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Evidence-based asset management applied to maintenance function control

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Abstract

Purpose – Every day a large volume of information is generated in the maintenance department relating to its business assets whose detailed analysis has a direct impact on the effectiveness of the company. Taking into account the aforementioned, it is necessary to develop and implement a set of indicators that allow a practical evaluation of the maintenance function in any firm. Therefore, the purpose of this paper is to evaluate the maintenance function through a thorough analysis of historical data of a biotechnology sector firm.

Design/methodology/approach – The method used to evaluate the maintenance function of a Cuban company is based on the quantification of a set of indicators, represented graphically. The data processed in this paper were obtained through an informatics application, designed to computerize the maintenance function in the firm. This application is validated and is part of the company quality management system, which is audited every two years by the national regulatory authority CECMED (Centro para el Control Estatal de Medicamentos, Equipos y Dispositivos Médicos de Cuba, by its Spanish acronym), for issuing the certificates of sanitary license and good manufacturing practices.

Findings – Evidence-based control alternatives were used to evaluate the adequacy of the maintenance function in a biotechnology company. The results demonstrate graphically the maintenance operations of the National Center for Scientific Research, production department, during a period from January 2013 to December 2017. Finally, based on the analysis, it was discovered that the performance of the maintenance department was inadequate and had poor effectiveness, and a new maintenance strategy was established to be followed for the next quinquennium.

Originality/value – The research proposal provides information on how to evaluate the proactive and reactive maintenance actions through graphical indicators. The results obtained together with traditional maintenance indicators such as availability, maintainability and reliability could be interesting to technicians or engineers who decide to evaluate directly the effectiveness of a maintenance department.

Keywords Maintenance strategies, Maintenance function, Key performance indicator, Maintenance optimization

Paper type Research paper

1. Introduction

Maintenance, like other processes in the sciences and engineering, has evolved on a large scale over time. The current changes in the industrial world have brought new policies that have adapted to the pace of life of world-class companies. Currently any company that wants to face these challenges must be prepared to assimilate the changes imposed by the development (Mehairjan *et al.*, 2016; Parida *et al.*, 2015; Shah *et al.*, 2017).

Maintenance is not a stranger to these changes, its effectiveness lies in which model should be applied, how it should be applied and how it will be controlled. It is not enough to know the problem and be timely; it requires having a well-structured management system that functions in an organized way and responds to the needs of the company so that its effectiveness generates the desired benefits. Taking into account the aforementioned, maintenance is considered as a main link to achieve the success of a company (Seecharan *et al.*, 2018). This is why latest generation strategies such as evidence-based asset management (EBAM), time-based maintenance, availability-based maintenance, age-based maintenance,

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among others, are presented as good alternatives to determine the operating conditions of a process, system or a particular asset.

The goal of maintenance management is to increase the availability of assets at a reasonable cost, with the premise that these assets operate in an efficient and efficacious way in an operational context (Tsang, 2002). Therefore, optimization of resources, costs and work efforts will result from the integration of different methods whose management has common aspects and requirements, in other words, a model that guarantees a correct control of the maintenance function (Ismail, 2014; Márquez *et al.*, 2009).

EBAM is the science of making the right decisions and optimizing asset management processes with the best information available and with clearly defined decision criteria. Data-driven decisions provide the most advantageous methodology to minimize costs and maximize the return on investment of physical assets. This technique requires the access to financial and maintenance data; therefore, to record accurate maintenance activities in a computerized maintenance management system (CMMS) is a critical factor (Campbell and Reyes-Picknell, 2015; Kans, 2009).

It is well known that developing and timely controlling a maintenance management schedule brings great benefits for a company (Roberts *et al.*, 2018). The benefits can be summarized as:

- quality increase of activities per employed resource;
- costs reduction in production line;
- better identification of the operational requirements and better performance of the assets; and
- an increase in opportunities and innovation responses.

Carvajal *et al.* (2015) developed and implemented a maintenance plan based on an analytical method, and recommend its re-evaluation every two years in order to evaluate its effectiveness continuously. Galán and Walker (2018) and Wienker *et al.* (2016) state that implementing a maintenance information system in an organization that is located at efficiency levels of around 80 percent can bring benefits such as (Carvajal *et al.*, 2015; Galán and Walker, 2018; Wienker *et al.*, 2016):

- reduction of the annual effort in maintenance due to the optimization of human resources;
- reduction of the annual use of materials and spare parts; and
- increase in efficiency in inventory management.

On the other hand, investigations indicate that decision analysis capability is often missing in existing CMMSs and collected data in the systems are not completely utilized. Taking into account the aforementioned Labib (2004, 2010), Duffuaa and Raouf (2015), Rastegari and Mobin (2016), Balouei Jamkhaneh *et al.* (2018), among others, propose different methods or techniques to select effectively a CMMS (Balouei Jamkhaneh *et al.*, 2018; Duffuaa and Raouf, 2015; Labib, 2004, 2010; Rastegari and Mobin, 2016).

Independent of scientific productions and literature reviews, it is evident that many companies control their performance based on the adequacy of control indicators, in order to compare itself with an established standard. As a consequence of this, the goal of this paper is to evaluate the maintenance function through a thorough analysis of historical data in a Cuban biotechnology firm.

2. Method

The method used to evaluate the maintenance function is based on the quantification of a set of indicators, represented graphically. These indicators allowed the evaluation of the performance of the maintenance function in a period of five years, from January 2013 to December 2017.

The data processed in this paper were obtained through an informatics application, designed to computerize the maintenance function in the firm. This application is validated and is part of the company quality management system, which is audited every two years by the national regulatory authority CECMED (*Centro para el Control Estatal de Medicamentos, Equipos y Dispositivos Médicos de Cuba*, by its Spanish acronym), for issuing the certificates of sanitary license and good manufacturing practices (Galán *et al.*, 2014).

The firm evaluated was the National Center for Scientific Research (CNIC by its Spanish acronym), production department. CNIC is a biotechnology company specializing in medicines and nutritional supplements production of natural origin. The main production lines are composed of technological equipment such as chemical reactors, crystallizers, distillers, centrifuges among other equipment, from the beginning of the twenty-first century. We can also find a clinical test laboratory equipped with modern and precision assets.

The company has implemented a quality management system, which includes the critical equipment monitoring as a risk-oriented technological surveillance framework. The framework for the technological surveillance of business assets was implemented using the FMEA technique (Galán, 2017). The quantified indicators are re-evaluated annually by the maintenance group of the aforementioned company.

Procedure

The proposed indicators to observe are:

(1) Department effectiveness: it refers to the departmental general time fund and reflects the part of it that is used in proactive or reactive maintenance activities. It is considered that the effectiveness should be between 75 and 85 percent so that the maintenance department is considered competitive:

$$D_e = \frac{E_t}{T_a} \times 100, \tag{1}$$

$$E_t = L_{mpp} + L_{mc,} \tag{2}$$

$$T_a = n \times \left[\left(JL - \sum HND\right) \times \left(DM - \sum DNL\right)\right] \times m, \tag{3}$$

where D_e is the department effectiveness; E_t the effective time or minimum time required to execute CM and planned preventive maintenance (PPM) actions; T_a the time available; m the constant equivalent to the number of months; n the amount of technicians available; JL the duration of working shift; DM the amount of working days in each month; $\sum HND$ the sum of hours dedicated to breakfast, lunch, breaks, etc.; $\sum DNL$ the sum of non-working days in each month.

(2) Load balance based on PPM: refers to the amount of equipment covered by the schedule maintenance in relation to the average hours to be dedicated to execute planned activities (AH_{ppm}). This control parameter united to the maintenance frequency of the assets (MF), the amount of equipment in each group (AE) allow to estimate in a general way the load balance based on PPM (Galán and Walker, 2018):

$$L_{ppm} = \sum_{i=0}^{n} AE_i \times MF_i \times AH_{ppmi}, \tag{4}$$

where n is the total families of equipment listed for maintenance; L_{ppm} the load of the annual preventive maintenance; MF the maintenance frequency; AE the amount of equipment in each group; AH_{ppm} the average hours to be dedicated to the planned maintenance of particular equipment group.

(3) Load balance based on corrective maintenance (CM): amount of equipment serviced or the number of work orders issued vs average hours to be dedicated to the CM (AH_{cm}):

$$L_{cm} = \sum_{i=0}^{n} AE_i \times AH_{cmi}, \tag{5}$$

where $n =$ is the total families of equipment listed for maintenance; L_{cm} the load of the annual CM; AE the amount of equipment in each family; AH_{cm} the average hours to be dedicated to the CM of the particular equipment family.

(4) Compliance with the PPM schedule: PPM schedule vs pending workload. The purpose of this indicator is to assess the effectiveness of maintenance planning. Additionally, pending tasks were located through preventive and CM work orders that were not executed, with the aim of determining the factors that caused its delay:

$$C_{ppm} = \frac{T_i}{T_{pi}} \times 100, \tag{6}$$

where C_{ppm} is the compliance with the PPM schedule; T_i the total interventions; T_{pi} the total planned interventions.

(5) Graphic analysis of costs for labor, spare parts and materials in the period analyzed:

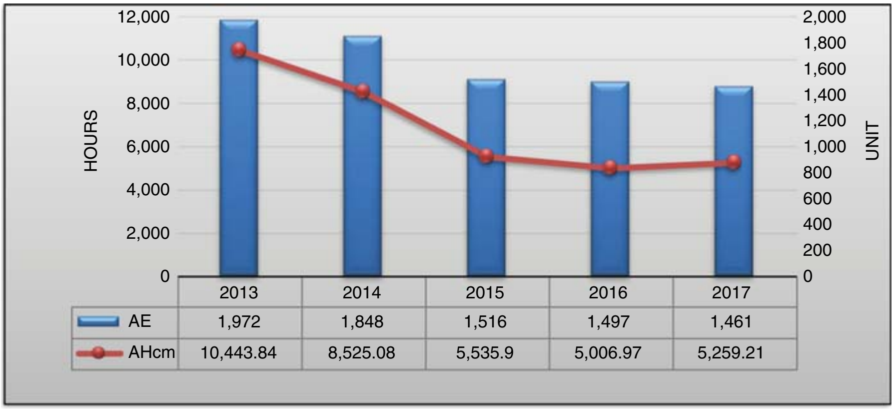
$$D_{rc} = \frac{T_{dc}}{T_{ic}} \times 100, \tag{7}$$

where D_{rc} is the department relative cost; T_{dc} the total department cost; T_{ic} the total installation cost.

3. Results

The first result refers to the first two indicators. Figures 1 and 2 show the load balance based on PPM and the load balance based on CM, respectively.

Figure 1.
Load balance based on planned preventive maintenance



	2013	2014	2015	2016	2017
AE	1,972	1,848	1,516	1,497	1,461
AHcm	10,443.84	8,525.08	5,535.9	5,006.97	5,259.21

Figure 2. Load balance based on corrective maintenance

Figure 3 illustrates the effectiveness of the maintenance department from January 2013 to December 2017.

Finally, Figures 4 and 5 reflect the compliance with the PPM schedule and graphic analysis of costs for labor, spare parts and materials in the period analyzed.

	2013	2014	2015	2016	2017
DE	74.74	67.03	60.41	53.56	54.65
ET	12,914.53	11,583.16	8,351.02	7,404.55	7,554.77
TA	17,280	17,280	13,824	1,3824	13,824

Figure 3. Department effectiveness

	2013	2014	2015	2016	2017
Pending workload CM	1.06	2.61	1.74	1.39	1.3
Pending workload PPM	16.05	7.68	11.67	8.07	2.2
Compliance with PPM	83.95	92.32	88.33	91.93	97.8

Figure 4. Compliance with the planned preventive maintenance schedule

	2013	2014	2015	2016	2017
PPM cost	1.48	4.35	7.01	7.99	8.77
CM cost	32.19	5.67	23.82	19.55	16.01
Total cost	33.67	10.02	30.83	27.54	24.78

Figure 5.
Graphic analysis of costs

4. Discussion

Initially, was identify the sample or quantity of equipment that will be examined and secondly the hours that were dedicated to the attention of these assets. It can be observed in Figure 1 how the tendency is to adjust the technical maintenance inventory[1], in other words, to separate the technical maintenance inventory from the general maintenance inventory[2] of the firm (CCEM, 2008; David and Gullickson, 1996; Denis, 2001). The goal at this point is to identify the equipment to be assessed by the maintenance technicians and estimate through a workload analysis, the minimum necessary staff to execute the PPM activities.

The graph shows how in 2014 there was an increase in the amount of equipment in the PPM program, which corresponds to an inadequate inclusion of the distribution systems in the PPM program, with the same number of technicians available (ten maintenance technicians). This problem was solved with the outsourcing of distribution systems since 2015. It can also be appreciated how the hours dedicated to these functions had been reduced from 2014 to 2017.

The goal of the second indicator is to reflect directly, how the number of CM orders decreased with the adequacy of preventive planning, see Figure 2. This has a direct impact on the reduction of hours destined to these functions, which can be used in planned actions or in technician training. Figure 6 shows a distribution of the time available used in the company under analysis. The firm dedicated 35 percent of the annual time available per technician to execute preventive and corrective actions, as well as 30 percent of the annual time available per technician to other activities. Sacristán (2000), Denis (2001) and others highlight the need to distribute the time available into similar portions to this proposal, with great emphasis on the percentage destined to other activities. The specific characteristics of

Figure 6.
The amount of time available per technicians for carrying out maintenance

Cuban companies guarantee that this distribution is adequate, taking into account the mandatory nature of the continuous improvement of technicians and professionals. This percentage includes criteria such as hours for vacations, professional development, non-working days due to illness, among others (Denis, 2001; Sacristán, 2000).

We conclude this analysis with the effectiveness in the use of the time available shown in Figure 3. The objective is to obtain an indicator that illustrates the adequacy of the time available used by the company to attend to the assets, in a calendar year. The visual control of this parameter facilitates decision making in the outsourcing process.

In 2013, the department could be considered to have efficiency (is related to how it is done)[3] but inefficacy (is related to what to do)[4], and over the years, it has gained efficacy and lost efficiency. It would be ideal to find an intermediate point between these indicators of comparative evaluation and increase the effectiveness (is related to what things are done and how those things are done)[5] of the department. As can be seen in Figure 3, regardless of the adequacy in the preventive actions and the decrease of unforeseen events, the effectiveness of the department still decreases and is considered as inadequate over the period under analysis. This effect is due to two fundamental aspects.

The first aspect is referred to the technicians' downtime, increasing the availability of assets increases technicians' downtime. This condition must be used by the managers of the company in the professional improvement of maintenance workers. In this case, the effectiveness of the department is sacrificed to obtain, in the medium-short term, highly qualified workers who are ready to perform tasks of greater magnitude (efficient workers). It was established as a company policy for 2022, to reduce the number of equipment with contracted services and to assume this responsibility by technicians of the company. This criterion will revert the indicator of effectiveness in the use of the time available because new equipment and distribution systems will be included in the PPM program, with the same number of technicians available (a staff of eight maintenance technicians is estimated for 2022).

The second aspect to consider is staff reduction, while preventive planning becomes more efficient, it will require less time to execute corrective actions. The quotient between the load balance based on proactive and reactive actions (L_{ppm} and L_{cm}) and the effective time available (T_a) allows to estimate minimal amount of technicians required in the department to improve the performance in the use of time available (Galán, 2015; Galán and Walker, 2018). Taking into account this consideration, the company bet to focus the attention on critical assets in the process and outsourcing the services for those equipment that do not belong to the technical maintenance inventory. This technique may be of interest to those companies that need to reduce business costs due to the use of workforce. In this case, a detailed analysis is necessary between workforce costs with the company's own technicians and the outsourcing of the services.

Another point of discussion can be seen in the graph in Figure 4. It demonstrates the adequacy of the PPM and the effectiveness of the corrective labor. We can observe how the pending workload decreases over the years and the adjustments executed to the maintenance management program. In 2013, the pending workload stayed at 17.11 percent of maintenance actions; it is considered an inadequate indicator with a direct impact on the efficiency and efficacy of the maintenance department. In contrast, in 2017 pending workload remained at 3.5 percent of all the proactive and reactive actions executed in the company, which evidence the good performance of the maintenance department during the period to increase the availability indicator of the company equipment.

We could not conclude the analysis without an evaluation of the costs of the maintenance department; Figure 5 illustrates this analysis in percentage values regarding to the department relative cost. According to the PPM, the costs associated to spare parts, materials and workforce are low compared to the CM. This situation does not mean that the

PPM costs are adequate; on the contrary, they mask a lack in the management system and spare parts acquisition to the maintenance warehouse. This aspect has a negative impact on the costs associated to corrective actions, which are increased by the inefficiency of preventive actions. Taking into consideration the aforementioned, we can conclude that a maintenance management system is not only based on the adequacy of their preventive and corrective actions, but also includes productivity and maintainability actions. In summary, it is necessary to ensure that the maintenance departments have a controlled and economically effective maintenance management program.

5. Conclusion

EBAM allows, from the analysis and modeling of the results obtained in the execution of maintenance operations, to renew the business asset management strategy. It is a continuous process that leads to the programming and activities planning to ensure production at minimum cost. It also allows the selection of techniques, procedures, human resources and new equipment depending on its life cycle.

In this proposal evidence-based control alternatives were used to evaluate the adequacy of the maintenance function in a biotechnology company. These diagnostic points give a general measure of the efficiency, efficacy and especially the effectiveness of the maintenance department, but must be accompanied by traditional indicators such as availability, maintainability and reliability.

Results graphically show the maintenance operations of the National Center for Scientific Research, production department, in a period from January 2013 to December 2017. Finally, based on the analysis carried out, the maintenance department was evaluated as inadequate and having poor performance effectiveness, and a new strategy was established to be followed for the next quinquennium.

Notes

1. Technical maintenance inventory: it includes only those equipment to be assisted by the company's technicians.
2. General maintenance inventory: it includes all assets of the company.
3. Efficiency: the gap between the observed performance and the best existing performance. It is based on the use of resources appropriately.
4. Efficacy: the degree which institutions achieve their organizational missions. Everything that is tangible and helps us to fulfill the objective.
5. Effectiveness: being effectiveness means of efficiency and efficacy at the same time.

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