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Research Article

Technological Model for the Development of a Predictive Maintenance System for Microenterprises

Humberto Moreno Posada
Tecnológico Nacional de México Campus Saltillo
Email: humberto.mp@saltillo.tecnm.mx
ORCID: 0009-0002-3625-6115

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ABSTRACT

In Mexican micro and small companies, it is common to find a series of problems related to the lack of adequate maintenance systems, which generates high costs, unproductivity, equipment with limited useful life and insufficiently trained personnel. These problems arise due to carelessness, misuse, and lack of maintenance in equipment and machinery, which, if not properly addressed, can negatively impact operational efficiency. However, the implementation of a predictive maintenance system can prevent these difficulties, as it allows for the early identification of possible failures through continuous monitoring of the operating conditions of the equipmen Predictive maintenance, based on statistical techniques and specialized analysis such as vibrations, thermography, ultrasound and oil analysis, is an effective tool to improve efficiency and extend the life of equipment. However, due to a lack of resources and knowledge, this type of maintenance is often limited to large companies. This article proposes an accessible and efficient technological model for the implementation of predictive maintenance in microenterprises, with the aim of reducing operating costs, improving productivity and maximizing equipment availability. The model developed seeks to offer a practical and economical solution, adapted to the conditions of small companies, contributing to their competitiveness in the market.

Keywords: Predictive maintenance, Microenterprise, Productivity, Maintenance systems

1. INTRODUCTION

In today's Mexico, international competition is a reality. In recent months, trade liberalization has fundamentally transformed the nature of the national industry. Today, Mexican companies must compete with world-class companies. The liberalization of markets has represented a transcendental change for the country.

The current challenge is to successfully face this competition and to turn the national economy into a prosperous platform for growth and development. The way in which the industry can face this challenge is through a reorganization of its structure, both in production processes and in the appropriate use of resources. In some cases, this reorganization could involve becoming suppliers to maquiladoras or other large consumers.

It is necessary to face this challenge with great determination, identifying what can be changed, improved and maintained. Domestic small and medium-sized enterprises present numerous areas of opportunity, such as saving resources, minimizing costs, and maximizing production. Maintenance is a

tool that, if used properly, will lead the company to generate savings and reduce costs. There are several types of maintenance (corrective, preventive, predictive), and predictive maintenance provides information about the operating conditions of the equipment, indicating which parts require attention. This makes it an effective means of determining how and where to carry out preventive maintenance. By having an effective preventive maintenance plan, corrective maintenance is eliminated, so predictive maintenance is considered the right means to achieve the objectives of saving resources, minimizing costs and maximizing production.

The lack of predictive maintenance programs in many national companies generates large costs, as the maintenance function has often been neglected. For many companies, maintenance has been, and continues to be, a necessary evil.

In addition, there is a lack of communication between management and those responsible for maintenance, as they are not given the necessary importance. Predictive maintenance uses statistical techniques, sophisticated equipment, and advanced technology, but it is expensive to use and only large companies implement it in a formal and organized manner. In national micro-enterprises, the implementation of predictive maintenance is not considered, as it involves large investments and statistical work, as well as a change in organizational culture

1.2 Defining the problem

It is very common to find the following problems in Mexican microenterprises:

1. A lot of lost production time due to numerous machine stoppages.
2. Frequent overtime work that is an extra cost for the company.
3. Poor maintenance and short life of machinery and equipment.
4. Costs generated by replacement of equipment.
5. Costs for repairs and repairs.
6. Constant occurrence of rejected products, repetitions and waste.
7. Poor security conditions.
8. Waste of labor.
9. Insufficient preventive maintenance.
10. Inadequate preparation of maintenance personnel.
11. Poor workshop facilities.

This shows a clear area of opportunity. If we manage to reduce costs and improve the aforementioned conditions, in some way we will be contributing to microenterprises being more efficient and productive, and managing to survive in the current situation. Unfortunately, in our country there is a thought that industrial engineering methodologies, as well as automated processes, are exclusive to large companies; however, you don't have to be medium or large to use these tools

1.3 General objective

To help microenterprises successfully face international competition, to achieve this, a structural reorganization must be carried out both in their production and in the appropriate use of resources.

1.3.1 Specific objective

The objective of this work is to provide the national microenterprise with a technological model that leads to the development of efficient predictive maintenance systems, in order to improve the productivity and competitiveness of these companies.

2. PROPOSED METHODOLOGY

This chapter describes the proposed technological model for the development of predictive maintenance systems. This model consists of two main parts: the methodology to carry out predictive maintenance and the technological tools that facilitate its implementation.

2.1 Methodology of the technological model for the development of predictive maintenance systems

The proposed model integrates the predictive maintenance approaches used in North America, Cuba, and Japan. The combination of these approaches allows for a more robust and efficient system. The steps described below are a guide to applying predictive maintenance, adaptable to any micro-business. The success of the implementation depends on the correct application of these steps.

1. Determine the equipment and machines to be inspected: The first step is to identify the equipment and machines that need to be inspected. Although all equipment requires inspection, some have a higher priority due to their higher likelihood of failure. It is advisable to classify equipment according to its probability of failure and the impact that its failure would have on the operation of the plant.

2. Determine the consequences if the equipment fails: Once the priority equipment has been identified, it is necessary to analyze the consequences of its possible failure. This should be done considering equipment that has a direct impact on the production flow. It is important to establish a system that allows you to quickly detect failures in the most critical equipment.

3. Create an inventory of equipment: A detailed inventory of the equipment to be inspected should be created, which makes it easier to track and assign responsibilities during inspections. Verification routes should be designed in a way that minimizes time and effort during inspections.

4. Assignment of inspection frequencies: The inspection frequency must be established according to the stresses to which the equipment is subjected and the type of operation it performs. Equipment that operates under extreme or high-precision conditions should be inspected more frequently, while those with less demanding conditions may be inspected less frequently.

5. Preparation of technological tools for monitoring: The technological tools necessary to implement predictive maintenance must be selected and calibrated appropriately. This includes equipment for measuring vibration, temperature, noise and energy consumption. The operating ranges of the equipment must be precisely defined.

6. Perform maintenance inspections: During the inspection, all relevant information about the condition of the equipment should be recorded. Machines that have been inspected should be clearly marked to avoid duplication. It is essential that the information is documented in a structured way, which will allow for further analysis.

7. Generation of work orders: Inspections must lead to the generation of work orders for those machines that require preventive maintenance. These work orders should contain all relevant information, such as the description of the problem, the name of the machine, and the necessary spare parts.

8. Re-inspection of repaired equipment: After repairs are made, a re-inspection should be performed to ensure that the anomaly has been corrected. If problems persist, the cause of the failures should be delved into and the necessary corrective measures taken.

9. Root cause analysis of failures: In case anomalies occur during reinspection, it is necessary to perform a root cause analysis to understand why the failure persists and avoid recurring problems. This step is critical to continuously improving the maintenance process.

10. Document savings and avoided costs: One of the most important benefits of predictive maintenance is cost reduction. Therefore, it is essential to document the savings generated by the application of this model, such as avoided costs from unnecessary repairs and reduced downtime.

2.2 Technological tools that integrate the new model

Predictive maintenance requires advanced technological tools to perform inspections and analyses. The methodology developed proposes an accessible solution that integrates several measuring equipment in a single tool, which reduces costs and makes the process more economical for micro-enterprises.

Key components of the system include:

- Measuring instruments such as temperature, vibration and current sensors.

- Signal adapters to process the information collected.
- Software to analyze data and generate detailed reports.

2.2.1 Basic Principle of Operation

The system uses a personal computer connected to the measurement sensors. The data collected is processed by the controller software, which allows statistics and graphs to be generated that help maintenance personnel make informed decisions about the condition of the equipment.

2.2.2 General definition of the technological model

The developed model allows simultaneous monitoring of up to 16 components or machines. Analyses are performed in real-time and results are graphically visualized, making it easy to identify problems before they cause serious failures. In addition, the system allows for reliability analysis using historical data collected during inspections.

2.2.3 Types of analysis of the proposed model

2.2.3.1 Vibration Analysis and Thermography: Vibration analysis and thermography are essential for detecting misalignment problems or faulty components in machines.

2.2.3.2 Analysis of electrical energy consumption: Monitoring energy consumption allows the identification of operational inefficiencies and machines that are consuming more energy than necessary due to failures in their operation, such as lack of lubrication or misuse of machinery.

2.2.4 System Description

The system consists of several transducers that measure different parameters (vibrations, noise, temperature and current consumption). This data is processed using a data acquiring card and analyzed with specialized software that generates detailed reports for further analysis and decision-making.

The predictive maintenance inspection process involves a series of structured steps to ensure that equipment and machinery are kept in optimal condition, preventing serious failures that can disrupt production. This process is key to maximizing equipment life and reducing operating costs.

1. Preparation for the inspection: Before starting the inspection, it is necessary to prepare all the technological tools and equipment that will be used during the process. This includes the calibration of measuring instruments such as vibration sensors, thermography, and other monitoring devices. Correct calibration ensures the accuracy of the readings during the inspection.

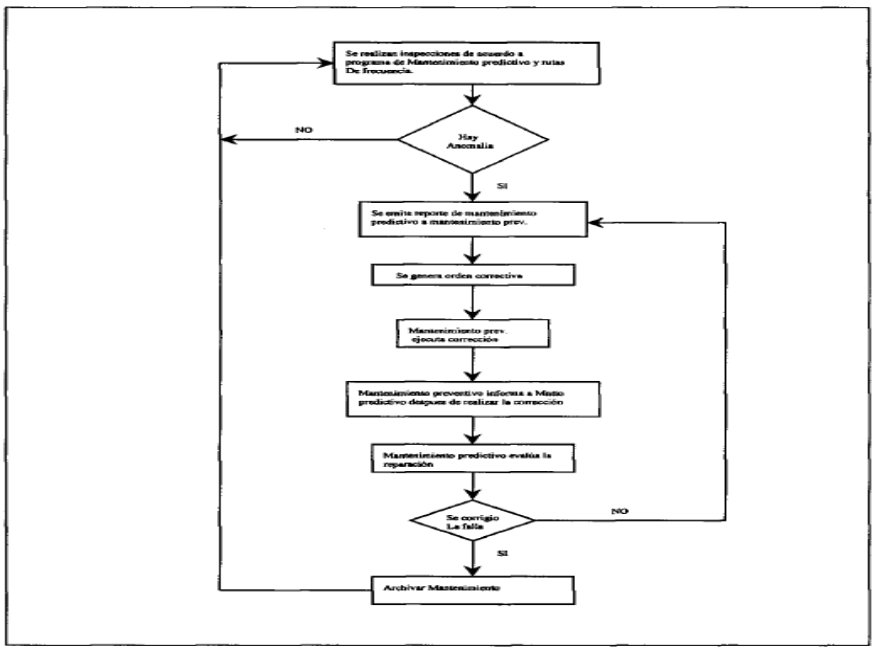

Figure 1: Predictive maintenance methodology flowchart.

2. Equipment inspection: During the inspection, the operating conditions of the machines should be verified, taking readings of key parameters such as vibrations, temperatures, and energy consumption. Machines must be inspected according to pre-established verification routes. These routes are designed considering proximity and travel times, with the aim of optimizing inspection time.

3. Documentation and labeling: Each inspected machine must be labeled to avoid duplication in inspection. In addition, all information obtained during the process must be recorded in structured formats to facilitate subsequent analysis.

4. Analysis of results: After completing the inspection, an analysis of the readings obtained is carried out. If abnormal conditions or outside the established parameters are detected, work orders must be generated to perform preventive repairs. The information must be reviewed in detail to make informed decisions about the actions to be taken.

5. Generation of work orders: Work orders are generated based on the anomalies detected. These orders must contain precise details about the equipment, the type of maintenance required, and the materials needed for the repair.

6. Re-inspection of repaired equipment: Once the equipment has been repaired, a re-inspection is performed to ensure that the faults have been properly corrected. If anomalies persist, a more thorough analysis should be performed and, if necessary, additional adjustments should be made.

7. Closure and analysis of avoided costs: At the end of the process, an analysis of the avoided costs must be carried out thanks to predictive maintenance. This analysis helps visualize the savings generated by preventing serious failures and unscheduled downtime.

3. MAINTENANCE FORECASTING

3.1 Introduction (Maintenance Forecasting)

A fundamental characteristic of maintenance is that it must be planned in advance, to such an extent that sometimes it is not considered part of the program, nor is it even taken into account. Maintenance forecasting consists of structuring low-maintenance, long-lasting qualities through the planned acquisition of machinery or equipment. This equipment is designed to minimize production downtime, maintenance effort, and at the same time, maximize the effective life of the machines. To achieve this, it is necessary to study and carefully search from the point of view of maintenance for everything that is convenient for the purposes indicated. It is important to remember that cheap often does not work well and that economies require that quality be purchased. Historical records of performance of certain types of machinery will be useful in assessing this quality.

3.2 Maintenance budget

A budget is an economic plan that represents the best possible estimate of the expenses that will be incurred in a given future period. Budgets are therefore an expression of expected results, which should reflect real plans based on real possibilities. Better planning, as a consequence of the budget, is only possible if future operations are considered in detail and if the budget figures express the effect of real plans for future operations. A well-prepared budget is an effective tool for control, as reporting on actual performance against estimates provides a basis for taking preventive action.

According to T. Newbrough (1995), a powerful tool in budget estimation is continuous supervision, which provides the necessary information. The most convenient way to estimate the cost of maintenance is to determine the extent of the maintenance requirements and to proceed to establish the value of the service centers that group the technical and repair functions. Using the previous year's costs as the basis for the budget is not a recommended policy, as the new budget should reflect the best ideas and the greatest care to be functional. It must also take into account improvement factors resulting from optimal methods, improvements in machinery and equipment, advances in processes, product design and savings derived from renovations and changes of facilities made in the previous year and planned for the following budget year. In this context, predictive maintenance plays a key role in reducing costs and optimizing the use of resources addresses the importance of foresight in maintenance, proper planning, and the use of budgets to keep costs under control, ensuring that businesses can operate efficiently in the long term.

4.3 Maintenance in the company of the future

As a company is automated, the personnel dedicated to maintenance tasks increases, while the personnel dedicated to production tasks is reduced, at the same time, the division between the two tends to disappear, becoming simply operation personnel. This is because mechanical and repetitive tasks are carried out by intelligent machines (robots in its broadest sense), which among other things are capable of indicating when and where there is a failure, establishing with maintenance personnel a relationship similar to that between a doctor and his patient.

For this reason, the maintenance personnel of the future will be highly qualified specialists, who know the production process perfectly, as well as the technical characteristics of the systems and equipment. The automated plants will be prepared to operate 24 hours a day throughout the year, which makes it mandatory to resort to predictive maintenance techniques. The computerized monitoring of the plant will allow not only to schedule and control production, but also to determine the condition of the equipment. Quality control and predictive maintenance techniques are likely to converge.

Specialized maintenance will provide great opportunities for the creation of service companies that allow companies to reduce their operating costs by outsourcing the most specialized tasks, which require expensive equipment and highly trained personnel. Routine maintenance management tasks will be computerized and will be part of the computer network, allowing production to be scheduled and controlled.

The rise of ecology will make it essential for the engineer responsible for maintenance to take on new functions, such as energy saving, recycling of industrial waste, implementation of clean technologies and, in general, everything related to the image of a company concerned about the preservation of the environment.

3.4 Maintenance and energy saving

Maintenance, considering energy savings, must be within the integral concept of energy management. Maintenance, in its general sense, seeks to restore the original conditions of the equipment or machinery, due to the wear and tear of sustained operation during a certain period. This wear, or loss of the nominal conditions of adjustment or imbalance, is reflected in increases in temperature, vibrations, stresses, etc., which directly affect operational efficiency.

Depending on the type of machinery or equipment, this loss of efficiency is not always evident or easily measurable. However, the reliability of continuous operation is the key to determining efficiency. Some equipment, such as generation turbines, has a loss of efficiency that is reflected in a decrease in production, which allows this loss to be quantified.

In general, lack of maintenance on heat transfer equipment, fluid loss, and other problems significantly affect energy efficiency. Common examples of these problems are:

- Fireside boilers full of soot.
- Embedded water-side boilers.
- Dirty heat exchangers.
- Hot or cold surfaces with deteriorated insulation.
- Leaks of steam, air, water, etc., from damaged seals or punctured pipes.
- Damaged accessories, such as relief valves, check valves, and others.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The research reveals that Mexican microenterprises face significant challenges in terms of maintaining their equipment and machinery. It is common for these companies to lack formal maintenance systems, which can lead to low operational efficiency, high repair costs, and lost productivity due to unforeseen failures. In addition, maintenance is carried out empirically or, in some cases, omitted entirely. These

practices can lead to serious consequences in terms of costs, production stoppages and long-term equipment deterioration.

Predictive maintenance, a technique that allows you to anticipate failures and take preventive measures before they occur, has proven to be effective in large companies. However, its implementation in micro-enterprises has been hampered by the high costs associated with the purchase of specialized equipment and the lack of technical training. Despite this, it has been identified that implementation costs have decreased significantly in recent years, which has made predictive maintenance more accessible to micro-businesses.

The study also concludes that, while predictive maintenance is being adopted mainly in large companies in developed countries, its potential in the context of Mexican microenterprises should not be underestimated. By applying a methodology tailored to their needs and resources, microenterprises can reap tangible benefits, such as longer life of their equipment, reduced operating costs, and ultimately increased competitiveness in the market.

However, one of the main obstacles is the resistance to change shown by many microentrepreneurs. This resilience stems, in large part, from a lack of information and understanding about the benefits of predictive maintenance, as well as concerns about upfront costs. In addition, micro-businesses lack historical data on the performance of their equipment, making it difficult to effectively implement reliability analytics, an essential part of predictive maintenance.

In this context, it is critical for micro-enterprises to recognize predictive maintenance as a long-term investment. If implemented properly, the benefits gained will far outweigh the upfront costs, achieving not only greater operational efficiency, but also a considerable reduction in unforeseen costs from failures and repairs.

4.2 Recommendations

Gradual implementation of the predictive maintenance model: It is recommended that micro-enterprises start with a gradual implementation of predictive maintenance. This could start with key areas of the company or teams that have a high impact on production. In the first instance, companies may choose to adopt simpler approaches, such as Japanese (autonomous maintenance) or Cuban (reliability analysis), which require less initial investment and provide a solid basis for applying predictive maintenance in the future. As the results begin to become visible and the effectiveness of the system is validated, companies can consider acquiring more sophisticated equipment.

Continuous training and training of personnel: Training is one of the most critical factors for the success of predictive maintenance implementation. It is essential that micro-enterprises invest in the training of their personnel, not only in terms of preventive maintenance, but also in the use of technological tools and in the analysis of data obtained through inspections. Continuing education programs should be established to update staff knowledge in statistical techniques, vibration analysis, thermography, and other condition monitoring tools. In addition, it is recommended that operators and technicians acquire knowledge in autonomous maintenance, which will allow them to identify and solve small problems before they become serious failures.

Implementation of historical data collection systems: Since micro-businesses generally lack historical data on the performance of their equipment, it is essential that a system for data collection and recording is established from the start of the predictive maintenance implementation. This data will be critical to conducting reliability analyses and determining recurring failure patterns. By gathering information about machine behaviors over time, companies can make more accurate predictions and make informed decisions about the preventive maintenance needed.

Adopting an organizational change mindset: Microenterprises must adopt a mindset that is open to change and innovation. Predictive maintenance should not be seen as an unnecessary expense, but as a strategic investment to improve competitiveness and efficiency. To this end, it is essential that the company's top management is actively involved in the implementation process and that the importance of predictive maintenance is promoted at all levels of the organization. In addition, it is necessary to promote an organizational culture that values prevention and continuous improvement.

Encourage collaboration with external companies and experts: Since many micro-enterprises do not have the knowledge or resources to fully implement a predictive maintenance system,

it is recommended that they collaborate with external companies specializing in maintenance or with consultants who can assist in the initial implementation. Strategic alliances with technology providers or predictive maintenance experts will allow micro-enterprises to access best practices, minimize implementation risks, and ensure that the system works effectively.

Constant evaluation of the results and adjustment of the model: Once the predictive maintenance system is implemented, microenterprises must carry out constant evaluations of the results obtained. It is important to monitor the savings generated, the improvement in the useful life of the equipment, and the reduction of unscheduled stoppages. Based on this assessment, the model should be adjusted according to the specific needs of the company. A flexible and adaptive approach will allow the microenterprise to optimize predictive maintenance based on its evolution and growth.

Promoting sustainability through energy savings: Energy efficiency should be a key component of predictive maintenance. It is recommended that micro-enterprises adopt maintenance practices that not only seek to optimize the performance of the equipment, but also to reduce its energy consumption. Implementing energy monitoring technologies and setting energy savings targets will contribute to the company's sustainability, while reducing operating costs and improving competitiveness.

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