Economic impact of automation in maintenance processes for the manufacturing industry in Colombia: a bibliographical review

Impacto económico de la automatización en procesos de mantenimiento, para la industria manufacturera en Colombia: una revisión bibliográfica

Impacto Econômico Da Automação Nos Processos De Manutenção Para A Indústria De Fabricação Na Colômbia: Uma Revisão Bibliográfica

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Abstract

Introduction: The article is the product of the research Economic Impact of Automation in Maintenance Processes, for the Manufacturing Industry in Colombia, developed at the Universidad Distrital Francisco José de Caldas, in 2021.

Methods: A literature review has been performed to identify, evaluate and synthesize the existing body of knowledge produced by researchers, academics or practitioners.

Results: The scope of this bibliographic review includes the different tools, techniques and processes of automation used in industrial maintenance. This is supplemented by cases of different companies that have implemented automation technologies in their maintenance management. Ultimately, statistics and data related to the subject in question, with particular focus on Colombian manufacturing companies, will be presented. The culmination of the aforementioned provide a panoramic vision of the economic impact of automation immersed in industrial maintenance and concurrently take a glance at the horizon of automation in Colombian manufacturing industries.

Conclusions: Although automation technologies have generated profits for companies, investment costs in these are often high. It is therefore recommended that companies that begin integrating automation technologies into maintenance processes should do so progressively, so as not to generate frustrations in relation to the investment.

Originality: Automation and industrial maintenance have typically been studied as separate topics. In this article, these two issues are related to the objective of providing solutions to manufacturing companies in the Colombian region.

Limitations: Because automation and industrial maintenance have been topics studied separately, there is little scientific information on automation in maintenance processes.

Keywords: Industrial Automation, Manufacturing Industry, Industrial Maintenance, Predictive Maintenance, Automation technologies.

Resumen

Introducción: El artículo es producto de la investigación Impacto Económico de la Automatización en Procesos de Mantenimiento, Para la Industria Manufacturera en Colombia, desarrollada en la Universidad Distrital Francisco José de Caldas, en el año 2021

Métodos: Para la construcción de este artículo, se tuvo en cuenta la revisión de la literatura como método para identificar, evaluar y sintetizar el cuerpo de conocimiento producido por investigadores, académicos o profesionales.

Resultados: En la presente revisión bibliográfica se reúnen las diferentes herramientas, técnicas y procesos de la automatización en procesos de mantenimiento industrial, además se exponen casos de diferentes empresas que han implementado tecnologías de la automatización en su gestión de mantenimiento, finalmente se presentan estadísticas y datos relacionados al tema en cuestión, centrando especial atención en las empresas manufactureras de Colombia, todo esto con el fin de dar una visión frente al impacto económico que tiene la automatización inmersa en el mantenimiento industrial y simultáneamente vislumbrar un horizonte de la automatización en las industrias manufactureras colombianas.

Conclusiones: Si bien las inversiones en tecnologías de automatización han generado ganancias para las empresas, estas suelen ser altas, además de los costos relacionados con la capacitación del personal de la empresa para realizar adecuadamente estos procesos. Por lo tanto, se sugiere que las empresas que deseen comenzar a integrar tecnologías de automatización en los procesos de mantenimiento lo hagan de manera progresiva para no generar frustraciones en relación con la inversión.

Originalidad: La automatización y el mantenimiento industrial han sido estudiados como temas separados, en este artículo estos dos temas se relacionan con el objetivo de brindar soluciones a las empresas manufactureras de la región colombiana.

Limitaciones: Debido a que la automatización y el mantenimiento industrial han sido temas abordados por separado, se encuentra poca información científica de la automatización en procesos de mantenimiento

Palabras clave: Automatización Industrial, Industria Manufacturera, Mantenimiento Industrial, Mantenimiento Predictivo, Tecnologías de la automatización.

Resumo

Introdução: O artigo é produto da pesquisa Impacto econômico da automação em processos de manutenção, para a indústria manufatureira na Colômbia, desenvolvida na Universidade Distrital Francisco José de Caldas, no ano de 2021.

Métodos: Para a construção deste artigo, considerou-se a revisão da literatura como método para identificar, avaliar e sintetizar o corpo de conhecimento produzido por pesquisadores, acadêmicos ou profissionais.

Resultados: Nesta revisão bibliográfica, são reunidas as diferentes ferramentas, técnicas e processos de automação em processos de manutenção industrial, além disso, são apresentados casos de diferentes empresas que implementaram tecnologias de automação em sua gestão de manutenção, por fim estatísticas e dados relacionados ao assunto. em questão, focando atenção especial nas empresas manufatureiras da Colômbia, tudo isso para dar uma visão do impacto econômico da automação imersa na manutenção industrial e simultaneamente vislumbrar um horizonte de automação nas indústrias.

Conclusões: Embora os investimentos em tecnologias de automação tenham gerado lucros para as empresas, estes costumam ser altos, além dos custos relacionados ao treinamento de pessoal da empresa para realizar adequadamente esses processos. Portanto, sugere-se que as empresas que desejam começar a integrar tecnologias de automação nos processos de manutenção o façam de forma gradual para não gerar frustrações no investimento.

Originalidade: Automação e manutenção industrial foram estudados como tópicos separados, neste artigo esses dois tópicos estão relacionados ao objetivo de fornecer soluções para empresas manufatureiras na região colombiana.

Limitações: Devido ao fato de automação e manutenção industrial terem sido temas abordados separadamente, há poucas informações científicas sobre automação em processos de manutenção.

Palavras-chave: Automação Industrial, Indústria de Manufatura, Manutenção Industrial, Manutenção Preditiva, Tecnologias de Automação.

1. INTRODUCTION

Much has been said about the concept of automation and its application in the diverse industries that currently make up the sustainable and scientific development benefiting society; mainly because of the return on investment, its long-term profitability and waste reduction. From the emergence of mechanization to its evolution in industrial automation, the technologies applicable to these systems have been generated with the objective of achieving productive and economic efficiency in companies with a

competitiveness based on a cost structure [1]; however, little is said about the close relationship that automation has with industrial maintenance processes and how the management of these two concepts cause an impact on a company's economy.

1.1. Literary review and research

Throughout history it is evident how the concepts of automation and maintenance have been evolving. Automation has its beginnings in prehistory with the development of simple machines minimizing the force that people had to perform, however, automated manufacturing emerged from the intimate relationship between economic forces and technical innovations such as the division of labour, energy transfer, factory mechanisation, and the development of transfer machines and feed systems.[2]

The division of labour, first dealt with by Adam Smith in 1776, involved the segmentation of productive processes into smaller independent tasks. This increased production and reduced the level of specialization of the workers. This was then followed by mechanization which, together with the division of labour and the evolution of energy transfer technology, succeeded in motorising the machines, increasing production efficiency; it also gave rise to the development of energy technology which in turn led to the industrial production system. Then, in the 1920s, the automotive industry evolved these concepts into an integrated production system, which consists of a series assembly system in order to reduce the production costs, culminating in the industrial automation period.

The evolution of industrial maintenance can be understood from its three generations. The first generation covers the time period until the Second World War. In this period, industry was not very mechanized, so the downtimes were not very relevant. The machinery was simple and in most cases designed for a certain purpose. This made it reliable and easy to repair, leading to no need for complicated maintenance systems or the need for highly qualified personnel.

During the Second World War, the second generation is found, where drastic changes are evidenced. The needs of products of all kinds increased and the workforce decreased, which led to the need for increased mechanization. By 1950, all kinds of more complex equipment had been built, and at this point the companies began to depend on such equipment, making unproductive machine time more evident. This concluded with the idea that breakages could and should be prevented, which resulted in the birth of the concept of scheduled maintenance. In the 1960s this was primarily based on the complete review of the material at fixed intervals. The cost of maintenance also began to rise significantly in relation to other operating costs, resulting in

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the introduction of maintenance control and planning systems. These have helped to bring maintenance under control, and have now been established as common practice.

Eventually, in the third generation, the changes are presented more and more rapidly. These changes can be classified into new expectations and new research where the continued growth of mechanization means that unproductive periods have a greater effect on production, total cost and customer service. This is made clearer by the worldwide movement towards just-in-time production systems, in which the low levels of "work in progress" inventory mean that small breakages can cause the shutdown of an entire plant. On another hand, new research is changing the most basic beliefs about maintenance, in particular, it becomes apparent now that there is a lesser connection between how long a computer has been running and its chances of failure. More extensive automation also means that there is a closer relationship between the condition of the machinery and the quality of the product. At the same time, quality standards are continually being raised. This creates higher maintenance demands within Industry 4.0.[3]

Nowadays, companies are currently working on the implementation of Industry 4.0 tools that allow them to be competitive both in a local and international context. Industrial automation is one of these tools, which corresponds to the automatic method of controlling the operation of an artifact, process or system integrated by various components through mechatronic-electronic and computational means, that replace the sensitive organs and the decision-making capacity of the human being. [4] However, when it comes to implementing industrial automation tools, companies have doubts about the economic benefits that these tools can bring to the company.

On the other hand, the impact of maintenance on the profitability of the company is high and there is the opportunity to increase automation levels in production plants through proper maintenance management. [5]

At the same time it is noted that the manufacturing industry in Colombia presents difficulties in the management of industrial maintenance which affects the economy of the organization. In this way, by implementing automation technologies that allow greater control in maintenance processes, it helps to motivate managers to be more competitive at the local, regional and global level. [6]

2. METHODOLOGY

A literature review identifies, evaluates and synthesizes the body of knowledge produced by researchers, academics or practitioners. [7,8] As a first exploration, recent research into the tools and techniques of automation used in industrial maintenance

were reviewed. This was followed by an analysis of Colombian and Latin American manufacturing industries that had implemented automation tools in their industrial maintenance processes. The questions that arose and led to this study were: What are the automation tools and techniques used in industrial maintenance? How have automation technologies been implemented in industrial maintenance processes in manufacturing industries? What has been the economic impact of companies that have implemented automation technologies in maintenance processes?

In the section of the articles that form part of the study, the following inclusion criteria were considered:

- Studies related to industrial maintenance in manufacturing companies
- Studies about automation immersed in maintenance processes.
- Studies of automation techniques and tools in the manufacturing industry.
- Articles in online refereed journals.
- Articles published between 2000 and 2021.
- Articles written in Spanish.

The consulted databases were: the Scientific Electronic Library Online (SciELO), Red de Revistas Científicas de América Latina y el Caribe, España y Portugal (Redalyc), Universidad Distrital Repository (RIUD), Google Academic, Springer and Science Direct. The search terms used were: automation in industrial maintenance, predictive maintenance, automation techniques and maintenance in manufacturing industries. Depending on the database, the language (Spanish) and year (2000-2021) filters were applied.

From this, a first list of 90 documents was obtained. After reading and analysing each document, those that did not meet the inclusion criteria were eliminated. Articles were also deleted with duplicate information, giving priority to the most recent ones. Lastly, 52 articles were identified for this study.

For the analysis of the articles, dynamic Excel tables were used, where each article was classified according to the authors, the year of publication, country of publication and a brief description. Table 1 shows an example of the synthesis table that was assembled:

Table 1. Synthesis table of case analysis.

Name of the article	Authors	Publication date	Country	Brief description
Diagnóstico del mantenimiento en Colombia	Colombian Association of Engineers	2018	Colombia	Booklet of the Colombian association of engineers about the current state of maintenance in Colombia
Mantenimiento predictivo de los equipos industriales mediante el uso de la inteligencia artificial	Ruben Bartolome	2018	Spain	This work presents an artificial intelligence software for predictive maintenance
Automatización Industrial	Roberto Sanchis, Julio Romero and Carlos Ariño	2019	Spain	Book on the generalities of industrial automation
Principios básicos de la termografía infraroja y su utilización como técnica para mantenimiento predictivo	Lidia Neita and Elkin Peña	2011	Colombia	This article defines the concept of thermography and its use in predictive maintenance
Técnicas de mantenimiento predictivo. Metodología de aplicación en las organizaciones.	Ana Sanchéz	2017	Colombia	In this work, different techniques and technologies used in industrial manintenance are presented

Source: Own work.

Caption. As an example, this table shows the way in which the analysis and synthesis table of the bibliographical references, selected for the writing of the review article, were made.

3. RESULTS

Automation has generated great advances throughout Industry 4.0, nevertheless, it can be seen that in Latin American countries, automation processes in manufacturing industries are very scarce. This is due to a set of factors that can highlight the size of the companies in this region; SMEs (Small and Medium-sized Enterprises) predominate, there is a lack of training in technology and a fear of low return on investments in automation by managers. In this order of ideas, the automation techniques and tools most commonly used in industrial maintenance processes are described below, with cases from Colombian and world industries that have implemented these tools. Lastly, statistics that help to show the economic impact of automation immersed in maintenance processes are presented.

A. Automation techniques and tools in industrial maintenance

Before discussing about the techniques and tools of automation in industrial maintenance it is worth reviewing the types of maintenance that can be found within the

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industry. The first of these is corrective maintenance, which consists in the correction of breakages as and when they occur. Next, is preventive maintenance, where a series of periodic inspections of the equipment are carried out, performing cleaning, lubrication, adjustment, checking and replacement of defective components in order to keep the equipment always running in an optimal state.[9,10]

Furthermore, technological advances and the development of new statistical techniques have led to the ability to conduct predictive maintenance; which the Electric Power Research Institute (EPRI) [11] defines as a process that requires technologies and trained personnel, and integrates all available equipment condition indicators (diagnostic and performance data, operator data records), maintenance history, and design knowledge to make timely decisions on maintenance requirements for major equipment.

Automation tools

When talking about automation tools, a large number of elements can be classified into sensors, actuators and control systems. Sensors are the elements that allow us to gather information about what is happening in the process. On the other hand, actuators are the elements that translate the electrical output signals of the control system into physical actions on the process; they can be powered pneumatically, hydraulically or electrically. Finally, the control system is usually formed by an industrial programmable automaton, although it can also be an industrial computer or a microcontroller-based card.[12]

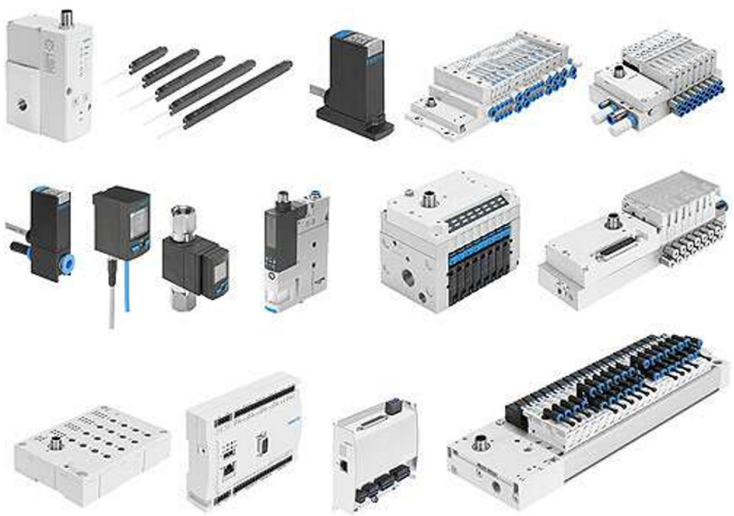

Figure 1. Sensors and actuators.[13]

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Automation techniques in industrial maintenance

The automation techniques used in industrial maintenance include vibration, thermography, ultrasound and oil analysis. For this analysis, it is necessary to make a good interpretation of machine vibration signals, as these indicate the state of health of the machine and facilitate the identification of the place and the type of failure, based on the tolerance levels of the machine given by the manufacturer or the technical standards.[14]

Thermography, according to ASTM E1316 [15], is defined as the process of displaying the actual temperature (variations in temperature or emissivity, or both) on the surface of an object or environment by measuring the variations of infrared radiation. Using this technique, a thermal image called a thermogram is obtained, displaying the thermal distribution of all elements of a system and sets the temperature present at each point on the surface of the object whether stationary or in motion. This is done instantaneously and at a safe distance, which is important for applications with electrical, mechanical and combustion systems in industrial maintenance. [16]

Ultrasound is a nondestructive mechanical inspection procedure based on acoustic impedance, which manifests as the product of the maximum speed of sound propagation between the density of a material. Ultrasound is a mechanical vibration with a range greater than that audible by the human ear that is transmitted through a physical channel and is oriented, recorded and measured in Hertz with the help of a device created for that purpose. Its application allows for the detection and characterization of discontinuities, the measurement of thickness, extent and degree of corrosion, the determination of physical characteristics and determine bond characteristics between materials. [17]

Figure 2. Ultrasound analysis.[18]

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Oil analysis consists of a series of laboratory tests that are used to assess the condition of used lubricants or residues present. By studying the results of the residue analysis, a diagnosis can be made on the wear condition of the equipment and its components. This allows those in charge of maintenance to plan the stoppages and repairs in advance, reducing the costs and stoppage times involved. [17] As has been said before, the previous automation techniques are the ones that stand out most in maintenance processes, however, we can mention other analyses used in various industries such as liquid penetrant analysis, magnetic particle analysis, Eddy current testing, X-ray and electric motors' analysis.

Industrial maintenance trends

Today, trends in industrial maintenance encompass both modern tools, methodologies, techniques and technologies. Some of these are briefly described below:

The development of software and algorithms of artificial intelligence have great potential within Industry 4.0 where its applications are growing [19], from auxiliary software in the management of the maintenance (such as the software SGMANTE elaborated in the Agrarian University of Havana [20]), to software that optimizes the total management of the industrial maintenance (as is the case of GEMA). [21]

Another trend in industrial maintenance is the use of augmented, virtual and mixed reality technology that permits: the visualization of production process data with SCADA-connected systems, ERP, etc; Teleassistance with tablets or smart glasses in video conferencing with a remote expert; Assisted picking using the image pattern recognition capability of smart glasses; Augmented manuals with tablets or smart glasses in which the operator is trained; Maintenance and inspection of elements in plant with augmented reality; Product/plant design with virtual reality and training with virtual reality and virtual reality helmets.[22]

In addition, the dynamic measurement of hydrocarbons has been used, where the quality of hydrocarbons determine characteristics that impact energy capacity. What is desirable in these measurements is that the values of impurities tend to zero; however, the product must conform to the quality agreed upon by the parties in the TC contract. [23]

It should be noted that the instrumentation of machines and equipment in real time is part of automation and that all these techniques seek to diagnose a possible failure and its origin.

Other automation technologies in industrial maintenance processes are the following:

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- Mobile Robotics
- Internet of Things Sensors
- Automated Picking

In terms of trends in maintenance methodologies and/or techniques, there is Total Productive Maintenance (TPM), which extends preventive maintenance to the entire company, gaining the support and trust of everyone from the top management down, going beyond the maintenance department, and involves the entire company. [24]

TPM is understood as a management system that avoids all kinds of losses during the entire life of the production system, maximizing its efficiency and involving all departments and all personnel, from operators to senior management, and guiding their actions based on activities in small groups.

Contrary to the traditional approach to maintenance, in which some people are responsible for "producing" and others for "repairing", when there are breakdowns, TPM advocates the continuous involvement of the entire workforce in care, cleaning and preventive maintenance, reducing breakdowns, accidents and defects.

Here, it is considered that there is no one better than the operator to understand the operation of the equipment, since they have regular contact with the machine/s.

TPM is a new direction for production. TPM, which organizes all employees from top management to production line workers, is a company-wide equipment maintenance system that can support facilities with more sophisticated production. TPM has the following characteristics:

- It seeks to obtain the highest possible performance. This is sought both in the teams and in the individual, like the system itself.
- It seeks to obtain a longer useful life, both in the equipment and in the installation.
- It requires the active involvement of all departments.
- It promotes the continuous improvement of the teams in order to have a greater cost effectiveness.
- It avoids faults and breakdowns, as well as a bad production, thanks to the operator's knowledge of the machine.
- It has greater safety for the operator and for the equipment.

It is important to highlight that TPM is based on the following 8 pillars:

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- Focused improvement
- Autonomous maintenance
- Scheduled maintenance
- Quality maintenance
- Prevention of maintenance
- Maintenance of support areas
- Versatility and development of activities
- Safety and environment.[25]

B. Colombian and Latin American cases

This section describes the processes that have been carried out in the management of industrial maintenance and their relationship with automation tools, within some manufacturing industries in the Latin American region and with a special focus on Colombian industries.

Latin America

- In Lambayeque, Peru, an automation system for a viscometer was designed and developed, based on the ASTM D445 standardized test method used in lubricant laboratories; viscosity is a critical input of predictive maintenance applied in heavy machinery, hydraulic systems, engines and the mining industry. This system incorporated a user-friendly operation and maintenance interface, with faster communication ports and reliable software for management and administration. In its development, free hardware such as the Raspberry Pi was used at the same time as free software like Python, Android Studio and Raspberry PI OS. [26]
- In an automotive company from Guayaquil, Ecuador, to improve control on the maintenance of the company's electric forklifts, a software that automates the functions of the management of the maintenance of the forklifts was elaborated. The development application MS SQL SERVER 2008 R2 was used for its development and analysis services, which is a data mining and analytical processing tool.

  This software transformed the process, initially carried out manually and demanding 9 steps and a time of 4 hours, into the current process requiring only 4 steps and 1 hour. This transformation also resulted in

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economic benefits as the method passed from corrective maintenance to that of preventive maintenance. [27]

- A group of engineers from Mérida, Venezuela designed an application for the automation of industrial processes, conceived as a multi-agent system (MAS or "self-organized system"), that manages corrective, preventive and predictive maintenance of any productive process. Although a multi-agent system consists of agents such as the Reliability Supervisor, Manager, Planner and Executor, in this case, the "Scheduler" agent is developed using the Methodology for Agent-Oriented Engineering with a model-driven approach, leaving a product that can be subsequently implemented in any maintenance management automation process, following the methodology and guidelines set out in that work. [28]

Colombia

- At Eterna S.A., a group of engineers designed and implemented a preventive maintenance plan based on predictive maintenance techniques such as vibration analysis and thermography. Based on the environmental and handling conditions encountered within the scope of the study, they recommend the frequent use of this type of predictive tool due to the high probability of failure. In addition to the preventive maintenance plan proposed for the company, the engineers provided a basis to formalize the maintenance management within the company. [29]
- In 2018, a study was carried out in 48 companies in the metallurgical sector of Colombia, focusing on CNC machinery. In this study it was found that the current situation of automated equipment presents weaknesses. This situation is due to the poor maintenance routines implemented by the companies, and has caused the premature deterioration of the machinery.

  The most common failures that occur in the equipment are presented by mishandling, corrosion, improper lubrication and descaling. Given these results, companies should take action regarding the maintenance implemented to improve reliability and increase productivity. For this purpose, the authors of the study made a proposal for a targeted model to cover the needs and maintenance requirements of automated equipment, considering its components, systems and subsystems. However, it is a general model that allows for its implementation in any type of machinery similar to automated equipment in the industrial sector.

The research proposal consisted of five phases: Initiation, in which the equipment's maintenance log sheet is gathered and new novelties are registered; Planning, where the schedule of activities is drawn up, staff administration is carried out, the activities to be implemented are organized and the necessary resources are estimated; Implementation, where the work scheduling is executed, answers are given to what types of supervision should be used, the channels of communication are defined and, finally, how the responses are handled; Control, where the recording of results is carried out and possible improvements are proposed; Start-up phase, where the operation is verified, corrections are made in case of a malfunction and the model is finished. [30]

- In 2018, a study regarding the companies dedicated to the sector of plastic extrusion in Bogota, showed an accelerated growth. This study focused on visualizing the state of maintenance management in this industry and proposing a maintenance plan for those companies that had deficiencies in their management. Small and medium-sized enterprises had quite a few shortcomings in the maintenance management of plastic extruders; a situation that caused companies to lose money as the result of downtimes, machine replacement and the generation of defective products.

  The following maintenance plan was proposed to correct these problems: Starting analysis; Record technical, electrical and mechanical variables; If the equipment complies with the requirements, the equipment maintenance log is updated, the data sheet is updated if any spare parts are required and electrical and mechanical performance is reported; If the equipment does not comply with the requirements, a work team is formed, a work order is scheduled and the necessary corrections are made to begin the maintenance plan cycle again. [31]
- For a company dedicated to the calibration of platinum thermometers the automation of the parameterization and data collection of a high temperature furnace was developed. For its automation, a computer, an interface RS232 and RS422, a process controller and furnace, and the LabView software was used. Once the corresponding applications were made, a program was obtained with which the company could properly parameterize the "set point" of the temperature and acquire uninterruptedly the data of the working temperature of the furnace. This technology was used to see anomalies in the furnace and carry out preventive maintenance.[32]

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- In 2017, an automation design was proposed for companies in the agricultural sector; especially those dedicated to the processing and packaging of beans. This design aimed to implement the basic elements of an automation system, a logical controller through a PLC, input and output elements such as position sensors, alarms, contactors and load cells. The design was analyzed through simulation and it was concluded that the implementation of automation technologies in the process reduces the collection and processing times of a ton of beans; when performed manually, the process required 8 to 10 days to perform, and with the implementation of the design it would happen in only 2 days. In addition, it was determined that the elements to be implemented are easy to install and require only simple industrial maintenance, which makes the design viable and easily covers the implementation costs. [33]
- Within the National Beverages Industry, the machinery involved in the process of filling and packaging of water was evaluated. It was determined that the three machines present in this process are the filler, the baler wrapper and the baler packer. The evaluation of the pieces of equipment showed quite a number of failures due to incorrect maintenance management, which is why, with the help of the RCM (Reliability Centered Maintenance) methodology, which is understood as the process used to determine what needs to be done to ensure that any physical resource continues to do what its users want it to do in its current normal production [34], a series of preventive maintenance routines were proposed to ensure that only the most effective maintenance practices were chosen for the machine and that the most appropriate actions are executed. [35]
- Continuing with the methodology of RCM, in the National Chocolate Industry (Industria Nacional de Chocolates), it was proposed to implement this methodology in the facilities located in Bogota. Despite having a preventive maintenance plan, in recent times, corrective maintenance was being done on weekends and the preventive maintenance plan was being ignored. The TPM methodology was introduced and combined with the RCM methodology. This merger has the advantage of improving the process to facilitate teamwork between maintenance and production functions, improve machine reliability and reduce operating costs. Both tactics are complementary, because while TPM improves productivity, RCM increases reliability and competitiveness.[36] However, the company already presented awareness of the TPM technique, while for the RCM methodology it was necessary to

conduct training to facilitate the ideal combination of implementing TPM and, once managed, to continue with RCM.[37]

- A company in the food sector updated its pasteurizer since it had problems with the legal requirements that this type of equipment needs. To achieve this, they hired the company Celtar Automatic Processes, located in Bogota.

  For this industrial automation project, it was sought to develop a program for the control of the sterilizer with the sterilization, production and washing phases, through a PLC (programmable logic controller), operated through a panel. With this, they wanted to have a better control of the operations of its process variables and thus obtain suitable products that meet the requirements for its subsequent consumption. Once the hardware and software developed for the pasteurizer have been installed, it is necessary for the company to carry out training for its correct operation and industrial maintenance. [38]
- The company Vogue S.A.S. - L'Oréal Colombia faced a merger of the two branches. Each unit performed its maintenance processes separately and, at the time of the merger, there were problems in managing the preventive maintenance being carried out. The company had a large amount of machinery and equipment that use automation tools and were susceptible to failure if proper maintenance was not performed. Therefore, a new preventive maintenance plan was set up in which the format used by the company was maintained to make it more friendly to the staff in charge. However, with the new maintenance plan, the time and frequency of incursion into each machine was increased without interfering with the production work; a situation that was presented previously and generated disorder in the plant. [39]
- The company Finart, dedicated to the elaboration of bijouterie products and accessories, implemented Autonomous Maintenance, which is one of the pillars of TPM and consists in generating in the operators the awareness of care and maintenance of the equipment at their disposal. As a first step, the staff was made aware of TPM in general and in particular the autonomous maintenance pillar. Once this was done, the implementation plan was drawn up in the vibration section of the plant and the results that this produced were analyzed, going from an availability of 71% in Chinese machinery to 80% and going from a total efficiency of the equipment of 48% to 71%; in addition to improving the work environment since there are no longer tensions due to the constant breakages that occurred. [40]

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- An artificial vision system was developed in Bogotá, where thanks to the Lab-View® programming platform (Laboratory Virtual Instrumentation Environment Workbench) it was possible to dimensionally verify each of the pieces proposed in the study that sought to verify the dimensions processed in CNC lathes. Artificial vision is presented as a new and successful technology, applicable to dimensional verification processes and geometric characteristics in general.[41]
- For the livestock industry there are also advances in automation issues. A livestock supervision system is proposed through satellite images, working with the binarized image that represents the R channel of the RGB image obtained with the UAV, mainly due to the similarity in the hue present in the dark brown and dark green colors, which can lead to errors when performing the final analysis, taking into account that in the brown color there is a greater concentration of reds than in the others, making it possible to distinguish between both tones.[42]

C. Statistics

In this section, statistics regarding the implementation of automation tools in maintenance processes of different companies are presented, providing a vision of the economic impact that this process can generate to a company.

It is convenient to know that in every company there are costs related to maintenance within the indirect costs of a company, alongside marketing, logistics, quality control, technology, and others. These areas are not considered relevant for management, which makes them unattractive to invest in them.

Currently, maintenance teams are responsible for showing the importance of these and their perception has changed. [43] These costs can be classified into five categories as shown below:

- New equipment, upgrades and replacements; this category includes all efforts in financial terms made by the maintenance department to modify or replace new machinery.
- Repair costs due to breakages that are incurred to maintain a business in proper operation and not affect productivity.
- Decommissioning costs incurred when removing equipment that has been replaced or that has become obsolete.

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- Maintenance costs; this category refers to all costs that are necessary to carry out maintenance activities, including the time of personnel assigned to this work, as well as the costs of supplies and tools that are necessary for maintenance.
- Miscellaneous costs that are given for maintenance; the most common are cleaning services, garbage disposal, machinery cleaning services, etc.

The information that is generated within the maintenance area must be translated into reports to better understand the costs and benefits of the maintenance plan. The way this information is processed is influenced by the company's accounting policies. Once the maintenance cost information is obtained, the respective budget is generated, which will define how many financial resources are allocated to the maintenance department and how it is going to be used. [44]

However, when generating reports with information from the maintenance area, the contexts that surround the company must be taken into account so as not to fall into deceptive indicators, such as the availability of a machine. Since there are machines that are of greater use and greater importance for the production of a company, it is not the same to have a 95% availability of the main equipment of the company to 75% in equipment that is used occasionally. [45]

Once it is understood that companies generate maintenance-related information and that the context in which it is presented should be taken into account, some statistics were collected from different studies in different Colombian manufacturing companies and the world.

1. Statistics of the Colombian metalworking sector regarding maintenance and automation.

The following figures correspond to information on industrial maintenance in the metalworking sector in Colombia.

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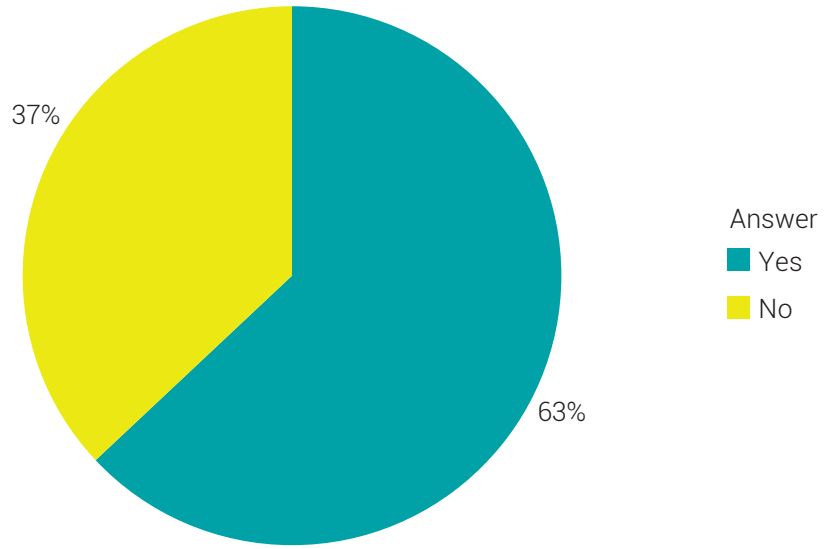

Figure 3. Percentage of companies that have a maintenance area in their organization structure.

Source: Own work

Caption. Percentages of companies in the metalworking sector in Colombia that have a maintenance area in their organization chart. Own elaboration, information adapted from the study, "Caracterización de las áreas de mantenimiento en empresas del sector metalmecánico". [46].

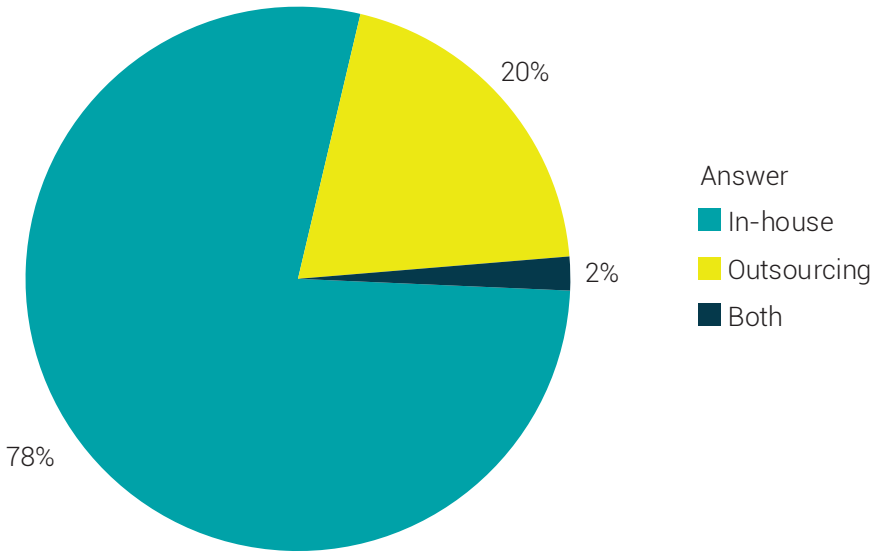

Figure 4. How industrial maintenance is performed.

Source: Own work

Caption. Way in which industrial maintenance is carried out within Colombian metalworking companies; 80% of the companies carry out their own maintenance and 20% prefer to subcontract. Own elaboration, information adapted from the study, "Caracterización de las áreas de mantenimiento en empresas del sector metalmecánico" [46].

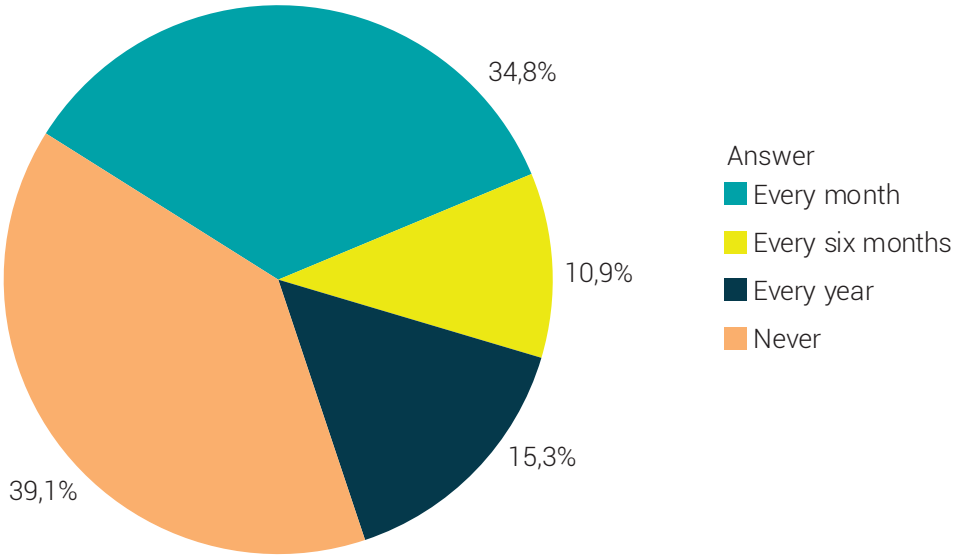

Figure 5. Periodicity with which the maintenance management audit is carried out.

Source: Own work

Caption. Frequency with which companies in the metalworking sector in Colombia carry out an audit of their maintenance management; it can be seen that 40% of companies never carry out an audit of their maintenance management. Own elaboration, information adapted from the study, "Caracterización de las áreas de mantenimiento en empresas del sector metalmecánico". [46]

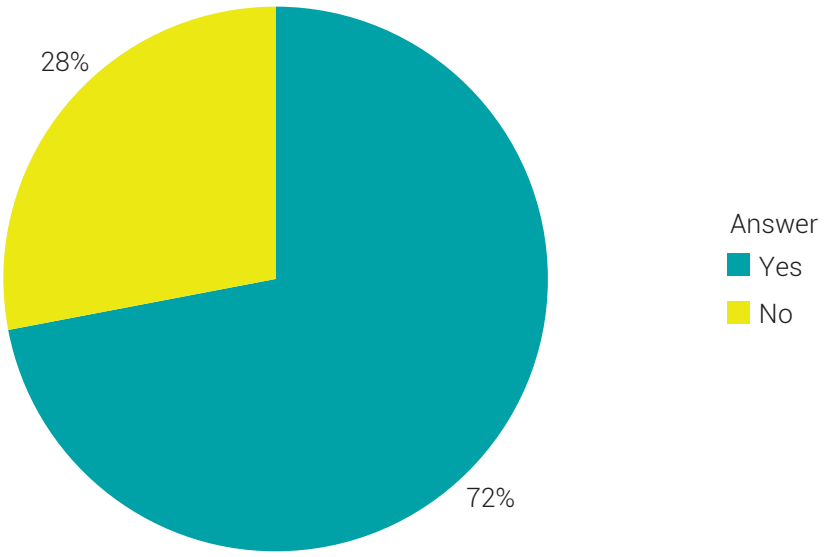

Figure 6. Percentage of companies that have a platform to record maintenance activities.

Source: Own work.

Caption. Proportion of companies that have a platform to record maintenance activities; although 72% of companies have a platform to keep information regarding maintenance, that 28% do not keep maintenance management information is a worrying reality. Own elaboration, information adapted from the study, "Caracterización de las áreas de mantenimiento en empresas del sector metalmecánico". [46]

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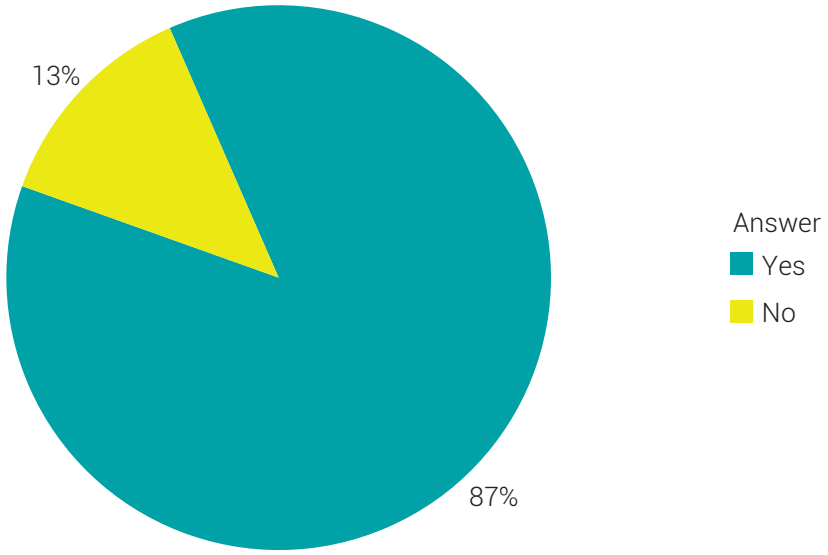

Figure 7. Percentage of companies that carry out industrial maintenance planning.
Source: Own work.

Caption. Proportion of companies that carry out planning compared to their industrial maintenance activities; 87% carry out some type of planning, while 13% of companies carry out maintenance when failures occur. Own elaboration, information adapted from the study, "Caracterización de las áreas de mantenimiento en empresas del sector metalmecánico". [46]

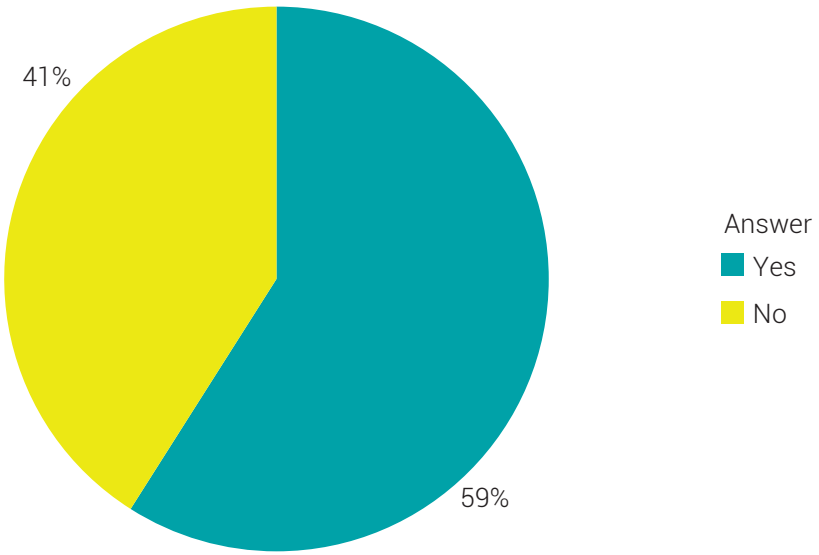

Figure 8. Percentage of companies that allocate a fixed budget to maintenance management.
Source: Own work.

Caption. Proportion of companies that assign a fixed budget to their maintenance management. Own elaboration, information adapted from the study, "Caracterización de las áreas de mantenimiento en empresas del sector metalmecánico". [46]

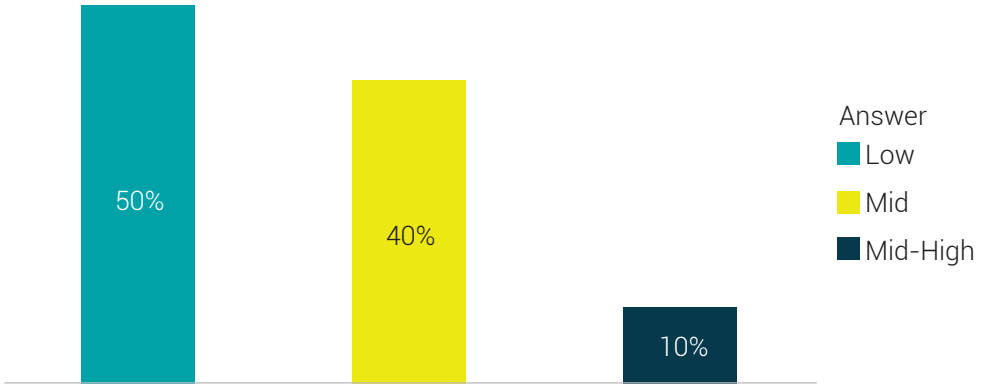

Figure 9. Technological levels in automation.
Source: Own work.

Caption. Technological levels in automation; this information reflects the technological gap of many companies in Colombia. Own elaboration, information adapted from the study, "Identificación de brechas tecnológicas en automatización industrial de las empresas del sector metalmecánico de Caldas, Colombia". [47]

2. Statistics from the region of Valle de Aburrá and Manizales regarding maintenance and automation

The following figures show the state of industrial maintenance in the region of Valle de Aburrá and from Manizales.

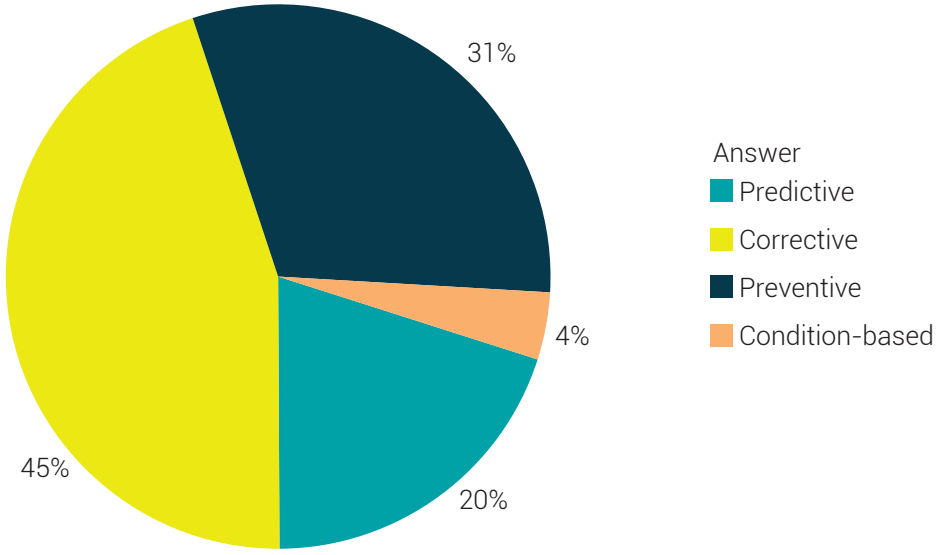

Figure 10. Type of maintenance performed.
Source: Own work

Caption. Type of maintenance performed by the company; it can be seen that 45% of the companies perform corrective maintenance. Own elaboration, information adapted from the study, "Mantenimiento y costos de gestión en un sector empresarial en el Valle de Aburrá" and "Caracterización del mantenimiento industrial en algunas de Manizales y municipios aledaños". [48]

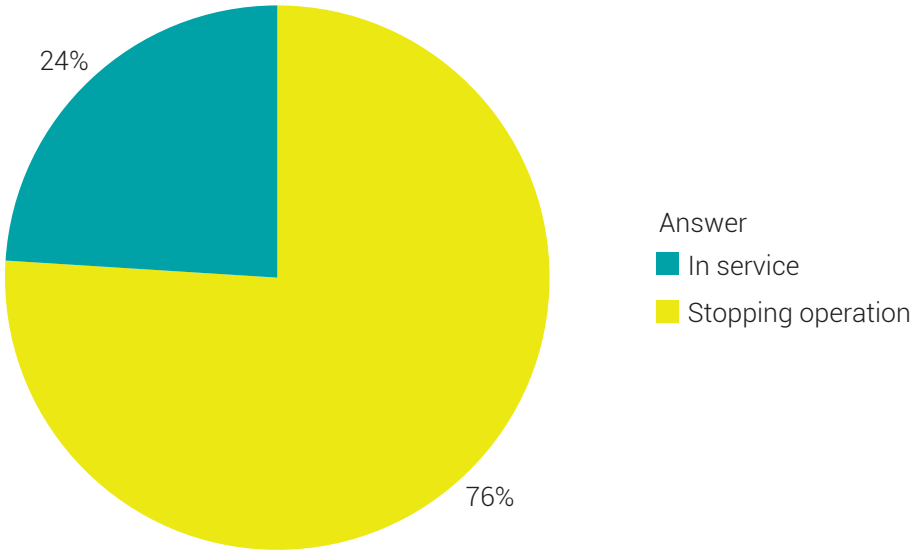

Figure 11. When maintenance is performed.
Source: Own work

Caption. When equipment maintenance is performed; 75% of the time, the companies in the region perform maintenance when the equipment and consequently production is completely stopped, generating costs. Own elaboration, information adapted from the study, "Mantenimiento y costos de gestión en un sector empresarial en el Valle de Aburrá" and "Caracterización del mantenimiento industrial en algunas de Manizales y municipios aledaños". [48]

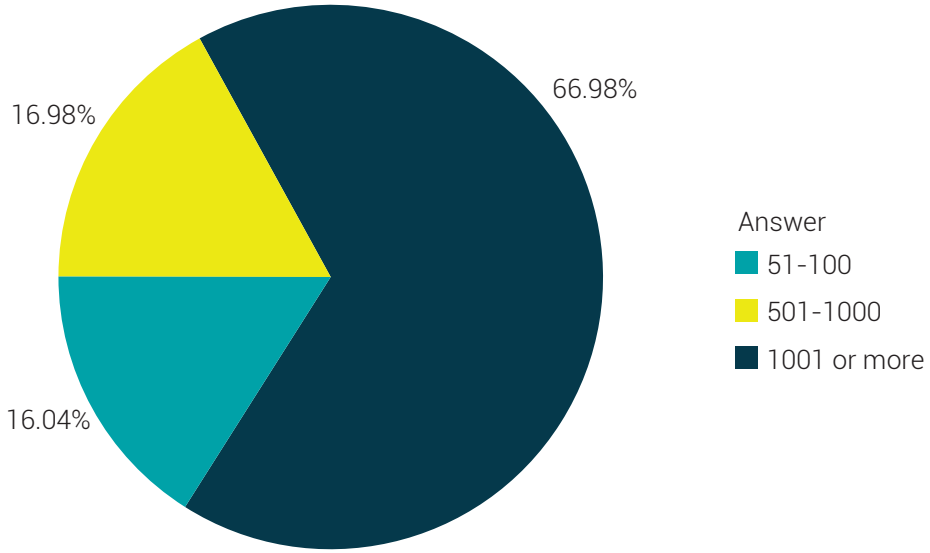

Figure 12. Industrial maintenance annual cost. S
ource: Own work

Caption. Annual maintenance cost in millions of Colombian pesos; this information helps companies to budget or self-assess their maintenance management when high costs arise. Own elaboration, information adapted from the study, "Mantenimiento y costos de gestión en un sector empresarial en el Valle de Aburrá". [48]

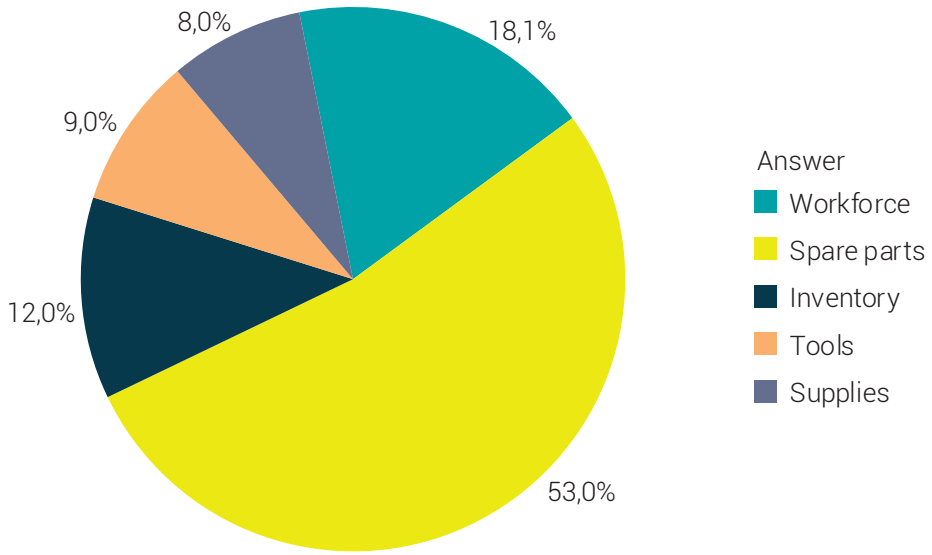

Figure 13. Distribution of maintenance costs.
Source: Own work

Caption. Distribution of maintenance costs; more than 50% of maintenance costs is for spare parts, this situation could be avoided by performing predictive maintenance as it extends the useful life of the equipment. Own elaboration, information adapted from the study, "Mantenimiento y costos de gestión en un sector empresarial en el Valle de Aburrá". [49]

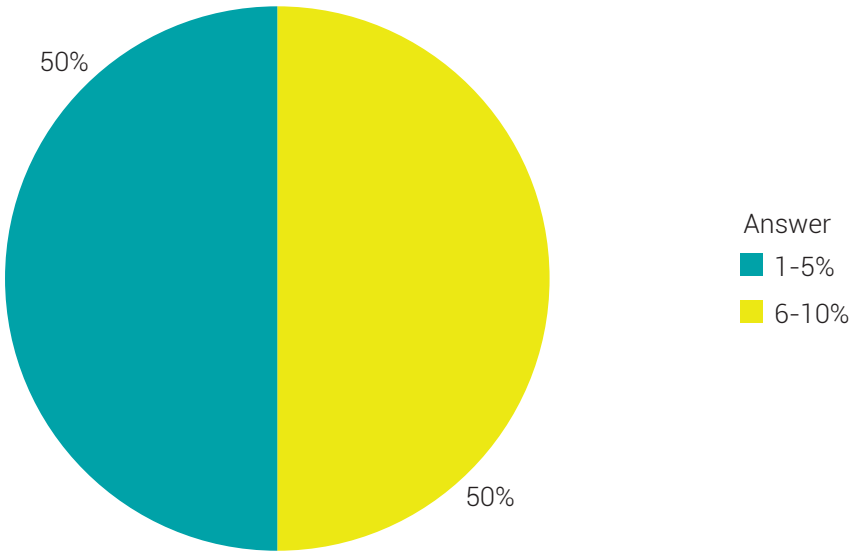

Figure 14. Maintenance cost versus the total of company assets.
Source: Own work

Caption. Proportion of the maintenance cost to the total assets of the company; Although it does not exceed 10% of the total assets, it is important that industrial maintenance does not represent more than 5% of the total assets to the company. Own elaboration, information adapted from the study, "Mantenimiento y costos de gestión en un sector empresarial en el Valle de Aburrá". [49]

3. Evolution of the global competitive index of Latin American countries.

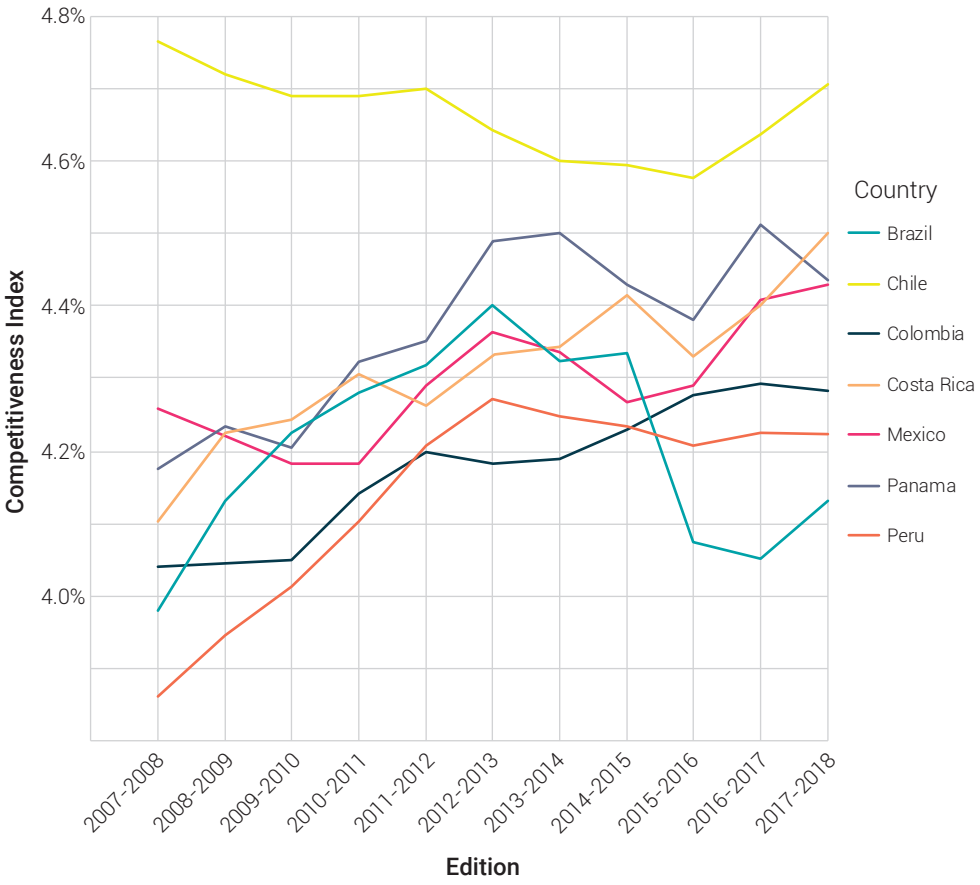

Figure 15. Evolution of the global competitiveness index in Latin American countries. [50]

Along with the information shown in the previous graph, in the most recent Digital Transformation survey conducted by the ANDI, it is pointed out that up to 59% of the Colombian entrepreneurs consulted said they had made or planned technological investments, and 82.8% of those who have made investments have done so to automate processes. With this, 57.8% seek to reduce costs and 48.4% aim to generate new revenue. [51]

The previous statistics show the lack of automation in the maintenance processes of the Colombian manufacturing industry. However, the intention of entrepreneurs to start entering the world of automation is observed, for which it is recommended to start by automating that which is easily dominated in the conditions of production by the knowledge and intelligence of the basic actors (workers, engineers, managers,

etc.); thus leaving open a whole field of what are still very complex tasks to master, so that the human intellect perceives, analyzes, operates and develops it. [52]

4. Statistics of studies and case studies regarding the implementation of automation technologies in industrial maintenance.

- Case Study: Predictive Maintenance in Spain

With the collaboration of the Industry 4.0 observatory and the Club of Management excellence, Fujitsu makes a report on predictive maintenance in the main industries of Spain [50]; below are the most relevant results of this study.

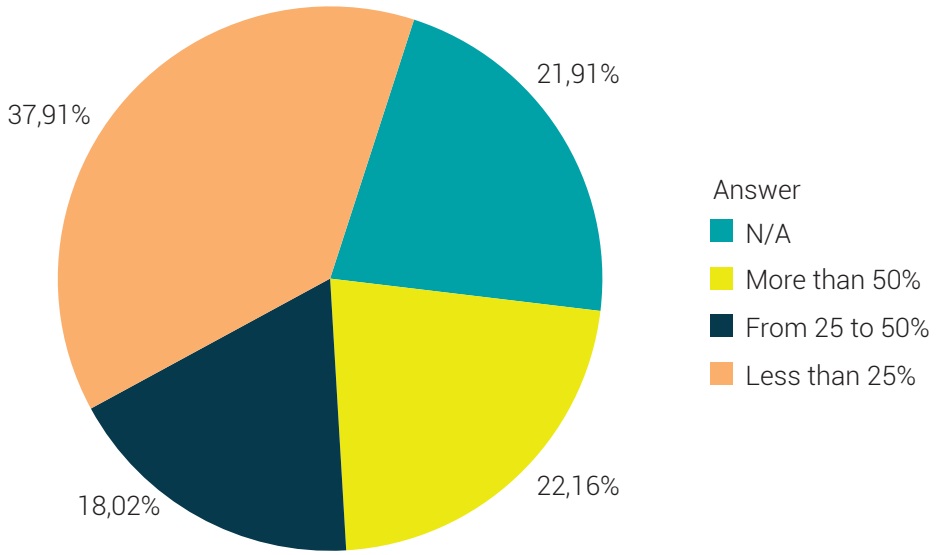

Figure 16. Time dedicated to control.
Source: Own work.

Caption. Time dedicated to control. Own elaboration, adapted from, "Predictive Maintenance in Industry 4.0". [53]

38% of companies say they spend up to 25% of plant operators' time on maintenance tasks and up to 18% spend up to half their time on these tasks.

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Figure 17. Investment in industrial maintenance.
Source: Own work.

Caption. Status of the investment position in industrial maintenance. Own elaboration, adapted from, "Predictive maintenance in Industry 4.0". [53]

49% of companies have started investing, 27% have invested in predictive maintenance initiatives long ago, 18% have not invested in predictive maintenance, but they will do so in the short-term, and 6% have not invested in predictive maintenance and will not do so in a short-term period.

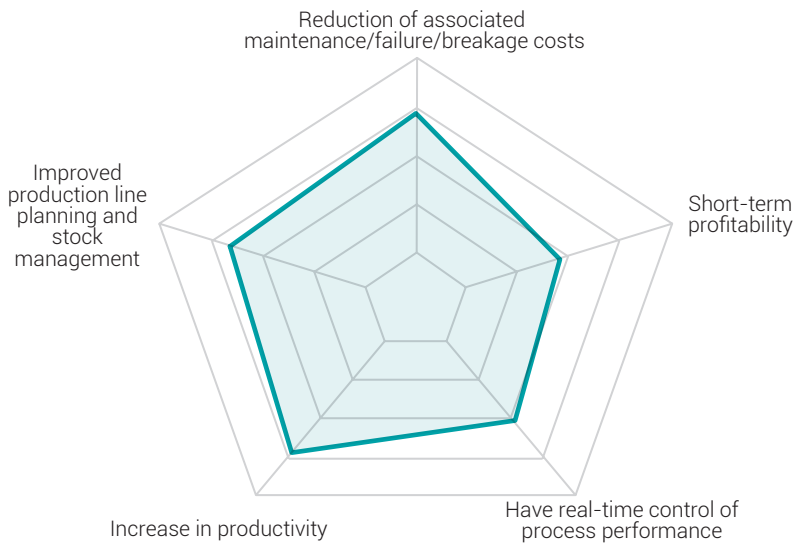

Figure 18. Motivators.
Source: Own work.

Caption. Motivators when investing in industrial maintenance, adapted from, "Predictive Maintenance in Industry 4.0". [53]

The motivations of entrepreneurs to invest in predictive maintenance are mainly the increase in productivity and the reduction of industrial maintenance costs, both with a score of 3.9 out of 5.

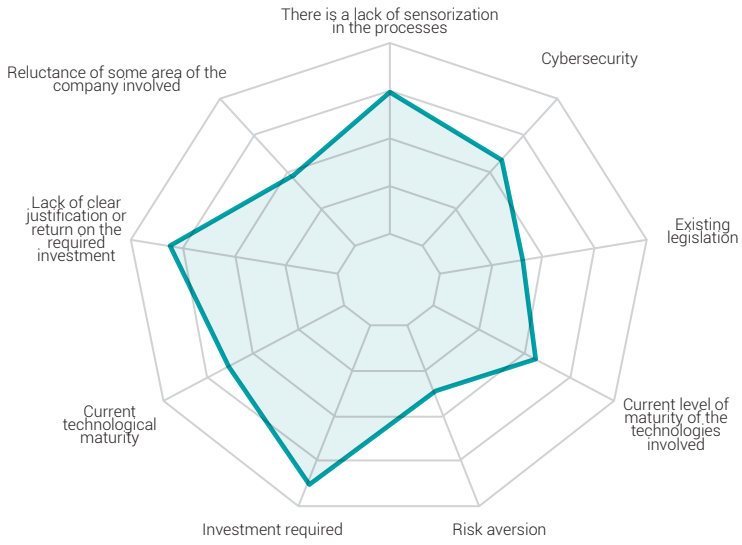

Figure 19. Barriers.
Source: Own work.

Caption. Barriers to investing in predictive maintenance, adapted from, "Predictive Maintenance in Industry 4.0". [53]

The barriers that companies face when investing in predictive maintenance is mainly the investment it requires, with a score of 3.6 out of 5.

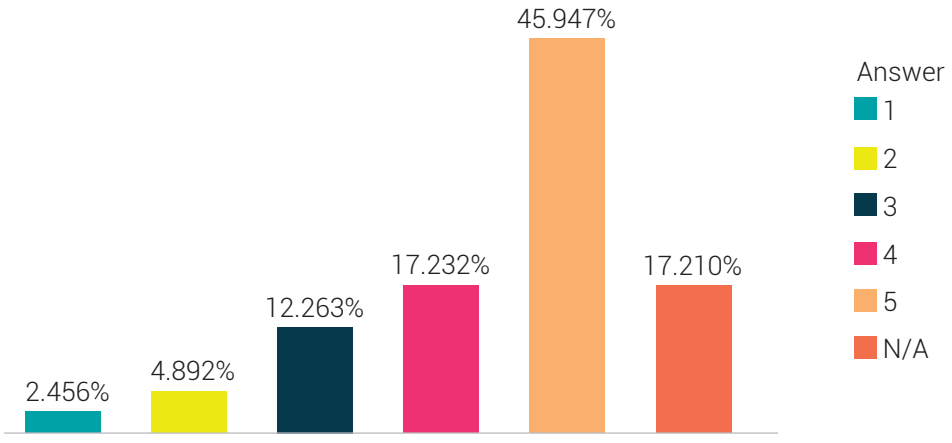

Figure 20. Investment recommendation.
Source: Own work.

Caption. Recommendation of companies to invest in predictive maintenance, measured from 1 to 5. Own elaboration, adapted from, "Predictive Maintenance in Industry 4.0". [53]

The intention and recommendation of the analyzed industries versus investing in predictive maintenance technologies is measured from 1 to 5, and approximately 65% would recommend such investment.

- Case Study: Predictive maintenance in a paint company located in Cuba.

In a paint and compressors company located in the city of La Havana, Cuba, a return-on-investment study of automation technologies is carried out, specifically in predictive maintenance technologies. With this, they created the following table describing the return on investment and evidencing the monthly savings that these processes bring to the company and the projected annual behavior.

COST AND RETURN ON INVESTMENT ASSESSMENT FOR A PAINTS AND COMPRESSORS COMPANY

EQUIPMENT DOWNTIMES

1. What percentage of critical equipment operating limitation downtimes was charged to the maintenance department in the last year?	%	20%
2. How many production hours are planned for the next year for critical equipment?	h	6000
3. What is the average downtime cost for critical equipment?	$	$1.000,00

How to calculate the cost per hour:

1 For each team, determine how much it costs the company to keep it out of operation for one hour.
2 Add up the hourly cost of all equipment to determine the hourly cost of all equipment.
3 Divide the cost by the total amount of equipment. This is the average cost of equipment downtime.

4. Percentage of the type of maintenance that was performed performed (index for efficiency loss per downtime)	%	15%

Guide	
Corrective	15%
Preventive	10%
Predictive	5%

TOTAL of downtime for all critical equipment	h	1200
Downtime per year	h	180
TOTAL COST of downtime per year		$180.000,00
TOTAL COST of downtime per month		$15.000,00
With predictive maintenance		5%
TOTAL SAVINGS		$5.000,00

STOCK

1. What is the current value of your monthly stock?	$	$10.000,00
2. What was the value of all the stock purchased in the last year?	$	$1.200.000,00
3. Corresponding percentage for each of the following existing conditions:		10%

Guide	
STOCK SYSTEM without predictive maintenance	10%
MANUAL STOCK SYSTEM with predictive maintenance	5%
COMPUTATIONAL STOCK SYSTEM with predictive maintenance	2%

Savings from duplicate purchases	$120.000
Savings for minimum stock in time	$1.000
TOTAL SAVINGS in stock	$10.083,33
With predictive maintenance	2%
TOTAL SAVINGS	$ 2.200,00

SCHEDULED PLANT SHUTDOWNS

1. What was the total of downtime last year for scheduled plant shutdowns?	h	200
	Monthly cost of maintenance of scheduled stops	$16.666,67
2. Corresponding percentage for each of the following existing conditions:	%	10%

Guide	
Without an OT system (Operational technology)	10%
Stock System OR manual OT	7%
Manual OT AND Stock system	5%
OT Predictive system AND Stock system	2%

TOTAL plant shutdowns due to system inefficiency	$1.666,67
With predictive maintenance	7,00%
TOTAL SAVINGS	$1.166,67
TOTAL SAVINGS REGARDING PREDICTIVE MAINTENANCE	$ 8.366,67

INVESTMENT IN PREDICTIVE MAINTENANCE

Anticipated cost of CONSUMAN's installation and setup for the following aspects

1. Vibrations	$4.183,33
2. Thermography	$ 2.510,00
3. Analysis of oil	$836,67
4. Electrical measurements	$836,67
5. Others	
TOTAL INVESTMENT REGARDING PREDICTIVE MAINTENANCE	$8.366,67
TOTAL MONTHLY SAVINGS	$9.516,67
TOTAL PROJECTED ANNUAL SAVINGS	$ 114.200,00

Figure 21. Return on investment.
Source: Own work

Caption. Return on investment of predictive maintenance in a paint company in Cuba. Own elaboration, adapted from the aggregated values of predictive maintenance. [54]

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4. DISCUSSION AND CONCLUSIONS

Throughout the article, there is an evident contrast between the different tools, techniques and processes carried out by manufacturing companies versus automation in industrial maintenance processes. Simultaneously, trends in automation technologies can be observed and how these have been implemented in different companies. Focusing on Latin America, it must be said that companies within the region have made efforts to implement automation technologies. However, when analyzing statistics and data in detail, we can highlight the technological gap that the region has, in addition to displaying insufficient maintenance efforts.

Colombia, facing towards the panorama of automation in industrial maintenance processes within manufacturing companies, does not present encouraging data, given that there is a high percentage of companies where there is no maintenance area. In addition, most companies carry out corrective maintenance, which translates into high industrial maintenance costs with a high share of the costs involving spare parts due to faults in the equipment.

Nevertheless, in recent years we have seen the intention of Colombian entrepreneurs to acquire automation technologies that will allow them to improve their production processes and increase their profitability. This gives a glimmer of hope for the future of automation in industrial maintenance processes in the Colombian manufacturing industry.

Lastly, given the economic impact of automation in industrial maintenance processes, the results in different companies around the world show that the profitability increases and the costs are reduced in the areas of maintenance, extending the lifespan of the equipment and having the possibility to act in time against possible failures that generate significant costs. However, it is necessary to clarify that although investments in automation technologies have generated profits for companies, these are often expensive, not forgetting additional costs related to training company staff to properly carry out these processes. It is therefore suggested that companies that desire to start integrating automation technologies into maintenance processes should do so progressively so as not to generate frustrations in relation to the investment.

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