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Requirements specification of a computerized maintenance management system – a case study

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Abstract

Given the need for a quick response to today's dynamic market, the maintenance function is considered increasingly important for industrial companies. Waste elimination, in particular the reduction of work in process and overproduction, required by Lean Manufacturing methodology that has spread across industries, highlights and also increases the impact of failures or malfunctions of equipment on productivity. Managing maintenance involves several activities such as: planning of preventive maintenance actions; scheduling of activities considering available resources and planned production; management of spare parts; analysis of data to reduce the occurrence of failures and to improve performance of the maintenance function. To support this function, companies adopt information systems designated by computerized maintenance management systems (CMMS) to provide timely and accurate information. Several CMMS are offered in market. However, its main drawback is that they do not perfectly match the particularities of each company. Thus, many companies prefer to develop their own system. This paper presents an ongoing project aiming to develop a CMMS for a manufacturing company. Crucial phases of the project, involving the identification of requirements and the specifications of the system, are described in detail, showing the approach that was followed and reflecting about its effectiveness and efficiency.

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1. Introduction

All branches of engineering have suffered a deep evolution over the time, driven by the companies in order to improve their processes and products quality and to reduce their total costs.

Industrial maintenance has been recognized as a function with significant impact on the overall results of industrial companies and whose efficiency has usually a high potential of improvement. Maintenance was forgotten during years in detriment of more visible organizational functions such as production or logistics, since for many companies it is considered a function without value [1]. However, some companies have already understood the importance of investing in maintenance due to the impact it causes in all business performance [2]. According to Dunn [3], maintenance costs represent between 15% and 40% of production costs.

The concept of maintenance has suffered many transformations over time. In the past, maintenance was described by Tsang [4] as a “necessary evil”, the act of replacing a component in a process machine after it broke.

Currently, maintenance is a complex management process that associates several organizational processes like production, quality, environment, risk analysis and safety [5]. Muchiri et al. [6] also consider that equipment maintenance and reliability are relevant factors that have a strong impact on organization’s ability to provide quality and timely services to customers. Considering that maintenance is an important function of organizations, maintenance

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management requires a multidisciplinary approach with a business perspective [7].

Maintenance management is defined as a set of activities to establish the maintenance objectives, strategies, and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvement of methods in the organization including economical aspects [8].

Throughout the industrial evolution, one of the most important resources that reveal to be determinant to develop the maintenance function is information. Information can be defined as a collection of data which is transmitted to a receptor that uses it to take decisions [9]. Information appears in organizations as a strategic resource, essential for a better operability and coordination between all players.

Information systems came up with computer science and include many activities from the information technologies to organizational activities, such as the use of techniques to define user requirements and respective solutions [9]. Information systems to support maintenance function are referred as Computerized Maintenance Management Systems (CMMS).

The organization should understand the role of a CMMS in order to define which information the system must record and provide to support maintenance strategy [10]. According to Wienker et al. [10], the implementation of a CMMS will allow a quick and effective communication and will bring many benefits such as improved planning and scheduling, easy access to historical data and report generation allowing cost reduction associated with spare parts and maintenance activities, etc..

The use of a CMMS in the organization will also facilitate the implementation of Total Productive Maintenance (TPM) philosophy with success [11,12].

This paper reports the initial development stages of a new CMMS for a company producing electronic parts for the automotive industry. The company developed its own computerized system to support the maintenance function, adding new features when the need and opportunity have arisen. However, aware of the improvement opportunities, the company intends to develop a new system based on the knowledge acquired. In this paper, the features for the new system are defined showing the advantages they are expected to bring.

The remainder of the paper organized as follows. Section 2 presents a literature review on CMMS. In Section 3, the current state of the system is described and a set of features for the new system is proposed. Finally, in the conclusion section an overview about the proposed improvements to the system is made and further works are described.

2. Computerized maintenance management systems

A CMMS is a tool to support maintenance strategy based on an information system and a set of functions that process data to produce indicators to support maintenance activities.

According to Cato and Mobley [13], Donoghue and Prendergast [14] and Zhang, Li, and Huo [15], usually the CMMS have assigned a set of functions and applications, including:

1. Assets Management: that consists of recording all assets (or equipment) and a historical record of repairs and equipment parts list;
2. Work Orders Management: that allows setting and releasing of work orders to the maintenance technicians.
3. Preventive Maintenance Management: that supports the planning, scheduling and control of activities;
4. Inventory control: giving access to spare parts availability.
5. Report Management: CMMS processes large amounts of data and produces performance indicators.

These functions allow a better efficiency and effectiveness for the maintenance function by taking advantage of Information and Communication Technologies (ICT) [16]. However, by analyzing the currently available systems in the market, some weaknesses and limitations were identified [17,18]:

- Condition monitoring data analysis;
- Equipment failure diagnosis;
- Limited support to resource allocation;
- Decision analysis support.

The systems available in the market do not perfectly match the particularities of each company and, therefore, many companies prefer to develop their own software instead of buying commercial packages.

The use of technology to support maintenance has led to the concept of E-maintenance that can be defined as a formalized and disciplined application of ICT through the whole systems life cycle [19].

According to Wireman [20], E-maintenance has the following purposes:

- Maintenance documentation record;
- Fast information access;
- Remote data gathering for KPI determination;
- Integration of maintenance systems with other information systems.

Supported by this definition, the main goal of E-maintenance is the creation of a more efficient maintenance function [21].

3. Requirement specification of the proposed computerized maintenance system

In order to define the features of the new system, the first step was a diagnosis that was made through interviews and analysis of the current system at the company. Improvements were defined considering the best practices highlighted in the literature and the requirements pointed out by the company.

Given that maintenance management is a wide area and can be divided into different functions, this research work was organized considering four major functions:

- Maintenance planning;
- Maintenance scheduling;
- Performance measurement and improvement;
- Spare parts management.

3.1. The current system

The company has an information system developed internally, which supports the maintenance strategy. This system allows the visualization of tasks associated to each maintenance intervention, the status of every machine through an interface overview, the planning and the scheduling through a Gantt Chart.

Concerning predictive maintenance, there are real-time machine monitoring and alerts following some parameter deviation from a specified value range. The definition of preventive intervention periods, the parameters that will be monitored and their limits is made taking into account the available information from suppliers and it is adjusted over time considering the experience of the maintenance technicians and recorded in the CMMS.

Apart from planning, scheduling is also integrated in the CMMS. However, the current system does not perform the scheduling, only giving limited support to the scheduler that, based on his experience, considers the technicians availability and skills, equipment availability and overlapping issues. The result of scheduling is shown through a Gantt Diagram. Each technician receives his own schedule, where he can see all the maintenance interventions that were attributed to him for that week.

When a breakdown occurs (unscheduled maintenance) it will change the schedule, at least, for that specific day. This requires a constant follow-up by coordinator and technicians to redefine the schedule in the CMMS. To each intervention, only one technician can be associated, even more than one solved the problem. Consequently, there are technicians without any registration of executed interventions.

The system has associated a skills matrix where the competences of each technician are registered supporting the selection for interventions. When a breakdown or a deviation of parameter occurs, there is a call system for a quick technician response. Considering the nature of the breakdown or the parameter, the system analyzes the matrix and automatically calls to a technician that has competencies to proceed with the intervention.

Another major analyzed function is the measurement of the maintenance performance through the calculation of several technical and organizational indicators. The calculation of economic indicators is not included in the maintenance management system. For some of the indicators, the system generates an ordered list of the most critical equipment. These rankings are used to develop projects to improve the design of equipment in order to reduce failures rate and production losses.

The CMMS includes information regarding the spare parts, such as, the associated machine, where and when the spare parts were used, their movements and the history of replacements. The spare parts management is not included in the system. This task is performed by another department and the needs and stock levels are defined considering maintenance planning and historic consumptions.

3.2. The new features

Three main features will enhance the current system and contribute to improve several functions of the system: Augmented Reality (AR), Failure Mode and Effect Analysis (FMEA) and integration with other company management systems.

AR consists of the integration of virtual information with the real world [22]. This kind of technology can be helpful in maintenance area facilitating the transmission of information and instructions to technicians [23].

FMEA is a technique used to develop a systematic analysis of the failures that can occur in a system. A tree structure of equipment is associated with FMEA, allowing the record of failures modes of groups, subgroups or components of each equipment and their respective causes, effects and severities. This approach allows:

- Setting a knowledge base that leads to improvements of the maintenance plans and failures rate decrease;
- Identifying critical equipment, groups, subgroups or failures modes;
- and reducing the time of failure diagnosis [24].

Finally, in its activity maintenance should interact with other management functions such as production management, quality management, and purchasing. Therefore, the integration of the CMMS with other company information systems that support these functions will bring several possibilities to the CMMS improvement, which can use the provided information and also provide information to these systems. Then, data redundancy is eliminated and error of information transmission is avoided.

Other features or improvements were identified and are presented below following the division by functions defined for the system analysis.

3.2.1. Maintenance Planning

Corrective maintenance originates high costs which also include loss of production incurred due to equipment downtime and, therefore, preventive maintenance should be performed to reduce these costs. However, the excess of preventive maintenance can also result in high costs once resources are wasted for executing unnecessary tasks [4]. The company does not know if excessive preventive maintenance is performed and if the adopted maintenance intervals can be reduced in order to reduce costs. For each failure mode, the most appropriate maintenance type (corrective maintenance, systematic preventive maintenance or predictive maintenance) must be selected and maintenance policy should be defined in accordance with the failure severity and associated costs. Maintenance models application is required to define the intervention periods more accurately and to support decision-making. These models take into account several factors such as reliability, availability and associated costs. For the use of these models, reliability analysis should be performed. This can be made using the recorded data by the system.

In terms of predictive maintenance, some improvement opportunities can also be highlighted. The definition of decision intervals and monitoring periods can be supported by appropriate maintenance models. In this way, the underlying analysis of monitored data will enable the identification of the machine status and set the appropriate time to intervene, before failure occurrence. Consequently, the useful life-time of the equipment will be extended.

The literature proposes several models to the rapid evaluation of the outcomes of alternative maintenance decisions in relation to an objective, that can be used to complement the management maintenance system of the company [25].

In conjunction with aforementioned quantitative models, the implementation of RCM (Reliability Centered Maintenance) methodology can support the identification of the best maintenance type [25]. The utilization of this methodology to maintenance type assignment can be supported by the new system.

3.2.2. Maintenance Scheduling

An effective schedule has to reflect the scheduled maintenance which has a deterministic nature, and the unscheduled maintenance (emergency breakdowns) which have stochastic nature [27], [28]. According to Duffuaa and Al-Sultan [28] “this stochastic nature makes maintenance scheduling a challenging problem”.

Consequently, to obtain an adequate schedule to the reality of the company the integration of different systems or tools in a decision support system (DSS) is mandatory. The DSS will execute a better scheduling, taking into account the current constraints related to technicians availability and their skills, and equipment availability (production scheduling).

The necessity of constant follow-up from coordinator and technician to review the scheduling defined by the system will decrease which is the major cause for re-scheduling.

3.2.3. Performance measurement and Improvement

Considering the current state, a balanced performance measurement system that reflects the maintenance performance in several areas of maintenance management is needed. Muchiri et al. [6] defend that the performance indicators should be defined after a careful analysis of the interaction between maintenance function and other organizational functions. Hence, a balanced maintenance performance measurement, developed considering the organizational functions and the areas inside maintenance management, will allow an effective measurement system. Considering the current system, this can be achieved by including the determination of economic indicators and the analysis of human resources management. To include an economic evaluation, the system has to consider measures such as spare parts cost, preventive, corrective and predictive maintenance costs and man power cost. With these measures, economic indicators related to maintenance costs as preventive, corrective and predictive maintenance rate, spare parts rate and failure average cost can be determined. The analysis of human resources management will allow collecting some measures and create additional organizational indicators as manpower utilization rate and manpower efficiency.

To assess equipment criticality, a multi-criteria model considering a set of key performance indicators will be integrated into the CMMS. This model will allow the ranking of equipment considering several criteria instead of only one at a time. This general criticality classification can be an input to the development of maintenance strategy and to the purchasing of spare parts. A suitable technique to assess equipment criticality is Analytic Hierarchy Process (AHP) [26]. AHP is used in a wide range of fields, especially in operations management. The AHP has been considered as a leading and one of the most popular multi-criteria decision-making techniques and it is used to solve decision problems by the prioritization of alternatives [27,28]. This technique can be used when it is required the consideration of qualitative and quantitative factors and it helps to define the critical factors through the definition of a hierarchical structure similar to a family tree [1].

3.2.4. Spare Parts Management

The classification of spare parts is essential [29] once it allows managers to focus on the most important items to define adequate inventory management policies.

Bacchetti and Saccani [30] stressed that most published papers propose a multi-criteria classification. The most frequently cited criteria are unit cost and criticality. Other criteria mentioned include demand variability, supplier availability and delivery lead times.

In order to improve management of spare parts, a multi-criteria classification is proposed. This classification will be made taking into account the most relevant factors for the company.

The registration of spare parts consumption associated to each intervention will allow the estimation of the cost of different maintenance types. This will contribute to identify which maintenance policy is more adequate.

Spare parts management should take into account the equipment reliability. The proposed reliability analysis will allow the rationalization of the stock of spare parts.

Table 1 contains a summary of the proposed features for the new system showing the improvements that it will bring over the current system.

Table 1 - The proposed improvements

Current information system	Future information system
Access to information about equipment and spare parts is held in specific locations and requires several queries.	Use of mobile devices and implementation of augmented reality to provide a 3D view of equipment and respective information.
List of recorded failure modes is identical for the various machines, not allowing an analysis of the causes, effects and frequency of occurrence of a particular machine failure mode.	Machine tree structure for the record of failure modes Implementation of FMEA tool.
Preventive maintenance intervals defined by supplier information and technicians experience.	Use of mathematical models to define the optimal preventive maintenance intervals.
Determination of the reliability indicator MTBF.	Failure time distribution and reliability analysis.
Decisions limits of monitored parameters defined by supplier	Use of mathematical models to define decision limits and

information and technicians experience.	monitoring intervals.
Deterministic scheduling made by a scheduler with visual support of a Gantt Chart considering several constraints.	Dynamic and stochastic scheduling with integration of decisions-making tools.
Use of technical and organizational indicators.	Application of a balanced performance measurement system including economic indicators.
Ordered lists of equipment based on one indicator.	Ordered list based on a multi-criteria model to assess equipment criticality.
Spare parts management supported by two different information systems.	Integration of spare parts management in the CMMS.
Spare parts stock management based on historical consumption and experience.	Implementation of a multi-criteria technique to classify spare parts. Spare parts management based on reliability knowledge.

4. Conclusion

The computerized maintenance management system is an important tool for companies to support the maintenance management activities.

The current system is adapted to the activities performed by the maintenance department, however there is several improvement opportunities, such as:

- analysis of failures to reduce its occurrences, and to plan maintenance activities and condition monitoring;
- access to the information in real-time at different places to facilitate technicians actions;
- support scheduling function attending both maintenance technician availability and production plan;
- support performance assessment and improvement initiatives;
- track the movement of spare parts affecting costs and ensure its availability when required.

The decomposition of the equipment by a tree structure and associated failures modes, recording its cause and effects, will facilitate failures analysis. AR will facilitate the access to information allowing the improvement technician performance and therefore the decrease of repair time of each intervention. The future system will include optimization methodologies to support decision-making.

This article deals with the requirements for the intended computerized system. In the future, the methodologies for decision-making process will be developed taking into account the company needs.

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