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Development of a system for maintenance management using radio frequency and embedded systems

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ABSTRACT
Maintenance and its processes are in constant evolution. With the new trends related to maintenance 4.0 and the digitalization of administrative processes, several opportunities related to cost reduction and rational use of human resources can be observed, aiming maintenance to have an active role in the manufacturing environment. This article presents the results obtained from the implementation of a system of order request and maintenance management, using radio frequency technology (RFID) and microcontrollers, to obtain a more assertive and dynamic information flow, which results in an increase of productivity in the manufacturing sector, as well as in the administrative sector, responsible for analyzing the data generated in the maintenance cycles. The satisfactory economic evaluation of the obtained result showed the importance of the work in the search for new methods of maintenance management.

Keywords: Maintenance, Standardization, Embedded systems, Radio frequency.

1 INTRODUCTION

In the current stage, with the development of the so-called industry 4.0, there is a marked tendency to automate processes. The restoration of operating parameters and the lengthening of working periods under the required performance, to ensure the availability of machines, are sometimes simple and other complex processes, but it has as a common characteristic that these are present in all companies, whether they are service or industrial, electronic, mechanical, etc. In other words, none escapes the need to develop maintenance in a systematic way.

Maintenance is a set of procedures that has as its main objective to leave the equipment of a company in working condition. Adapted from (BRITSH STANDARD, 2018)

NBR 5462 (1994) expresses that corrective maintenance is the "Maintenance performed after the occurrence of a breakdown intended to put an item back in a condition to perform a required function."

For Kardec (2013) the inefficient management and the lack of maintenance of the assets compromise the competitiveness and profitability of the companies.

Seeking better results in production, efficiency and maintenance costs, Maintenance Engineering has brought to the market a new possibility of easy access and effective failure management in industrial equipment that is called Predictive Maintenance (Oliveira, 2012)

In the company where the research was developed is headquartered in the Industrial Pole of Manaus and has as its social object the development of batteries, in the same there were difficulties related to the creation and maintenance work orders, need for alerts as well as lack of real-time data of the main indicators of maintenance which was reflected later in the productive results. Faced with these problems, the objective of this work was to develop a digital maintenance request system capable of creating work orders for technicians, alerting them inside the maintenance room and sending the collected data to a database that will be accessible for further analysis.

For the development of the work were proposed different activities that allowed the fulfillment of the proposed objective through the use of current technologies such as radio frequency (RFID) and the use of microcontrollers, to obtain a system that ensures that the flow of information flowed quickly and dynamically, thus ensuring greater efficiency in production which translates into increased productivity, greater facilities in the analysis by the team responsible for analyzing the data generated in the maintenance cycles thus obtaining a decrease in the maintenance request cycle time (enabling reduction in the downtime of the line), the standardization of the failure modes (facilitating the analyzes) and a reduction in the number of parties involved in the process among other advantages.

2 DEVELOPMENT

2.1 MAINTENANCE

Predictive Maintenance that can also be called Maintenance under Condition that consists of analyzing the parameters of the equipment and can prevent a failure that hinders the continuity of production. For this maintenance to occur, it is necessary that the equipment is in operation, since its objective is to maintain its productivity for a long period, but not all equipment is amenable to

Predictive Maintenance, since it must be considered the cost-benefit, monitoring conditions and types of failure arising from the mechanisms (Duchovni, 2003).

According to Falconi (2004), the maintenance indicators provide the maintenance manager with access to data that allows a critical analysis of the results of his methodology and maintenance performance, through these results it can promote actions on the points to be improved.

To play a strategic role, Maintenance needs to be focused on the business results of the organization. It is necessary, above all, to stop being only efficient to become effective, that is, it is not enough just to repair the equipment or the installation as quickly as possible, but it is necessary mainly to maintain the function of the equipment available for the operation, reducing the probability of an unplanned production stop (Kardec & Nascif, 2013).

In this strategy the system that allows you to manage both the maintenance orders and the management of the maintenance itself has a vital importance because it is the instance where both the requests of the materials and the maintenance actions are produced, this means that this step depends on the speed and quality of the maintenance.

2.2 EMBEDDED SYSTEMS

Embedded systems are devices with data processing capacity and that are inserted in a particular device or product, to perform a function or serve a specific application. Embedded systems are present in all areas of modern life, from the simplest everyday activities like doing laundry, to the most complex like sending an email. Therefore, in the applications of process automation in industries would be no different because they are compact solutions, with high processing capacity and financially accessible.

According to Oliveira and Andrade, (2010), the embedded systems are composed of a processing unit, which is an integrated circuit, fixed to a printed circuit.

According to Denardin & Barriquello (2019) real-time systems are embedded. This means that the computer system is completely encapsulated and dedicated to the device or system it controls.

2.3 RADIO FREQUENCY TECHNOLOGY (RFID)

Radio Frequency Identification (RFID) is a wireless technology that uses radio signals to identify, locate, track, and trace the movement of an item without human intervention (Finkenzeller, K. (2010)).

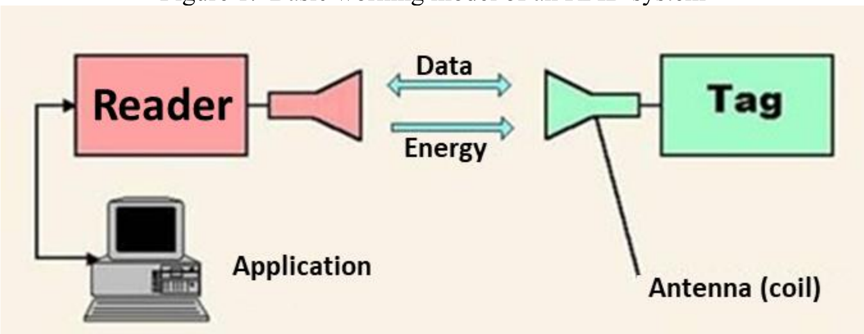
An RFID system is always composed of two main components: the transponder (tag), located on the object to be identified and the detector or reader, which, depending on the design and technology used, can be a reader or reading and writing device. The reader typically contains a high-frequency module (emitter and receiver), a control unit, and a coupling element for the transponder (Finkenzeller,

K. (2010). In addition, many readers are equipped with an additional interface so that it can transmit the received data to another system (PC, control system).

The application of this technology depends on its correct sizing, since the reading range varies according to the frequency of the reader. Then, one must consider the process flow and the characteristics of the place where it will be installed, so that there are no operational problems at the time of implementation. According to Table I, we have 4 types of frequencies, each of which has its main characteristics and applications.

The use of this technology extends to several areas, especially logistics and inventory control, as it allows the differentiation of items at reasonable distances and with low energy consumption, in Figure 1 shows a basic model of operation of an RFD system.

Figure 1. Basic working model of an RFID system



2.4 DATABASE AND ACCESS TO INFORMATION

According to Rezende (2006) a Database (DB), is a collection of data that concerns a particular organization, which requires a set of four basic components: data, hardware, software and users.

For Elmasri and Navathe (2011, p.3) "A database is a logically coherent collection of data with some inherent meaning", where a database is architected and built to serve a specific purpose. In other words, a database is a grouping of persistent information for an end purpose, where the information it contains must be readable, consistent, and available.

Costa (2018) presents a high availability solution for MySQL database and addresses the use of tools that complement high availability for database, using a load balancing tool and replication cluster.

Larsson (2019) presents a case study demonstrating in practice the execution of database in Kubernetes, where procedures were performed for analysis as to performance, resizing and backups of an application.

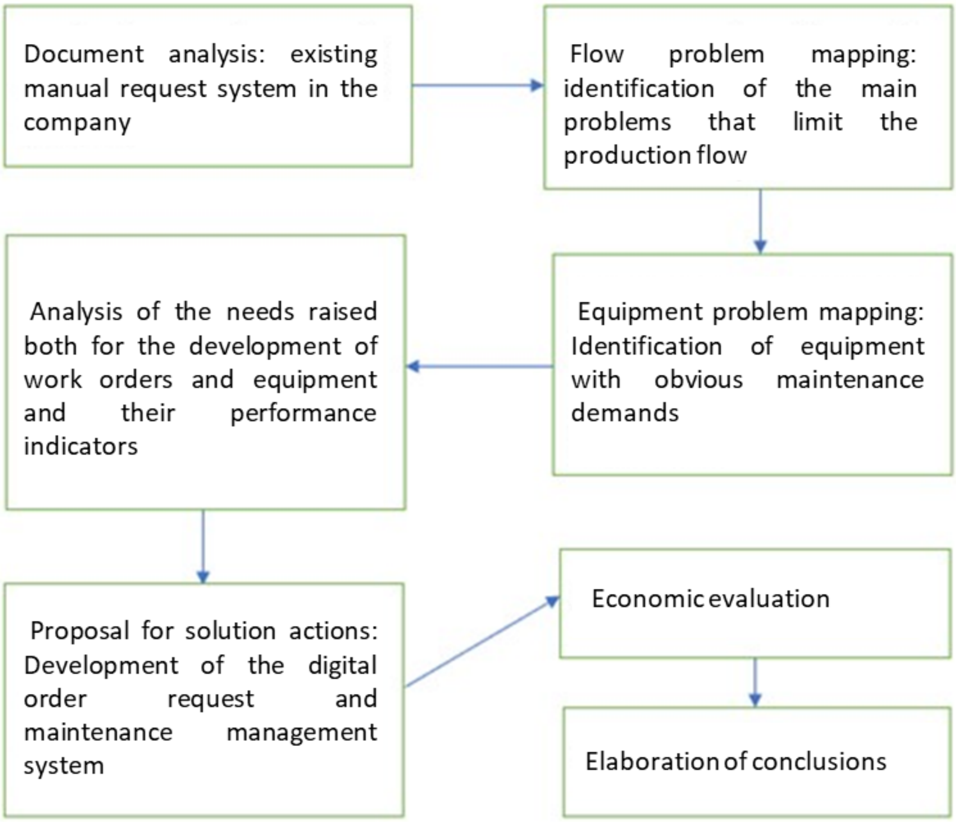
With the recording and availability of this data in the network, it is possible to generate KPIs (Key Performance Indicators) such as line / sector with greater unavailability, equipment, and types of failures more recurrent, skills and tools most requested, which can be analyzed by the sector responsible for planning and control of maintenance, assisting in the proposal of solutions aimed at improving production processes, Autonomous Maintenance and Maintenance 4.0.

Databases are technologies used in several areas and have proven to be an important ally in the management of any business and the industrial area is an example of this. The industry can be characterized by several meanings, from a small company to a factory of any size of an industrial park, that works with transformation activity, that use machinery that aims to create a third product and use data and technologies in their processes (Souza, 2018).

3 MATERIALS AND METHODS

For the development of the research was followed the following methodological sequence of work in Figure 2.

Figure 2. Sequence followed in the search.



At each stage of this sequence, actions were developed sequentially that led to the fulfillment of the proposed objective. In the epigraph of the results will be explained.

4 RESULTS AND DISCUSSIONS

4.1 DOCUMENT ANALYSIS: MANUAL REQUEST SYSTEM EXISTING IN THE COMPANY.

In the company mentioned in this study, the implementation of Total Productive Maintenance (MPT) is verified, which according to Resende and Dias (2014), can be defined as a management model that seeks the continuous improvement of the production system through the elimination of losses, reduction of production stops and the development of man and his relationship with the equipment.

Thus, maintenance requests are made from the operators themselves, taking into account the knowledge about the equipment they operate, and the results expected by the production process. The present study confirms the effectiveness of the methodology, but it is observed that the manual form of request becomes inefficient when compared to the technologies currently available in the market, which allow the development of systems fully adapted to the local reality with low implementation cost. In Figure V, we can see the model of labels currently used to perform the maintenance request, which are separated by colors:

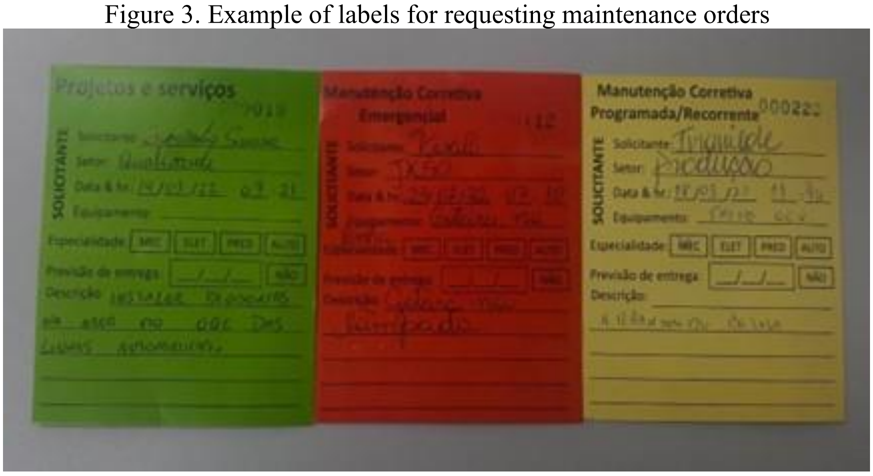
Green: projects and services to be carried out on the line aiming at improving efficiency or reducing costs;

Red: corrective maintenance of an emergency nature. Cause rework on the line or even stop production, generating loss of profit;

Yellow: scheduled/recurring corrective maintenance. They do not generate rework, as the resulting losses can be compensated with other equipment in the line.

Figure 3 shows an example of the label system for requesting maintenance work orders.

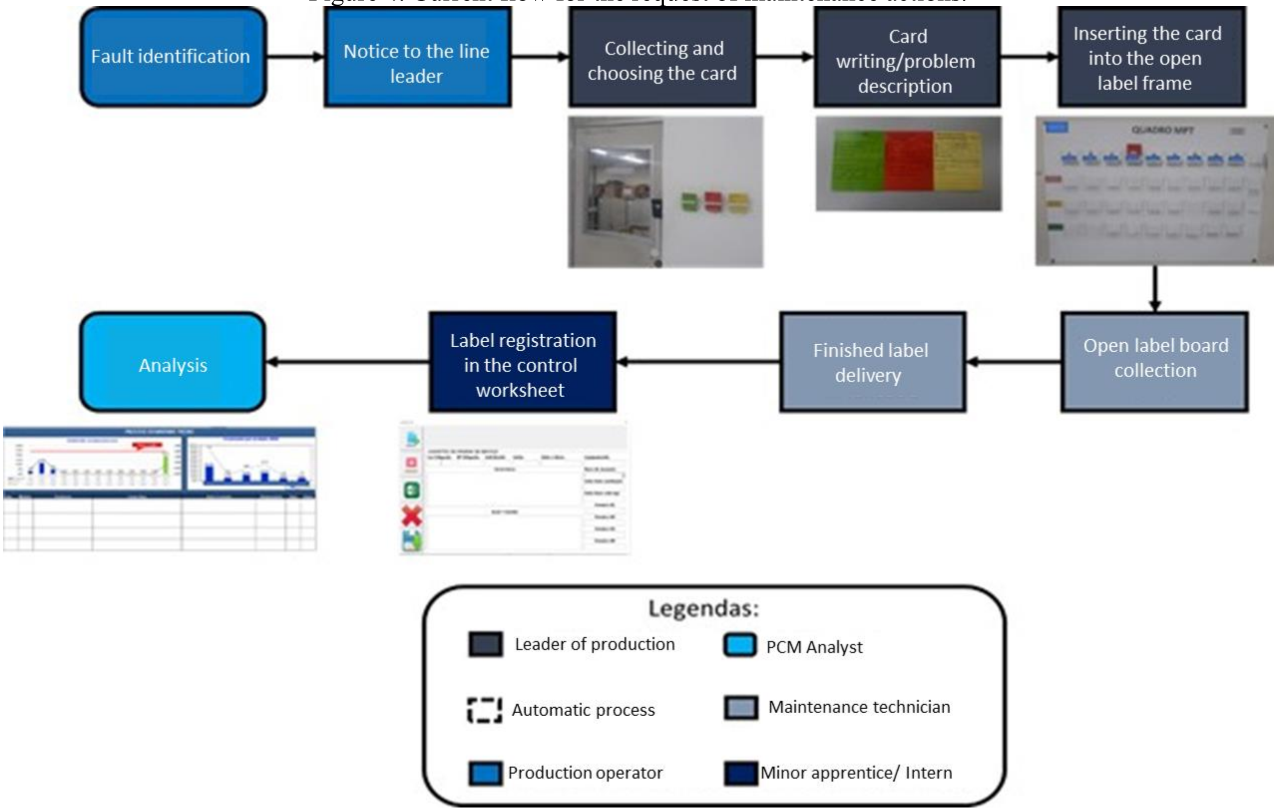
Figure 3. Example of labels for requesting maintenance orders



The maintenance request system in force in the studied environment can be viewed from Figure 4, where the flow for the request of maintenance orders is shown. Analyzing this flow and based on the experimental empirical observation of it, one can find the three main bottlenecks:

- Average cycle closing time: With each request issued, it is estimated that on average, it takes 7 to 10 minutes for its closing, considering all the displacement of the parties involved, the writing and recording of the information in the control worksheet. According to data collected at the company used as the basis for the study (June/2021), there were about 74 stops related to emergency corrective maintenance, which generates an average of 10.48 hours of line stops per month of production;
- Number of people involved in the process: Due to the characteristics of the process and the methodology implemented, there are always five people involved in the maintenance request, namely: production operator, line leader, maintenance technician, minor apprentice / trainee and analyst PCM (maintenance planning and control), resulting that any loss of information in the process generates great losses in the end, due to possible communication failures;
- Lack of standardization of records: Because it is a methodology of written steps (in the process of request and registration), the lack of standardization can hinder the root cause identification analyses (Ishikawa, Pareto Diagram, 5 whys...), making it necessary a major rework of standardization to identify the main problems observed in each equipment, which ends up generating only reactive solutions based on experience and not on data;

Figure 4. Current flow for the request of maintenance actions.

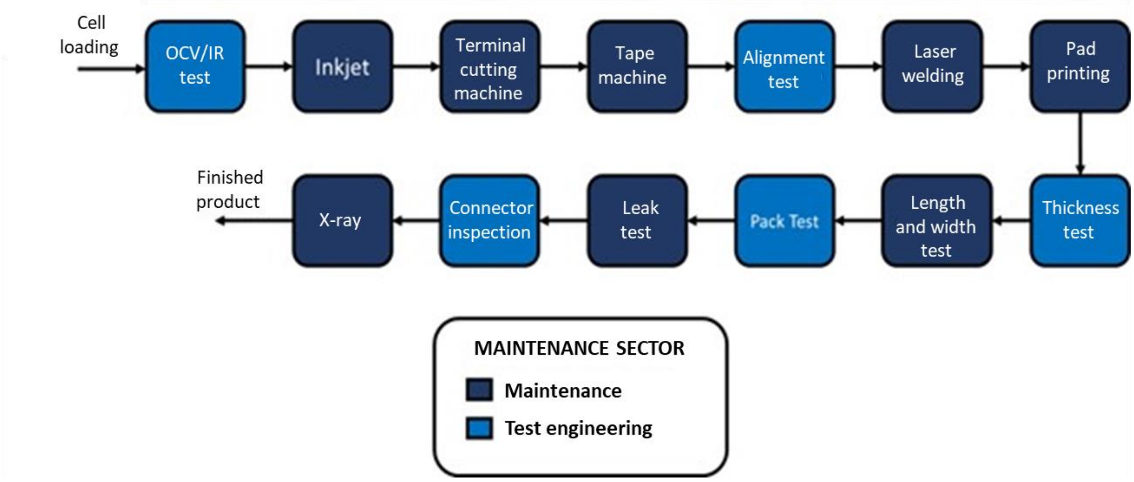


This analysis also allows us to observe the possibility of developing several improvement actions, the project being one of them. The prototype developed will focus on three main aspects: reduction of cycle time, reduction of involved parties and standardization of records.

4.2 MAPPING OF FLOW PROBLEMS: IDENTIFICATION OF THE MAIN PROBLEMS THAT LIMIT THE PRODUCTIVE FLOW

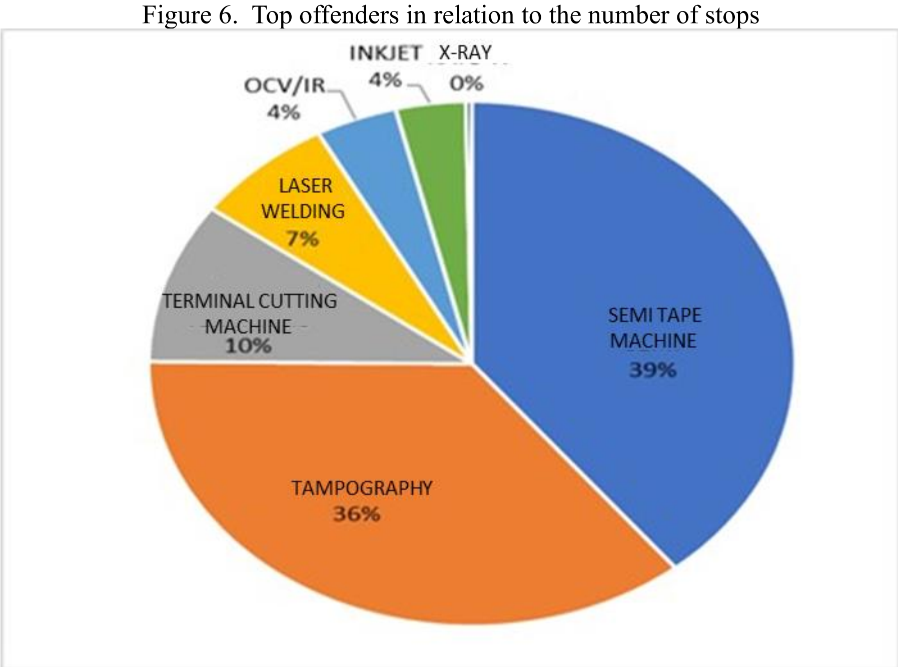
The production process of cell phone batteries (in the company mentioned) follows the flow mentioned in Figure 5, in which there is some equipment of responsibility for maintenance and others of test engineering, for which maintenance also provides support, but is not directly responsible.

Figure 5. Production flow of cell phone batteries



Still in relation to the equipment mentioned, when analyzing historical data collected from the second half of 2021 (after being properly filtered and standardized in a database in Excel), it is possible to generate an important indicator for maintenance engineering, which are the main offenders in relation to the number of stops (Figure 6):

Figure 6. Top offenders in relation to the number of stops



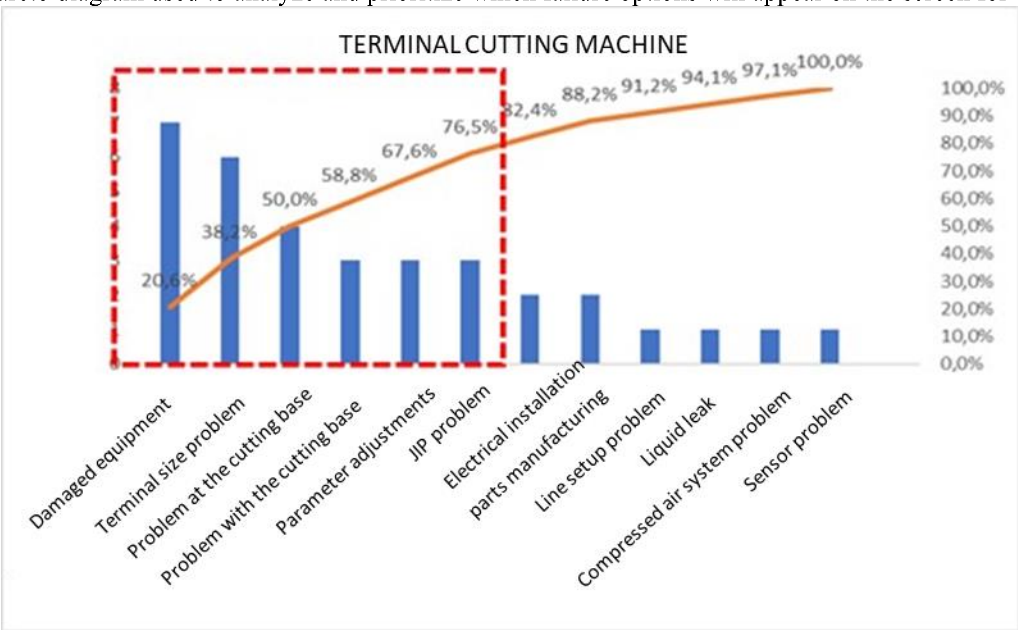
This analysis allowed to establish the three main offenders of the production process: semi-automatic tape machine with a percentage incidence of 39 %, pad printing with 36 % and the terminal cutting machine with a lower incidence, occupied a value of 10 %. These results were the basis for the development of the system proposed in this article.

4.3 ANALYSIS OF THE NEEDS RAISED BOTH FOR THE DEVELOPMENT OF WORK ORDERS AND EQUIPMENT AND THEIR PERFORMANCE INDICATORS

Thus, three labels were created (Figure XI), whose main function within the prototype is to identify, through conditional structures (after being passed in the RFID reader), which machine and which line the production operator refers to. The same, in the case of implementation in a non-simulated environment, should be fixed on the machine or next to it in an acrylic pocket (or equivalent material) with the appropriate identifications.

After the identification, an in-depth study was needed in each of the three machines, especially in relation to their main bottlenecks of emergency shutdowns (taking into account that the planned shutdowns are already recorded in the maintenance plan). Thus, we first standardized all the problems collected from the historical data of the second half of 2021, to obtain a database that would allow analysis. Next, the Pareto Diagram method was used to prioritize the items that will appear on the screen for the user, avoiding some confusion due to the large number of options available (Figure 7).

Figure 7. Pareto diagram used to analyze and prioritize which failure options will appear on the screen for the operator



This diagram allowed to establish the 6 failures of highest incidence: damaged equipment, problems related to terminal size, problems in the blades, problems in the cutting bases, parameter adjustments and problem in the JIG. The remaining failures have a lower incidence.

For the data not contemplated in the 80% said to be priorities, in the operator interface there will be an option of "OTHER", being possible to access all other failures. However, the analysis of the Pareto Diagram should be redone every quarter or if any significant improvement has been implemented in the maintenance process, to ensure that the priority data remains relevant and with the objective of maintaining a cycle of continuous improvement.

4.4 PROPOSAL OF SOLUTION ACTIONS: DEVELOPMENT OF THE DIGITAL ORDER REQUEST SYSTEM

For the project mentioned, it was thought to use a database in order to collect the information of all maintenance requests, recording their main data collected: SM Number (Maintenance Request); Location/Line/Sector; Equipment; Type of service requested; Equipment failure and Skill/Tool required;

With the recording and availability of this data in the network, it is possible to generate KPIs (Key Performance Indicators) such as line / sector with greater unavailability, equipment and types of failures more recurrent, skills and tools most requested, which can be analyzed by the sector responsible for planning and control of maintenance, assisting in the proposal of solutions aimed at improving production processes, Autonomous Maintenance and Maintenance 4.0.

For the present prototype, there will be no implementation of the database, however, it is seen as crucial for the installation in the non-simulated environment a method of data storage, so that the information can be consulted and analyzed whenever necessary. Among the existing options, it is analyzed as a good alternative the MySQL database, due to its capacity, versatility and for being widely used, ensuring a greater source of useful information on the subject in the industry.

Regarding the interface of the maintenance team, it was thought (in addition to the use of the monitor with the information of the request) in the use of industrial flags of three colors, as shown in Figure 8, to increase the speed of capturing the message through complementary signals.

Figure 8. Luminous tower of three colors

For the prototype implemented in a simulated environment, 3 LEDs were used to simulate complementary signaling, as shown in Figure 9.

Figure 9. LEDs used in the prototype to simulate complementary signaling to the maintenance team

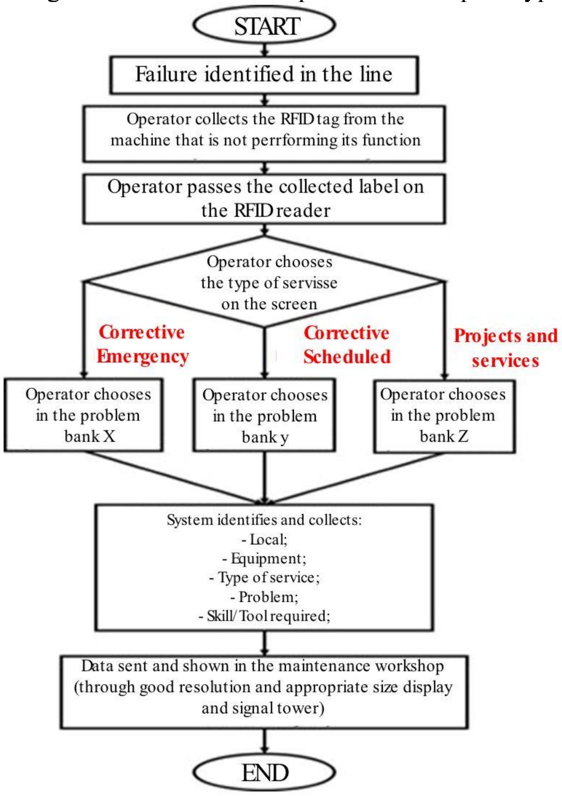
Finally, it is possible to analyze the flowchart of project operation through Figure 10 and its operation in simulated environment test in Figure 11. With iterations performed in a simulated environment, each process will last about 60 seconds. However, considering the operator's displacement in full-scale locations, it is possible to approximate the time of the maintenance request cycle in about 2 to 3 minutes. Therefore, using the same data collected previously (74 emergency shutdowns per month), there is a time spent of 3.1 hours per month, which means a reduction of 70.59% in the time spent on maintenance request cycles monthly, which can be translated, consequently, into:

- Downtime of the production line reduced;
- Lead time (waiting time) of line operators reduced;

In addition to the two benefits mentioned, with the digitization of the process it is possible to eliminate two other major problems: the number of people involved in the process, reducing from five to three, and the standardization of records, which makes the data much simpler to be analyzed. Figure 10 shows the flowchart of the prototype's operation.

In this flowchart it can be observed that the system weighs a great weight to the development of the operator and so it is necessary to train the operator in the use of both the equipment that operates and in the issues related to the maintenance of the same, because precisely he is the one who collects the RFID tag of the machine with operation failures; it also passes the collected tag on the RFID reader and also decides or chooses the type of service that appears on the screen (emergency corrective, scheduled or projects and services).

Figure 10. Flowchart of operation of the prototype.

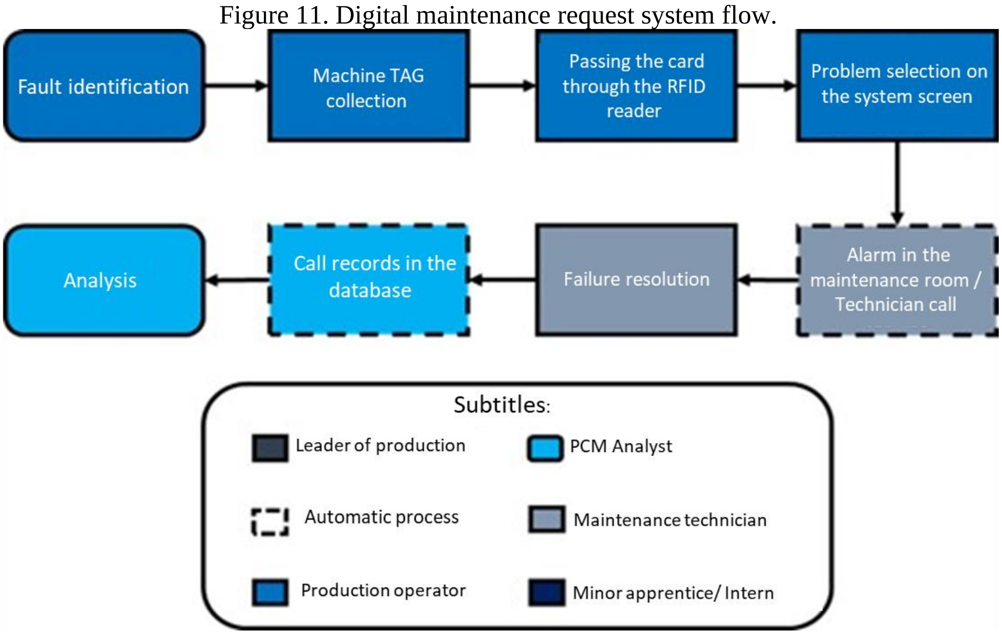


Then the system identifies and collects the data and sends it to the maintenance workshop.

The phrase "You do not manage what you do not measure, you do not measure what you do not define, you do not define what you do not understand, and there is no success in what you do not manage" credited to Deming (Falconi, 2004) summarize the importance of the data collected in any process, being applicable also to maintenance. To optimize the existing procedure, an automation of the cited process was proposed through embedded systems and RFID technology. With the implementation, the system will work according to the image shown in Figure 11:

As can be seen, the simplification of the process makes it much more precise and simpler, involving only 3 people, in addition to automating and standardizing two key steps of the process, which are the transmission of information to technicians and the registration of failures in the system, which allows the analyses to be carried out in a much clearer and more detailed way.

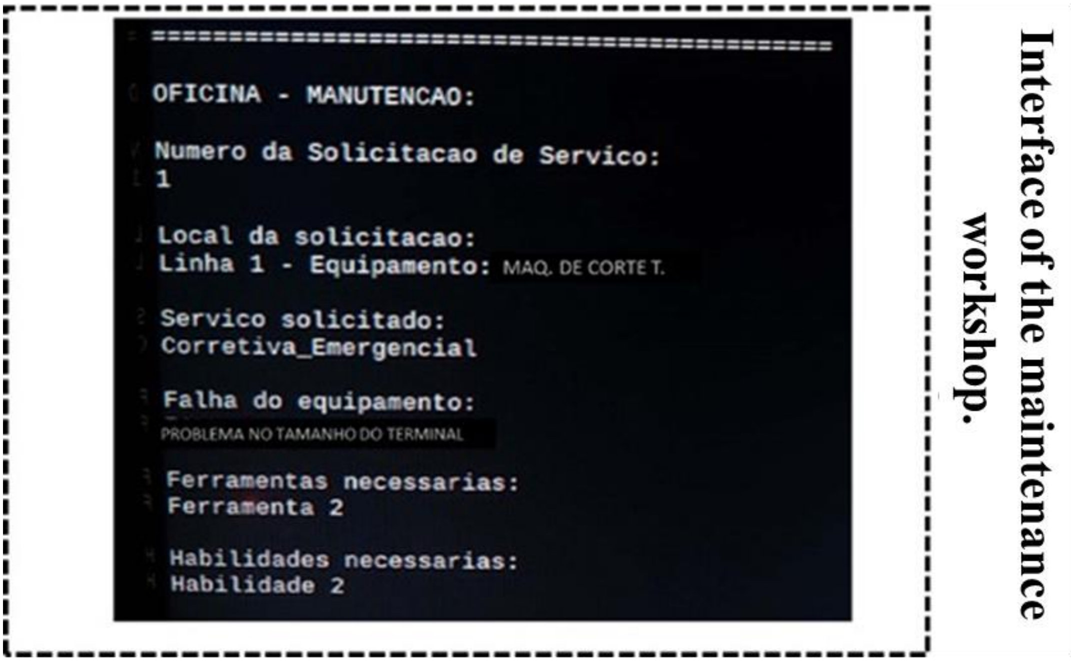
Figure 11. Digital maintenance request system flow.



In essence, the interfaces developed and that show the stages of the operation of the proposed system can be represented in the following figures: 12 and 13.

Figure 12. Operator interface

Figure 13. Interface of the maintenance workshop.



4.5 ECONOMIC EVALUATION

For the economic evaluation, the costs related to the manual maintenance request system, which only has a single related consumable cost, which are the labels, are observed. Quarterly, more than 1200 labels were purchased, depending on the remaining inventories, which cost the company on average (considering 2021 data) R $ 980 / quarter and R $ 3920 annually.

When analyzing the implementation of the system proposed in this work, we must identify the necessary components and their associated costs:

Observations:

In	Components	Quantity	Unit cost, R$	Total cost, R$
1	Raspberry pi 3B	2	576,30	1152,60
2	RFID Reader MFRC522	2	18,50	18,50
3	Tags RFID	18	7,51	135,18
4	Light tower	1	254,05	254,05
5	Monitors 19.5"	2	499,99	999,98
6	Keypad	1	44,90	44,90
7	HDMI Cables	2	12,90	25,80
Total cost				**2631,01**

There were 2 units of the Raspberry pi 3B component. One unit to collect the information coming from the production line and another unit to receive the collector data and project on the maintenance room monitor;

There were 18 units of the RFID Tags component- R$7. One unit for each machine on a production line;

There were 2 units of the 19.5" Monitors component. One for the operator interface and one for the maintenance team interface;

There were 2 units of the HDMI Cables component. One for the operator interface and one for the maintenance team interface;

Once the collected data is processed, it can be assumed that the implementation of the pilot project in a production line would cost the company approximately R$2631.01, making the estimated time for the investment to generate sufficient returns to cover its cost (Payback) to be approximately 8 months, considering only the cost associated with the labels. The return on investment (ROI), on the other hand, is in the range of 49.72%, thus demonstrating the economic viability of the aforementioned project.

5 CONCLUSIONS

The present allowed to develop a practical, efficient, and economically viable alternative to the manual maintenance request system implemented in an industry of the battery branch in the Industrial Pole of Manaus, to optimize and bring efficiency gains to the process.

It was possible to describe a prototype capable of replacing the current method of manual maintenance request through the digitization and consequent standardization of some key processes, being this, able to create work orders for the technicians and alert them within the maintenance room (providing data related to the machine, location, problem, and skill/tool required).

For future work, it is seen as essential the implementation of the database for recording and querying the data generated by the system, in addition to the development of the graphical interface

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