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# OPTIMIZATION OF PREVENTIVE MAINTENANCE IN WIND TURBINES THROUGH LEAN SERVICE

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**Abstract.** *In view of the energy crises caused by the growing consumption of electric energy and the instability of the rain regime, which supplies flooded areas of hydroelectric plants, wind energy is highlighted for having an unlimited, renewable, and decentralized source, being considered a clean way of obtaining energy. Base of wind energy, the wind turbine, also called aerogenerator, is mainly composed of blades, hubs, gearbox, generator, nacelle, tower, and foundation. A set of wind turbines is called a wind farm and there are two species of them, onshore and offshore. Onshore wind farms are located on land, close to the seacoast or inland, and offshore wind farms are installed at sea. Its installation must be done outside the migratory routes of birds in the region, to avoid the collision of these animals. Maintenance as a strategy to increase the availability of assets and to ensure the capital invested allows the offer of more competitive products, which benefits companies and the population. Based on this strategy, it is essential to adopt tools and techniques for maintenance management, such as Lean Service. Such a technical concept consists of the application of lean services, which aim the optimization of processes, resulting in zero waste. Tools of this technique can be applied to wind turbines, such as Standardization, Operator Balance Graph and Pareto's Digram. Such elements increase the quality of service and the delivery of results to the organization, while reducing maintenance costs and waste. The main objective of this article is to propose a new model for the execution of preventive maintenance of onshore wind turbines, using the fundamentals of Lean Service. With the application of Lean Service tools, it is possible to present a new model of preventive maintenance, which reduces the likelihood of equipment failures and the risk of energy shortages in certain locations.*

**Keywords:** *Wind energy, Preventive maintenance, Lean service, Wind turbine*

## 1. INTRODUCTION

Wind energy has been showing rapid growth, exceeding 9% between the years 2017 and 2018, reaching the mark of 597 GW of installed capacity worldwide in 2018 (World Wind Energy Association, 2019). In this scenario, Brazil currently ranks 8th, with more than 15 GW of installed capacity in the world ranking (Associação Brasileira de Energia Eólica, 2019). Furthermore, it was observed that regions such as the State of Rio Grande do Norte present winds at constant speeds during most of the year, favoring the production of wind energy (Alves, 2010), allowing for an excellent performance of wind turbines.

However, the development of increasingly larger wind turbines and with modern, high-tech systems has become a challenge for the Maintenance and Operation (O&M) sector. It is usually installed in remote regions, with segments of difficult access and the use of expensive equipment (Chen; Yan; Liu, 2016). The solution that many companies are adopting is to use a maintenance management methodology that aims to reduce maintenance costs, increase availability and improve service quality. In the wind sector, one of the biggest difficulties faced by companies that perform maintenance on wind turbines is planning the execution of maintenance activities and the resources used in the activities. Allied to this, inefficient work methods and the lack of standardization of maintenance services processes reduce productivity, as well as the quality of the tasks performed.

One of the maintenance management strategies used to reduce waste and increase machine efficiency is Lean Service or Lean Services. This management model, when properly applied, ensures that equipment operates within technical specifications, increases service quality through qualified personnel and optimizes processes with established integrated systems (Brunner, 2017).

Considering the notes made, the main objective of this work is to propose an optimized method for the execution of preventive maintenance of onshore wind turbines through the fundamentals of Lean Service and as a specific objective to apply the tools of this philosophy.

## **2. THEORETICAL REVIEW**

This theoretical review illustrates and discusses concepts relevant to the understanding of maintenance in wind turbines.

### **2.1 The modern wind turbine**

The wind turbine uses the kinetic energy of the wind to rotate its blades, transforming it into mechanical energy and only then transforming it into electrical energy (Manwell; McGowan; Rogers, 2009). Currently, the Horizontal Axis Wind Turbine (HAWT) model is the most used for the production of electrical energy. According to Manwell, McGowan and Rogers (2009), the wind turbine is classified as onshore when installed on land and offshore when installed at sea. In addition, the turbine can contain one or more blades installed. This article will only deal with the three-blade HAWT onshore wind turbine.

Manwell, McGowan and Rogers (2009) describe that the modern wind turbine is composed of mechanical and electrical systems, generally having the following subsystems: blades, hub, gearbox, generator, nacelle, tower and foundation.

### **2.2 Maintenance of the wind turbine**

According to Kardec and Nascif (2010), maintenance aims to promote the availability of equipment and facilities following a production or service program, preserving the environment, maintaining machine reliability and reducing costs.

Maintenance activities or tasks should be understood as procedures that must be performed for the maintainability of the turbine and its subcomponents (Kovács et al., 2011). Such tasks can be characterized as torque, inspection, lubrication and replacement. In this work, only preventive maintenance activities that occur once a year were addressed.

Preventive maintenance activities are always performed by a team of at least two technicians for safety reasons. When approaching the turbine, the team stops the machine to start maintenance activities (Kovács et al., 2011).

Onshore wind farms are mostly located in rural areas, in remote regions, mainly because in these regions there are few obstacles (constructions and topography) that affect the wind speed (Agarwal; Verma; Gaurh, 2016). Furthermore, before and during the execution of any maintenance activity, the climatic conditions of the region, such as temperature, precipitation and wind speed, must always be observed (Kovács et al., 2011). Only after the ideal conditions are reached will it be possible to carry out maintenance activities on the turbine.

The use of high-cost machines such as cranes, hydraulic and torque tools should be well-planned to impact maintenance service costs (Kovács et al., 2011). To optimize the tools, the sharing of this material between maintenance teams should be considered.

Wind turbines are programmed to operate 24 hours a day with scheduled interventions throughout the year, preferably during the low wind period, as the period in which the wind speed is below 4 m/s is called (Manwell; McGowan; Rogers, 2009). Unexpected breakdowns and unplanned interventions directly impact availability.

The strategy that many wind turbine maintenance companies use is to schedule preventive maintenance for this period of low wind in the region. Therefore, during the year, the wind farm's electricity production will be little affected. But for this to happen, first it is necessary that the maintenance takes place within this period so that in a second moment the execution of the activities is well planned to optimize the maintenance time.

### **2.3 The Lean and High Quality Philosophy**

Lean appeared in the Toyota company after World War II, in 1945, through the engineer Taiichi Ohno. Lean is a continuous improvement strategy based on Just in Time that companies adopt to maximize Customer Value and minimize (if not, eliminate) all forms of waste (Piva; Prando; Morilla, 2017).

From this concept comes Lean Manufacturing, which according to Bhamu and Singh Sangwan (2014) is a set of tools and concepts whose main objective is to eliminate production waste and increase product quality.

Currently, the economy leaves the factory floor and turns to the after-sales service sector. In the wind segment, for example, the quality of maintenance service for wind turbines can define the future of the businesses of manufacturers that offer this service in an increasingly competitive market.

Many literatures define Lean focused on production, where there is a tangible product. But in services this does not happen and that is why it is necessary to differentiate Lean Manufacturing from Lean Service (Andrés-López; González-Requena; Sanz-Lobera, 2015). It is then necessary to apply the concepts of lean manufacturing to the specifics of the service sector. Thus, Lean Service appears, which is based on a lean mentality, with some adaptations, aimed at service providers that adopt Lean practices in their processes and operations (Barbosa et al., 2011). This concept of Lean applied to services aims to meet customer demands with processes without waste, using only the necessary resources (equipment, facilities, labor).

Zhao, Rasovska and Rose (2016) describe that in Lean Service, value is applied to the service created through the knowledge of a person or a group and that the tools of this philosophy can be applied in the flow of knowledge. The same authors also emphasize that knowledge is perhaps the only source of competitiveness.

The authors Womack and Jones (2004) suggest the following steps to implement the Lean Service:

- Mapping of key service processes that are required by the customer (internal or external), identifying those responsible for each stage of the process.
  - Selection of the fundamental processes of the value stream illustrating the current scenario of the company.
  - Involvement of the entire company in Lean Service to identify what adds value in the eyes of the customer.
- Everyone's involvement is essential to disseminate Lean concepts and increase service quality.

Lean comprises several tools that help to disseminate its philosophy by optimizing processes, increasing service quality and delivering results for the organization. In this topic, given the diversity of tools mentioned above, only those used as the object of this work will be addressed, namely:

- Standardization: consists of defining the best method and sequence to optimize and increase the efficiency of an activity. This requires: efficiency; identification of key service processes; sequencing of steps; categorization of steps; development of standard procedures.
- Operator Balance Chart (GBO): In this article, the GBO was based on the time available for each technician and a disposition of the activities performed within that period. So that the total time of activities must not exceed the available time and the unused time must be minimal so that there is high productivity.
- Pareto diagram: is a bar graph related to the frequency of occurrence of each item. This chart is based on the Pareto principle that 80% of consequences are the result of 20% of causes.

### 3. COMPANY SUBJECT OF STUDY

The company studied in this work is present in several countries, including Brazil, where it is one of the largest in the wind turbine manufacturing segment. This multinational offers both the sale of these machines and the maintenance service.

As part of the company's Lean strategy, all activities that did not add value to the customer were being eliminated, resulting in more efficient processes and cost savings. In this scenario, it was observed that it was possible to improve the execution of preventive maintenance activities that presented disparities in the execution time in different parks using the same resources.

Another factor that motivated the company to make its activities more efficient was customer dissatisfaction with the high number of interventions on the machine for maintenance, negatively impacting the quality of service. From this, the company decided to use maintenance management tools, based on the Lean philosophy, to improve preventive maintenance processes.

As part of this process, guided visits were carried out with the maintenance team to the turbine, collection of quantitative data, informal opinion poll with those involved in maintenance and studies to improve the processes used in maintenance. Then, the following actions were established to analyze the maintenance data: development of the activities chronoanalysis table; construction of the GBO chart by technician; development of the Standardized Work Table, use of bar chart and Pareto chart as a complement to the study.

Based on the analysis of the results of the current preventive maintenance model, a new model for the execution of preventive maintenance tasks with restructuring of the maintenance team was suggested.

The current model of preventive maintenance execution was divided into two days, the maximum time signed in the contract, per wind turbine and two technicians performed a set of activities defined in the maintenance checklist. At the beginning of each day, the team would travel by car from the park's base of operations to the turbine with the tools and materials to be used in the activity. Upon arriving at the wind turbine, it was in fact that maintenance began.

A negative factor of this model is that the sequence of activities and how they would be carried out was at the discretion of each team. In addition, the team's travel time to the turbine, preparation time for work or post-work time was not counted in the schedule. At the end of the day, the team returned to the base to finalize administrative procedures regarding the maintenance of the day.

The demand for the preventive maintenance team was calculated according to the total number of turbines in the park. The structure and resources for maintenance of the turbines in the wind farm where this study was carried out are shown in Table 1.

Table 1. Current structure of the park for maintenance.

Item	Quantity	Unit of measurement
Number of technicians	6	
Number of installed turbines	100	
Daily demand	1.5	turbine/day
Intervention period	2	day/turbine
Total park intervention period	67	day
Working time per day	8	hour/technician
Travel time to turbine	1	hour
Time available for maintenance	6	hour/technician

The current maintenance model, shown in Table 1, is divided into three teams composed of two technicians each. Based on the aforementioned information, a meticulous study of the time used in the execution of each Management Activity (AM) was carried out, resulting in another table. This table includes all activities that must be performed in preventive maintenance, the time of each activity, the segment of the wind turbine where the activity was carried out, the type of activity and the minimum number of technicians per activity. From this table it was possible to identify which were the longest activities, which were the shortest, which activities were the most critical and which needed the two dedicated technicians. It was identified that it was possible to reduce the time of some activities by eliminating unnecessary movements in the turbine and optimizing the sequence of activities by segment and by technician.

Table 2. Chronoanalysis table of the current model of preventive maintenance activities.

Activity	Time (min)	Turbine section	Type of activity	Technicians
AM01	30	Tower	Torque	1
AM02	20	Nacelle	Torque	1
AM03	15	Nacelle	Torque	1
AM04	30	Nacelle	Torque	1
AM05	50	Hub	Torque	2
AM06	15	Hub	Torque	1
AM07	5	Hub	Torque	1
AM08	10	Hub	Torque	1
AM09	5	Hub	Torque	1
AM10	10	Nacelle	Inspection	1
AM11	90	Hub	Torque	1
AM12	20	Nacelle	Torque	1
AM13	10	Nacelle	Torque	1
AM14	80	Nacelle	Torque	1
AM15	105	Nacelle	Torque	1
AM16	10	Nacelle	Torque	1
AM17	10	Base	Inspection	1
AM18	10	Base	Lifting	2
AM19	5	Base	Inspection	1
AM20	10	Nacelle	Inspection	1
AM21	5	Nacelle	Replacement	1
AM22	5	Nacelle	Inspection	1

AM23	60	Nacelle	Inspection	2
AM24	5	Nacelle	Inspection	1
AM25	10	Nacelle	Inspection	1
AM26	10	Nacelle	Inspection	1
AM27	5	Nacelle	Inspection	1
AM28	45	Nacelle	Lubrication	1
AM29	15	Nacelle	Lubrication	1
AM30	5	Nacelle	Inspection	1
AM31	10	Nacelle	Inspection	1
AM32	50	Nacelle	Lifting	1
AM33	20	Nacelle	Inspection	1
AM34	10	Nacelle	Lifting	1
AM35	10	Nacelle	Inspection	1
AM36	10	Nacelle	Inspection	1
AM37	20	Nacelle	Inspection	1
AM38	10	Nacelle	Inspection	1
AM39	10	Nacelle	Lubrication	1
AM40	20	Nacelle	Inspection	1
AM41	15	Nacelle	Inspection	1
AM42	10	Hub	Lubrication	1
AM43	30	Nacelle	Inspection	1
AM44	80	Nacelle	Lifting	1

Based on a table, the Operator Balance Chart (GBO) was built for each technician of the team. The total time was calculated as the time or time that the technician has to carry out maintenance for us for two days, a week or relocation, multiplied by the intervention period per turbine. The result was 720 minutes per technician.

In the Figure 1, it can be observed that when all maintenance activities performed by a technician were placed in sequence, Technician 1 would have an unused time of 180 minutes and Technician 2 would have 140 minutes, totaling 320 minutes. However, the GBO chart does not show in detail the execution of each activity, but the occupation of available time for each technician by the total of activities.

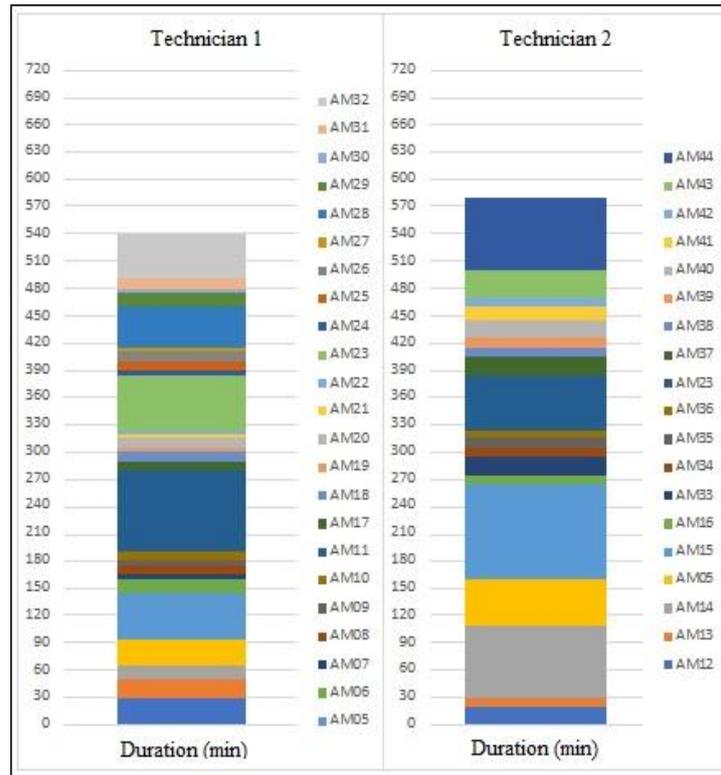


Figure 1: GBO graph of the execution time of activities by technician of the current model.

The Standardized Work Table shown in Figure 2 was developed for this maintenance model to identify where activities could be optimized, providing an overview of maintenance execution.

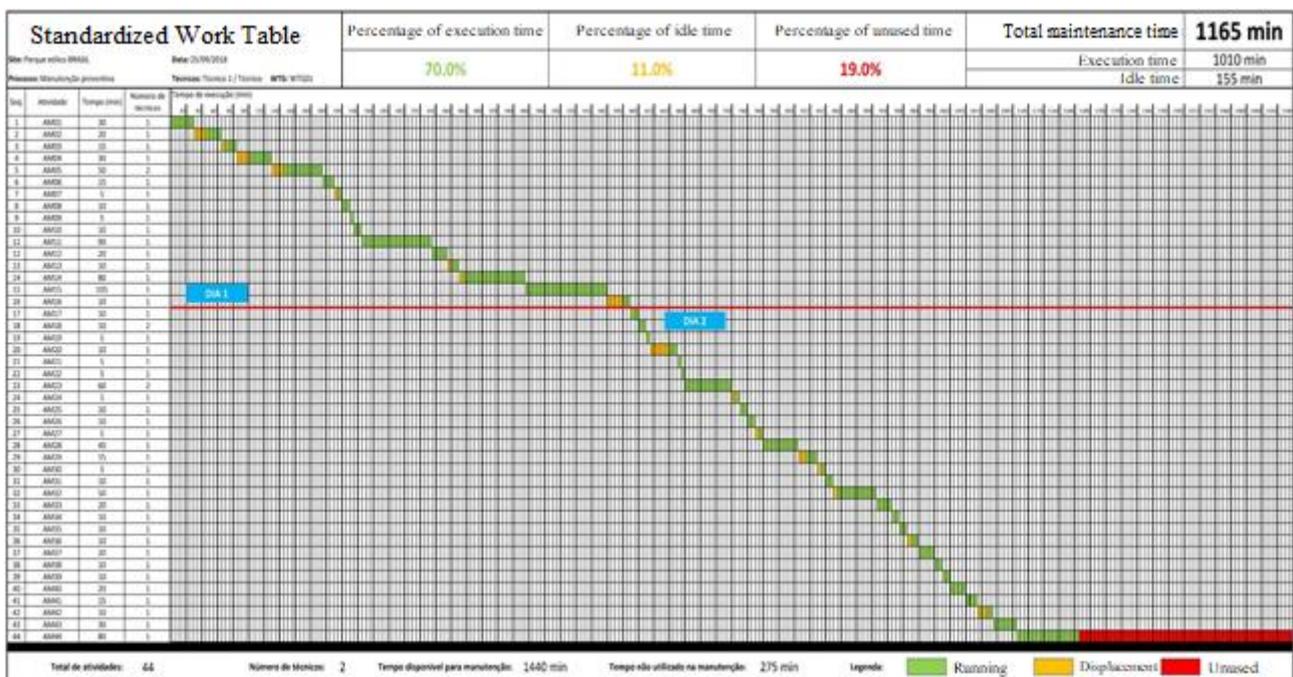


Figure 2. Standardized Work Table of the current maintenance method.

Based on Lean Service concepts and the graphical analysis performed, it was realized that there was 30% (430 minutes) of maintenance time that could be optimized. More importantly, if maintenance service performance were increased it would be possible to decrease the number of days the wind turbine was down for maintenance and therefore machine availability would increase.

The first step for this optimization was to order the maintenance checklist activities according to the layout and arrangement of the segments in the wind turbine, that is, as the team climbed the machine, it would carry out the activities. Activity checklists were reorganized and standardized.

Following the Lean Service methodology, unnecessary movements in the turbine were eliminated and through the suggestions of the opinion survey, a new table of activities chronoanalysis was elaborated. To avoid unnecessary movements in the turbine, the technician was concentrated as much as possible by turbine segment and by type of activity.

Some activities in the first maintenance model were overrunning. These activities had their execution time revised.

Through this Lean study, a new preventive maintenance model can be developed with a maintenance team rearrangement, reducing maintenance time.

After studying the model of three teams and two technicians initially used by the wind turbine maintenance service company, it was observed that in the Standardized Work Table (Figure 3) the time of 430 minutes was not applied directly in the execution of activities. Through this analysis, it was concluded that if the activities were rearranged in order to minimize the movement of technicians in the turbine and make better use of the time in performing the tasks and also that the number of technicians would be increased from two to three technicians per team, with the remaining six technicians from the wind farm, it would be possible to reduce one day of machine intervention.

By adding one more technician, two teams with three technicians, it was possible to increase the availability of the wind turbine, carrying out all the activities of the old model and without increasing service costs. In addition, six more activities were added to the new model, including cleaning activities, which increased the quality of the maintenance service. All of these fifty activities were listed in the chronoanalysis table.

Table 3. Chronoanalysis table of the new model of preventive maintenance activities.

<b>Activity</b>	<b>Time (min)</b>	<b>Turbine section</b>	<b>Type of Activity</b>	<b>Technicians</b>
AM01	30	Torre	Torque	1
AM02	20	Nacele	Torque	1
AM03	15	Nacele	Torque	1
AM04	30	Nacele	Torque	1
AM05	50	Hub	Torque	2
AM06	15	Hub	Torque	1
AM07	5	Hub	Torque	1
AM08	10	Hub	Torque	1
AM09	5	Hub	Torque	1
AM10	10	Nacele	Inspection	1
AM11	90	Hub	Torque	1
AM12	20	Nacele	Torque	1
AM13	10	Nacele	Torque	1
AM14	80	Nacele	Torque	1
AM15	90	Nacele	Torque	1
AM16	10	Nacele	Torque	1
AM17	10	Base	Inspection	1
AM18	10	Base	Lifting	2
AM19	5	Base	Inspection	1
AM20	10	Nacele	Inspection	1
AM21	5	Nacele	Replacement	1
AM22	5	Nacele	Inspection	1
AM23	60	Nacele	Inspection	2
AM24	5	Nacele	Inspection	1
AM25	10	Nacele	Inspection	1
AM26	10	Nacele	Inspection	1
AM27	5	Nacele	Inspection	1
AM28	40	Nacele	Lubrication	1

AM29	15	Nacele	Lubrication	1
AM30	5	Nacele	Inspection	1
AM31	10	Nacele	Inspection	1
AM33	20	Nacele	Inspection	1
AM34	10	Nacele	Lifting	2
AM35	10	Nacele	Inspection	1
AM36	10	Nacele	Inspection	1
AM37	20	Nacele	Inspection	1
AM38	10	Nacele	Inspection	1
AM39	10	Nacele	Lubrication	1
AM40	20	Nacele	Inspection	1
AM41	15	Nacele	Inspection	1
AM42	10	Hub	Lubrication	1
AM43	20	Nacele	Inspection	1
AM45	15	Hub	Cleaning	1
AM46	10	Gearbox	Cleaning	1
AM47	10	Gerador	Cleaning	1
AM48	15	Nacele	Cleaning	1
AM49	5	Yaw	Cleaning	1

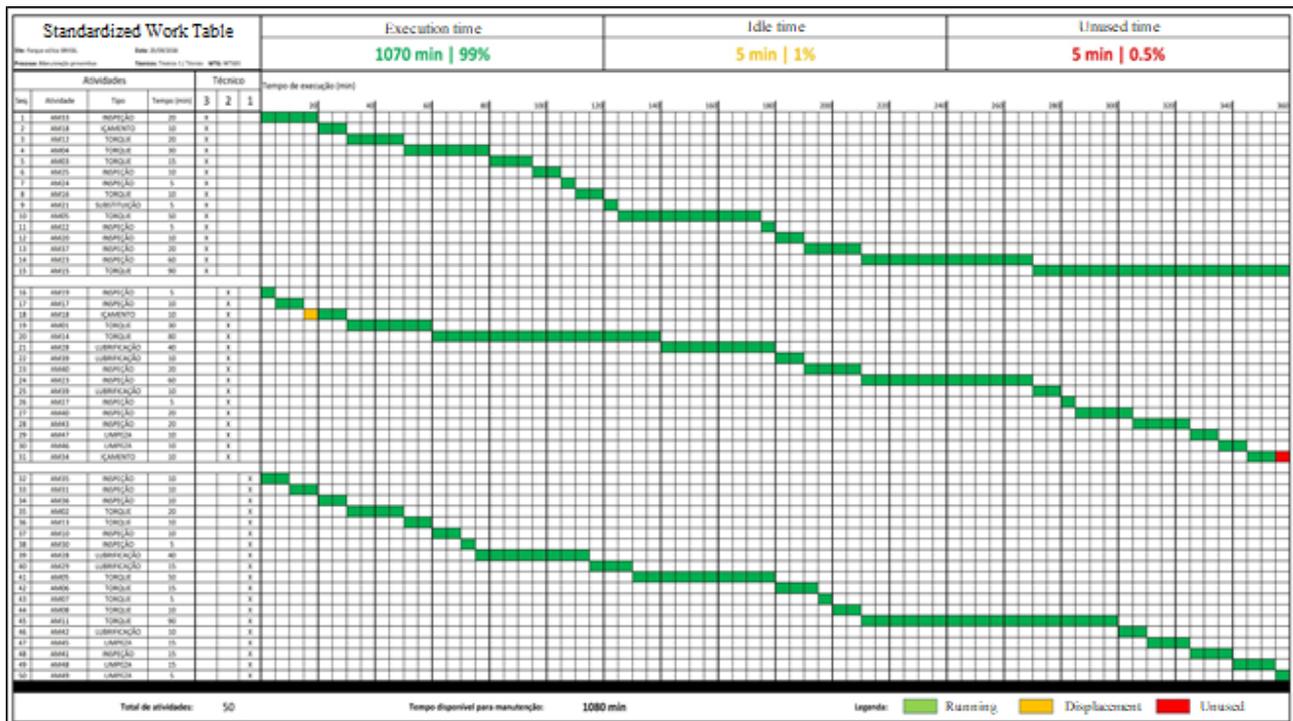


Figure 3. Standardized Work Table of the new maintenance model.

The preventive maintenance data in the park with the new model had the following structure:

Table 4. New park structure for maintenance.

Item	Quantity	Unit of measurement
Number of technicians	6	
Number of installed turbines	100	

Daily demand	2	turbine/day
Intervention period	1	day/turbine
Total park intervention period	50	day
Working time per day	8	hour/technician
Travel time to turbine	1	hour
Time available for maintenance	6	hour/technician

Table 4 reinforces the positive results of the new model, when it shows that the park's total intervention period fell from 67 days to 50 days, a difference of 17 days more for the wind farm's electricity generation.

That received a more efficient layout contemplating the sequence of activities for each technician. But the main change in this method was the optimization of the execution time, which jumped from 70% to 99%, strengthening the Lean Service concepts. Total Time dropped to 360 minutes per technician, improving work distribution among technicians and optimizing maintenance time.

#### 4. CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

After a theoretical foundation on wind energy with a focus on types of maintenance and a more in-depth approach to Lean Service, it is concluded that the application of concepts and tools from the philosophy of continuous improvement with a focus on process optimization, added to the improvement of quality, can bring excellent results for the company. In the case in question, all these applications significantly resulted in a better maintenance service for wind turbines.

With the expansion of the wind energy segment in the world, companies in the maintenance sector have the possibility to expand their contracts. However, as it is a highly sought-after segment, it is essential to invest in a management methodology aimed at making the best use of resources, improving the quality of the service offered and reducing costs.

The case study covered in this work showed that it is possible to use Lean Service concepts and tools to optimize processes. The result obtained with this methodology was expressive and enabled the emergence of a new model of preventive maintenance for wind turbines.

Therefore, this work concluded that through the foundations of Lean Service and its tools it was possible to obtain an optimized preventive maintenance execution model. This new model made it possible to reduce the number of days that the wind turbine was idle, increased machine availability and the number of activities, while maintaining the same number of technicians in the wind farm.

This work may motivate comparative studies between the two maintenance models studied in this work, comparing labor costs and which model would present the best cost-benefit ratio. Another recommendation for future work would be to optimize the use of tools and other resources by maintenance teams.

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