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# An assessment procedure to measure and improve the maintenance management information practices maturity: a case study

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## Abstract

**Purpose** – This article presents a procedure for assessing the maturity of maintenance management information practices and defining improvement actions. It focuses on supporting companies, small and medium enterprises (SMEs) in determining their information technology (IT) needs and introducing suitable informative infrastructures.

**Design/methodology/approach** – A comprehensive procedure for assessing the maturity of maintenance management information practices and defining improvement actions is proposed. It consists of five steps: designing the current state of maintenance, identifying IT needs based on maintenance goals, applying an assessment model to identify weaknesses and strengths, proposing improvement actions based on maturity level and enabling continuous improvement. The procedure provides the applicability of the assessment model to evaluate the maturity levels of different databases: Equipment, Maintenance Personnel, Work Order and Report.

**Findings** – 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.

**Originality/value** – The proposed procedure and the maturity model contribute to the field of research by addressing the specific needs of SMEs in assessing their maintenance management information practices. The model provides a roadmap for 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.

**Keywords** Industrial maintenance, Information technology, Maturity models, Case study

**Paper type** Case study

## Introduction and background

Companies are under pressure to constantly enhance their operations in the present industrial environment to remain competitive. Over the years, the maintenance function has faced many changes, from cost-generating to a key function that helps increase business performance and ensure system availability, dependability, safety and sustainability (Franciosi *et al.*, 2018).



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Maintenance has evolved from reactive (Maintenance 1.0) to preventive (Maintenance 2.0) to condition-based (Maintenance 3.0) to the current predictive and prescriptive Maintenance approach (maintenance (4.0) (Jasiulewicz-Kaczmarek *et al.*, 2020). Data and information are one of the most essential resources for any maintenance operations. Moreover, their management changed over time. In the Maintenance 1.0 age, data was limited as it existed mostly in equipment operator experience. In the Maintenance 2.0 age, data acquisition and processing changed with increased demand for products and mechanization. Maintenance managers began to employ more systematic methods to document and analyse maintenance data, such as recording raw data in written documents rather than stored in machine operator memory. However, data was still handled manually by maintainers leading to a low utilization rate. The introduction of the industrial revolution (referred to in the literature as the information age) further increased the role of information technologies and the responsibilities of maintenance managers. Maintenance data has become increasingly important due to the increase in digitization and automation, as well as the complexity of production equipment. Information Technology (IT) systems such as CMMS (Computer Maintenance Management System) have been used to store, manage and analyse data from the maintenance processes.

However, due to implementation costs and the competencies necessary to maintain maintenance IT systems, many manufacturing companies, especially Small and Medium Enterprises (SMEs), still found it difficult (Zach *et al.*, 2014; Hicks *et al.*, 2006; Singh *et al.*, 2008). Thanks to new technologies of Industry 4.0 (such as the Internet of Things and cloud computing), the possibility of collecting, storing, processing and analysing has significantly increased.

IT systems implementation in SMEs is constrained by several factors and obstacles. According to Wisniewski and Blaszczyk (2019), the maintenance department's maturity level appears to be the most frequent issue. Many small manufacturing enterprises are not unaware of the maintenance data classes that must be gathered and maintained to introduce adequate information infrastructure coherent with their needs.

Maturity models are helpful tools in this context. According to Becker *et al.* (2009) "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". As a result, maturity models may be used to evaluate the level of maturity of information maintenance management processes and provide recommendations for SMEs in introducing a needed information infrastructure.

However, the literature review of Tortora *et al.* (2022) noted the absence of such a maturity model. The current maintenance maturity models (Wendler, 2012; Macchi and Fumagalli, 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 considered.

Moreover, due to organizational structure and business context, applying these models to other organizations may not be simple (Chemweno *et al.*, 2015). In addition, these models provide the assessment of maturity level, but they do not define the actions that must be undertaken to reach the highest level.

The paper is organized as follows: in section 2, a state-of-the-art on IT systems in SMEs is provided in order to highlight the limits of the existing systems for smaller organizations and demonstrates the need to develop an IT readiness and improvement model to support companies with effective guidelines for a successful IT implementation (literature gap). An overview of existing maintenance maturity models is presented and a brief description of the main structure and functionality of the M3AIN4SME model developed is performed. In section 3 the procedure proposed is presented and then a case study showing the application of the proposed procedure is reported in section 4. Finally, the main conclusions and further development are included in section 5.

## Literature review

*Information technology in SMEs*

Maintenance Management Information Systems (MMIS) have become very popular over the years, demonstrating significant advantages, especially in large organizations (Hemmati *et al.*, 2020, 2018).

In scientific literature much has been written about maintenance management information technology (MMIT) (Kans, 2007). Some papers are focused on showing the important role played by IT in improving maintenance management and, consequently enhancing the performance of manufacturing industries (Kans, 2007; Shankar *et al.*, 2023). A critical literature was also reviewed on Computerized Maintenance Management Information System (CMMIS) and found that it has provided timely information for rigorous decision making for maintenance problems, maximum availability of production equipment and results in the effective planning, controlling and scheduling the maintenance activities. It also showed the importance of training for the employees (Verma, 2016). Without computer-based support it was practically impossible to manage maintenance effectively and efficiently (Wienker *et al.*, 2016). Although the benefits of using MMIT has been explored by several studies, a lot of publications indicates various barriers and condition for a successful implementation of IT in SMEs. For example, the study by Velmurugan *et al.* (2023), aims to identify the most critical factors influencing the implementation of digitisation of Maintenance Management system. The study and the results of the experiments revealed the two most critical factors, namely the ease of maintenance planning and scheduling and ease of maintenance administration, have been identified to influence the implementation of digitisation; in the paper of Hamdan *et al.* (2016) the success factors and the internal and external barrier of IT implementation in SMEs in Malaysia are studied and analysed based on an empirical study. Even if they are not focused on IT in maintenance, they analyse the organisational structure of SMEs and their process identifying the critical approach to IT for their characteristics that put at the risk the success of any IT project.

Hence, studies on the role of IT in competitiveness have mainly focused on large organizations (Beheshti, 2004). Larger companies usually have the resources to either customize commercial IT applications or develop in-house solutions. Instead, for SMEs, there are different obstacles that make the adoption of information systems in business processes complex (Zach *et al.*, 2014), SMEs suffer from the lack of a strategic perspective that could limit the ability to recognize the potential of implementation of information systems in addition, SMEs generally have limited skilled resources to support the effective adoption of information systems in business processes. Even the development of the I4.0 paradigm in an SME finds many difficulties: 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 (Majstorovic *et al.*, 2020). Most of the activities are governed by informal rules and procedures with a low degree of standardization and formalization. Therefore, these features make the solution available off the shelf, often not suitable for their needs. Psarommatis *et al.* (2023) highlights that traditional maintenance practices remain the most widely used in SMEs and suggests that future research should focus on bridging traditional and advanced maintenance policies to enable SMEs to achieve advanced maintenance and its benefits arise.

Furthermore, based on the critical factors for implementing IT in SMEs, 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.* (2020), 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 and Zowghi (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.* (2016) 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.

These works 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.

Related to the implementation of IT in maintenance management in SMEs, several surveys have shown the existence of various obstacles (Fumagalli *et al.*, 2009; Wisniewski and Blaszczyk, 2019). The most frequently cited reasons are the maturity level of the maintenance department, high implementation costs, lack of system knowledge, scarce and low-skilled workforce and other difficulties.

Therefore, Hamdan *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 (2013) 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 and Ingwald (2010), 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 (2007), confirms that no articles were found within the area. Moreover, this procedure has to 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 actually maintenance management information practices is necessary (as suggested also by Kans, 2007). In this frame, maturity models are useful tools that allow this evaluation. By analysing the maturity models on maintenance management and the procedure proposed by Kans (2007) on determining the IT requirements in maintenance, a procedure that include the maturity model proposed by the authors in a previous work (Tortora *et al.*, 2023), was proposed and designed.

Table 1 shows the different types of Maintenance Management Information Systems, in order to show the databases, they manage and their main characteristics, highlighting advantages and disadvantages.

The evaluation of the level of maturity of the maintenance department has significant importance for the success of the adoption of information systems. More specifically, by analysing IT maturity related to maintenance processes, SMEs can be trained to effective adoption of these systems.

### *Maturity models*

According to de Bruin *et al.* (2005), maturity models were designed to evaluate the maturity of a process or activity based on a comprehensive set of criteria. The maturity model aims to evaluate the current level at which an organization is in relation to certain pre-established good practices. Besides, starting from this measure, the models generate improvement actions giving decision-makers guidelines to achieve an ever-higher maturity level. There are several different types of maturity models, but they generally share the common property of defining a number of dimensions or process areas in various stages of maturity levels, with a description of the characteristic performance in several levels of granularity. According to de Bruin *et al.* (2005), the most popular way of assessing maturity is a five-point Likert scale. This scale

**Table 1.** Main features of different types of Maintenance Management Information Systems

| MMIS | Database included | Characteristics | Advantages | Disadvantages |
|---|---|---|---|---|
| Computerized Maintenance Management System (CMMS) (Mahaku *et al.*, 2005) | • Work order DB<br>• Maintenance plan DB<br>• Inventory DB<br>• Personnel DB | CMMS is software designed to assist in the planning, management and administrative functions required for maintenance activity | Focus on all the maintenance processes and activities | It takes a long work time to fully exploit the potential of the software |
| Enterprise asset management (EAM) (Gorski *et al.*, 2022) | • Deep Equipment DB<br>• Inventory DB<br>• Maintenance plan DB<br>• Maintenance strategy management | EAM system has the function of asset management, performing appropriate monitoring of failures, costs and maintenance | The software allows for to improve efficiency and reliability of the asset | It takes a long work time to fully exploit the potential of the software.<br>Not much focus on human maintenance activity |
| Computer Integrated Maintenance Management (CIMM) (Velmurugan *et al.*, 2022) | • Equipment DB<br>• Maintenance strategy management | Machinery-inside systems that provide useful maintenance information taken by IoT technologies<br>Definitions are less used and less investigated in academic literature | Useful maintenance features available within newly purchased products | Personnel must be formed to enable the full use of the system<br>Not much focus on Human maintenance activity |
| Supervisory Control And Data Acquisition (SCADA) (Yadav and Paul, 2021) | • System Status DB<br>• Alarm DB | The system that allows monitoring and control physical system. Used for plant application or for geographically distributed systems | The system helps to quickly detect maintenance problems | No focus on maintenance activity |

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allows the attribution of a numerical value to qualitative data according to the degree of agreement or disagreement with statements about the attitude being measured. During the last 2 decades, the application fields of maturity models have widened. However, not much-published literature is reported on the development and application of maturity models in asset maintenance (de Bruin *et al.*, 2005).

The available literature can be classified into different clusters related to the aim whereby the maturity models are developed.

Some of the models/methods/tools were focused on the assessment of the maintenance maturity level of specific aspects, such as maintenance strategies, such as RCM (Hauge and Mercier, 2003), prescriptive maintenance and knowledge-based maintenance (Nemeth *et al.*, 2018, 2019) and predictive maintenance (Errandonea *et al.*, 2022).

Others are focused on the definition of maintenance management information technology needs (Kans *et al.*, 2012; Kans, 2008).

Kans (2008) promotes the use of a structured procedure for the identification of IT requirements for maintenance management. The IT functionality requirements are identified after the definition of the current maintenance state through the description of maintenance strategy, policies, procedures, organization and decision hierarchy. The IT maturity is determined considering information quality, data source and documentation available, above all, on the operation level. In this way, the demands of IT support in the maintenance organization are met.

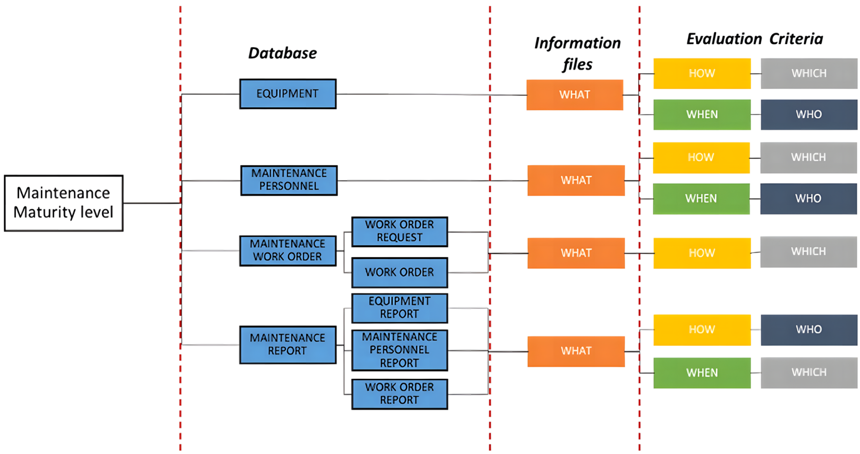
Despite the benefits offered by these models, there are still some limitations to be overcome (dos Santos-Neto and Costa, 2019). Some of the current maturity models are of complex application in manufacturing organizations, the mathematical formulation proposed requires companies to have prompt, reliable and precise data. Moreover, some of them require companies to have a credible and clear maintenance performance measurement, as well as a structured maintenance organization. In most manufacturing companies, especially small companies, most of the activities are governed by informal rules and procedures with a low degree of standardization and formalization. Finally, very few models try to define the improvement guidelines to reach a higher maturity level.

*The maturity and improvement model M3AIN4SME*

The approach proposed by Becker *et al.* (2009) was applied to develop the maturity model on Maintenance management information practices in SMEs (M3AIN4SME), as presented for the first time by Tortora *et al.* (2022). Breaking down a typical maintenance process, all the most significant and relevant informative resources were identified and grouped in four databases: Equipment (EQ), maintenance personnel (MP), work order (WO) and report (REP). The model architecture and the main concepts are shown in Figure 1, which include the databases forming the maintenance information infrastructure and the criteria defined for measuring the maturity.

The EQ DB contains, stores and arranges all the information files and documents needed to prepare, perform and close out a maintenance task safely for restoring the machine to a functional state that is physical data, technical data, failure data, maintenance data and improvement data.

MP DB includes all the information documents 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.




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

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**Figure 1.** The main structure of the proposed model

The WO DB contains the needed information for planning and scheduling any type of maintenance intervention (work order request) and also for work to be carried out (instructions to perform a maintenance work order).

The REP DB aims to collect, analyse and store all data needed to document and improve the maintenance process. Therefore, the database includes the collection of data and feedback information derived from the equipment to be maintained, the maintenance personnel performing the maintenance intervention and the work order executed.

A survey is carried out using a well-designed approach to assess the maturity level of the information management practices adopted. There is a questions section for each DB.

The questions are associated with a set of closed answers: in particular, each question contains a set of practices related to the management, keeping up and organization of the file/document included in each DB, and the answers are ranked according to a description ranging from the initial/basic practice (ML 1) to the good/best one (ML 4). To quantify the level of maturity for each database, a weighted average of the level of maturity of the single information files of that specific database is performed. Similarly, the level of maturity of the single information content is calculated as a weighted average of the levels of the four evaluation criteria (HOW, WHICH, WHEN and WHO), according to the mathematical formulation detailed in Tortora *et al*. (2022).

The maturity model provides in output a description, as well as the meaning, of the maturity level reached for each DB and criteria, detailed in Tortora *et al*. (2022).

The maturity level highlights the strengths and weaknesses of the current maintenance information management practices. Different graphics (e.g. bar chart and radar chart) with the maturity level for each database and of each evaluation criterion are displayed as the result of the assessment process. Then, starting from the assessment results, an improvement program is built. The improvement can be pursued in two directions, horizontal (by increasing the information contents/systems to the actual information infrastructure) or vertical (by improving the method for handling information infrastructure). An example of the assessment procedure is presented in Figure 2.

## A procedure for determining and improving maintenance management information practices maturity level

This study aims to contribute to this research's field by proposing a procedure (Figure 3) 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

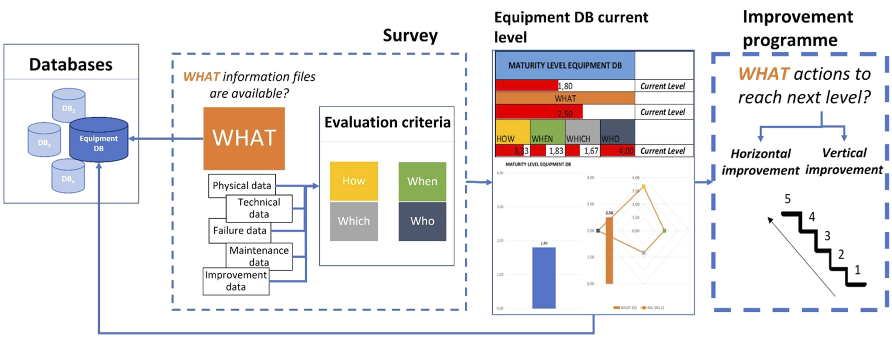


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**Figure 2.** The assessment and improvement procedure

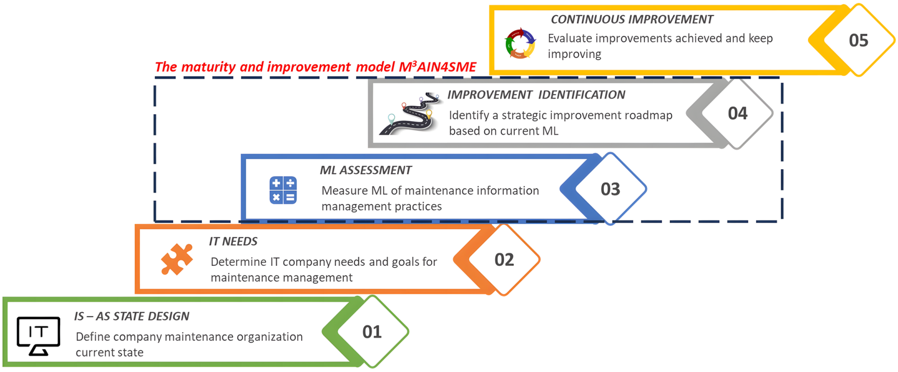


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**Figure 3.** Procedure for determining maintenance management information practices maturity level

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 by Tortora *et al.* (2022), 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. The improvement recommends actions, that is the novelty of the research proposal as in the existing models is missing, define different steps and a logical sequence for reaching higher MLs. If a company does not manage some important documents, it is not able to introduce more effective management practices. Therefore, the roadmap considers information already included in all different database and suggest the actions that must be followed to reach improvements in small and coherent steps.

So, the improvement model is general, the actions defined to reach all the next level are linked and follow a precise rule, taking into consideration the correlation between databases and information contents. Therefore, starting from the current ML (calculated as detailed in the developed model), the improvement is designed along horizontal and vertical direction. The first actions to do, along horizontal direction, are based on expanding with other data and files Equipment and Maintenance personnel DBs, which are the first most important databases whose data and informative flows are relevant and necessary for the creation of all other databases, until their competition. At the same time create a simple work order, and related report system, including firstly the promptest information, that are simpler to detail (from data and information included in Equipment and Maintenance personnel DBs) and gradually fill them with other data and information obtainable in a more elaborate way. Moreover, 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.

## Procedure application: a case study in a manufacturing company

In this section, the procedure proposed (Figure 3) 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, they produce plastic parts obtained through a plastic injection moulding process. The production site under analysis consists of a moulding 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 analysed, mainly based on breakdown maintenance interventions. In Figure 4, 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 “non-required time” of plant.

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, for example more than 4 h.

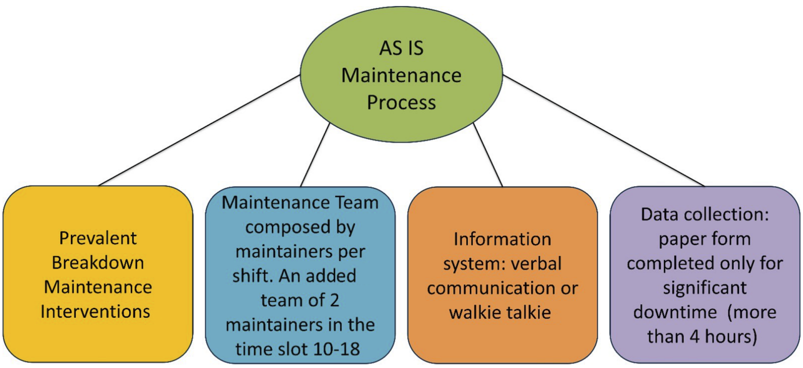


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**Figure 4.** AS-IS maintenance process

*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.

Recording maintenance work is one of the main critical issues encountered. Maintenance collection forms are filled out only for major stops (more than 4 h). 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. The as-is data collection method does not allow us to analyse 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

**Table 2.** The main critical issues relating to information systems in maintenance processes

| Summary of critical issues encountered | IT need | Expected advantages |
|---|---|---|
| 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, considering partial interventions | Improve traceability of incomplete maintenance interventions to complete them as soon as the spare part becomes available |
| Updating of spare parts warehouse is lacking | Implement a Spare Parts Warehouse Management system | Improved spare parts management leads to better maintenance performance |
| Difficulty in knowing the status of the moulds during maintenance | Digitization of information relating to the mould maintenance process | Greater accuracy of information which increases the speed of the mould change process |

**Source(s):** Created by the authors

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. 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.

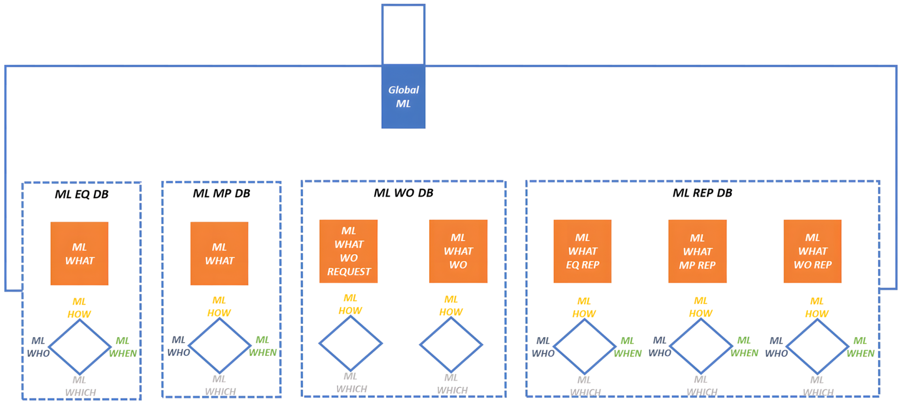
Given the critical issues and the need for intervention in the company's as-is information systems, the maintenance manager suggested adopting an information system maturity model for maintenance processes. This model will enable the development of a targeted and effective plan to achieve a restructuring 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.

*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 5.

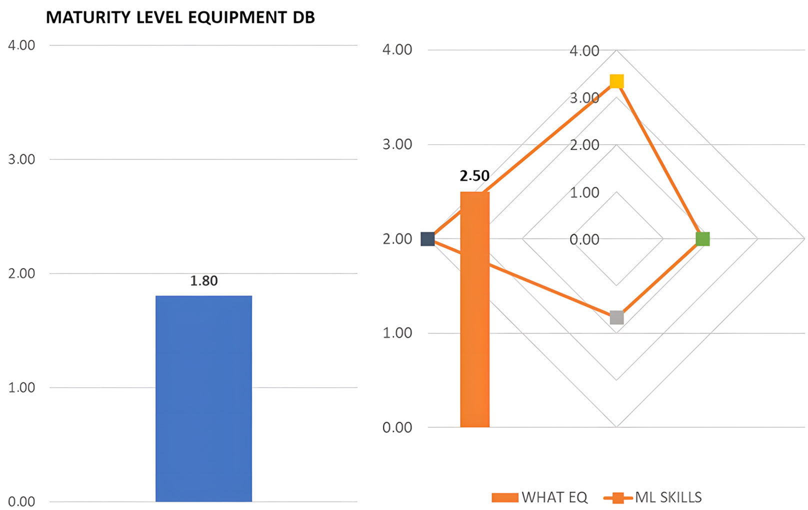
The global maturity level was 1.86/4. The maturity levels of each database as well as each evaluation criteria (WHAT, HOW, WHEN, WHICH, WHO), were described further in the text.

For the EQUIPMENT Database (EQ), the maturity level was 1.80 out of 4.0 (Figure 6). 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




**Source(s):** Created by the authors

**Figure 5.** Summary of the ML results




**Source(s):** Created by the authors

**Figure 6.** Equipment DB results

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.

For the MAINTENANCE PERSONNEL (MP), the maturity level was 3.0 out of 4.0 (Figure 7). 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, that is 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.

For the WORK ORDER database (WO), the maturity level was 0.94 out of 4.0 (Figure 8). 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.

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.

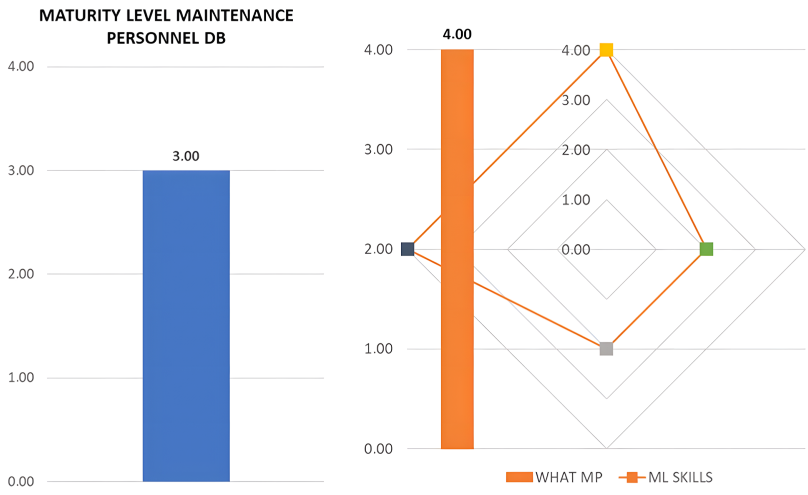



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**Figure 7.** Maintenance personnel DB results

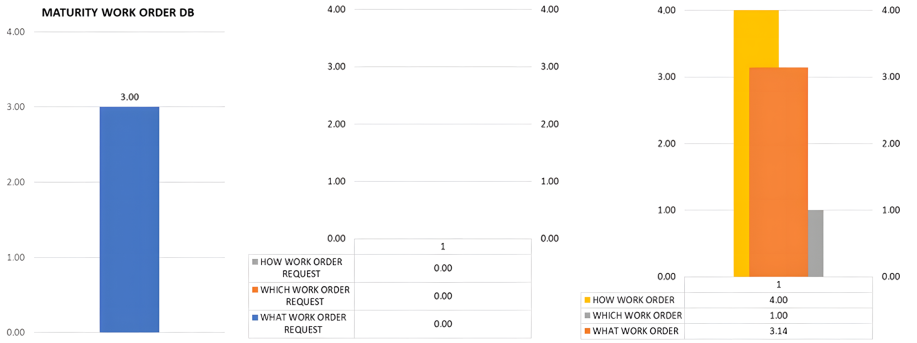


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**Figure 8.** Work order DB results

The database relating to the Report has the aim of collecting, analysing 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 useable, this data must be validated and classified according to its type and characteristics.

The collected reports must be periodically analysed 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 9).

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).

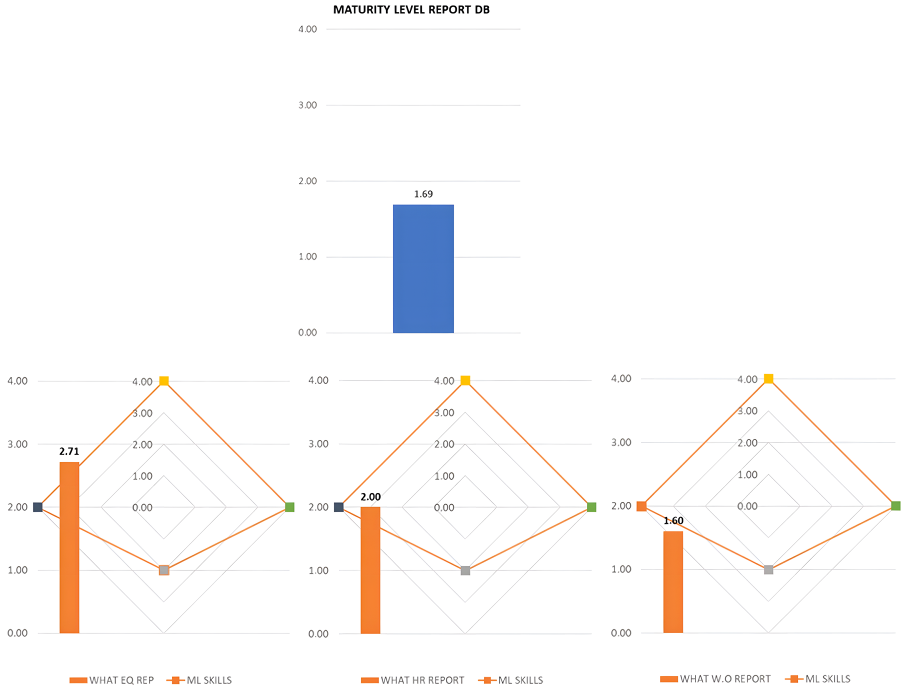
Monitoring and measuring the performance of maintenance personnel are necessary to manage the tasks and skills of each one with the aim of promptly training internal human resources who must have the levels of competence and certification necessary to carry out maintenance activities.

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, for example 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 analysed 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.




**Source(s):** Created by the authors

**Figure 9.** Report DB results

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.

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

*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 10 (the green colour identifies what has already been achieved by the company, and the other boxes are the actions to do).

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.

## EQUIPMENT DB

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

(1) Make equipment registry (equipment code, location cost): The definition and structuring of a machine register are necessary to analyse 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.

(2) 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:

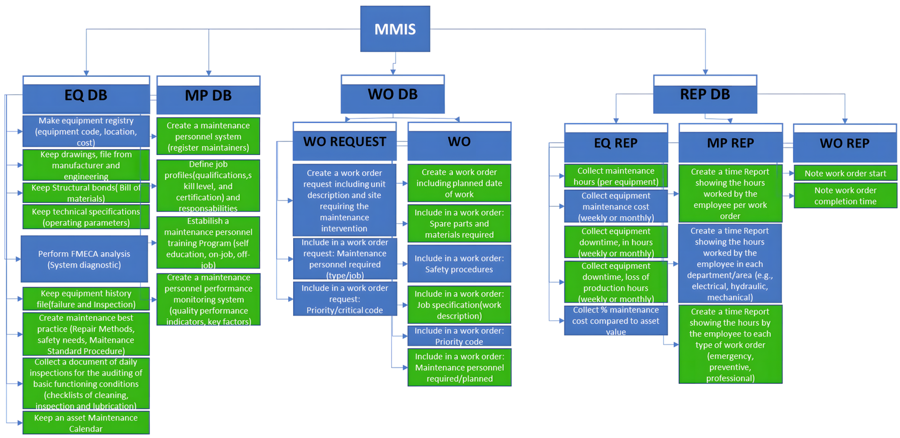



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**Figure 10.** Horizontal improvement. Green box: what have been already achieved by the company

(1) 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 analyse to program the improvement interventions. For Equipment Report DB, the company has to include the following:

(1) Equipment maintenance cost: (weekly or monthly).

(2) 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 analyse the maintenance organization. First, it summarizes the work performed in each department (line, building, cost centre, 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.

*Vertical improvement*

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

For EQUIPMENT DB (Figure 11), the improvement actions recommend making to complete information and standardize them. It is envisaged to gradually improve the frequency

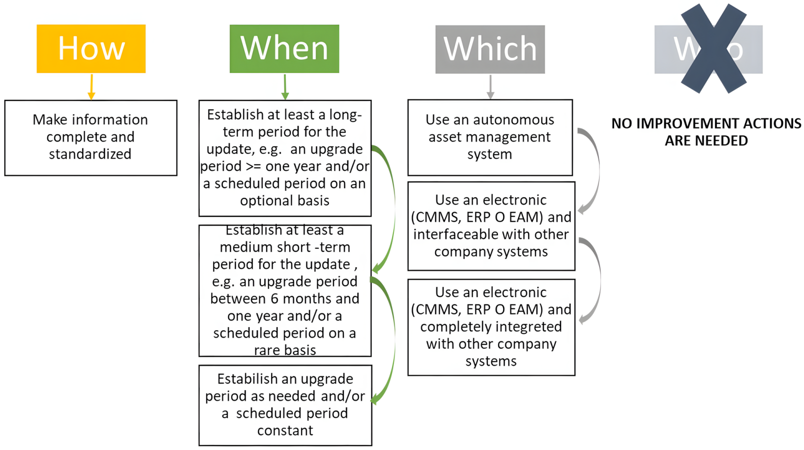


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**Figure 11.** EQ DB vertical improvement

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.

For the MAINTENANCE PERSONNEL DB (Figure 12), it is not expected any particular developments other than the use of a system interfaceable with other company systems.

The WORK ORDER DB (Figure 13) 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.

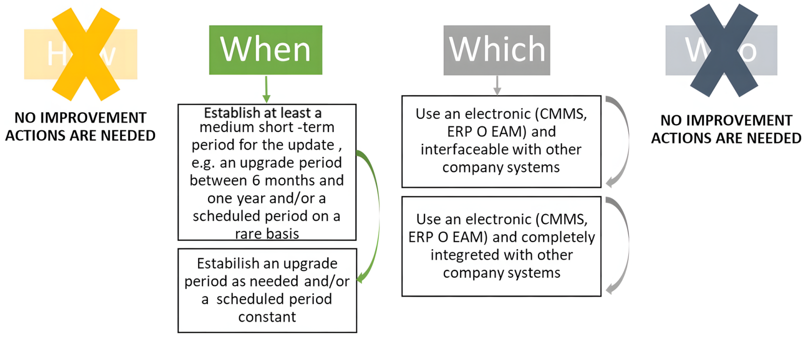


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**Figure 12.** MP DB vertical improvement

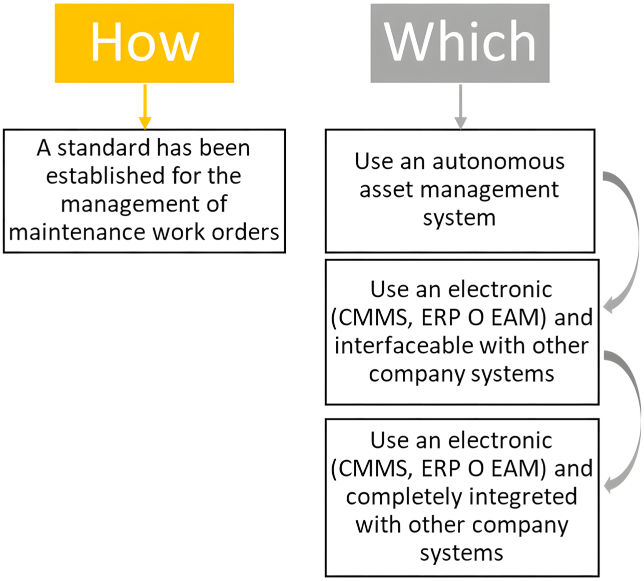


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**Figure 13.** WO DB vertical improvements

For the REPORT DB (Figure 14), 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.

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

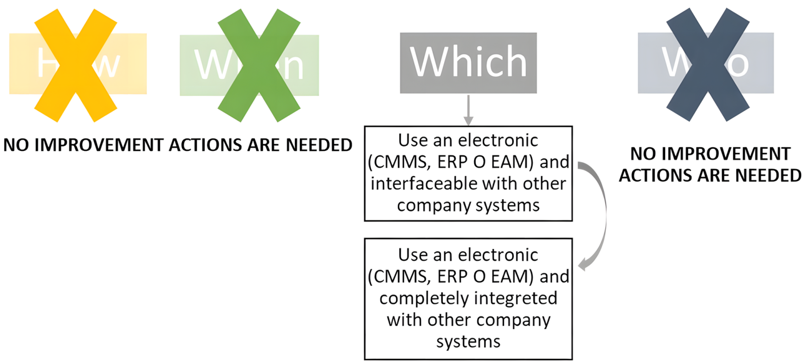


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**Figure 14.** REP DB vertical improvements

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:

(1) Cost of the software;

(2) Cost of hardware;

(3) Personnel training cost;

(4) Consulting cost;

(5) General expenses (include management costs, etc.);

(6) 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, that is 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 Table 3, a comparison between the more commonly used devices to support an informative system was provided.

## Discussions and conclusions

The application of the proposed 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 (Tortora *et al.*, 2022). 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.

**Table 3.** Main features of common devices to support informative system

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

**Source(s):** Created by the authors

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.

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.

## Limitations and future developments of the study

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.

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.

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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