

Maintenance Management Practices of Companies of the Industrial Pole of Manaus

Marcelo A. de Oliveira, Isabel S. Lopes, *Member IAENG*, and Danielle L. Figueiredo

Abstract—The study presented in this paper aims to identify the practices of maintenance organization and management adopted by companies in the industrial pole of Manaus in Brazil in relation to their production equipment. A questionnaire was developed and sent to the company of the industrial pole and the received data was analyzed using descriptive statistics. This study is part of a project that aims to define different levels of maturity in this area and identify the determinants factors to achieve higher levels of efficiency and effectiveness.

Index Terms—Maintenance strategy, maintenance management, maturity level, survey results.

I. INTRODUCTION

THE importance of maintenance function and, therefore, of maintenance management, has grown in recent years. Maintenance has achieved a significant role in organizations performance because it is directly responsible for the proper operation of the production process. Maintenance area needs to keep equipment in good working conditions and available to achieve high productivity level of quality products.

According to Kumar and Parida [1] maintenance is defined as the combination of all the technical and administrative actions, including supervision, intended to retain an item, or restore it to a state in which it can perform a required function. Maintenance management makes use of some tools and techniques to improve efficiency and minimize the impacts of unplanned stoppages looking for reducing costs.

The Industrial Pole of Manaus is one of the most modern in Latin America, bringing together major industries in the areas of electronics, motorcycles, optical products, computer products, chemical industry. Through a survey, data was collected about the maintenance practices adopted by the maintenance function of these companies in order to identify its current situation and ascertain the potential improvement that this management function can bring. This will allow proceeding with a maturity model indicating the path to follow to achieve higher levels of performance in this area.

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M. A. Oliveira is with the Centro Algoritmi, University of Minho, Campus de Gualtar, 4710-057, Braga, Portugal, phone: +5592 8191-8036; e-mail: marcelo@maoconsultoria.com.

I. S. Lopes is with the Centro Algoritmi, University of Minho, Campus de Gualtar, 4710-057, Braga, Portugal; e-mail: ilopes@dps.uminho.pt.

D. L. Figueiredo is with the Centro Algoritmi, University of Minho, Campus de Gualtar, 4710-057, Braga, Portugal; e-mail: Danielle_lima@ig.com.br.

The survey aimed to comprise the management process of the overall equipment of companies that act at Manaus industrial pole concerning maintenance methodologies, maintenance department structure, KPI utilization, maintenance planning and staff development. The identification of real state of maintenance area leads us to a better planning of actions to implement the more appropriate management strategy and to propose suitable computerized tools, performance indicators, technical analysis and management tools and techniques, providing a set of potential improvements necessary for the successful evolution of the maintenance process and the resulting progress in the maintenance management level.

This paper is organized as follow. The second section presents a literature review, describing maintenance management concepts. The third section addresses data collection and analysis, evaluating the data obtained from organizations that act in different sectors. Overall findings of the survey are shared in section 4. The last section presents the conclusion and future work.

II. LITERATURE REVIEW

A. Maintenance management

Maintenance management establishes goals and objectives through standards and work procedures in order to obtain a better utilization of available resources, which are staff, equipment and materials. Effective maintenance extends equipment life, improves equipment availability and retains equipment in proper condition [2].

Cholasuke et al. [3] identified nine factors associated with high effective maintenance management: policy deployment and organization; maintenance approach (type of maintenance employed); task planning and scheduling; financial aspect; continuous improvement; human resource management; contracting out maintenance; information management & CMMS; spare parts management.

Marquez and Gupta [4] propose a framework that comprises three pillars to support maintenance management, namely:

- The information technology pillar;
- The maintenance engineering;
- The organizational (or behavioral) pillar.

According to Carnero and Noves [5], the complexity of a modern industrial unit is increasing and maintenance management is now considered an important factor for improving the performance of the operation, the security, availability, service life and cost reduction and, to this end, the use of computerized systems is essential. These systems are known as computerized maintenance management systems (CMMS). Fernandez et. al. [6] states that

information is a significant factor for a successful management of maintenance and is the basis for computerized systems. Sherwin [7] explains that, currently, with the advance of computational systems, it is possible to determine a better way to manage the maintenance by optimizing their activities, integrating the maintenance function with the other activities through advanced IT systems (Information Technology), which became more necessary in the current days and, therefore, have become more economically feasible.

B. Maintenance methodologies

According to Smith [8], maintenance aims to "preserve the functional capabilities of equipment and systems in operation". Moubray [9] says that the purpose of maintenance is to "ensure that physical assets continue to do what the users want them to do".

Many tools available today have adopted the word maintenance. It is important to note that these are not new types of maintenance but tools that allow the application of the main types of maintenance. Highlighted among them are: Maintenance Engineering; Lean Maintenance; Total Productive Maintenance; Reliability Centered Maintenance; Reliability Based Maintenance and Condition Based Maintenance.

Maintenance policies applied correctly aimed at preventing and/or eliminating the occurrence of failures. Lack of fulfillment of what was previously defined as "proper performance" is defined as *failure*.

Alsyouf [10] sustains that proper maintenance practices can contribute to overall business performance through their impact on the quality, efficiency and effectiveness of a company's operations.

C. Performance measures

According to Muchiri et al. [11], indicators should support monitoring and control of performance, help the identification of performance, gaps, support learning and continuous improvement, support maintenance actions towards attainment of objectives and provide focus on maintenance resources to areas that impact manufacturing performance. [11] grouped them in maintenance results indicators and maintenance process indicators. The literature, in the context of maintenance, provides various expressions and terminology for performance indicators, once they eventually adapt to the reality of companies. Campbell [12] proposes a classification for performance indicators as follow:

- Overall maintenance results;
- Maintenance productivity;
- Maintenance organization;
- Efficiency of maintenance work;
- Maintenance costs;
- Maintenance Quality;

Gulati [13] suggests that the first step in developing metrics is to involve people who are responsible for the measurements and ensure that the metric is specific, measurable, attainable, realistic and timely.

EN15341 Standard [14] highlights that maintenance performance is the result of complex activities, which can be evaluated by appropriate indicators to measure actual and expected results. Performance indicators are necessary to

ensure stability and predictability of the maintenance process. This standard proposes the following classification:

- Economic indicators;
- Technical indicators; and
- Organizational indicators.

In general, indicators are measures or numerical data set about processes that we want to control and improve. The most commonly used in maintenance are: Availability, Costs, Production losses due maintenance activities, Rework, Mean time between failures (MTBF), Mean time to repair (MTTR) and Overall equipment effectiveness (OEE).

III. DATA COLLECTION

A. Questionnaire

To gather data about the organization and maintenance management practices adopted by Manaus industrial pole companies, a questionnaire was developed. The questionnaire has five parts that cover the following topics:

- Section I - *General Information*: This section aims to identify the company profile, activity, and number of employees, number of equipment under the responsibility of the maintenance area and origin of the company.
- Section II - *Maintenance management*: identify the techniques, strategies and management tools used for maintenance.
- Section III - *Maintenance Indicators*: identify the degree of use of performance indicators in the management of maintenance.
- Section IV - *Procedures and Maintenance Plans*: identify the degree of organization and planning of maintenance in the company.
- Section V - *Maintenance Staff*: assess the degree of organization, development and training of the maintenance staff.

B. The sample

The questionnaire was sent to the industrial plants of the industrial pole of Manaus, in Amazonas state (Brazil), to be filled in by the maintenance area. The industrial pole is organized in 19 sectors as shown in Fig. 1 including companies of the plastic industry, manufacturers of mobile phones, modems, set top boxes, televisions, laptops, audio, CD and DVD manufacturing, motorcycles, air conditioners, cameras, alarm and protection systems, car alarms, naval industry, metallurgical industry and so on.

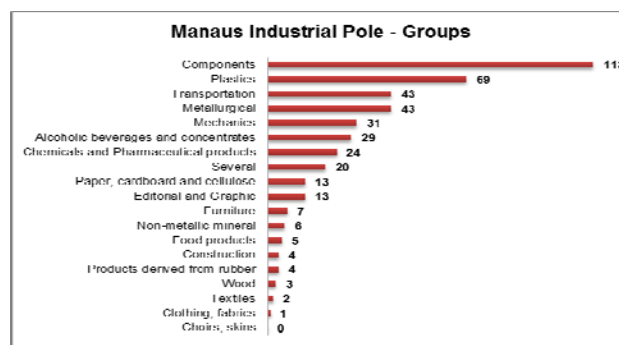


Fig. 1. Industrial pole by groups

There are approximately 430 companies registered and operating in the industrial pole of Manaus, according to the

official document provided by Suframa [15], which is the agency that manages the industrial pole of the region. The questionnaire was sent to all companies registered in the industrial pole and 71 companies from various sectors participated in the research, resulting in a response rate of 16.5% (see Fig. 2).

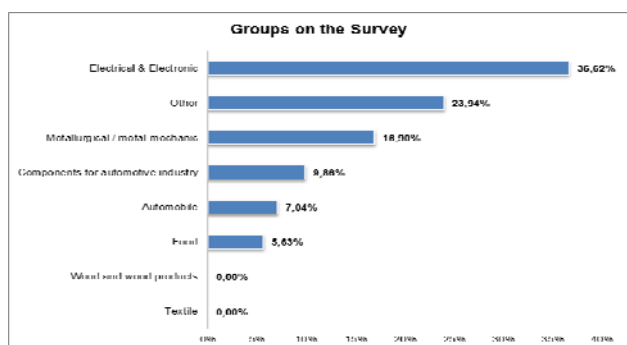


Fig. 2. Segments that take part in the research

With respect to the origin of the surveyed companies, 44% have national capital, i.e., they are local, while 56% have international capital, i.e., are multinational.

Fig. 3 and Fig. 4 refer respectively to the number of employees that companies have and the amount of equipment that are under the responsibility of the maintenance area. In relation to staff, 75% of the companies have more than 100 employees.

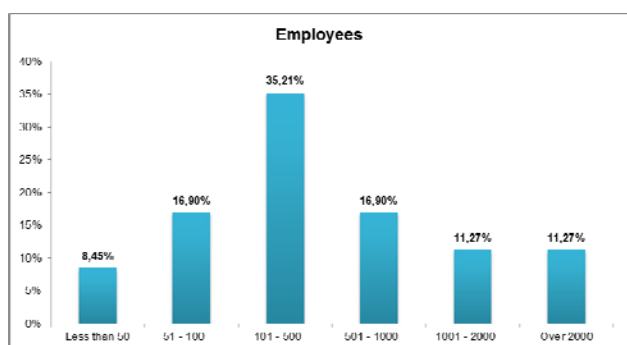


Fig. 3. Number of employees of the companies

When referring the total number of equipment under maintenance area responsibility it was observed that about 70% of them have more than 50 units to manage.

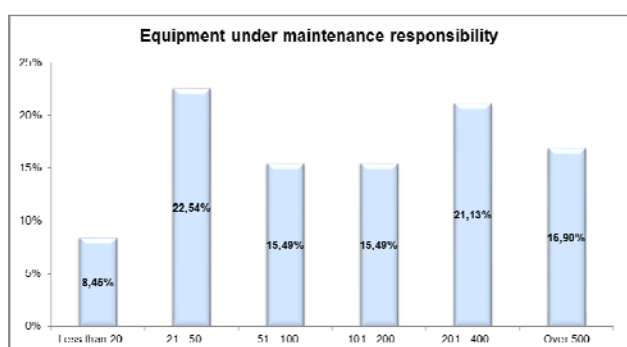


Fig. 4. Number of equipment under maintenance responsibility

IV. DATA ANALYSIS

A. Maintenance Management Function

Maintaining production equipment is regarded as a strategic factor inside the organization. Most respondents to the questionnaires (90.14%) stated that the maintenance of production equipment is seen as a strategic factor within the organization, as shown by Fig. 5.

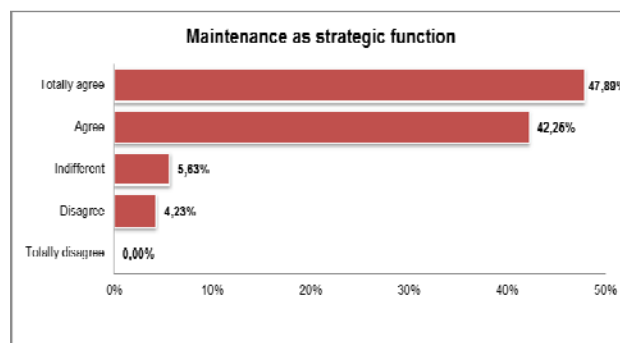


Fig. 5. Maintenance as strategic function for the companies

Regarding outsourcing practices 76.06% of companies outsource services related to preventive and corrective activities covering 25% or less of equipment, as shown by Fig. 6. Besides, concerning companies that outsource maintenance activities, 73.24% of them affirm that 40% or less of services are performed by machinery suppliers.

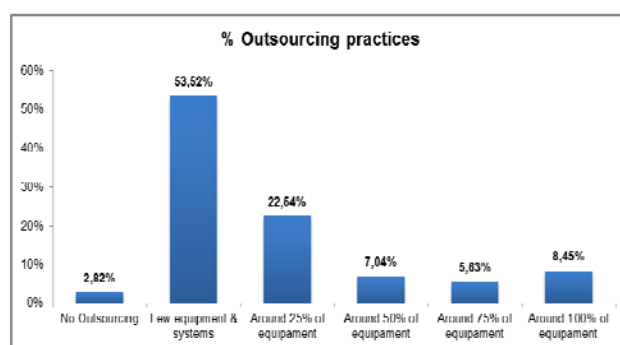


Fig. 6. Outsourcing Practices

The maintenance team is an important factor that demands strategies to improve competence level. Thus, it is necessary to manage activities and resources allowing the maintenance area to accomplish its function. Fig. 7 presents results regarding the size of the maintenance staff. It can be noticed that 57.15% of the companies have between 5 and 20 employees working in the maintenance area and, it was observed that it is linked to the company size and the number of equipment, as it was expected.

According to the data obtained in the survey 84.51% of the companies adopt a preventive policy, 35.21% assumes that adopt predictive and 12.68% detective approach. In terms of maintenance policies, it was noticed that around 15.49% adopt only corrective policies.

Preventive activities stand out over the others, although most of the time the maintenance staff is dedicated to corrective as opposed to preventive actions (see Fig. 8). Fig. 8 presents the percentage of time that companies dedicate to preventive maintenance activities. Although a large number of companies have indicated the practicing of preventive

maintenance, about 69.02% of companies spend only 40% or less of their time on preventive activities.

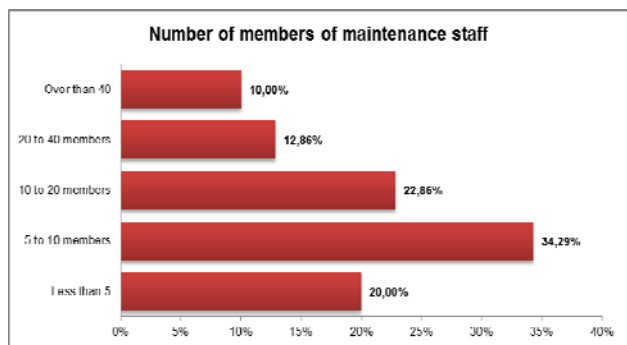


Fig. 7. Number of members of maintenance staff

60.56% of the companies indicate that TPM is the model of maintenance management adopted by the company. However, the majority adopt a strategy focused on production rather than productivity and efficiency, which usually increases the probability of equipment downtime.

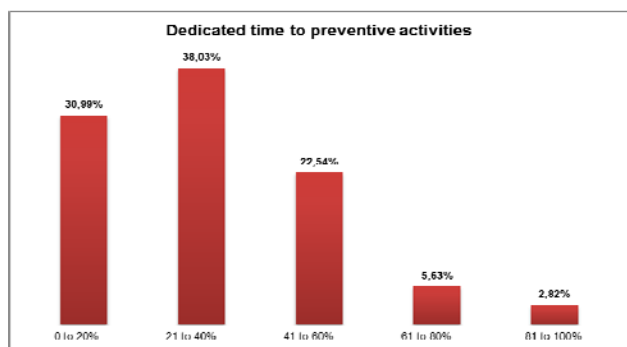


Fig. 8. Dedicated time to preventive activities

To analyze the techniques used to assist maintenance, a Likert scale with five levels regarding the frequency of use of such techniques was adopted: 1.Never, 2.Rarely, 3.Occasionally, 4.Often, 5.Very often.

Table I presents the average obtained for each technique. The average is not very high, since it is below 4 for all the techniques. Three techniques stand out namely Cause-and-effect analysis, 5S and 5 Whys, while the others are used rarely or never used, fact that can be linked to a lack of training in such techniques.

TABLE I
 TECHNIQUE UTILIZATION

Technique	Average
FMEA (Failure Mode and Effect Analysis)	2,00
PDCA	2,92
RCA (Root Cause Analysis)	2,04
FTA (Fault Tree Analysis)	1,59
5S	3,65
8D	1,76
Reliability Analysis	1,90
Tree Analysis	1,45
Hazard Analysis	1,79
RDB (Reliability Block Diagram)	1,45
Cause and Effect Analysis	3,17
5 Whys	3,32
Other	0,34

Besides, a list of potential difficulties was evaluated and, limited budget, insufficient number of technicians, lack of

training, insufficient spare parts available in stock and non-compliance of the delivery date by supplier of parts were the main points highlighted.

B. Maintenance performance measurements

Regarding performance measurement, it was observed that 78.87% of companies state using any kind of KPI to evaluate its performance.

A Likert scale with five levels regarding the frequency of use of such KPI's was adopted. The average was calculated and presented in Table II. As observed, the averages are not very high, since the values are below 4.

TABLE II
 TYPICAL KPI ADOPTED BY COMPANIES

KPI	Average
MTBF by machine	2,59
MTBF by line/area	2,08
MTTR by machine	2,89
MTTR by line/area	2,56
Availability	3,14
Downtime	3,35
Economical	3,14
MWT	1,94
OEE	2,63
Backlog	2,41
Other	0,23

Companies typically use more frequently economical indicators, availability and downtime to support maintenance staff in seeking improvements such as reducing the waiting time between calls, the time to perform an activity and the downtime due to equipment failures.

MTBF and MTTR are lagging indicators that show how good the maintenance plan to prevent stoppages just as MTTR to inform how prepared is the team to solve a problem, however they are weakly used.

A Likert scale with five levels regarding the degree of concordance (1.Totally disagree, 2.Disagree, 3.Indifferent, 4.Agree, 5.Totally agree) about topics associated to downtime, repair time, waiting time and outsourcing was adopted. The average was calculated and presented in Table III. The averages obtained are low, which means that the degree of concordance is low, except for the second statement. Company, in general, does not recognize that the downtime, the time to repair, the waiting time to repair is high. However, the result does not seem to reflect the reality, it can be due to the fact that the questionnaires respondents are themselves responsible for the maintenance area and, of course, there was a tendency to not to expose the department itself. They also generally agree with the fact that the downtime has been decreasing as an effort in this area.

TABLE III
 OVERALL MAINTENANCE PERFORMANCE

Technique	Average
The downtime due to equipment malfunction is considered high	2,97
The downtime of equipment has been decrease as a result of the effort in this area	3,68
The time resolution of faults (repair time) is considered high	2,97
The waiting time for starting a repair is considered high	2,72
Subcontracting occurs as a result of internal capacity lacking	3,16

In addition, the average associated with the statement “Subcontracting occurs as a result of lacking of interval capacity” is medium showing that other reasons origin the outsourcing of services, such as knowledge, for instance.

C. Procedures and maintenance planning

In general all companies have any maintenance plan in which time intervals to execute the maintenance actions are established. The most common time planning frequency is monthly (46.48%) and yearly (49.30%) as shown by Fig. 9. Oddly enough is the low use of daily planning (5.63%), considering that many companies in the survey reported that adopt TPM and, for this reason, would we assume that daily activities planning would be held more frequently.

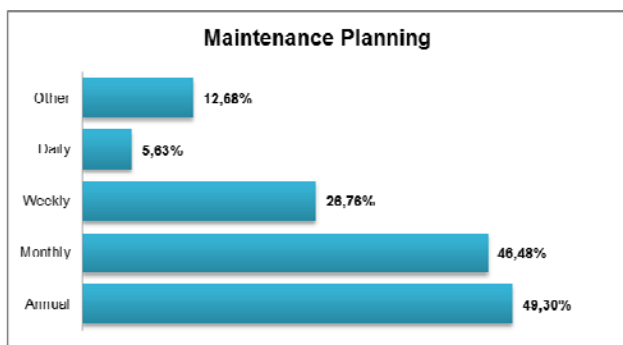


Fig. 9. Maintenance planning

Regarding the frequency of use of some activities to support maintenance management, a Likert scale with five levels was adopted. The average was calculated and presented in Table IV. The averages are not very high, since the values are all below 4. The realization of some daily activities such as cleaning, inspection and minor repair by operator is not very frequent. The number shows that the frequency of analysis of failure data is more frequent.

TABLE IV
OVERALL MAINTENANCE ACTIVITIES

Activity	Average
The operators perform some maintenance actions, such as cleaning, lubrication, inspection and minor repairs	3,23
The maintenance area analyzes failure data and implements improvements to avoid failures or mitigate their effects	3,64
Turnover activities	3,03

A maintenance management system is an essential tool for all maintenance organizations, helping to improve maintenance department’s efficiency and effectiveness. Fig. 10 shows the support tools used by maintenance in its daily activities. 16.90% of companies adopt a CMMS, 40.85% make use of spreadsheets, 23.94% combines CMMS and spreadsheet and 18.31% use manual register to organize maintenance activities. Considering those that use any CMMS, 48.28% adopt standard CMMS available in the market and others make option to develop their own software (17.24%) or to subcontract a specialized company to develop the software (34.48%).

Table V list some CMMS features. A Likert scale with five levels regarding the frequency of utilization of such features by maintenance staff was adopted. The averages presented in Table V are referred only to companies that have this feature in the maintenance software. So, it allows to evaluate how useful is the software.

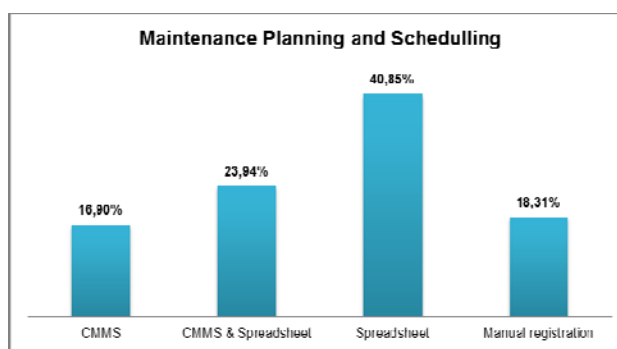


Fig. 10. Maintenance planning and scheduling

For most of the features the average is considered high (value above 4), which shows a great use of these features by the maintenance staff. The lowest values are registered for: method to support failure analysis; registration of work instructions; data analysis for monitoring equipment condition and Planning to purchase spare parts and materials.

It was also identify that, major applications has only standards functions, such as equipment register, work orders control and generation, maintenance historical and maintenance activities planning.

D. Maintenance staff

With respect to the organizational structure of the

TABLE V
CMMS FUNCTIONALITY

Activity	Average
Equipment, parts and groups registration	4,54
Generation and control of work orders	4,64
Historical equipment repair	4,61
Historical about preventive maintenance works	4,64
Historical about improvement works	3,85
Annual planning of preventive tasks	4,28
Monthly planning of preventive tasks	4,27
Weekly planning of preventive tasks	3,92
Allocation of human resources to the maintenance	4,04
Inventory control of parts and materials	4,00
Planning to purchase spare parts and materials	3,70
Registration of work instructions	3,68
Determination of performance indicators	4,30
Method to support failure analysis	3,21
Maintenance budget	4,09
Data analysis for monitoring equipment condition	3,44

maintenance area, not all companies have a consolidated department, and the teams are usually subordinated to other areas, commonly engineering or production. In 47.89% of cases, it was noticed that maintenance department has a formal structure, including management positions and other technical functions. Related to education level of maintenance staff, 64.29% of the companies assumes that 20% or less of their staff have high graduation which can be considered a low qualification level, i.e., the majority of people in this area has no upper level having only technical skills. Only 5.71% of the companies assume that around 81-100% of their staff has high graduation, as shown by Fig. 11.

The survey pointed that 59.15% of the companies recognized having a formal training plan for maintenance staff. However, it is not guaranteed that it will be accomplished due to many reasons such as constraints, for instance.

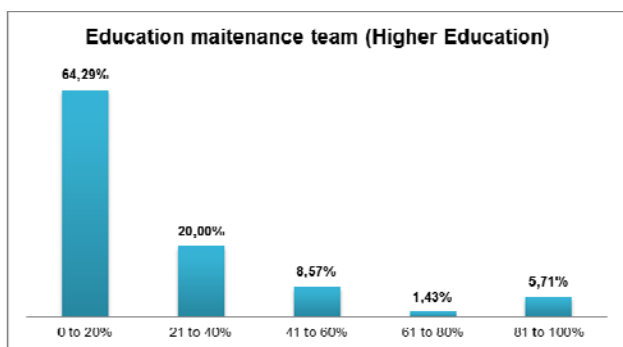


Fig. 11. Maintenance educational level

Table VI refers to trainings and aims to assess the type of trained practiced. A Likert scale with five levels regarding the frequency of trainings was adopted. Table VI presents the averages obtained for each type of training. The average is high as regards training about equipment. Training in the production process and method of operation as well as in maintenance methodology, techniques and tools has an overall low frequency.

Lastly, the survey identifies that 56.34% of the companies provides training sessions for 40% or less of maintenance staff, while only 15.49% of the companies provides training to around 81-100% of their team. So, the survey allows us to conclude that the investment in competencies improvements was low in the last year.

V. SURVEY FINDINGS

TABLE VI
OVERALL TRAINING

Activity	Average
Maintenance technicians receive training in the production process and method of operation	3,46
Maintenance technicians receive training on equipment	3,54
Technicians receive training in methodologies, techniques and tools to help maintenance management	2,89

In general, maintenance management of the companies of the Manaus industrial pole has many opportunities for improving, especially respecting to prevention and training, regardless of the segment of the company, its origin, its size, number of employees or maintenance staff size.

Although most agree that the maintenance of production equipment is seen as a strategic factor within the organization, the survey data show that corrective policies is still predominate, attributed in many cases to the company's own strategy. It was observed a low level of training of the teams, reduced budget affecting the organization and planning of activities, lack of time to implement activities and even outsourced due to lack of own staff or lack of training of the technical team. Another important fact about this issue is that prevention programs are not adequate or sufficient to prevent or reduce the frequency of failures. This is strongly evidenced by the limited use of indicators for maintenance management and of tools, methodologies or techniques to support failure analysis. While companies affirm that activities aimed at reducing the downtime are performed, the percentage of time devoted to preventive activities is very low, according to the collected data. Aspects as limited budget, low number of technicians, parts shortages and training were considered by companies as

factors that strongly contribute to a maintenance performance under expectation. Even with respect to the planning of preventive activities, the majority performs annual and monthly planning, evaluation/revision is relatively insufficient since for a high number of companies, it is made only using the directions offered by manufacturer's manual. Activities plan based on the machine's manual makes the maintenance plan outdated and barely able to act on faults with the passage of time.

For most companies, maintenance activities are managed and controlled without the use of CMMS, which shows a potential for growth in this area, since the majority adopts manual records or spreadsheets, not allowing better efficiency in the data analysis to improve planning and control activities. With respect to those who adopt some kind of CMMS, some had to adapt it according to their needs especially in solutions for reporting, allowing a better analysis of the results achieved and the consequent proposal to improve these. Moreover, most of those that adopt some sort of CMMS have acquired it on the market and these, in turn, are limited in features.

Regarding the use of techniques, the most elementary are used, particularly PDCA Cycle, 5S or 5 Whys, and there is a strong adherence to TPM though without much practical result. The use of indicators for maintenance management was also considered as elementary, where a significant number ignores the specific terms, their composition and how to interpret them. In particular, the most used are MTBF, MTTR, Downtime, OEE, economic indicators and availability.

Indeed, the use of a suitable CMMS according to reality or maturity level of the organization would allow a better planning of activities, use of more appropriate management indicators as well as having added support tool the failure analysis.

Regarding the structure of the maintenance department, few of them are autonomous, because, usually, maintenance is in charge of the engineering and/or production. In general, companies have a highly technical maintenance group without higher hierarchies. In addition, factors such as training and education level were considered points of attention and real opportunity for improvement.

Finally, the survey data show that companies of the industrial polo have a significant margin of costs reducing. It allowed the identification of improvement opportunities with various gains, such as: reduce losses in the production process, increase productivity, increase operational efficiency, increase asset availability, better control of activities, use of appropriate management models, among others.

VI. CONCLUSION

The effectiveness of the maintenance function in an industrial unit depends on the equipment involved, the training of personnel, and mainly on the adopted strategy for maintenance management. In addition to modern equipment ownership, it is necessary to understand the concern about flaws, in its details, in order to attack not the consequences but the causes using the most appropriate tools and techniques. Maintenance area should advocate the existence of an effective planning and monitoring of activities using

the most appropriate resource and applying the more advantageous tool and techniques.

Most companies have a basic level of maintenance management which means that they have the opportunity to make improvements and to obtain important gains. They have also the capacity to become more competitive, increasing throughput and reducing losses.

This survey shows many opportunities to make improvements in the maintenance area in general, such as using CMMS, implementation of deep preventive culture, adopting meaningful KPIs and reinforce training plan to the maintenance team.

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