Methodology for maintenance management based on diagnostic criteria

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Abstract
The present research was as objective to design a methodology for diagnostic of maintenance management, to can apply any field of production or service. In the design a study realized in different methodology was used expect tools work, storm brain and the Delphi method. The methodology obtained called Methodology by Diagnostic Criteria had as main characteristics to consist of a checklist (see Diagnostic sheet made in Excel) of the quantitative type, consisting of 5 functional areas, 21 dimensions, 38 criteria and 186 diagnostic criteria, simple to contextualize any field of action of the maintenance engineering. The methodology was applied in the transport area of an Ecuadorian university.

Keywords: management maintenance; diagnostic method; diagnostic criteria; functional area.

Metodología por criterios de diagnóstico para la gestión de mantenimiento

Resumen
La investigación tuvo como objetivo diseñar una metodología para el diagnóstico de la gestión del mantenimiento, aplicable a cualquier campo de la producción o de los servicios. Para su diseño se realizó un estudio de diferentes metodologías, fueron utilizadas herramientas de trabajo de expertos, tormenta de ideas y el método Delphi. La metodología obtenida denominada Metodología por Criterios de Diagnóstico tuvo como principales características consistir en una lista de chequeo (ver Hoja diagnóstico realizada en Excel) del tipo cuantitativa, conformada por 5 áreas funcionales, 21 Dimensiones, 38 Criterios y 186 Criterios de diagnósticos, sencilla de contextualizar a cualquier campo de acción de la ingeniería de mantenimiento. La metodología fue aplicada en el área de transporte de una universidad ecuatoriana.

Palabras clave: gestión del mantenimiento; metodologías de diagnóstico; criterios de diagnóstico; áreas funcionales.

1. Introduction

To design an improvement process of any kind, one of the important elements to account on is to know the real state of the process that was analyzed, for this it is necessary to prepare a diagnosis. Due to this, is necessary to do actions to have methodologies that allow obtaining reliable results applied to the field of study [1]. This research did in maintenance engineering is developed in the field of management.

Next, different methodologies for the diagnosis of maintenance management (GM) are analyzed.

Acosta develops a methodology to evaluate maintenance management [2], in which this process to do the integrated manner, that is, the recognized aspects of quality are not considered and functionality is incorporated into the technological and environmental aspects of safety, as negative

aspects is considered that it is very complex in its applicability, it is based on giving weight to the areas and therefore levels of priority in its analysis which can predefine the results.

Vázquez, proposes a methodology focused on the philosophy of W. Edwards Deming who states: "Through the adoption of appropriate management principles, organizations can increase quality and at the same time reduce costs". This methodology is based on a checklist but only focuses on quality elements [3].

Diaz, establishes a methodology for bioproduct plants, although it is applicable only in this context, it is based on aninquiry type tool and does not establish priority orders, all areas have an equal impact on the final result [4].

The objective of this work was to design a methodology for the diagnosis of maintenance management that could be of any sector, prepared on the basis of a checklist and indicators specific to the entity being diagnosed. The Methodology by Diagnostic Criteria was obtained, which was applied in 2 companies, one in Ecuador and the other in the Dominican Republic.

This methodology is a tool that have among advantage to be based in a checklist, whereby the evidence was obtained from direct observation in the area and the results were compared against a desired state, as well as the methodologies studied in It has a better contextualization to the field that is going to be diagnosed because the measurements, the criteria and the diagnostic criteria are taken as a reference.

2. Methods

The Methodology by Diagnostic Criteria is an instrument that allows to know in what state is the maintenance management into a company and how approximate is a predetermined pattern. This pattern was obtained on the basis of criteria raised in a brainstorming and group work of experts in the area to be diagnosed and their comparison with the current state.

For its contextualization to a specific entity or area it is necessary to follow the following steps:

1. Selection of the area to be diagnosed.
2. Selection of the group of experts or specialists.

The competence of the experts was determined by a coefficient of competence that is calculated according to the opinion of the specialist on their level of knowledge about the problem being solved and with the sources that allow them to argue their criteria [5]. In case of not being able to gather in the entity a group of experts that comply with this validation, the analyzes are assumed with a group of specialists from the same entity but who prove that they comply with this code

Table 1.
Valuation applied criteria diagnostic.

Quality of evaluation		Mark
Very inadequate	VI	1
Inadequate	I	2
Either inadequate or Good	EI-G	3
Good	G	4
Very good	VG	5

Source: The Authors.

through their level of instruction, working time in the entity and working time in the process that is analyzed [6].

The work team is made up of the selected experts and the evaluator who will do the diagnosis.

3. Validation of the dimensions, criteria to be evaluated, the diagnostic criteria and the diagnostic criteria to be taken as a reference.

The validation of these elements is done with the group of experts or specialists through brainstorming, always assuming the final results by consensus [7], the Delphi method can also be used [8, 9]. In order to determine the values of the reference diagnostic criteria, the historical data of the entity must be taken, in case of not having these historical data, the Benchmarking values of the process analyzed must be taken [10, 11].

4. Application of the methodology

In the application of this new methodology, the evaluator should take as a reference the reference diagnostic criteria mentioned in step III and compare them with the current status based on the following criteria shown in Table 1 [12]:

The ranges proposed in the methodology designed to evaluate the state of maintenance management in bioproduct plants proposed in [3] are taken as a basis. The ranges determined are:

• Below 2.8 is considered a bad value.
• Between 2.81 and 3.4 is regular.
• Greater than 3.41 is a good value and it is recommended to detect the existence of opportunities for improvement.

The final result obtained in the analysis sheet compared with the above ranges gives a qualitative criterion of the state of maintenance management in the entity under analysis.

In this link you can download the diagnostic sheet proposed in this work to diagnose maintenance management, as well as the summary sheet of the information collected, made in Excel

3. Results and discussion

For the definition of functional areas, dimensions, criteria and diagnostic criteria, a detailed analysis of 7 methodologies was carried out, where the areas and functions to be evaluated were identified, which allowed determining which are the most cited. in methodologies, their differences and similarities. They were:

1. Methodology to evaluate maintenance management. 2012, Cuba [2].
2. Methodology for diagnosis in bio-products plants. 2016, Cuba [4].
3. Manual for Evaluating Maintenance Systems in Industry.1993, Venezuela [13].
4. Methodology of Analysis and diagnosis A & D. 2002, Brazil [14].
5. Maintenance audits. 2009, Spain [15]
6. Methodology to audit Maintenance Management. 2011, Venezuela [3]
7. Method for diagnosis in industrial SMEs. 2013, Colombia [16]

8. Methodology of the Company for Technical Cooperation Deutsche GesellschaftfürTechnischeZusammenarbeit. 2000, El Salvador [17]

Through the analysis it was concluded that the most common functional areas are: General Organization, Human Capital (they are declared in all) and Planning-Programming, where in 80% of the studied methodologies are implicit in this area the analysis of outsourcing and control of the Maintenance, Economic Control and Maintenance Engineering. The other areas vary according to the criteria and objectives of each author.

In the General Organization area, attention is paid to the level of the organization, policies and strategies as well as the management of warehouses and the management of information through computerized aids. In the Human Capital area, at the level of training and sense of belonging. In Planning, Programming, Outsourcing and Control, all the sub processes that compose it are given vital attention. Regarding the Economic Control area, the cost control and budget preparation are analyzed and in the Maintenance Engineering area, everything related to the

Table 2.
Structure of methodology.

Functional area	Dimension	Quantities of criteria	Quantities of criteria diagnosed
General organization	Political general	4	20
	Informatics aids	2	10
	Warehouse and raw material	2	10
Human capital	Executive training	1	3
	Training of the personal of maintenance	1	4
	Worker training	1	3
	Training hold and stimulation	1	6
Economic control	Control of cost of maintenance	1	3
	Use of economic indicate	1	4
	Budget of maintenance	1	3
Planning, Programming, Outsourcing and Control	Planning	1	8
	Programming	1	3
	Work order	1	3
	Outsourcing	2	11
	Control	1	8
Maintenance Engineering	Preventive and corrective maintenance	5	21
	Quality control	2	9
	Management environmental	1	11
	Security management	1	10
	Technology of maintenance	3	12
	Technology of diagnostic	5	20
Total	**21**	**38**	**184**

Source: The Authors.

types of maintenance implemented in the organization is analyzed, as well as the interrelation of maintenance with other areas and concerning diagnostic technologies.

Taking into consideration the previous methodologies and the analyzes performed on them, the methodology for the diagnosis of maintenance management called Methodology by Diagnostic Criteria was designed, with the structure shown in Table 2.

3.1. Application example

It was taken a University of Ecuador, the development of the steps are summarized below:

1. Selection of the area to be diagnosed.

The area of the university selected by the management of the same is that of maintenance to the school transport fleet, due to the repeated failures that are affecting the availability of the same, the transport management as well as the address of the institution present concerns With the costs associated with this process that have been increasing, these failures in most cases have led to the non-compliance of transportation plans, affecting the arrival of students and / or teachers, affecting the teaching process and the satisfaction of the clients [12].

2. Selection of the group of experts or specialists

In the research presented in [12] the final selection of the group of experts is made up of 7 specialists.

3. Validation of the functional areas, dimensions, criteria to be evaluated, the diagnostic criteria and the diagnostic criteria to be taken as a reference.

For the assessment of the proposed functional areas, a direct survey was made to the group of experts and three workers with extensive knowledge of the area were added, for a total of 10, in order to obtain better criteria [6].

For a better assessment of the proposed functional areas, three knowledgeable workers were added to the group of experts for a total of 10. A direct inquiry was made to the group of experts [6].

In the data collection, an accumulated percentage calculation was made taking as a criterion a minimum of 70% to be approved. Table 3 shows the results obtained.

4. Application of the methodology [18]

The application of the methodology allowed to obtain the results that are explained below starting from the analysis of each functional area until the total valuation.

The application of the methodology, starting from the analysis of each functional area until the total evaluation, allowed to obtain the results that are exposed next:

Tabla 3.
Inquiry results.

Indicator	Percentage accumulated
General organization	92
Human capital	84
Economic Control	84
Planning, Programming, Outsourcing and Control	90
Engineering	81

Source: The Authors.

Tabla 4.
Results in the area of general organization.

General organization	Value
1.General political	3.46
2.Informatic aids	1.35
3. Outsourcing and raw material	2.05
Total value of general organization	2.28

Source: The Authors.

General organization area:

Table 4 shows the results obtained in this area for each dimension

A value of 2.28 declared as BAD was obtained, in this result the dimensions, Computer media in the first instance, followed negatively, and followed by Warehouses and material resources. The General Policy dimension obtained a rating of GOOD although it is to be noted that this result is very close to a regular evaluation. Of the 42 diagnostic criteria that are evaluated in this area, 19 obtained an evaluation between bad and very bad for 45% and only 12 obtained an evaluation between good and very good for 28%.

In general, the most serious problems are related to:
• Maintenance is not located in the managerial organization chart in the place that should correspond to it, does not participate directly in the decision-making process and there is no clarity in the flow of information.
• There is no clear function design and knowledge of the operators and maintainers.
• The amount of maintenance work that can be done is not known.
• There is no coherent maintenance policy that allows drawing strategies and concrete actions.
• As there are no clear policies, the strategies do not comply with what was expected, in a general way they work reactive and without planning.
• The non-existence of computerized means to manage the process.
• The management of historical records of maintenance for each team is poor, as well as information on indicators that allow corrective actions to be taken in the face of problems that occur.
• Warehouse management for maintenance is not good, there is only a small room where some basic spare parts such as oil or fuel filters, some belts, and other tools are stored, but it is not an area that manages to solve the problems that arise happened.

Human capital area:

Table 5 shows the results of the Dimensions that are evaluated in this area.

Table 5.
Results of human capital.

II- Human capital	Value
1 Executivetraining	1.00
2 Maintenance training	1.25
3 Worker training	1.00
4 Training hold and stimulation	1.80
Total value of human capital	1.26

Source: The Authors.

Table 6.
Results of economic control

III- Economic control	Value
Control of cost of maintenance	2.00
Use of economicindicate	2.25
Budget of maintenance	1.33
Total value of Economic control	1.86

Tabla 7.
Results of Planning, programming, outsourcing and control.

IV- Areaplanning, programming, outsourcing and control	Value
1 Planning	2.00
2 Programming	2.00
3 Workorder	2.60
4 Outsourcing	1.80
5 Control	1.50
Total value of areaPlanning, programming, outsourcing and control	1.98

Source: The Authors.

From the results shown in the previous table, it can be determined that this area also obtains an evaluation of MAL, where all its dimensions are evaluated as bad. Of the 16 diagnostic criteria evaluated, 15 obtained an evaluation between bad and very bad.

The main problems found were:
• The non-training of personnel, both managers and operators and not control thereof, as well as the non-stimulation for training.
• The non-control of the performance of those responsible, maintainers and operators, only verify that the workers fulfill their duties even if they are routinely.
• Given the reactive work of the tasks, the analysis of indicators that allow all workers to improve their efficiency is not encouraged.

Economic control area:

The evaluation of the Economic Control area was carried out on the basis of evidencing the status of the control functions of the costs and use of the indicators of the maintenance process. Table 6 shows the results of the Economic Control area.

In general, the state of the area and all its dimensions were evaluated as BAD. Of the 10 diagnostic criteria evaluated, 7 obtained between bad and very bad and the remaining 3 were evaluated as regular.

The main problems found were:
• The non-training of personnel, both managers and operators and not control thereof, as well as the non-stimulation for training.
• The non-control of the performance of those responsible, maintainers and operators, only verify that the workers fulfill their duties even if they are routinely.
• Given the reactive work of the tasks, the analysis of indicators that allow all workers to improve their efficiency is not encouraged.

Planning, programming, outsourcing and control area:

The area Planning, programming, outsourcing and control, brings together several subprocesses within the

maintenance process, for the evaluation of it was taken into account that the status of internal maintenance processes such as planning, programming and outsourcing will be demonstrated as well as the management of work orders. Table 7 shows the results.

This area obtained an evaluation of BAD, its Dimensions and Criteria also obtain this evaluation. It was conformed, for its evaluation by 33 Diagnostic criteria, 24 of them obtained an evaluation between bad and very bad for 73%, only 6 obtained an evaluation between good and very good for 18% and the rest were evaluated as regular.

Among the problems that most affected this evaluation were:

The almost null participation of a staff for the planning, almost all the work is done in a reactive way, the worker who attends this area is only responsible for giving fulfillment to the daily tasks. This situation is similar in the programming.

• There is no compatibility of decision making between administration and maintenance.

• There is no mechanism for the generation of work requests or a computer system that makes this process efficient, only requests are made for daily failures. This document presents very little information that allows the analysis of costs or failures.

• There is no defined procedure for the selection of maintenance service providers, and it is only carried out according to the economic criteria and in some cases the hiring of any company or personnel to perform a task is very subjective.

• The works to be contracted are defined by the maintenance area but it does not intervene in the contracting. The contractors are not obliged to submit work orders and only an invoice is presented on the work carried out that contains very little technical information, reducing to information of expenses incurred.

• Control over contracting is deficient, with the economic factor prevailing. The contracts do not impose clauses to enforce quality indicators. No activities or studies are carried out for homologation of contractors.

• Documented procedures for conducting internal audits have not been established. It is worth noting that this is the first work that is done of this kind.

• No corrective actions are planned for the deficiencies found in the audits or internal evaluations with determined completion periods, nor is there a system to investigate the causes of the nonconformities of the maintenance service.

Engineering area:

For the evaluation of this area, the status of other processes such as environmental management, quality, the environment, among others, the use of diagnostic technologies as well as the types of maintenance that are currently implemented were taken into account. Table 8 shows the results achieved in their Dimensions.

In general, this area and its 6 dimensions reach an evaluation of BAD. Thirteen Criteria and only 68 Diagnostic

Table 8.
Results of engineering area.

V- ENGINEERING	Value
Preventive and correctivemaintenace	1.45
Quality Control	1.08
Management enviromental	1.45
Management security	1.70
Maintenancetechnology	1.00
Technology	1.25
Total value of engineering	1.32

Source: The Authors.

Criteria were evaluated, from which they were evaluated as poorly and very poorly 61 for 90%.

The problems that impact on this evaluation are varied, some of them are listed below:

• There are no checklists to evaluate the status of preventive maintenance actions and the tasks are not planned or scheduled. Prima reactive maintenance, this validates the results of the planning process where similar results were obtained.

• The maintainers do not have the necessary tools and tools to perform their functions. There is no storeroom where the little tooling they have is controlled.

• Compliance with maintenance work is not effectively controlled, the few planned maintenance actions are carried out in a fortuitous manner and there is no management of indicators to trace corrective actions on the problems that arise.

• We do not have the necessary infrastructure to achieve compliance with the provision of maintenance service, the space available is very small and does not meet the necessary requirements.

• There are no rules or procedures for maintenance tasks that are executed. There is also no metrological assurance.

• There is no clear quality policy and knowledge of workers in the area, there is only the policy of the UTM.

• Repetitive or chronic breakdowns are not analyzed, nor are corrective actions taken to eliminate the occurrence of same. Neither work in groups or teams to make any technical decisions.

• Procedures for environmental and safety management are not documented. UTM guidelines are not known to workers in the area. There is no clear policy on the environmental safety process and safety management.

• No controls are carried out on environmental predators, gas escapes, liquid and solid waste discharges, nor are offenders penalized.

• Technical diagnosis technologies are not known to the maintainers and there are no policies or actions for training in this area of workers.

As a general result of the application of the methodology, the results obtained in the different areas in Table 9 are shown:

In a general way, it is observed that the results of the areas obtained values below 2.8 so that the state of maintenance management in the area served by the school transport fleet in the university can be evaluated, such as BAD.

Table 9.
Resumeof results obtened in eacharea and total value.

No.	Functionalarea	Value
I	General organization	2.28
II	Human capital	1.26
III	Economic Control	1.86
IV	Planning, programming, outsourcing and control	1.98
V	Engineering	1.32
	Total value of tool	1.71

Source: The Authors.

From the previous analysis the results of the work allowed proposing a total of 14 tasks and 45 actions that once implemented will contribute to improving the state of bus availability and thus fulfill its fundamental function that is to guarantee the transfer of students and workers.

This methodology presents as advantages with respect to [2] and a [15] that priority values are not presented with respect to any functional area, giving them the same weight in the valuation of the final result to all. Compared with [3,4,13] it is shown that it can be applied to any context, not being directed to a particular type of company. As stated [17] its methodology it is totally qualitative, it is an evaluation of the maintenance function that is characterized by proposing a questionnaire to evaluate 6 questions divided into 6 functional areas of maintenance.

In comparison with the methodologies cited above, the one designed in this work uses as a tool for the collection and recording of information, a checklist where you can validate the desired state and have a predefined real state for the context to be evaluated, and can be used as a tool for continues improvement, because once the actions derived from the analysis of the current state have been implemented and after some time has elapsed for its new application, the progress of the organization can be measured more easily, by having the diagnostic criteria already established, so that it would only be necessary to review how the elements to be evaluated are found, not being necessary a prior work for their implementation

4. Conclusions

A new methodology called Methodology for maintenance management based on diagnostic criteria was obtained based on a checklist. It is easy to implement and easy to contextualize in any field of action.
On its application it was found that it exceeds the methodologies studied because it has a better contextualization to the field to be diagnosed because the dimensions, criteria and diagnostic criteria to be evaluated are obtained directly from the diagnosed entity.

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