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Maintenance database

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Abstract

Maintenance activities represent an increasingly high cost in any manufacturing system or in different types of structures. Its achievement or not has a major impact on availability of equipment or structures. Nowadays cost reduction, minimizing downtime and ensuring reliability levels are central objectives in any sector of industrial activity and maintenance is observed as an important service. To achieve these goals, decision support systems should be available, optimizing the exploration and maintenance plans and ensuring companies meeting their goals. For this it is necessary to make collections of reliable and consistent data. Its analysis and treatment will allow to compute reliability values, to validate FMECA and re-plan production and maintenance. This paper focuses on the need for the existence of a maintenance database and proposes an architecture for connecting the multiple vertices that generate information to feed the database. The architecture presented should drive developments in building a platform that ensures data to be collected and processed and to link OEM, customers and maintenance providers, as shareholders of maintenance database and with the responsibility in feeding it with data during different phases of the product life cycle. The existence of a maintenance database will provides reliable information for analysis and will contribute significantly to plan the installation phase of equipment and its use.

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1. Introduction

The globalization and the fluctuation of the markets challenge all industries to be effective in designing their products, efficient in theirs manufacturing process, reliable in delivering their products and to pursue customer satisfaction during their products usage lifecycle phase. It is also recognized that the product lifecycle is becoming shorter and original equipment manufacturers (OEM) need to look continuously for innovation and improvements in the performance of their products if they want to keep their competitiveness.

OEM innovation has been occurring in their overall business model with companies to enhance their abilities to design and supply high customized products, equipment or system solutions following the customer needs throughout product life-cycle. In this context maintenance services has been increasing its relevance in sustain a long term relationship between OEM and end users or customers.

To assure a desired maintenance service level and satisfying the customer needs OEM has also been looking for partnerships with suppliers and other partners in which can be included maintenance services providers, dependently from customers location. Hence, the OEMs have to design and adapt their business models according each customer requirements with the aim to increase dependability and to assure an acceptable cost throughout product lifecycle.

Based on a survey on enabling technologies to improve the performance of Flexible Manufacturing Systems (FMS), conducted by a CIRP Working Group on "Flexible Automation-Assessment and Future" in collaboration with the ERC for reconfigurable manufacturing systems, mentioned by Ni *et al* [1], it is

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revealed that industry considers the cost of maintenance as the second more important critical factor for the success of large FMS. This shows a very low level of industry satisfaction due to the high cost of maintenance of FMS and their disappointment with the low level of availability of the systems, when compared with the expectation when those systems were installed.

Maintenance activities represent an increasingly high cost in any industry or structure (bridges, pipelines, wind turbines, offshore structures, etc). The decision making for effective maintenance is increasing in complexity with the increase in size of the systems, distant locations of customers and also due to the several independent sources of information [1]. With the aim to keep their competitive position customers are demanding improved system availability, safety, sustainability, cost-effectiveness and operational flexibility. Also there is a need for tailored support 24 hours a day, seven days a week, to keep the expectation established during the customers' decision of investment [2].

To fulfill the needs mentioned above the product design requires changes to integrate technology that, through a new organizational structure, can provide safe and cost-effective solutions or services to support an effective use of products, systems, facilities and structures, across different industries. Maintenance activities can be offer as solutions or as a service which has a major impact on availability of equipment or structures and its operational cost.

Cost reduction, minimizing downtime and ensuring reliability levels, nowadays are central objectives in any sector of industrial activity. To achieve these goals, due to the complexity of the systems and the strong dependency between critical activities, e.g. production, maintenance and quality, decision support systems should be available to propose effective plans and achieve the desired results. However, for an effective use of such systems it is necessary to have collections of reliable and consistent data about product performance that should support those systems running. The analysis and treatment of collected data will allow calculating values of reliability, to validate FMECA and re-plan production and maintenance operations or actions.

In this paper we focus on the need for the existence of a database about product or components performance data. It is proposed an architecture for connecting the multiple vertices of agents, e.g. OEM, customers and maintenance providers, that generate information to be added in the database and to take use of this data for equipment or product design and maintenance planning.

The existence of such database and the linkage between those different agents will provides reliable information for analysis and will contribute significantly to plan the installation phase of equipment and its use.

2. Maintenance service

For some systems, such as aircrafts, submarines, nuclear systems and bridges, it is extremely important to avoid failure during actual operation because it can be dangerous or disastrous. For others systems like the manufacturing systems the priority may be to avoid failures in order to satisfy production requirements. All physical assets and structures, such as a machine, an assembly line or a FMS, deteriorate with time and operation and they require maintenance in order to uphold the safety, reliability and availability of the system so that the system can continue to operate and produce goods.

In general, two different categories of engineering problems can be identified with respect to maintenance issues: those for which the priority is to guarantee safety and reliability and those for which the priority is to guarantee availability. Correspondingly, for the first category, inspections and maintenance are planned in order to keep the equipment or structure in a healthy state, avoiding failures, whereas for the second category the priority is to define a maintenance plan that ensures availability, taking into account the life cycle costs, by properly balancing the costs of failure and times between failures with time to repair and their costs [3]. Therefore when an industrial company is purchasing a single equipment or a manufacturing system the maintenance requirements to be evaluated are related to product performance, in terms of its maintainability, availability, reliability and safety [4].

Usually the system purchased from the original equipment manufacturer is accompanied by a recommended maintenance schedule and a guaranteed reliability and availability at a given operation condition.

OEM use the warranty to provide maintenance services in the event of failure, repairing any faults that occur within the warranty period and often at no additional cost to the buyer [5]. The warranty is tied to the sale and is factored into the selling price.

Over the last decade, manufacturers have begun to change their value proposition offering extended warranty, which gives the customer coverage beyond the standard warranty period, at a non-significant additional cost. For well acceptance of extended warranty by the customers contributed the involvement of other partners such as financial institutions, insurance companies and independent operators that provide services such maintenance services. These new business models were found to be highly profitable for many products, e.g., consumer electronics, that manufacturers reduced the basic guarantee for forcing customers to choose extended warranties.

Maintenance service contract between the buyer of the equipment, e.g. the customer, and the service provider, usually the manufacturer or an independent specialized third party, were done to provide the maintenance service.

The terms and conditions of the contract together with the feasible options available are important to guide the customer to decide whether or not to purchase the equipment and associated maintenance. The customer is interested in a certain level of availability of the equipment, to assure throughput and quality of products, and the maintenance service provider should schedule and adopt a correct maintenance strategy to assure the customer requirements.

An effective maintenance strategy is an important source of revenue for the contractor because he, the customer, easily considers maintenance as not part of his core activities and for this reason it is willing to pay to reduce its business risks and other (financial) burdens. In this way a contractor can focus on its manufacturing activity and diversify his ‘‘product” range and may be able to achieve a higher profit [5].

3. The need for a Maintenance Database

Despite of OEM recommend maintenance schedule they may be not optimal because operational conditions may be quite different from those considered at the design phase. So, it is necessary to obtain complete and exact data concerning equipment functioning, accidents and their consequences, maintenance operations and their costs, in order to know real operational conditions. The best case would be if such information were collected from the same equipment (specific failure data) or from analogous equipment in similar conditions. This information must also be used on equipment to be planned for implementation combined with expert judgments on new equipment reliability parameters or using standard values or standard reliability models (e.g. MIL-217 or Bellcore). So, there is a need for reliability data collection in relation to all types of components from the field records of installations and operations, in order to allow us to analyze, compare, or predict the reliability levels of complex systems [6].

- According to Cooke [7], there are, at least, three categories of users of reliability databases and all of them need different types of data:
- Risk and reliability analysts for analyzing and predicting a reliability of complex systems;
- Maintenance engineers for measuring and optimizing the maintenance performance;
- Component designers for analyzing and optimizing the component performance.

Table 1 summarizes these categories and its needs.

Table 1: Needs for different users of reliability databases.

	Users	**Needs**
Reliability and Maintenance Databases	Risk and reliability analysts for analysing and predicting a reliability of complex systems	Data to compute system reliability and availability the users need to know the reliability of components and hazard functions. Reliability and availability can be estimated from failure on demand if downtime has been properly included in the database.
	Maintenance engineers for measuring and optimizing the maintenance performance	Data to measure the performance of maintenance and to manage maintenance plans. Operational data brings together the effects of maintenance and the intrinsic reliability of the component. Also these users wants to know what would be the behavior of component failure in the case it were not maintained
	Component designers for analysing and optimizing the component performance.	Data about failure mechanisms that reveal the weak points of design. These users are interested in distinguishing failure modes according to failure mechanisms. Where this is not possible, engineering knowledge is used to infer failure mechanisms from other information.

The systematic collection of reliability-data dates from the Titan Missile program [8]. Since the 1980s there have been many attempts to provide systems for collecting and organizing raw data, and to standardize the information presented in the data banks. But these efforts have been partial and focused on some particular industrial areas. Besides, there is a lack of accurate data, leading to suboptimal parameter estimates and inaccurate decisions about replacement intervals and preventive maintenance activities [9].

According to the study presented by Cunha [10] certain aspects with negative impact in the performance of production planning task are identified and its integration with other productive tasks is discussed. Also, studies carried out by Duarte [11] provide a basis to conclude, albeit empirically, that the information related to equipment busy and idle times recorded by independent production and maintenance planning systems may be substantially different. Only a system that records these data in a unified and coherent way will allow the calculation of appropriate estimations of the most important reliability parameters, such as the distribution of failure rate, mean time between failures (MTBF) and mean time to repair (MTTR). From another point of view, the integration of all this information will allow that priorities and therefore ranking of different productive services – production operations and maintenance services - may be defined in an integrated overall way. In practice, this means that as long as the reliability of a piece of equipment is decreasing, the degree of priority of the maintenance action required to restore it to its functional state, increases. This leads to a situation where maintenance operations acquire a priority status against production. The importance of such a policy is undeniable because only in this way is it possible to ensure realistic availability of equipment. In this way it is closed one of the information loops of this system.

In our perspective, the construction of a reliability and maintenance database demands a collaborative effort from the OEM, the customers, e.g. the equipment owners, and the independent maintenance providers. These three agents are the vertices of a collaborative triangle that must be built to increase efficiency of production systems, and in particular through a dynamic planning of maintenance operations. Fig. 1 illustrates this perspective.

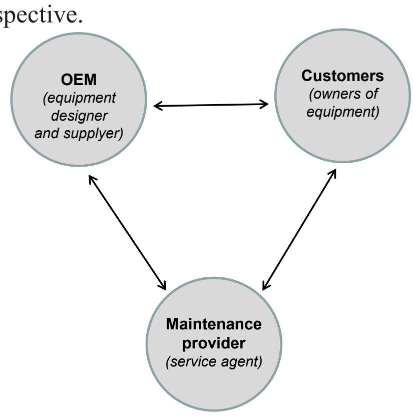


Fig. 1: The collaborative triangle for maintenance efficiency.

The appearance of e-technologies allows the integration and the process of data generate, by several sources, contributing in this way for the construction of such a database. Once filled with data the database must be complemented by a set of tools that can compute or estimates the reliability and maintenance parameters. These tools should also be able to make diagnosis, prognosis and schedules for maintenance activities. Therefore they should be considered an important element in a support decision management system. Fig. 2 is a schematic diagram of what we have just said.

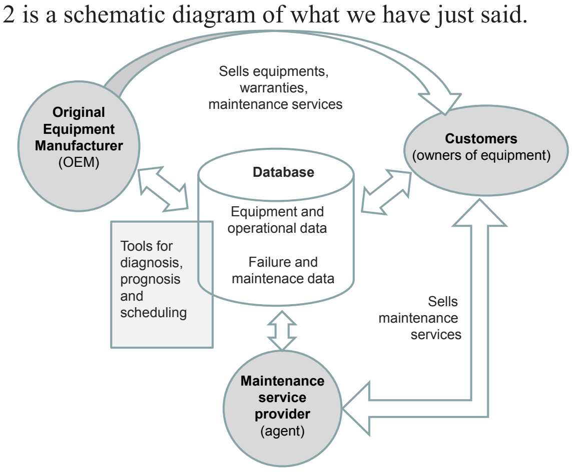


Fig. 2: Maintenance Database collects specific information and is a supplier of processed information.

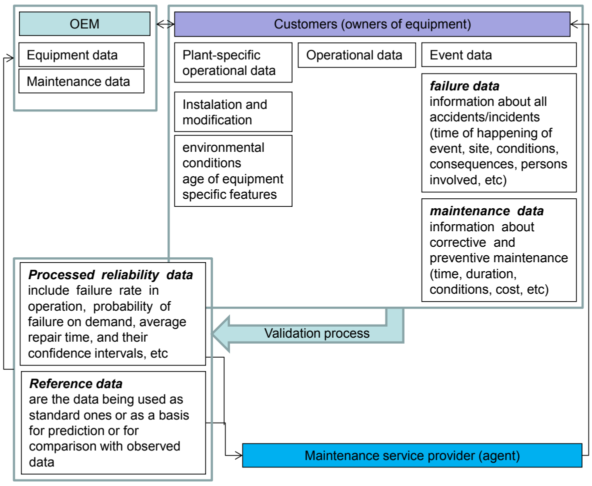
4. Database requirements and impact

Recognizing that reliability, availability, maintainability and safety as product characteristics, are mainly established at the design stage of the equipment or system and can partially change in usage phase, with a huge influence on production system performance, the maintenance database should contain these information about equipment characterizing its performance and the conditions of it use. This means that in the maintenance database should be recorded plant-specific operational data, environmental conditions, operational data and event data such as failure data and maintenance data. Some examples of parameters to be collected for each equipment, by each user in each factory, are the following:

P_O_T	Planned Operation time
R_O_T	Real Operation time
DT_F	Unavailability time due to failure *i* (*P_O_T*)
DT_I	Unavailability time due to incident *j*(*P_O_T*)
C_F_i	Cause of failure *i*
C_I_j	Cause of incident *j*
FM_i	Mode of failure *i*
IM_j	Mode of incident *j*
Cons_F_i	Consequence of failure *i*
Cons_I_j	Consequence of incident *j*
T_C_i	Repair time (failure *i*)
Temp	Temperature
Vibr	Vibration

Estimates for the reliability and maintenance parameters, diagnosis, prognosis and schedules for maintenance activities should be based on this data. However several problems arise when trying to make a collection of data for equipment operating in quite different conditions. The production rhythm in which the equipment operate, environmental conditions, vibrations and many other factors influence in a significant manner the values of the parameters under study (for example, the hazard function, the mean time between failures). Equipment performance, in terms of indicators of reliability, availability and maintainability, is a function of the intensity of manufacture, a clean environment, etc.

To allow comparisons it's necessary to standardize the data collected, which will require a qualitative and quantitative statistical analysis. Figure 3 shows how OEM, customers and maintenance providers interact to



feed the maintenance database.

Fig. 3: OEMs, customers and maintenance providers interact to feed the maintenance database.

Forecasting techniques are also an essential tool to infer the possibility of any damage or equipment failure, thus allowing an intervention *a priori* that prevents it. Equipment condition monitoring allows collecting data of the values of essential parameters. All these types of information help to create a picture of what may happen in the future. The higher the volume of data and its quality, the lower will be the error. If recorded data highlight a trend in the observed values it may be forecasted when the parameter will overcome the limits of alert or alarm of the signature. Some of the forecast techniques to be embedded are shown in Fig. 4, however, it is quite important to emphasize the applicability conditions of these methods:

- There is sufficient quantitative information about the past;
- The historical pattern will continue into the future – stability hypothesis.

There are more sophisticated quantitative methods but, empirical studies, concluded [12] that the post-sample accuracy of simple methods is, on average, at least as good as that of complex or statistically sophisticated ones. Furthermore the averaging of the forecasts of more than one method results in more accurate predictions than the individual methods themselves.

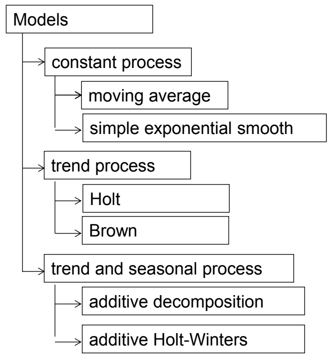


Fig. 4: Forecasting models.

To avoid a high effectiveness in data collection it is required a careful study related with the equipment structure and selection of components that must be identified to be monitored. It is our perspective that those should be critical components in terms of equipment functions or in terms of failures.

With the design and implementation of this maintenance database it will be possible:

- To enhance the standardization of information and therefore the link between different companies information systems and maintenance database.
- To build reference data, e.g. equipment morphological and performance data, to be used of by different industrial sectors and subsectors.
- To streamline configuration processes of facilities and data comparison.
- To leverage an analytical approach to maintenance analysis by applying the methodology RAM - Reliability, Availability, Maintainability or similar (for example, RCM – Reliability Centered Maintenance).

In terms of maintenance planning and considering that each company can have its own policy and use its own information technology (IT) system the proposed maintenance database will open the opportunity to feed those systems with reliable data to support effective planning tasks. The availability of this data to those systems in each company can be considered a service to be provide which will allow:

- To configure installations according to a standardized vision for each industrial sector or subsector.
- To build in an easy way the database and the associate records for each company, exporting standard equipment information, prepared by equipment brand and model or by family and function.
- To prepare the maintenance plan through the exportation of standardized equipment information.
- To import/export data regarding the use of equipment in different industrial sectors, referenced by brand

and model or by family and function to enhance the benchmarking

- To import/export data regarding the use of equipment in different industrial sectors, referenced by brand and model or by family and function to synthesize typical values on a standardized morphology, and obtain reference information concerning the performance of equipment.

A critical issue for the implementation of this concept is the ability to collect data directly from the equipment or through the link with the maintenance planning systems. Iung *et al* [13] present a list of several innovative technologies that can be used to support the data collection and implement the architecture we propose, specifically:

- New sensors to be installed in equipment to collect and transmit data about its status.
- Global Positioning System to calculate the location of operators or maintenance tools.
- Wireless technologies and specific standards to ensure the integration and interoperation between different management systems (CMMS, EMS), Maintenance Database, the OEM, etc.
- Tools based on statistical methods for diagnostics and prognostics and maintenance replanning.
- Web services.

In our perspective the design and implementation of such a database should be driven by a maintenance service provider or by a consortium, and opens new business opportunities for components suppliers and maintenance service providers. For the customers it can be a contribution to improve its throughput, quality and to reduce operational costs, which can have impact for the final user. For OEMs it will be a source of information for upgrading and designing new products.

5. Conclusions

OEMs are supplying their products in the global market and there is a trend in OEM business models that enhances the value of maintenance services for their products. The new technologies available allow something new which is the ability to monitor equipment or component's performance in real time and to collect data. The possibility to collect selected data allows to define and analyze strategies to improve maintenance services with relevant benefits for the equipment owners. The need of an "open" maintenance database determines the use of a set of tools to process data. The concept of an "open" maintenance database is something new and for this reason there are many opportunities to exploit that interlink OEM or technology suppliers, service providers and customers. One outcome of this concept is a clear understand about the need for a linkage between these three actors, OEMs, service providers and customers, and the opportunity with this collaboration to increment in the innovation capacity in terms of product and processes, reducing product life-cycle cost with benefit to the final customer of goods produced through those equipment or systems.

From our point of view, the open maintenance database will contribute significantly to shortens the process of loading data to model the installation by providing the structure of standardized equipment. It will ensures the use of a standardized structure that meets the requirements of industrials sectors and ensures compatibility for data analysis and benchmarking. Also it will shortens the processes of analysis and comparison – benchmarking – and it will provides reliable information for analysis.

It should be notice that there is a lot of work to be done to implement this database, especially about the technical representation of the data to be collected.

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