Towards a tool for SMEs to Maintenance Management process self-assessment and improvement: literature overview and research proposal.

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Abstract: One of the most important resources that reveal to be determinant to improve the maintenance management process is information. Information is, indeed, considered as a significant source of performance improvement, but may be difficult to identify, structure, analyses, and reuse properly. Over the years, many methodologies, tools, techniques, and strategies have been developed to systematize maintenance information flow. Among them, maintenance management information systems (MMIS) have become very popular over the years proving considerable benefits above all in large organizations. On the contrary, the Small and Medium Enterprises (SMEs) often lack the managerial expertise to plan, organize and direct the use of information resources, and many SMEs hold insufficient in-house expertise for successful information system adoption. In literature, few studies have been undertaken to explore and understand the barriers and motivation that bring SMEs to a low success rate in the implementation of MMIS. Furthermore, no research work considers SMEs' context and the issue of readiness of the organizations in introducing these systems. For these reasons, in this paper barriers and their implication in implementing MMIS for SMEs are discussed. The paper aims to draw a framework for a new MMIS able to provide for the small companies a general procedure/guideline to help them to identify the current state of maintenance information flow and drives actions to increase efficiency and effectiveness. The framework outlines the essential steps that should be developed to manage the information maintenance flow effectively. Moreover, the presence or not of these factors in the specific industrial context allows assessing the maturity level of the maintenance process. The assessment of maturity facilitates the identification of improvement actions that lead to better performance.

Keywords: Maintenance; information technology; Maintenance Management Information Systems (MMIS); Computerized maintenance management systems (CMMS); Small and Medium Enterprises (SMEs).

1. Introduction

The maintenance concept has suffered many transformations over the years. In the past, maintenance was described by Tsang (1995) as a "necessary evil" and simply the act of replacing a component in a process machine after it broke. Nowadays, maintenance is instead considered a complex management process that associates several organizational processes as production, quality, environment, risk analysis, and safety (Stamboliska et.al., 2015, Franciosi et.al., 2020). Muchiri et al. (2011) considered that equipment maintenance and reliability are relevant factors that have a strong impact on the organization's ability to provide quality and timely services to customers. For these reasons, maintenance management, defined as a set of activities to establish the maintenance objectives, strategies, and responsibilities implementing maintenance planning, maintenance control, and supervision plans (EN 13306:2007), requires a multidisciplinary approach (Murthy et al., 2002). Maintenance management of an industrial plant has, indeed, always been a complex activity that involves handling a large amount of information. Information appears in organizations as a strategic resource, essential for better operability and coordination between all players and nowadays it is considered as a significant source of performance improvement, but may be difficult to identify, structure, analyse and reuse properly. Several frameworks, standards, and methodologies have been developed over the years to guide these activities. (Campos et al., 2011). In the same way, the application of computerized tools and information and communication technologies (ICT) to improve organizations' business processes and operations, has always been present in the history of the maintenance function (Kans, 2009). In particular, the Maintenance Management Information Systems (MMIS) are typically deployed and utilized in business operations to facilitate reporting and decision making. In many business organizations, so-called computerized maintenance management systems (CMMS) are used to capture, store, retrieve and transmit data and information related to maintenance procedures for plant, equipment, and infrastructure. Huge benefits have been reached in large organizations through these systems, instead, many Small and Medium Enterprises (SMEs) have some difficulty, in adopting a structured MMIS that leads to a positive return. Several studies have investigated various factors affecting information technology (IT)/information system (IS) adoption in SMEs (Zach et al.,2012) Scientific literature deals with very general content relating to the analysis of characteristics of SMEs which could put at risk the success of any IT projects, but in all cases, the research studies are not specifically related

to MMIS. Moreover, few studies try to explore the barriers and motivation of poor implementation of MMIS in SMEs. Nevertheless, a brief overview of the available literature in this field was addressed to bring out the main linkage troubles between these three topics. In order to draw a system suitable for SMEs need, in this work an in-depth study on characteristics and trends of information technology in maintenance management systems was carried out to capture the approaches developed in literature and the main features of available systems/models highlighting the main research gaps and challenges and especially to understand why these systems are not fitting SMEs context. Since the readiness level of a company influences MMIS development, the identification of the level of maturity of a company concerning the maintenance process represents a necessary step to understand the strengths and weaknesses of the company´s key capabilities and as a result to identify the improvement and innovation actions. Based on this consideration, this work provides a brief analysis of the available maintenance maturity systems to contextualize the main characteristics of maturity models and highlight the main research gaps. By matching the best practices highlighted in the field of maturity system and MMISs, this paper proposed a framework, that includes different steps, that will allow, starting from the measure of the current maturity level, the definition of direction/ indication for improving maintenance performance, through the identification of the next steps that should be taken to reach higher maturity levels. The paper is organized as follow: Section 2 sheds light on the literature results concerning the relationship between SMEs, IT and maintenance, and different aspects of MMISs in the industrial organization; Section 3 provides a survey on maintenance maturity models; in Section 4 the main literature outcomes and gaps are highlighted, and in Section 5 the research proposal is described, to fulfil the gaps discovered, and finally conclusions and future research developments are presented.

2. Literature overview

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 highlighting the main research gaps and challenges.

2.1. 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).

2.2. Maintenance Management Information Systems

The examined literature in the field of MMIS was sorted into two main topics: common features of MMIS, and MMIS implementation rate.

2.2.1. Common features of MMIS

Since a huge amount of maintenance data needs to be analysed fast and efficiently, to make better decisions, MMISs became needed systems to improve the overall maintenance process. The literature highlights the growth in this field in the last years. Different positive and negative features were discussed in many studies. Indeed,

the scientific literature on this topic can be divided into different clusters related to the specific issues of MMIS addressed. Some studies focused on describing and/or on improving the common features of an 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: consists of recording all assets and a historical record of repairs and equipment parts list.
2. Work Orders Management: allows setting and releasing of work orders to the maintenance technicians.
3. Preventive Maintenance Management: supports the planning, scheduling, and control of activities.
4. Inventory control: gives access to spare parts availability.
5. Report Management: allows to process a big amount of data and produce performance indicators (KPI).

These functions allow better efficiency and effectiveness for the maintenance function by taking advantage of ICT (Carnero et al., 2006). Besides, in literature, the main uses of MMIS appear to be as a storehouse of maintenance information and data. Companies consume a significant amount of management and supervisory time compiling, interpreting, and analyzing the data captured within an MMIS. Based on these 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.

2.2.2. MMIS implementation rate

Despite the relevant benefits associated with MMIS as a support tool in maintenance management, different factors affect its implementation. Several surveys showed the existence of various barriers to MMIS implementation (Wisniewski et al.2020; Fumagalli et al., 2009). The most frequently indicated reasons are (Wisniewski et al.2020): maturity level of the Maintenance Department, high implementation costs, lack of knowledge of the system, unskilled and few workforces, and difficulties in changing organizational culture. 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 the smaller industrial contexts which are still unaware about the key-role played by the maintenance function.

SMEs should be ready to adopt a MMIS. This requires a change in 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 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.

3. Maintenance maturity model

Since 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, an exploratory study on these systems was carried out. The purpose of the Maintenance maturity models (MMM) analysis is to understand what the main aspects are for developing a maturity model for the maintenance information management domain. The identification and characterization of maturity levels have been discussed in various knowledge areas, such as in project management, quality management, and systems development, and the practical application of findings has led to the achievement of better results (Olivera et al., 2019). The first maturity model was introduced in the quality management area by Crosby (1979). 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.

Over the past few decades, maturity models have been developed and applied in different areas encompassing product development, software management, patient safety culture, information management, and risk management (Alfano et al., 2020, Maier et al., 2012; Becker, 2009; Mettler, 2009). However, 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. Whilst several CMM have been developed in the past few decades, the applicability of such models in asset maintenance is rather limited (Wendler, 2012). Moreover, all these models reviewed in the study of Olivera, 2019, 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. 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).

In the maintenance maturity models available in literature, the information maintenance management domain, if considered, often represents one of the measurement classes and therefore not very well detailed.

4. Literature outcomes: 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 1).
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.

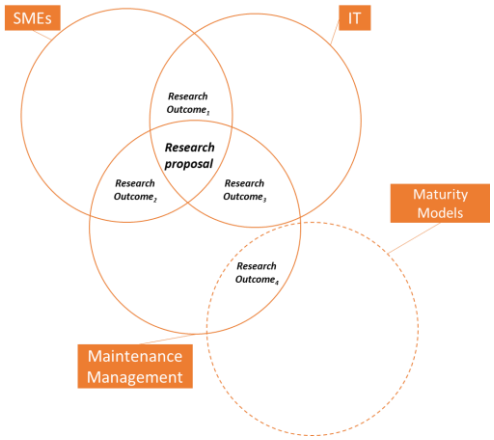

Figure 1: Venn Diagram of research outcomes.

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.

5. Research proposal

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, as illustrated in Figure 2. The framework shown in figure 3 aims, indeed, to measure and improve the effectiveness of any maintenance information management procedure through the development of a self-assessment and improvement tool. Several steps need to be performed.

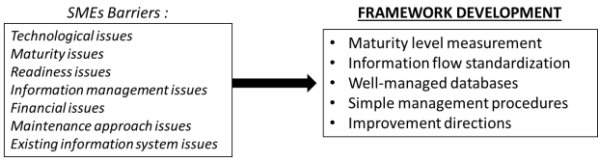

Figure 2: Framework development needs/objectives.

Focusing on the operational level, which is the first level where maintenance information arises, the first step consists of breaking down the execution of a maintenance process. The decomposition (step 1) helps to identify how the company's maintenance process is performed. The allocation of information flows, in input and output of each maintenance subprocess, represents the step 2 which allows the identification of maintenance information infrastructure, composed by a set of databases.

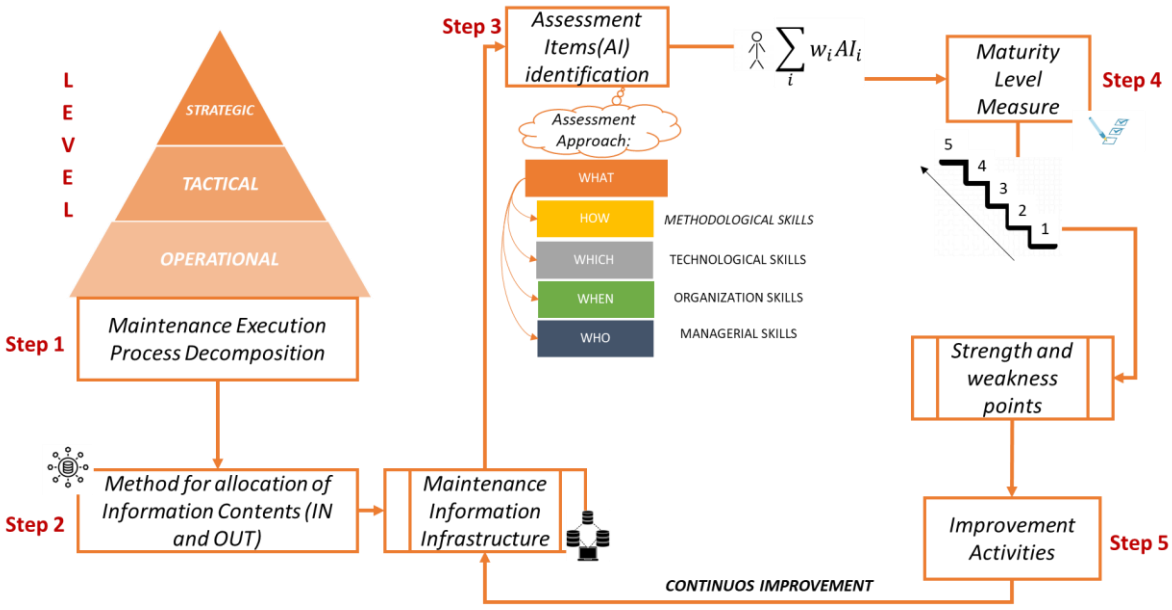

Figure 3: Research proposal

Identified databases are used as the assessment items or measurement classes for the maturity measurement of the maintenance department (step 3). The maturity assessment is performed through a well-designed questionnaire. A set of questions are included, for each of the databases, to assess the management information practices used. Different evaluation criteria must be considered: WHAT information flows are recorded in each one?

The completeness of information flow consequently depends on: HOW are the information flows qualitatively? WHICH support tool is used to record information flows? Every WHEN information flows are updated? Has a responsible been designed to manage this information (WHO)?.

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.

The proposed approach allows on one hand to measure ML (step 4) considering that all the evaluation criteria are not equally important, so a relative importance weight is assigned, on the other hand, it allows identifying the areas where improvements can be made. This allows highlighting the strengths and weaknesses of the current maintenance management information system of a company.

The maintenance improvement programs (step 5) will be based on setting targets and related to the weaknesses of each factor a roadmap, with the selection of maintenance management best practices to achieve a ML level highest, will be designed. The improvement program may be grouped in these stages: planning; analysis; integration; action; and implementation and results. This enables the company to achieve a high maintenance effectiveness standard more than once, and also a continuous improvement process will be activated, in order to keep the goal towards a higher maturity level.

6. Conclusion and future development

After the recognition of maintenance in improving performance and its direct impact on corporate competitiveness, there is no doubt that maintenance has assumed increasing importance over time. Moreover, the amount of information that should be created, stored, and preserved for proper maintenance management, have risen exponentially and continues to rise due to the growing complexity of the maintenance process. The evidence showed that MMIS appears to be an important tool for companies allowing fast and efficient analysis of this enormous amount of maintenance data. To reach the successful implementation of these systems, companies must have achieved a high maturity level of the maintenance department. Unfortunately, the research outcomes showed that SMEs generally must face several barriers, bringing them to a poor approach to IT. The research proposal suggested in this paper aims to provide a simple procedure that allows small companies to solve the constraints and reach progressive maturity levels, starting from their current maturity situation. The method in addition to being a self-assessment tool, it will provide and support knowledge on behaviours and practices. Future development will concern a detailed procedure for implementing each framework step.

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