of easiness, timeless, goodness) in identifying weakness points in the maintenance management process (1 no quality-5 high quality) for report DB

2) Support in the decision-making process (in terms of planning improvements) for all DB (1 no support-5 valid support)

In particular the scale is so defined (table 5):

Table 7: Benefit scale

Benefit	***Value***
Having available this information flow allows 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 an initial non existent-level (ML= 0), as a maturity should not 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 (Figure 23).

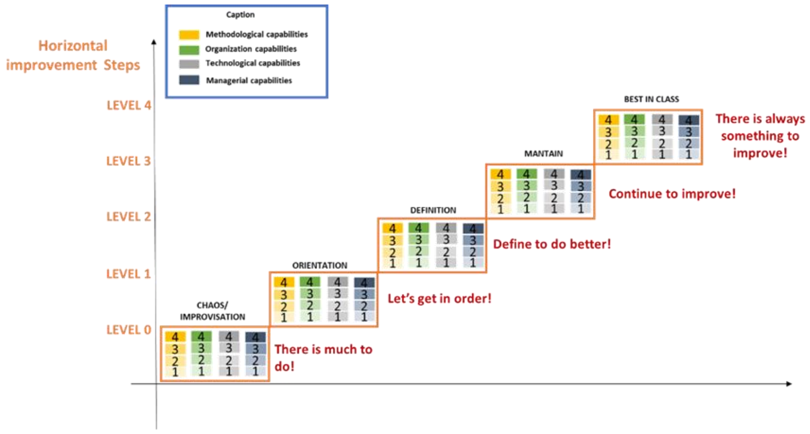


Figure 23: Horizontal Improvements steps

<u>Current Level 0</u>

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 database, to be collected is evident. The stakeholders are not aware of the importance and relevance to have structured and systematized DB. No consistent understanding of maintenance information needed to improve maintenance management practices exists in the company. In particular, 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 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 LEVEL NEXT LEVEL

The starting point identify 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 24.

Moreover, the red and green stamps, on the figure, represents respectively the value of the effort and benefit according to the scale defined above.

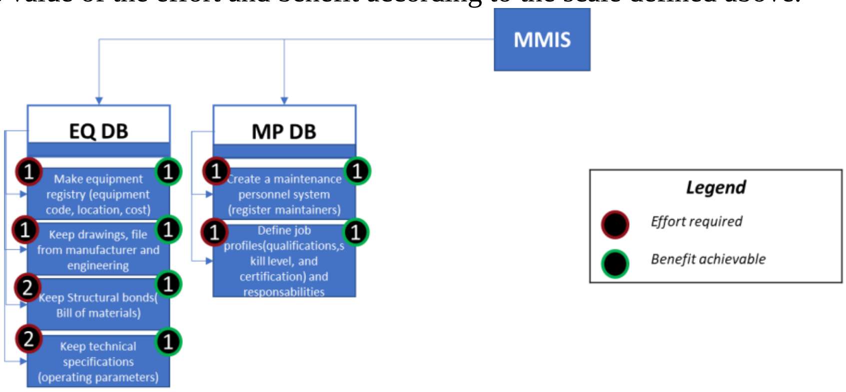


Figure 24: Horizontal improvement actions to reach level 1

Level 1: Orientation

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 LEVEL NEXT LEVEL

The actions to do, along horizontal direction, 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 25, the equipment and maintenance personnel DB keep filling up, while the work order DB start to appear with the first data to include.

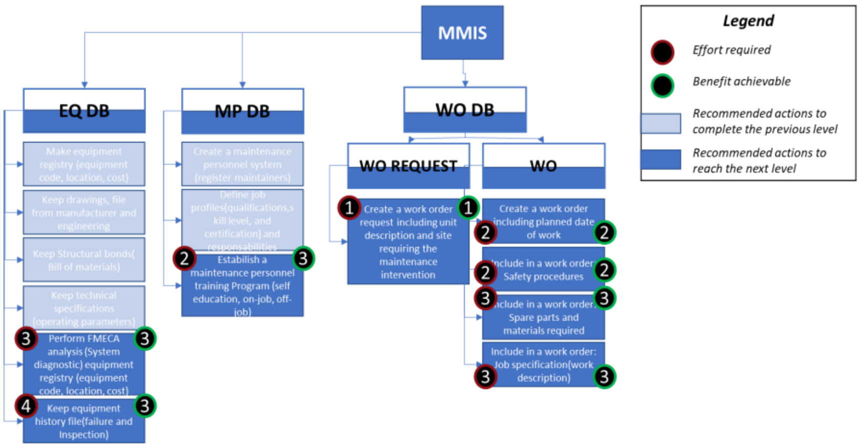


Figure 25:Horizontal improvement actions to reach level 2

<u>Level 2: Definition</u>

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 O REACH LEVEL NEXT LEVEL

The actions to do, along horizontal direction, 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 26.

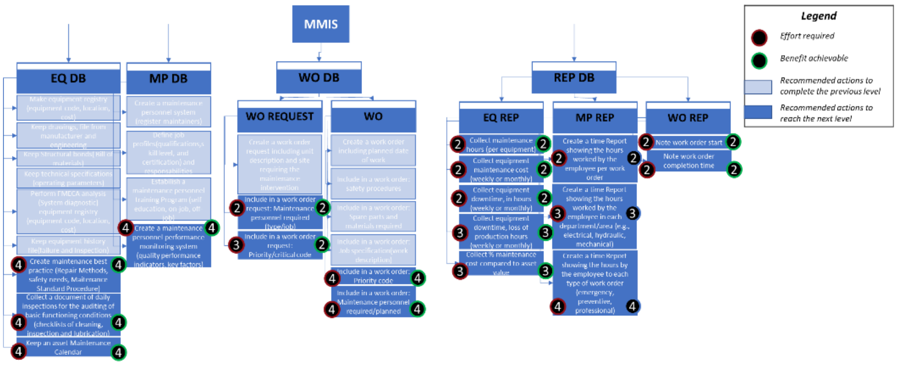


Figure 26:Horizontal improvement actions to reach level 3

Level 3: Maintain

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 27, in this way all DB are completed.

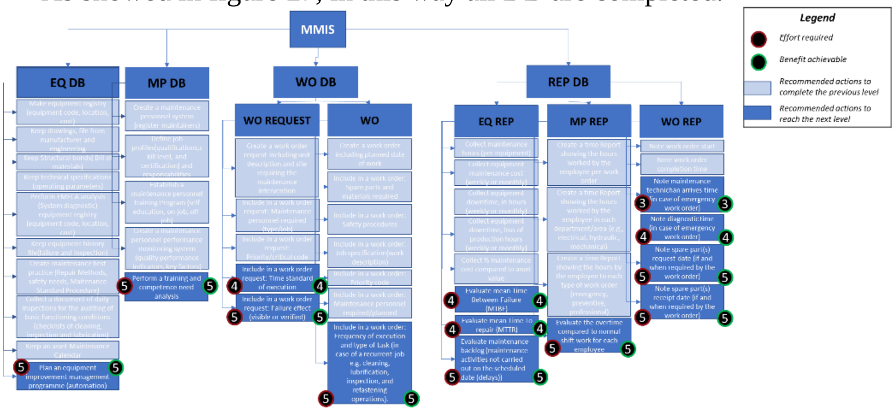


Figure 27:Horizontal improvement actions to reach level 4

Level 4: Best in class

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 o-reorganised using effectively coordinated steps. The actions to do are to improve them continuously and create the others that support the maintenance management.

II.3.2.2 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 28 and these actions make use for all DB.

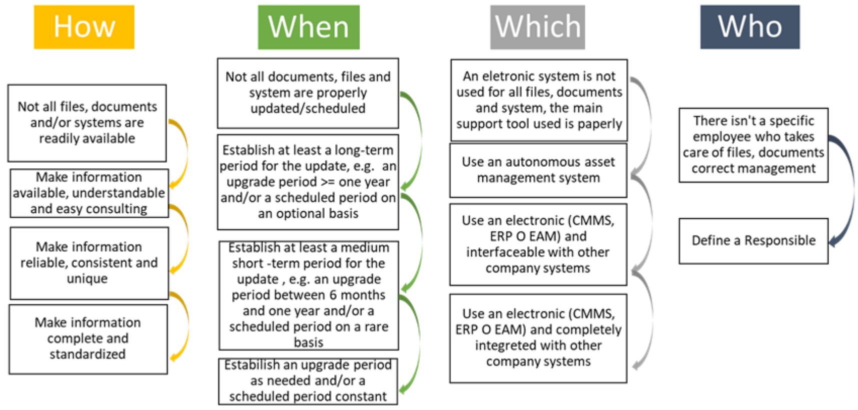


Figure 28: Vertical improvements steps

TPM techniques, methods and tools to implement equipment and maintenance personnel database informative flows.

In order to provide a complete support in the creation of DB and/or collection of data and information flows concerning equipment and maintenance personnel database, the most relevant and useful TPM techniques, methods and instruments are suggested.

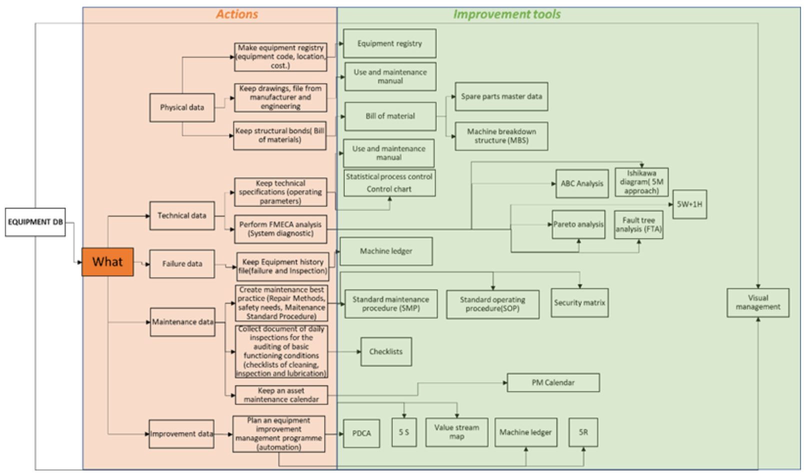


Figure 29: TPM tools for Equipment DB creation

In the figure 29 are showed the TPM tools for Equipment DB creation.

The equipment registry is one of the most important tools in the maintenance process. It can be used for all maintenance activities such as planned maintenance, training and repair programs, as well as help with regulatory compliance and safety programs.

In an enterprise asset management (EAM) or computerized maintenance management system (CMMS), there are already set up with specific fields for creating equipment registry. In any case those fields should be examined, renamed and added others related to suit specific needs and reach completeness and accuracy.

If equipment registry has to be built, a minimum number of data fields for the basic information have to be defined. Of course, smaller plants can manage with cheaper versions of programs or even with simple spreadsheets if they are configured correctly.

Some important fields are: equipment name, manufacturer name, model number, serial number, location installed in the plant, description and date installed. It can be added fields for service vendor, warranty period, capacity, functional location, superior equipment number, bill of materials (BOM) file and the original purchase order number if desired.

A use and maintenance manual is a document that provides essential details about property and equipment upkeep. The manual provides with detailed guidance on extending asset life cycles, minimizing unplanned shutdowns, reducing maintenance costs, and keeping workers safe. O&M manual users include organizational managers, executives, maintenance technicians, and third-party contractors.

The maintenance manual often are provided by machine manufacturer with drawings and all useful information (such as operating parameters), collected during the construction and validation of machine that can be used for improving maintenance activities as well as guaranteeing the well-functioning of machine.

Use and maintenance manuals are crucial for organizations wanting to optimize asset management. Someone outlines how to complete tasks related to proactive maintenance, reactive maintenance, safety inspections, standard operating procedures (SOPs), inventory management, and more.

A maintenance bill of materials lists the replacement parts and/or materials that comprise an asset, such as a piece of equipment. These items must be repaired or replaced to keep the asset in working order. Hence, a maintenance bill of material (BOM) is a complete formally structured list of the components making up a technical object or an assembly. The object numbers of the individual components as well as their quantities and unit of measure are also included.

In order to obtain a well-structured bill of materials filling with all relevant information, two tools can be consulted or created if they are not owned by the company:

- spare parts master data (spare parts coding) used to univocally determine and identify each spare parts as well as to monitor e control the inventory level of each part.

The coding is usually alphanumeric type and can be reported on a ID plate also containing a bar code so as to allow optical reading through an automatic system.

The alphanumeric coding contains:

• The serial number of the piece;
• A chronological reference;
• A reference of a functional type in relation to its use.

Spare parts can be classified into two families:

• Those used in case of systematic breakdown;
• Those used in case of accidental breakage.

For those belonging to the first group, it is possible to estimate the necessary stock based on the MTBF value. For the second group it is better to rely on the statistical value.

- The Machine Breakdown Structure is a decomposition of the machine. The various functional groups and the relative components are identified. This decomposition aimed at identifying and codifying above all the final elements since they are are the components objects of maintenance. Components can also be classified according to their criticality. The most suitable maintenance will be applied to a component subject to maintenance according to the criticality of the machine and the impact of the component on the reliability of the machine itself.

In order to control and continually monitor operating parameters of a machine, control chart can be used. The trend of some critical functioning parameter can support the management to define the health status of a machine as well as to improve their values setting related to the work and use of the machine. Monitoring critical parameters can help also to define a condition-based maintenance strategy.

To perform a FMECA analysis different tools and technique can be used as creative ways of looking at causes of problems. FMECA should be combined with other analytical tools such as fault tree analysis for example. Once the predominant causes are identified, then tools like the Ishikawa diagram or Fish-bone Analysis 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 keep a history failure files of a machine, a machine ledger can be used. It is a large data collector, through which every maintenance intervention, either scheduled or not, is collected. This tool allows handling different maintenance information and data.

To create standard documents on maintenance activity should be performed different methods can be implemented: a standard maintenance procedure (SMP) for example is a detailed list of written instructions that describes how a maintenance task is to be performed.

A maintenance SOP (standard operating procedure) 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.

For defining best practice in the safety fields a security matrix technique can be used. A security matrix helps to define and standardize safety measures.

The check-lists, are verification tools that allow the operator to be sure that he has not forgotten or skipped a critical step during the application of a maintenance procedure. So, the checklists reduce the risk of neglecting important steps in the execution of any activity. Moreover, following checklists ensure the respect of regulatory standards, improve workplace safety, and improve communication between departments.

A Preventive Maintenance (PM) Calendar is a document that contains a list of tasks that need to be done on a regular basis in order to keep equipment up and running.

To set equipment improvement programme first of all data and information collected in all the database have to be examined. Several techniques can be implemented to support the improvement programme definition like: Plan do check act cycle, the 5S (Sort, set in order, shine, standardize, sustain), the 5R (refuse, reduce, reuse, recycle, rot.), value stream map and more. The aim is to promote the continuous improvement trough the analysis of in order to analyse the maintenance process, identify the waste and efficiencies, plan the improvement and measure the benefits achievable.

Finally, the visual management technique can be used for all informative flows with the aim to use visual graphs to facilitate the comprehension and have a simple and immediate visualisation of information.

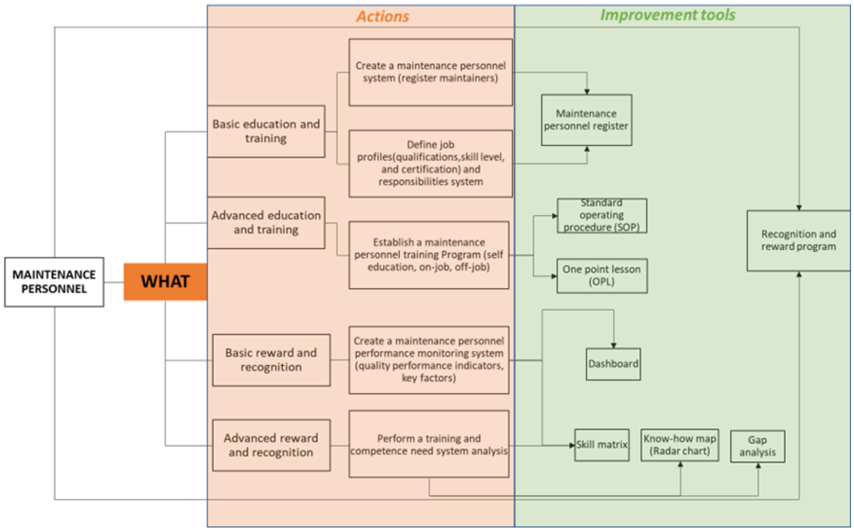


Figure 30: TPM tools for Maintenance personnel DB creation

In the figure 30 are showed the TPM tools for Maintenance Personnel DB creation.

Maintenance personnel register is the simplest but the most important document. It contains all information related to maintainers as : name, age, qualification, certification, responsibilities etc. The aim is to have a list of all employee involved in the maintenance process.

A key factor contributing towards maintenance efficiency and effectiveness is a well-structured training program for all employee to have workers able to perform maintenance activities properly.

The tools to transfer knowledge in a quickly and effective way are One-point lessons and lessons learned.

One point lessons (OPLs) are short, visual instructions that guide frontline workers on how to perform a single, relatively small action or task.

OPLs are closely related to standard operating procedures (SOPs), but the two should not be confused.

Where SOPs can be long, text-heavy documents, one point lessons have the following characteristics:

Short: an OPL is usually only a single page and creating one should take one hour max.

Visual: OPLs contain lots of images (the rule is 90% images, 10% text)

Focused: OPLs are limited to a single action or task. It can therefore be a part of an SOP, clarifying one of its steps.

In short, an OPL should be simple, concise, and precise, so that operators can put its guidelines into practice effortlessly.

As OPLs deal with very specific actions, they should also be easy to find.

They should, for example, be hung near the areas they apply to or be categorized according to a machine's error codes.

To improve a performance, there is need to monitor.

KPIs allow effective assessment of personnel and skills. In this way it is possible to determine if all personnel are sufficiently trained or if action is needed. Some KPIs that can be used for maintenance personnel are:

• Training gaps emerging from the skill Matrix: identifying training gaps allows the planning of training activities. The goal is to close the gaps and thus increase the skills of the staff;

• Losses (€) due to lack of training/skills: Lack of training or skills of maintenance personnel can lead to costs. For example, a failure that has occurred on a machine can also be due to a lack of knowledge.

• Savings (€) due to the recovery of gaps: by filling the gaps, the company increases the knowledge of the operators. An operator who is aware of his actions is able to operate more efficiently and also guarantee savings.

Linked to the monitoring system, there is a need then to fill any training gaps. 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. The goal, therefore, will be to manage these skill matrixes and close the gaps, which means having increased the knowledge of the personnel. This should create more capacity and security. These training plans must in any case be reviewed periodically because some could lose knowledge over time if they are not continuously stimulated.

The final scope is to consider who has the required knowledge and skills to perform maintenance properly.

Finally, in order to make maintenance personnel feel an integral part of the company contributing to the grow of the company, there is a need to recognize workers added value through a recognition program with prizes for anyone who reaches a milestone. In this way the worker is encouraged to always do his best.

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 documents for 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 contents. The defined improvement is therefore 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.

For example, 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 in order to fill work order document and report with data in real time.

A logical procedure for determining maintenance management information practices maturity level through the M^{3}AIN4SME model.

Much literature has been published on the critical factors for implementing IT in SMEs, through them some authors proposed actions, strategies, guidelines to avoid an unsuccessful implementation of IT and suggesting, through a descriptive and literature-based approach how face these critical factors. In a systematic review of Chouki et al 2019 based on 132 selected studies, 18 barriers categorized according to internal and external parameters have been identified. They provide a scientific and managerial implications and guidance for the adoption of IT in SME. Sarosa et al., 2003 proposed a guideline to assists SMEs in adopting IT. The guidelines are formulated based on existing literature and authors' experience in assisting Indonesian SMEs. In Wienker et al., 2015 the authors focused on understanding the reasons of the low success rate of IT implementation and outlines the essential elements that must be included to ensure a success. Emphasis is put on the need to gain and retain the support of top management to overcome the barriers to change by convincing them that such support makes good business sense. It provided guidelines, but they are general and not specific for a successful IT adoption in maintenance, moreover they are not focused on the real needs of the company.

Moreover, Hamdan, A. R., et al., 2016, states that to ensure a successful implementation of IT among SMEs, an IT readiness model for SMEs could be one of the potential researches to be carried out.

Some works can be seen as such contribution. Grooss 2024, offers a conceptual tool for assessing the digital maturity of maintenance processes in SMEs and identifying areas for improvement but not suggesting actions for improve the digital maturity. In Kans 2012 a number of criteria which are crucial in decision making for selecting a MMIT application are suggested. The model proposed assist the company in the selection of MMIT applications but do not give a measure of their current maturity.

An important aspect to consider for being able to take full advantage of IT is the matching of IT functionality to IT requirements. In Kans 2010 [28], the existence of functionality gaps in maintenance management IT has been investigated. This work sheds light on the needs of defining a procedure for IT requirements for maintenance management or for connecting maintenance management needs with IT.

Kans et al.2007, confirms that no articles were found within the area. Moreover, this procedure must include the assess of the current state of maintenance information management. Basically, in order to determine the IT needs in maintenance for a SME, the assessment of the current state on the actual maintenance management information practices is necessary (as suggested also by Kans et al., 2007).Therefore, by including the model developed a procedure was designed.

It is (Figure 31) able to provide support and guidance for assessing the maturity of maintenance management information practices and the consequent definition of improvement actions. The procedure has been designed based on the literature analysis trying to fill the gaps and lacks emerged. It encourages SMEs to assess their organizational, managerial and technological capabilities within the management of maintenance information, promoting a more realistic evaluation of their digital readiness. Drawing upon a deep and accurate analysis of operative level of maintenance process, this procedure transcends the limitations of the existing maturity models, identifying the informative infrastructure necessary to improve the overall maintenance process. The scope is to support companies in determining IT needs and in introducing a suitable informative infrastructure.

The procedure consists of 5 steps. First, the definition of the current state of maintenance should be designed. The main maintenance concepts applied on the company in terms of maintenance strategies adopted, maintenance organizational hierarchy arranged, available information resources, and how these are utilized are important aspects to highlight in the designing of the current state. The initial step involves comprehending the context on the IT management of the company as the literature highlighted the needs for SMEs to adopt a system suitable for their needs.

Then the purpose and goals of maintenance in terms of IT needs should be identified. This step is achieved examining the company’s data foundation and information system infrastructure if used, to pinpoint the real needs and in particular if the current systems' functionalities satisfy their work procedure.

When the current state of maintenance has been defined, the maturity and improvement model M3AIN4SME developed in this project can be applied to find out the weakness and strengths points on maintenance management information practices. The application of the model aims :1) provide a clear and customized measurement able to quantify the maturity of Maintenance Information maintenance practices in industrial context; and 2) To define actions enhancing maintenance practices. Based on the measure of the ML, the roadmap with the definition of the improvement actions is proposed.

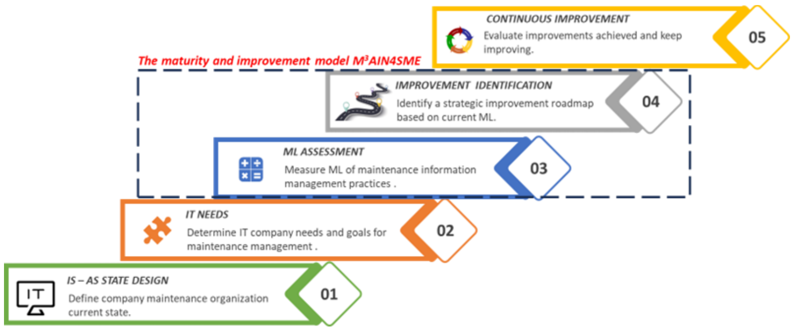


Figure 31 Procedure for determining maintenance management information practices maturity level

The company can prioritize the actions, which can decide how and what actions to undertake to reach a higher ML. Finally, continuous improvement must be enabled to achieve a high maintenance effectiveness standard more than once.

Chapter II

III Chapter: Case study

In this section, the procedure proposed (Figure 31) has been applied and tested in a manufacturing company. The results of all the steps are detailed in the next subsections.

AS-IS state design

The company operates in the automotive sector, it produces plastic parts obtained through a plastic injection molding process. The production site under analysis consists of a molding department equipped with about 40 injection presses, operating on three work shifts, with the presence of about 60 operators employed in the department per shift.

As expected by the procedure, the AS IS maintenance process was analyzed, mainly based on breakdown maintenance interventions. In Figure 32, a summary of the AS-IS maintenance process is shown. Maintenance is one of the areas that depend on the plant manager. The maintenance manager reports directly to the plant manager. The maintenance service is managed by a team of two maintainers per shift. The team is made up of a maintenance technician with mechanical specialization and an electrician. Another team made up of two maintainers joins the 10-18 time slot. The maintenance teams deal exclusively with breakdown maintenance during the working hours of the production department; some scheduled maintenance activities are carried out during periods of plant downtime.

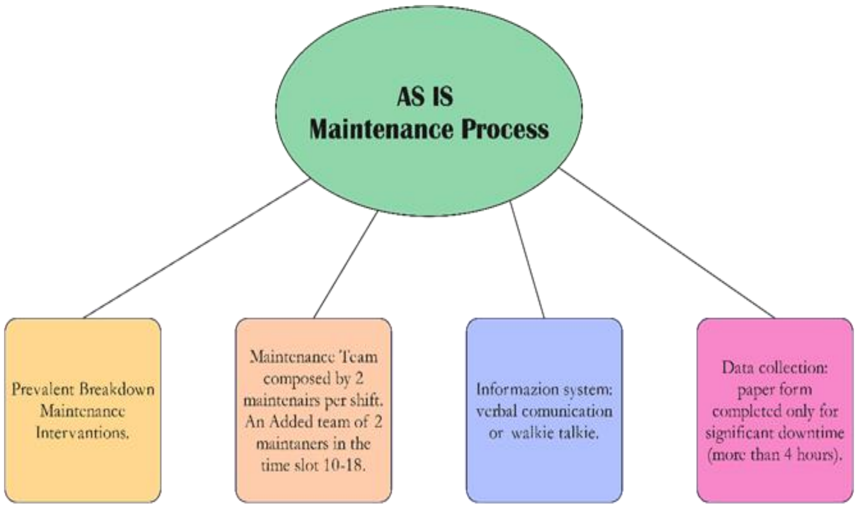


Figure 32: AS-IS state design

A specific information system is not used yet for the management of maintenance activities; the main communications are made verbally also through the use of walkie-talkie devices. The interventions are carried out using a standardized written form in order to keep track of the machine failures and to build machine failure history files. However, the form is completed only for interventions that produce a significant machine downtime, e.g., more than 4 hours.

IT Needs

The company had information systems for the management of maintenance processes, but due to the lack of standardization, the operations to allow the correct functioning of these systems were too time-consuming. Therefore, the information managed by them was fragmented, and the documents incomplete. In table 2, presents the primary critical issues related to the maintenance process information systems and the main digitalisation requirements identified within the company.

Table 8: The main critical issues relating to information systems in maintenance processes.

Summary of critical issues encountered	IT NEED	Expected advantage
Lack of a standardized and traced procedure for requesting intervention.	Introduction of clear and defined procedures and tools for requesting maintenance intervention.	Improved quality of information collected.
Maintenance intervention form filled out only for some interventions and often not complete and precise.	Digital maintenance intervention form for "mandatory" compilation and automatic collection of data relating to individual interventions.	Increase in the quality of information collected relating to faults and malfunctions of the machine fleet.
High variability and a load of extraordinary maintenance requests.	Thanks to a more efficient management system, develop preventive and predictive maintenance techniques.	Reduction in the frequency of unexpected breakdowns.
Difficulty in finding and consulting procedures for interventions and machinery diagrams.	Digitization of procedures and machine diagrams.	Speed up the retrieval of machine diagrams.
Due to a lack of spare parts, some maintenance interventions are only partially completed. Additionally, there is a lack of tracking for these interventions.	Digitize information tracking, taking into account partial interventions.	Improve traceability of incomplete maintenance interventions to complete them as soon as the spare part becomes available.

Recording maintenance work is one of the main critical issues encountered. Maintenance collection forms are filled out only for major stops (more than 4 hours). This implies that all information relating to interventions of shorter duration is not collected and consequently cannot be analysed. The forms are paper and the process of transcribing them into spreadsheets takes a long time and is not value-added, which leads to the fact that they are often not transcribed correctly. The analysis and processing of the electronic register of machine faults are also very expensive in terms of time and energy. Therefore we are often discouraged from carrying out such analyses. The current data collection method does not allow us to analyze the real causes that affect maintenance inefficiencies and therefore production. For example, this system does not allow us to establish exactly how long the machine was stopped for the maintenance to arrive and take charge of the problem, what the time was for the actual intervention, and what the time in which production takes over the functioning production unit and puts it back into production. This aspect plays a significant role in the current difficulty of calculating and monitoring the performance of the system. The lack of an information system to support maintenance management processes represents a highly critical element at present. In most cases, the request for maintenance interventions arises randomly and unpredictably, which prevents it from being possible to level the loads on the maintenance workers. For this reason, maintenance workers are forced to manage high peaks of work at times and inactivity at others, in which, however, they cannot carry out other activities because they must guarantee full availability and availability in the event of a request for intervention. The absence of a detailed and precise preventive maintenance process translates into production units subject to frequent and numerous breakdowns, which often involve the need to manage high peaks of activity: many breakdowns in the same time interval. The production and maintenance departments are, therefore, more exposed to situations of agitation and fear because they are forced to manage unforeseen delays. Better management of the information flows of maintenance processes can contribute to implementing correct management of preventive maintenance policies which would allow a more balanced management of maintenance loads.

Another criticism is the inconvenience of consulting machine diagrams. The maintenance technician must go to the maintenance box every time to collect the diagrams, as they are not available on the machine or the technician's individual devices. Additionally, the diagrams are large and difficult to consult during production, which lengthens intervention time. Digitising these documents would aid the maintainer during consultation phases. Additionally, eliminating travel time to the maintenance box would significantly reduce intervention times.

In situations where the necessary spare parts are not available to complete a maintenance intervention, the maintenance technician may identify alternative and temporary solutions to repair the fault based on their experience. However, it is important to note that these alternative solutions may only serve as a temporary fix and could potentially lead to further issues down the line. Temporary solutions identified due to a lack of spare parts often remain in place even after the requested part arrives, which can trigger cascade effects and problems with other components of the machine. To prevent this, the digitalisation of information tracking should include temporary interventions, allowing for prompt completion of the intervention once the spare part becomes available again.

The download of spare parts from the warehouse information database is often neglected, particularly when the warehouse employee is absent. Maintenance workers are occupied with expediting the completion of the intervention and are unable to manage the collection of information related to the just-completed intervention. The implementation of a warehouse management system for spare parts can improve the availability of necessary components. This is achieved by maintaining precise accounting of the parts in stock and allowing for targeted reorders to be carried out.

A challenge arises during the mold maintenance process. The mold in need of maintenance is stored in the designated area after being dismantled from the press. This ensures that the issue is not overlooked and prevents the reassembly of a poorly maintained mold. However, this good practice conflicts with the size of the production plant, the number of molds, and the fragmentation of storage locations for the molds, resulting in a different problem: a lack of information on the location of the requested mould. It is difficult to determine the exact position of each mold, causing delays in identifying it. Moreover, there is no structured information process that enables the identification of molds undergoing maintenance and those that are ready to be used. This information is crucial during the production planning phase. A more precise system that indicates the position of the mold and its maintenance status would expedite the setup process and enhance production scheduling.

Given the critical issues and the need for intervention in the company's current information systems, the maintenance manager suggested adopting an information system maturity model for maintenance processes. This model will enable the development of a targeted and effective plan to achieve a restructuring of maintenance processes, along with the introduction of digital technologies that can significantly improve process efficiency. The decision to use the maturity model was based on past experience. In the past, the implementation of a system for managing inflexible maintenance processes did not consider the actual needs of small and medium-sized enterprises and, as a result, did not yield any tangible benefits.

III.1 Assessment model results

Through the application of the developed maturity model, it was possible to define the actual state of the firm maintenance process. The model defines the global maturity level of the maintenance process, and the maturity level for the different database analyses (EQUIPMENT, MAINTENANCE PERSONNEL, WORK ORDER, and REPORT), as shown in Figure 33.

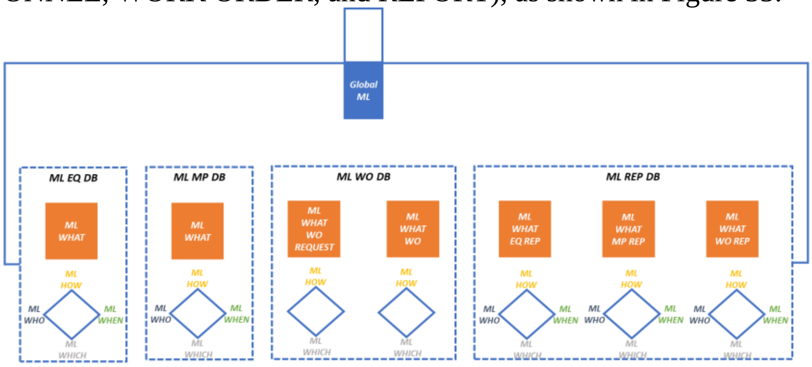


Figure 33 Summary of the ML results

The global maturity level was 1.86/4. The maturity levels of each database as well as each evaluation criteria (WHAT, HOW, WHEN, WHICH, WHO), were described below.

For the EQUIPMENT Database (EQ), the maturity level was 1.80 out of 4.0 (Figure 34). The results highlight that some documents and files concerning the physical and technical state of the machines and some data relating to machine failures and maintenance practices are available within the organization. Machine-related information management practices appear to be evolving (WHAT = 2.50/4). Most documents are unique, consistent, and reliable regardless of how long they are stored or how often they are accessed. The information available is not redundant. Moreover, for some documents, the definition of standards is still missing (HOW=3.33/4). Responsibilities are well-defined and assigned (WHO= 4.00/4). Most machine maintenance files and documents are updated in a long-term period, within an upgrade period greater than one year. This means that the company makes improvements over the long term. The weakness is represented by the tool used for the collection and management of maintenance documents which consists of an autonomous system not integrated with the other systems (WHICH= 1.67/4). In particular, it is a standalone application for the management of maintenance interventions, and for the collection of other documents, the main collection system is paper-based.

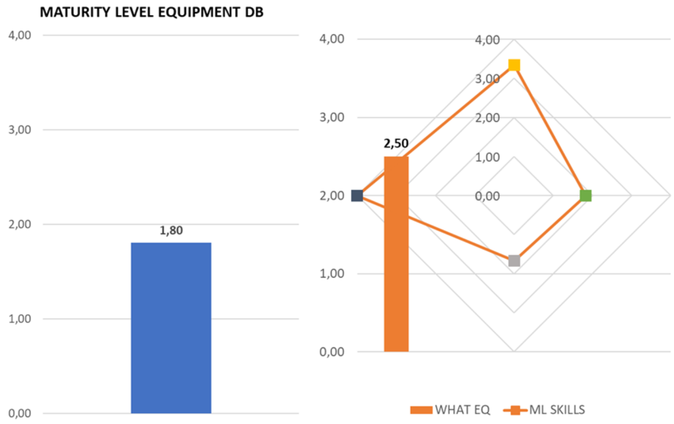


Figure 34 Equipment DB results

For the MAINTENANCE PERSONNEL (MP), the maturity level was 3.0 out of 4.0 (Figure 35). The documentation for the management of maintenance personnel is well-defined and systematized within the organization. The possible documents are available and can be consulted by the staff on shift (WHAT and HOW=4.00/4).

The update period is based on the long term. This may mean that the company makes improvements over the long term (WHEN= 2.00/4).

The weakness point is always represented by the WHICH, i.e., the support tool for the registration, maintenance, and updating of these documents (WHICH= 2.00/4). The tool used to collect most of the maintenance personnel documents is an autonomous maintenance management system that is not integrated with other systems. This can lead to various inefficiencies, especially in the definition of the most suitable personnel for carrying out maintenance operations. This confirms that the company is in an early stage regarding technological transformation.

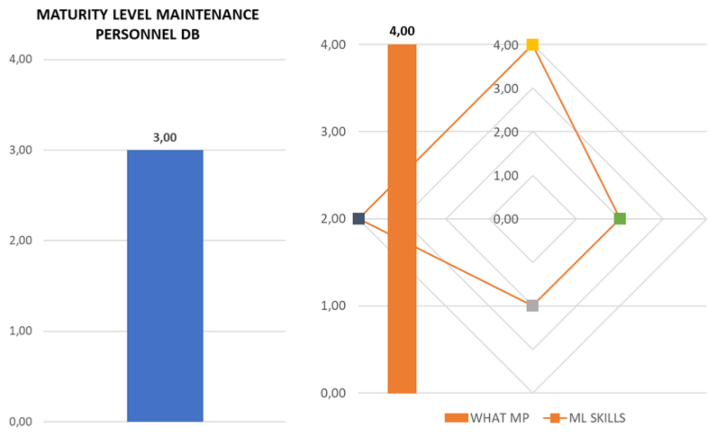


Figure 35 Maintenance Personnel DB results

For the WORK ORDER database (WO), the maturity level was 0.94 out of 4.0 (Figure 36). The results underline the missing of request for a maintenance work order, whether it is emergency, preventive/planned. Having a work request system is a requisite for efficient and effective planning and scheduling of a maintenance operation. In fact, a work order request should contain all the information needed to decide when to carry out an intervention, who has the right skills to carry it out correctly, and when, congruent with production, to carry it out. In addition, the work order request allows the collection of some useful information for the classification of failures, for example, the visible effect of a failure for which intervention is required.

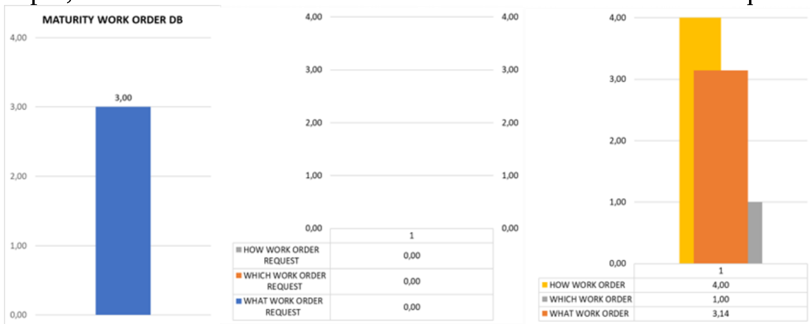


Figure 36 Work order DB results

On the other hand, the company has an excellent system for managing work orders. The work order provides all the information useful to the maintenance technician to be able to carry out the intervention efficiently (WHAT=3.14/4) with the definition and sharing of a standard (HOW=4.00/4). The weak point, also in this case, is the tool in use for the management and keeping all information regarding the work order. The tool in use is properly (WHICH=1.00/4). This approach involves a series of wastes, furthermore, the information cannot be crossed with data included in the other databases, compromising the possibility of carrying out relevant and meaningful analyses.

The database relating to the Report has the aim of collecting, analyzing, and archiving all the data necessary to document and improve the maintenance process. All raw data internal to the maintenance process (like corrective and preventive maintenance reports, spare parts data, tools used, operation execution time, costs, etc.) or external to the maintenance process (production data) must be validated and kept in an appropriate database. To be usable, this data must be validated and classified according to its type and characteristics.

The collected reports must be periodically analyzed to formulate indicators and usually must be compared with the defined expected values/objectives in order to identify the area where improvements can be made and also to monitor and evaluate the effectiveness of maintenance actions in a continuous optimization cycle.

Therefore, the database report must include the collection of data and feedback information from the equipment, maintenance personnel, and work order.

For the REPORT database, the maturity level was 1.69 out of 4.0 (Figure 37).

The assessment results show that the company creates almost all the reports relating to the equipment, recording and monitoring a lot of information (WHAT EQ=2.71/4). Related to maintenance personnel and work order, the company does not have an efficient and effective reporting system (WHAT MP= 2.00/4, WHAT WO=1.60/4).

Monitoring and measuring the performance of maintenance personnel are necessary to manage the tasks and skills of each one with the aim of promptly training internal human resources who must have the levels of competence and certification necessary to carry out maintenance activities.

The analysis of maintenance personnel reports must help to identify and eventually define maintenance services performed by external companies that have the necessary levels of competence and certification to perform maintenance activities.

Even for the work order report management system, the company does not have an efficient database. Technicians often informally describe or record information or do not record it at all, resulting in inconsistencies and/or unreliability in the data.

Some of this data (related to the performance of a work order) can be difficult to calculate, e.g., diagnostic time, since it is difficult to calculate when the diagnosis stops and the resolution of a problem begins, but this operation time decomposition allows to highlight the waste in carrying out the maintenance intervention.

All these data have to be collected and analyzed in order to identify the real problems and formulate an appropriate set of corrective actions aimed at firstly improving the whole maintenance process and especially the work order system, works execution, system availability, work backlog, as well as the quality of work performed.

In any case, the company demonstrates that it has developed a standard for the collected data (HOW EQ, MP, WO=4.00/4), and the analysis is carried out constantly (WHEN EQ, MP, WO=4.00/4), The weakness point remains the tool used for data collection (WHICH EQ, MP, WO=2.00/4), therefore the technological capabilities of the company. The support system used is not integrated and synchronized with all company functions, leading to a series of inefficiencies.

Figure 37 Report DB results

III.2 Improvement identification

Based on the assessment results, the improvements are defined along horizontal and vertical directions as provided by the model.

III.2.1 Horizontal Improvement

The Horizontal improvement is designated 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. In this case, the value is included in the interval 2-3 out of 4.

In summary, most data and information are collected but not systematized and well-defined at all. Almost all files regarding the physical and technical condition of the machines and all machine failure and maintenance data are accessible within the organization. Almost all the documents and/or systems interested in the management of "maintenance personnel" are arranged by the organization.

The company has a simple and not very efficient maintenance work order management system, as a work order request is not used.

It uses a work order which provides the earliest and promptest information to the maintenance technician to perform the maintenance intervention at 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.

The actions to enrich the informative infrastructure are shown in Figure 38 (the green and red stamps represent the efforts required and benefit achievable related to the qualitative scale defined in the section 2).

In the next subsections, a description of the actions suggested to the company to complete the ML 2 and 3 are detailed for EQUIPMENT DB, WORK ORDER DB, AND REPORT DB. No action is required for the MAINTENANCE PERSONNEL DB.

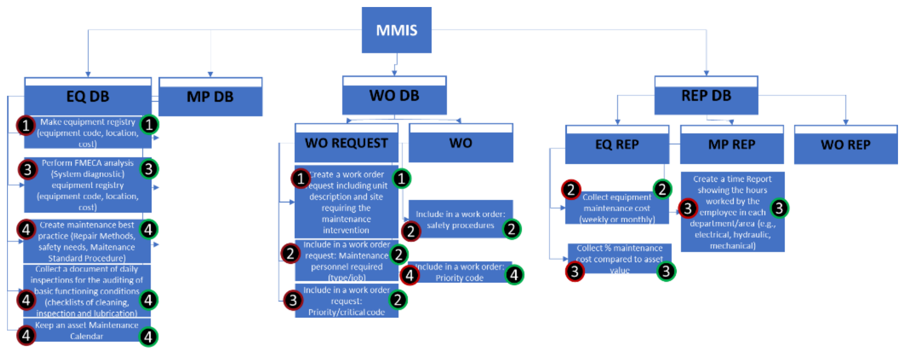


Figure 38 Horizontal Improvement

EQUIPMENT DB

To reach level 3, the step suggested to the company related to EQUIPMENT DB are the following:

Make equipment registry (equipment code, location cost): The definition and structuring of a machine register are necessary to analyze and aggregate information regarding the maintenance activity and the performance of the machines. A useful register has been provided to the company in order to correctly collect the information, the register, therefore, contains the most important information to be managed, such as the name of the equipment, name of the manufacturer, name of the model, serial number, position, etc.

Perform FMECA analysis (system diagnostic) equipment: FMECA analysis is a very useful method to determine the impact that a potential failure would have on a product or process and evaluate the risks. The detailed steps for the implementation of this analysis method in company processes and all the tools useful for carrying out the analysis were provided, such as Equipment ranking, Pareto analysis, ABC analysis, 5W + H; Ishikawa diagram; Fault Tree Analysis.

WORK ODER DB

To reach level 3, the step suggested to the company related to WORK ORDER DB are the following:

Create a work order request including unit description and site requiring maintenance intervention: The work order system is a fundamental building block of any successful maintenance organization. If the work orders are not used, the organization cannot expect a large return on investment from the maintenance organization. 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. As the company doesn't use a work order request, the initial and more promptest information (that does not require a complex analysis and data crossing) has to be included like:

- Maintenance personnel required (Type/job)
- Priority/critical code of the intervention

Instead, for a helpful work order, the information that can be included are:

- Safety Procedures
- Priority code

REPORT DB

Large lists of information can take too much time to study by a manager, for this reason, it is essential to use the reports necessary to manage and periodically analyze to program the improvement interventions. For Equipment Report DB, the company has to include the following:

- equipment maintenance cost: (weekly or monthly).
- maintenance cost compared to asset value.

These reports give managers the opportunity to monitor assets' performance, identify the problems, and promote efficiency measures such as modification of maintenance practices or functioning of assets.

For Maintenance Personnel Report DB, the company has to include a time Report showing the hours worked by the employee in each department/area (es. electrical, hydraulic, mechanical).

This is one of the most significant reports that can be produced to analyze the maintenance organization. First, it summarizes the work performed in each department (line, building, cost center, etc.) by occupation. The summary should include the total resource spent. The second part should list the percentages of the total resources spent on the entire plant or facility and what percentage was used by each department. The final part should show what percentage of the work performed in each department was emergency work, planned work, PM work, or other, as monitored by maintenance managers. The time report ensures monitoring and measuring the maintenance personnel performance in order to manage the jobs and skills of each one with the aim to train in a timely manner the internal human resources who must have the necessary skill levels and certification to perform the maintenance activities.

III.2.2 Vertical Improvement

The actions regard HOW manage information, WHEN update, WHICH system use to hand, and WHO has the responsibility to control and analyze them (Vertical Improvement) for each DB, can be defined by stakeholders related to the step already reached (highlighted in the next figures with the green color) and mainly linked to their objectives and plans.

For EQUIPMENT DB (Figure 39), the improvement actions recommend making to complete information and standardize them. It is envisaged to gradually improve the frequency of information collection and to introduce the use of an information system, which at first can be stand-alone and then increasingly integrated with other company systems.

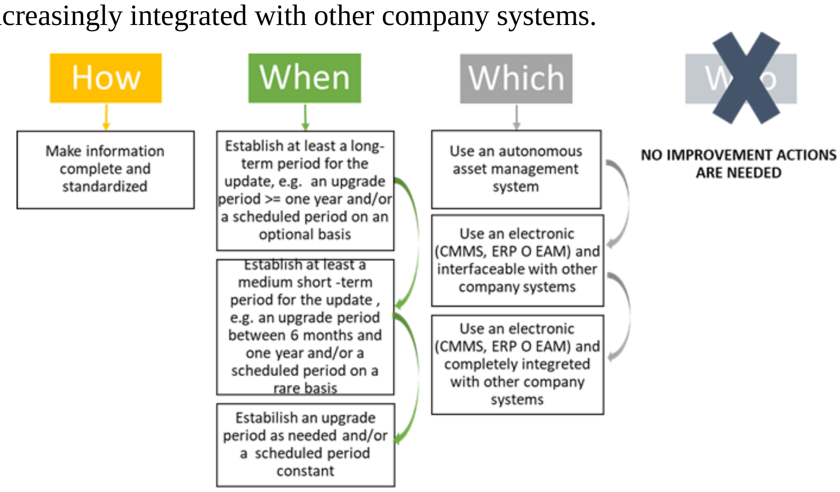


Figure 39 EQ DB vertical improvement

For the MAINTENANCE PERSONNEL DB (Figure 40), it is not expected any particular developments other than the use of a system interfaceable with other company systems.

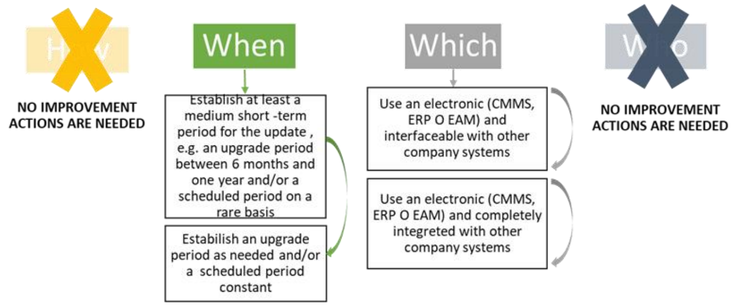


Figure 40 MP DB vertical improvement

The WORK ORDER DB (Figure 41) is the most critical element of the case in question, which requires substantial improvements.

The vertical improvement recommends the introduction of standardized word orders for each activity required for maintenance, as well as the implementation of an informative system to handle in a more effective way the maintenance work request and work orders. A work order is represented by the following steps: 1) a request is made, 2) the request has been reviewed by a planner, who decides that the work request is needed, 3) the planner has determined what resources are needed to perform the work 4)the work is entrusted to the necessary resources. The improvement actions recommend the implementation of work orders for both scheduled and emergency maintenance activities. Furthermore, work orders should affect not only the maintenance department but different groups of the organization, such as OPERATIONS, MAINTENANCE ENGINEERING, INVENTORY, PURCHASING, and ACCOUNTING.

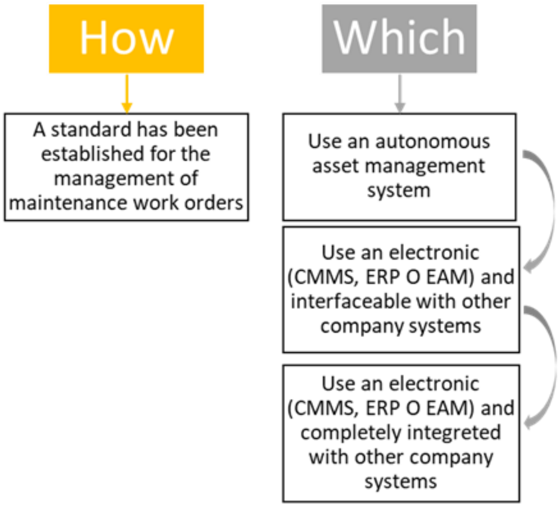


Figure 41 WO DB vertical improvements

For the REPORT DB (Figure 42), the improvement actions concern the tool to use for the creation of the report. The implementation of specific maintenance software allows the possibility to create valuable and helpful automatic statistics based on data collected. It is worth underlining that the improvements for the REPORT DB are strongly affected by the data and information available for the other DBs.

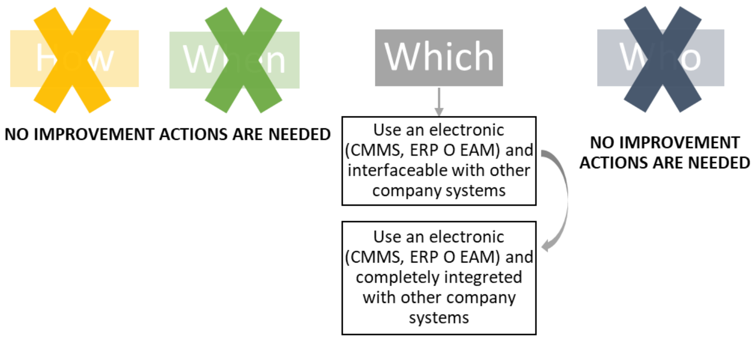


Figure 42 REP DB vertical improvements

As the weakest point is represented by the lack of a non-paper management system that supports the maintenance activities (WHICH criteria), a clear frame concerning the tools and devices supporting an informative system to improve IT skills was provided to the stakeholders.

The implementation of an informative maintenance management system (both it is autonomous and integrated), supported by advanced and intelligent data sources, allows for the collection of information without any effort by the operator, and all the information necessary for the correct maintenance process will always be available and accurate.

The introduction of an information system involves several benefits but also requires efforts in terms of costs and time. Therefore, the roadmap shows the different solutions, but depending on the company's technological capabilities and physical and financial resources, the company can decide the next step to take to improve its level of maturity.

The effort required to implement an IT involves very high costs as it is an innovative software that makes use of advanced and intelligent data sources at a high cost.

In general, the costs for implementing the CMMS are:

- Cost of the software;
- Cost of hardware;
- Personnel training cost;
- Consulting cost;
- General expenses (include management costs, etc.);
- Specific staff training is required.

The hardware part could or not consist of devices such as PC; Smartphones; Tablets; Smartwatches; Smart glasses. The introduction of these devices, among other things, involves problems related to data security and privacy and often causes a rejection by employees as they are frightened by the change.

An IT system, however, has the ability to collect and store information in an easily searchable form and provides the best information to operations and maintenance managers to perform proper maintenance tasks and operate equipment efficiently.

The notification of the work order request and the compilation of the work order are immediate, i.e., the information is transferred to the operator in real-time. In fact, the system allows to automate the generation of a work order request and a work order. A common maintenance software provides a dashboard with several fields to be filled in with the appropriate standardized information. Often, however, it is not the operator who enters the appropriate information, but the process is supported by devices (like sensors, wearable devices, and tablets..) whose technology allows the information to be detected automatically.

In the table below, a comparison between the more commonly used device to support an informative system was provided.

Table 9 : Main features of common devices to support informative system

Device	Main features
PC	No connectivity and PC battery life problems; No automatic transfer of data and information (manual entry with the possibility of errors); Not recommended for use in workshops characterized by hostile environmental conditions; Low usability: the device is not mobile and unwieldy; High purchase and installation costs
Smartphone	Medium/high usability: the smartphone is a handy and user-friendly mobile device Detects all basic information about the asset and provides photos or videos of the asset Low purchase cost and no installation costs. Asset information and data can be acquired and transferred automatically by scanning the QR code through the asset's smartphone camera. The battery life is not able to cover a work shift.
Smartglasses	Use completely, hands-free The information can be called up and compiled via voice command The maintenance instructions are shown during the task Use of virtual assistance to support the intervention The autonomy of the battery can cover a work shift; Detects all the information relating to the asset and the surrounding environment. Full Wi-Fi coverage is required; Real-time operator data and work order performance recorded Very high purchase cost. Specific staff training is required for the its use.
Smartwatch	Hands-free use; The device is equipped with LTE technology; Detects all the basic information relating to the asset and provides photos of the asset; Low purchase cost and no installation cost The information can be called up and compiled via voice command No staff training is required. The device is vulnerable to hostile working environments. Limited input and output capabilities (limited display to see documents)

III.3 Discussions and conclusions

The application of the procedure allowed for the assessment of the current state of the company's maintenance process and for the improvement in the management of information infrastructure. The global maturity level was determined, using the M3AIN4SME model. The maturity levels of each database (Equipment, Maintenance Personnel, Work Order, and Report) were also evaluated.

The company manages some documents and files related to the physical and technical condition of the machines and data on machine failures and maintenance practices. However, the management of machine-related information needed improvement, particularly in terms of standardization and integration with information coming from other repositories.

The documentation for managing maintenance personnel was well-defined and systematized within the organization. However, there was a need for an improved tool for handling personnel documents, which would enhance efficiency and effectiveness.

The company lacked a work order request system, which is crucial for effective planning and scheduling of maintenance interventions. On the contrary, instead, the existing work order system provided the necessary information for maintenance technicians to perform interventions efficiently.

There was a lack of an efficient reporting system. The data collection and management tools used were not integrated with each other, leading to inefficiencies and inconsistencies in analysis.

Based on the assessment results, improvement actions were proposed. Horizontal improvements focused on enriching the informative infrastructure, whereas vertical improvements addressed how to improve management practices.

Hence, for each database, specific improvement actions were recommended. These included creating an equipment registry, performing FMECA analysis for equipment, introducing work order requests, standardizing work orders, and implementing a well-structured reporting system.

The proposed improvements aimed to enhance the maturity level of each database and the overall maintenance process with the aim of introducing a suitable information infrastructure. The company was provided with a roadmap for the implementation of these improvements, considering its starting point, resources, and objectives.

The implementation of an information system was identified as a helpful solution for the company’s needs. It would allow for the collection, storage, and retrieval of maintenance information in a more efficient and accurate manner. It is important to acknowledge that implementing an information system involves costs and efforts, including software and hardware expenses, personnel training, and data security considerations. However, the benefits of an efficient and integrated information system outweigh these challenges, as it enables better data collection, analysis, reporting, and decision-making.

The maintenance department teams positively heard the results of the assessment and the steps to follow proposed by the roadmap. Therefore, the steps proposed for the achievement of level 3 of the horizontal improvements, envisaged for the EQUIPMENT, WORK ORDER, PERSONNEL, and REPORT DBs, were then adopted. In particular, a digital architectural model was developed which, by exploiting modern IoT technologies, would allow the collection of information relating to the management of the WORK ORDER, the Database that was most deficient among all. On the other hand, according to the vertical improvements, the roadmap provides that the maintenance department must organize an action program aimed at achieving the proposed objectives that can best meet the needs and peculiarities of the company. Therefore, the maintenance team gave a higher priority to improve the company's information systems because the WHICH criterion was more critical in all the databases used. The company has therefore envisaged the strengthening of the current information systems by developing the synchronization of the maintenance information systems with the company ERP and implementing a new IoT system that allows real-time monitoring of the production units.

IV Chapter: Future direction: data-driven maintenance

In this section, an overview on the technologies proposed in recent literature on smart and intelligence maintenance linked with the model proposed is presented for a future research direction.

The research study conducted by Macchi et al.2021, that stresses and highlights challenges and advice for information and data management, paved the way for this research.

The assessment and improvement model proposed, in fact, is an attempt to fill the gap highlighted by Macchi et al. 2021.

The authors underlined the development of a "*Map required data/repositories to be collected/connected, fundamental to support information and data assets 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 decision making process and where they should be stored (in which databases) with the aim to support small-medium companies to data standardization and formalisation by defining a common structure of maintenance data (a sort of taxonomy)

Nonetheless, when talking about information and data, the connection with current available technologies is advisable.

The advent of new technologies of Industry4.0 (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.

Furthermore, increasing easier access to data and stakeholders' awareness of the possibilities offered by data in the decision-making process drives enterprises to shift towards a new type of maintenance strategy called data-driven maintenance (Antomarioni S. et al., 2019, Basciftci B. et al., 2020).

Concerning small-medium enterprises, research fields of this work, the main problem is related to the lack of which intelligent information sources can be used to collect data and moreover, extract the value from collected data. It is obvious that the intense development of information and communication technologies and their applications in production systems, and the development of sensor technology (e.g. smart sensors that allow, among others, digital signal processing and wireless data streaming) have caused that the maintenance system managers, above all of large enterprise, have gained a lot new data sources. Due to implementation costs and IT competences, many manufacturing companies (especially small and medium-sized enterprises) still found it difficult.

Furthermore, concerning data analysis existing literature lacks detailed procedures and solutions.

To effectively introduce advanced data sources and apply the analysis of large data sets in maintenance systems, it is necessary to integrate skills and knowledge in information and communication technologies with engineering knowledge and expert knowledge. (Jasiulewicz et al. 2020)

In this frame SMEs are constrained in terms of skills and resources.

Therefore, below for each DB included in the model, the possible technologies to use as intelligent source of data, as well as the identification of advanced techniques to extract useful information and/or knowledge from data, are suggested. The analysis is complemented by authors' industrial experience in the field (Table 8).

Table 10 Intelligent data source associated to databases

Data/information related to:	***Data/information taxonomy (data mapping)***	***Data storage***	***Intelligent data source (key technologies)***	***Advanced data analysis techniques***
Equipment	Model proposed	Written documents/Databases/Cloud services	System information management, Cloud-connected sensors, digital twin, simulation, tablets with smart software, smartphones.	Fuzzy logic, neutral networks, evolutionary algorithms, supervised and unsupervised machine learning
Maintenance personnel			Wearable devices, Virtual reality, augmented reality, tablets with smart software, smartphones	
Work order			Tablets with smart software, smartphones, virtual assistant	
Reports			Cloud-connected sensors, digital twin, simulation, tablets with smart software, smartphones, Wearebale devices, Virtual reality, augmented reality, System information management.	

By using sensors embedded in machines, equipment's condition and overall operational state can be monitored in real time and all relevant data can be captured. The data can then be analysed to predict for example when failure events will occur.

The digital twin allows to send data from the operational level in real time, and this allows you to create current virtual simulations of real machines (real-world machines) in order to predict for example Remaining useful life or to decide about changing in the production lines, to evaluate new machine investments, to introduce new methods and standards.

Wearable devices, AR, and VR and virtual assistant can support maintenance technicians to properly perform repair and maintenance activities, as well as, collecting a large set of data automatically on maintenance personnel. These technologies allow moreover to support the training activities.

Tablets with smart software, smartphones can be viewed as virtual assistant that can support maintenance technicians to make right decisions, to perform repair activity providing all the needed documents/information.

The use of intelligent data source, hence, allows to have data and information always up to date; time and cost saving, error rate reduction, knowledge is retained in the system and not in people, improving the efficiency and availability of production equipment, flexibility in approaching customer requirements. Moreover, data are collected automatically and in real time.

In this scenario, the data may be widespread in the company, stored in different repositories and formats. Some data may come directly from sensors, as variables monitoring a specific failure mode of the asset, or from local or cloud-based databases, as work orders or events the asset underwent, or even from specific software tools, as the technical drawings of the asset/asset systems or, as other case, the procedural descriptions of maintenance actions.

To manage different data format Macchi et al 2021 suggest to create an IoT infrastructure to connect all different data source, combining all data and estract knowledge from them.

Data analysis techniques allow to predict upcoming issues in an equipment and system, support decision making processes (on investments, changes of service strategy ..) evaluating different scenarios. This is the future direction towards which the most advanced industrial companies are moving.

V Chapter: Conclusion

Information management is the most critical issue amongst 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 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.

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 decision making process and where they should be stored (in which databases) with the aim 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, with the aim of adopting a maintenance system suitable to their maturity and organisation. Starting from the strengths and weaknesses points highlighting 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.

In conclusion, the proposed procedure and maturity model provides valuable guidance for SMEs and other companies seeking to enhance their maintenance management information practices. By following the defined steps and implementing the recommended improvements, companies can improve their maintenance effectiveness, achieve higher maturity levels, and leverage the benefits of information technology in their maintenance operations. Continuous improvement should be embraced to ensure the sustained growth and competitiveness of businesses in the dynamic industrial landscape.

V.1 Study limitations

While the proposed study offers valuable insights and recommendations for assessing the maturity of maintenance management information practices, there are several limitations that should be considered, that represents the natural evolution of the study.

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; Analytic Hierarchy Process (AHP) approach, based on the expert opinions, will be used to set the weights expressed in the mathematical formulation of the method.

The study primarily emphasizes the importance of information management practices and the use of IT systems. However, it may not fully address the broader technological aspects of maintenance in the context of Industry 4.0, such as the Internet of Things, data analytics, or artificial intelligence. Further research could explore the integration of these advanced technologies into the maturity assessment framework. While the study acknowledges the efforts associated with implementing IT systems, it does not provide a comprehensive cost-benefit analysis. Considering the financial constraints faced by SMEs, a more thorough evaluation of the economic implications and return on investment (ROI) of adopting and integrating information systems would be beneficial. The study offers a snapshot assessment of the current state of maintenance management information practices and proposes improvement actions. However, it does not provide insights into the long-term sustainability and continuous improvement of these practices over time. A longitudinal perspective would enable a better understanding of the evolving nature of maintenance management and the impact of implemented improvements.

Moreover, further research and validation studies are needed to verify the effectiveness and applicability of the model in different contexts.

Study, formalisation and integration of the interrelations and dependencies among the DBs and the informative contents of each one to, for example, automatically detect possible inconsistent responses.

Addressing these limitations and conducting further research in these areas would contribute to a more comprehensive understanding of maintenance management information practices and facilitate the development of effective assessment models and improvement strategies.

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Appendix A

	Lev.0-1	Lev.1-2	Lev.2-3	Lev.3-4
WHAT EQUIPMENT	Some files regarding the physical and technical condition of the machines are available within the organization. The information management practices regarding the equipment are really basic.	Some files regarding the physical and technical condition of the machines and some machine failure data are available within the organization. The information management practices regarding the equipment are really basic.	Some files regarding the physical and technical condition of the machines and some machine failure and maintenace data are available within the organization. The information management practices regarding the equipment are increasing.	All files regarding the physical and technical condition of the machines and all machine failure and maintenace data are available within the organization. An improvement programme is prepared by the company. The information management practices regarding the equipment are the best in class.
HOW EQUIPMENT	Most machine maintenance equipment files and document are not readily available. The methodological skills of the company are low	Most machine maintenance equipment files and document are available but not complete and standardized. The methodological skills of the company are low	Most equipment maintenance files are unique, consistent and reliable regardless of the storage period or the frequency of accesses. The information available are not redundant.	Most equipment maintenance files are complete, standardized, well organized for access and retrieval. The information available is significant and correctly managed.
WHICH EQUIPMENT	The support used for the collection of most data is paperly. This approach demonstrates poor company technological capabilities which leads to waste of resources and many inefficiencies	The support used for the collection of most maintenance 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	The support used for the collection of most maintenance files is an eletronic software that can be interfaced with other company systems (for example Enterprise Asset Management (EAM) or CMMS or ERP). The software includes more	The support used for the collection of most maintenance files is Electronic (CMMS, ERP O EAM) and completely integrated with other company systems. It is a maintenance application system that is completely integrated with all

	in data and information management.	maintenance interventions. The company's technological skills appear to be in an initial phase.	features than an autonomous management system and this demonstrates the increase of company technological capabilities with a reduction in waste and inefficiencies towards an integration, albeit initial, between different functions.	company's system. There is a complete exchanging data/information between all company systems. This allows the company to have perfectly synchronized processes and achieve excellent performance. High degree of automation.
WHEN EQUIPMENT	Most machine maintenance files and documents are not updated when needed. Outdated information compromises the integrity and reliability of the database itself.	Most machine maintenance files and documents are updated in a long term period, within an upgrade period greater than one year	Most machine maintenance files and documents are updated in a medium-shor term period, within an upgrade period between one year and six months	Most machine maintenance files and documents are updated as needed
WHO EQUIPMENT	There isn't a specific employee who takes care of equipment maintenance files correct management			There is a specific employee who takes care of equipment maintenance files correct management
WHAT MAINTENANCE PERSONNEL	Very few documents and/or systems interested with the management of "maintenance personnel" are available within the organization. The information management practices regarding the equipment are really basic.	Not many documents and/or systems interested with the management of "maintenance personnel" are available within the organization. The information management practices regarding the equipment are really basic.	Most documents and/or systems interested with the management of "maintenance personnel" are available within the organization. The information management practices regarding the equipment are increasing	All the documents and/or systems interested with the management of "maintenance personnel" are available within the organization. The information management practices regarding the maintenance personnel are the best in class.
HOW MAINTENANCE PERSONNEL	Most of maintenance personnel documents and/or most of systems are not readily available. The methodological skills of the company are low	Most of maintenance personnel documents and/or most of systems are available but not complete and standardized. The methodological skills of the company are low	Most of maintenance personnel documents and/or most of systems are unique, consistent and reliable regardless of the storage period or the frequency of accesses. The information available are not redundant.	Most of maintenance personnel documents and/or most of systems are complete, standardized, well organized for access and retrieval. The information available is significant and correctly managed.
WHICH MAINTENANCE PERSONNEL	The support used for the collection of most of data is paperly. This approach demonstrates poor company technological capabilities which leads to waste of resources and many inefficiencies in data and information management.	The support used for the collection of most of maintenance personnel documents 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. The company's technological skills appear to be in an initial phase.	The support used for the collection of most of maintenance personnel document is an eletronic 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 the increase of company technological capabilities with a reduction in waste and inefficiencies towards an integration, albeit initial, between different functions.	The support used for the collection of most of maintenance personnel documents is Electronic (CMMS, ERP O EAM) and completely integrated with other company systems. It is a maintenance application system that is completely integrated with all company's system. There is a complete exchanging data/information between all company systems. This allows the company to have perfectly synchronized processes and achieve excellent performance. High degree of automation.
WHEN MAINTENANCE PERSONNEL	Most of maintenance personnel documents are not updated when needed and maintenance personnel systems are not scheduled when needed . Outdated	Most of mainetnance personnes documents are updated in a long term period, within an upgrade period greater than one year, and the maintenance personnel	Most of maintenance personnel documents are updated in a medium-short term period, within an upgrade period between one year and six months and the maintenance personnel	Most of maintenance personnel documents are updated as needed , i.e costantley and the maintenance personnel systems are scheduled as needed.

	information compromises the integrity and reliability of the database itself.	systems are scheduled on an optional basis	systems are scheduled on a rare or irregular basis	
WHO MAINTENANCE PERSONNEL	There isn't a specific employee who takes care of some/all maintenance personnel files correct management			There is a specific employee who takes care of some/all maintenance personnel files correct management
WHAT WORK ORDER DB work order request	The company does not have an efficient and effective maintenance work order management system. The company uses a work order request in which provides little useful information to the planner. The organization has poor methodological capabilities	The company does not have an efficient and effective maintenance work order management system. The company uses a work order request in which do not provide all the useful information to the planner. The organization has not good methodological capabilities	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. The organization has goodmethodological capabilities	The company has an efficient and effective maintenance work order management system. The company uses a work order request in which provides all useful information to the planner. The organization has the best methodological capabilities.
WHAT WORK ORDER DB work order	The company does not have an efficient and effective maintenance work order management system. It uses a work order in which provides little useful information to the maintenance technician to perform the maintenance intervention at the best. The organization has poor methodological capabilities.	The company does not have an efficient and effective maintenance work order management system. It uses a work order in which provides do not provide all useful information to the maintenance technician to perform the maintenance intervention at the best. The organization hasnot good methodological capabilities.	The company has an efficient and effective maintenance work order management system. 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 organization has good methodological capabilities.	The company has an efficient and effective maintenance work order management system. 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 organization hasthe best methodological capabilities.
WHICH work order management	The support used for the management of work order and/or work order request is mainly paperly. This approach demonstrates poor company technological capabilities which leads to waste of resources and many inefficiencies in data and information management.	The support used for the collection of work orders and/or work order request data is mainly 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. The company's technological skills appear to be in an initial phase.	The support used for the collection of work orders and/or work request data is mainly an eletronic 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 the increase of company technological capabilities with a reduction in waste and inefficiencies towards an integration, albeit initial, between different functions.	The support used for the collection of work orders and/or work request data is mainly an Electronic (CMMS, ERP O EAM) and completely integrated with other company systems. It is a maintenance application system that is completely integrated with all company's system. There is a complete exchanging data/information between all company systems. This allows the company to have perfectly synchronized processes and achieve excellent performance. High degree of automation.
HOW work order management	A standard has not been established for the management of maintenance work orders			A standard has been established for the management of maintenance work orders
WHAT EQUIPMENT REPORT	The company does not have an efficient and effective reporting management system. It creates very few reports related to the equipment whose records and monitors little data. This does not allow for the creation of	The company does not have an efficient and effective reporting management system. It creates not all reports related to the equipment whose records and monitors little data. This does not allow for the creation of meaningful	The company has an efficient and effective reporting management system. It creates almost all reports related to the equipment whose records and monitors many data. This allows for the creation of meaningful statistics that can support	The company has an efficient and effective reporting management system. It creates all reports related to the equipment whose records and monitors all data. This allows for the creation of meaningful statistics that can support the decision making process.

	meaningful statistics that can support the decision making process. The organization has poor methodological capabilities.	statistics that can support the decision making process. The organization has not good methodological capabilities.	the decision making process. The organization has good methodological capabilities.	The organization has the best methodological capabilities.
WHAT MAINTENANCE PERSONNEL REPORT	The company does not have an efficient and effective reporting management system. It creates very few reports related to the maintenance personnel whose records and monitors little data. This does not allow for the creation of meaningful statistics that can support the decision making process. The organization has poor methodological capabilities.	The company does not have an efficient and effective reporting management system. It creates not all reports related to the maintenance personnel whose records and monitors little data. This does not allow for the creation of meaningful statistics that can support the decision making process. The organization has not good methodological capabilities.	The company has an efficient and effective reporting management system. It creates almost all reports related to the maintenance personnel whose records and monitors many data. This allows for the creation of meaningful statistics that can support the decision making process. The organization has good methodological capabilities.	The company has an efficient and effective reporting management system. It creates all reports related to the maintenance personnel whose records and monitors all data. This allows for the creation of meaningful statistics that can support the decision making process. The organization has the best methodological capabilities.
WHAT WORK ORDER REPORT	The company does not have an efficient and effective reporting management system. It creates very few reports related to the maintenance work order whose records and monitors little data. This does not allow for the creation of meaningful statistics that can improve the work order management process. The organization has poor methodological capabilities.	The company does not have an efficient and effective reporting management system. It creates not all reports related to the maintenance work order whose records and monitors little data. This does not allow for the creation of meaningful statistics that can scan improve the work order management process. The organization has not good methodological capabilities.	The company has an efficient and effective reporting management system. It creates almost all reports related to the maintenance work order whose records and monitors many data. This allows for the creation of meaningful statistics that can improve the work order process. The organization has good methodological capabilities.	The company has an efficient and effective reporting management system. It creates all reports related to the maintenance work order whose records and monitors all data. This allows for the creation of meaningful statistics that can improve the work order process. The organization has the best methodological capabilities.
HOW REORTS	A standard has not been established for the management of maintenance reports			A standard has been established for the management of maintenance reports
WHICH REPORTS	The support used for the collection of report is mainly paperly. This approach demonstrates poor company technological capabilities which leads to waste of resources and many inefficiencies in data and information management.	The support used for the collection of report is mainly 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. The company's technological skills appear to be in an initial phase.	The support used for the collection of report is mainly an eletronic 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 the increase of company technological capabilities with a reduction in waste and inefficiencies towards an integration, albeit initial, between different functions.	The support used for the collection of report is mainly Electronic (CMMS, ERP O EAM) and completely integrated with other company systems. It is a maintenance application system that is completely integrated with all company's system. There is a complete exchanging data/information between all company systems. This allows the company to have perfectly synchronized processes and achieve excellent performance. High degree of automation.
WHEN REPORTS	Most of the maintenance reports are not analysed when needed. Outdated information compromises the integrity and reliability of the database itself.	Most of the maintenance reports are analysed in a long term period, within an analysis period greater than one year	Most of the maintenance reports are analysed in a medium-short term period, within an analysis period between one year and six months	The maintenance reports are analysed as needed.

WHO REPORTS	There isn't a specific employee who takes care of maintenance reports correct management			There is a specific employee who takes care of maintence reports correct management