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# Predictive maintenance in LED street lighting controlled with telemanagement system to improve current fault detection procedures using software tools.

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**Abstract. Predicting the lifetime of LED light sources becomes quite challenging because the time to failure is long. The LM-80 and TM-21 methods are the main used by companies to establish the product lifetime. Accurate the RUL prediction can facilitate predictive maintenance. Predictive maintenance allows estimating when a failure will occur. In this context, the maintenance can be planned in advance, eliminating unplanned outage and maximizing the useful life of the equipment. In this work, the LM-80 and TM-21 methods are used for the acquisition and extrapolation of luminous flux data, wich are entered into an algorithm developed from an exponential degradation model. With the result obtained, it is possible to establish actions that allow predictive maintenance in LED street lighting controlled by a remote management system and achieve a longer service life.**

**Key words.** Led, Maintenance, Degradation, Telemanagement

## 1. Introduction

In present days, the telemanagement systems are a key piece for electrical grids and all their components to be integrated into the concept of smart cities and smart grids, and can provide a centralized control system, allowing selective control and dimming actions [1]. As defined by a Smart Grid is an electrical network that can incorporate the requirements of all connected users, generators, consumers and those who do both, in order to offer efficient, sustainable, economic and secure electricity supplies. Smart lighting technology has proven to be the most available for goverments institutions in the face of limited budgets [2]. Thus, in the case of public lighting, remote management systems contain a large range of information concerning luminaires such as their location, hours of operation, or consumption current. In addition, combining remote management techniques with LED street lighting contributes significantly to energy efficiency [3].

Although LED luminaires are known for their high efficiency, durability and high mechanical safety, as well as their long service life. [4], they do fail due to maintenance deficiencies, wear and tear, and light degradation. These failures influences the reduction of light levels an project costs.[5].

The advances in LED technology is aimed at optimizing maintenance costs but has also been used to reduce electricity consumption costs. Telemanagement systems have been a new step, including predictive control, proactive systems, integrated intelligent systems, however, the maintenances are still done in a classical way [6].

Predicting the lifetime of LED light sources becomes quite challenging because the time to failure is quite long [4]. Considering lumen degradation, the Alliance for Solid State Lighting Systems and Technologies recommends a threshold of 70% lumens to determine the lifetime of LED luminaires for general lighting applications. The cause of lumen degradation differs between technologies and depends on the product and system design [5].

The Illuminating and Engineering Society (IES) defines the lifetime of LED luminaires under its LM-79 and LM-80 standards. Likewise, the Energy Star TM-21 procedures specify the method for lumen maintenance over time with its current input and operating condition [7]. The LM-80 and TM-21 methods are the main used by companies to establish the product lifetime. Lumen flux life is defined as the time in which the maintained percentages of the initial luminous flux fall below a critical threshold [8].

There are different variables used in these standards, such as ambient temperature, light color quality known as chromaticity, time of use, and catastrophic failures. For example, the LM-80-08 standard mainly suggests tests at different temperatures with a minimum of 6000 hours where data are collected every 1000 hours, data collection at 25°C, luminous flux samples, chromaticity and catastrophic failures [9].

To provide lifetime information, it is necessary to use prognostics and health management (PHM) techniques for real-time or off-line prediction of the RUL of LED luminaires, based on a degradation of their luminous intensity over time. [4]. Accurate RUL prediction can facilitate predictive maintenance. Specifically, degradation generally refers to an accumulation of change in the performance characteristics of a system over time and degradation will generally lead to system failures [10].

Normally, a degradation model consists of random and deterministic components, with the former being sufficient to grasp the change of the deterioration process while the latter assume a constant physical phenomenon.. One of the methods that exist for the prediction of the lifetime of an element is the exponential degradation model, which fits the time evolution of a health indicator (HI) and predicts how long it will last until it crosses a value called as a threshold of failure (PIE) [11]. When a degradation process reaches an unacceptable level, the product is considered to have failed [12].

Predictive maintenance allows you to estimate when a failure is about to occur. This way you can plan maintenance in advance, eliminate unplanned downtime and maximize equipment life. This type of maintenance not only predicts a future failure, but can also identify more complex problems in your equipment and help you identify which parts need to be repaired [13]. Trends, behavior patterns and correlations can be predicted using statistical methods or machine learning models to predict failures in advance to improve the decision making procedure for the maintenance activity, mainly to avoid breakdown time [14]. Thus, in order to perform the proposed predictive maintenance, a process is designed based on data acquisition and processing, identifying its conditions, performing tests using MATLAB software, implementing and integrating the model and analyzing the results obtained. This will also allow visualizing the lifetime characteristics of the elements based on historical data to predict the RUL and calculate the time until a device failure occurs. The type of RUL calculation algorithm employed depends on the condition indicators extracted and the amount of data available.

To perform the illumination level measurement, a luxmeter located at ground level is used which takes up to four samples under the luminous flux of an LED luminaire that has had about 4000 hours of operation. Likewise, luminous flux samples are taken from a LED luminaire of the same characteristics, but with a time of use not exceeding 500 hours. The purpose of this is to obtain data on the lumen degradation of the luminaires over time of use.

## 2. Metodology

This section shows the lumens degradation method used by the luminaire manufacturer in order to establish a lifetime for their products. Details are given on how the degradation values can be obtained by measuring the luminous flux and then using an algorithm to find the useful life of the luminaires based on feedback of historical data. Also, it is shown how the telemanagement system is used for the control and dimming of a group of LED luminaires installed in the Province of Manabí, Ecuador, and how it directly influences the useful life of the equipment. Figure 1 shows the details of the process.

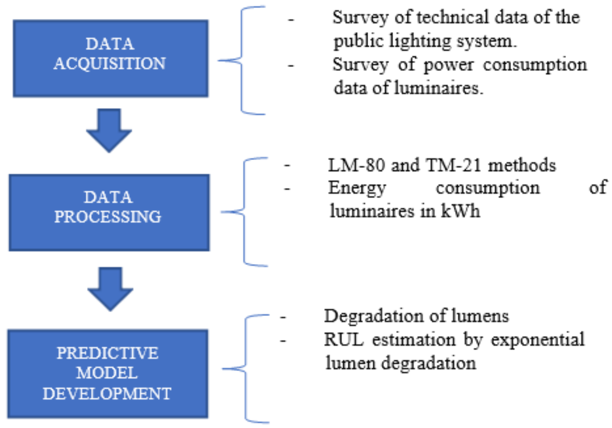


Figure 1. Blocks diagram

### *A. Data acquisition.*

*A.1. Technical data collection of the street lighting system.*

The chosen luminaires have the technical characteristics shown in Figure 2. Among these characteristics is the nominal luminous flux given in lumens.

| TECHNICAL INFORMATION | | | | | |
|---|---|---|---|---|---|
| ***Manufacturind Standards*** | IEC 60598 - 1 IEC 60598 -2 -3 RETILAP | | | | |
| ***Maker*** | **ROY ALPHA S.A.** | | | | |
| ***Reference*** | RALED III | | | | |
| ***Origin*** | Colombia | | | | |
| ***Test Protocols*** | CIDET | | | | |
| ***Certificates of Manufacturer*** | ***ISO 9001*** *:2015* ***ISO 14001*** *: 2015* ***OHSAS 18001*** *:2007* | | | | |
| ***Total Rated Power of the luminaire (W)**** | 71 | 140 | 160 | 173 | 211 |
| | **86** | **130** | **154** | **172** | |
| ***Nominal Voltage*** | From 120 to 277 V | | | | |
| ***Luminaire Output luminous flux ***** | 9,100 | 17,000 | 19,900 | 21,000 | 24000 |
| | **19,300** | **12,797** | **21,797** | 23,977(T02) | |
| ***Useful life of the Led L70B10 to 25°C***** | 100.000 Hours | | | | |
| ***Color Temperature*** | 4000 K | | | | |
| ***Optics*** | RA02/**T02** | | | | |

Figure 2. Technical data of the luminaries [15]

According to the LM-80 report, the manufacturer of this luminaire model performed the respective tests to obtain data with temperatures of 85°C and 105°C, as shown in Figure 3.

**LM-80 Test Inputs**

| Description of LED Light Source Tested (manufacturer, model, catalog number) |
|---|
| RALED III 80 LEDs 210W Modulo FasFlex DAX LED CREE XPG3 18-P421-1 |

| LM-80 Testing Details | |
|---|---|
| Total number of units tested per case temperature: | 25 |
| Number of failures: | 0 |
| Number of units measured: | 25 |
| Test duration (hours): | 9072 |
| Tested drive current (mA): | 1050 |
| Tested case temperature 1 ($T_c$, °C): | 85 |
| Tested case temperature 2 ($T_c$, °C): | 105 |
| Tested case temperature 3 ($T_c$, °C): | |

| Test Data for 85°C Case Temperature | | Test Data for 105°C Case Temperature | |
|---|---|---|---|
| Time (hours) | Lumen Maintenance (%) | Time (hours) | Lumen Maintenance (%) |
| 0 | 100.00% | 0 | 100.00% |
| 168 | 99.99% | 168 | 99.37% |
| 1008 | 99.72% | 1008 | 98.28% |
| 1512 | 99.54% | 1512 | 97.69% |
| 2016 | 99.32% | 2016 | 97.41% |
| 2520 | 99.23% | 2520 | 97.15% |
| 3024 | 99.13% | 3024 | 96.98% |
| 3528 | 98.93% | 3528 | 96.69% |
| 4032 | 98.74% | 4032 | 96.40% |
| 4536 | 98.68% | 4536 | 96.35% |
| 5040 | 98.69% | 5040 | 96.19% |
| 5544 | 98.69% | 5544 | 96.24% |
| 6048 | 98.73% | 6048 | 95.87% |
| 6552 | 98.57% | | |
| 7056 | 98.52% | | |
| 7560 | 98.39% | | |
| 8064 | 98.28% | | |
| 8568 | 98.42% | | |
| 9072 | 98.26% | | |

Figure 3. LM-80 report of manufacturer [16]

*A.2. Energy consumption data collection by remote management.*

Using a data management perspective, a smart city incorporates data analysis and processing with the security and privacy of the measurements taken and fosters the integration of applications to increase the overall quality of life of its citizens [17]. The energy consumption of the street lighting system is essential in the concept of smart cities. Telemanagement software tools allow optimizing control and monitoring activities of various elements within a lighting system. The QULON CMS remote management tool is an intelligent and cost-effective solution aimed at optimizing the infrastructure of lighting projects, focusing on energy savings, cost optimization and reduction of environmental impacts. This tool stores historical data of each luminaire monitors the public lighting system in real time and allows the application of dimming techniques for optimization and cost reduction.
Figure 4 shows the behavior of dimming in the power of the luminaires during the operating hours. It must be noted that the reduction in the power of the luminaires does not imply non-compliance with the lighting levels indicated by the national regulation (Arconel 006/18), for each hour of operation.

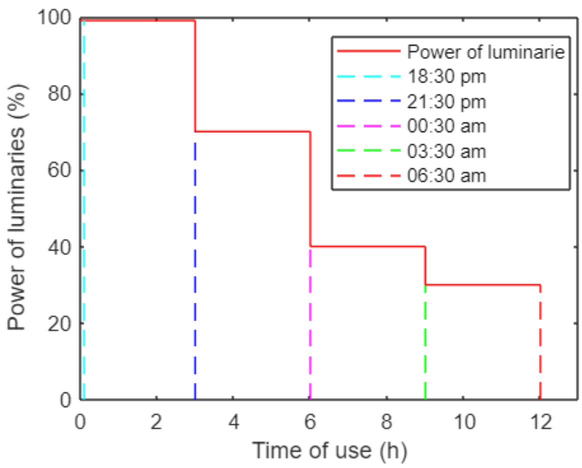

Figure 4. Dimming of luminaries

This case study has a dimming up to 70%, as shown in Table 1.

Table 1. Power dimming of the luminaries

| POWER (W) | DIMMING (%) | TIME OF USE (h) |
|---|---|---|
| 210 | 0% | 3 |
| 147 | 30% | 3 |
| 84 | 60% | 3 |
| 63 | 70% | 3 |

*B. Data processing.*

*B.1. LM-80 and TM-21 methods.*

Using the data obtained, the developer proceeded to extrapolate the data to obtain the lumen depreciation curves at a temperature of 85°C and 105°C as shown in Figure 5, where the curve is also represented at an ideal temperature of 25°C.

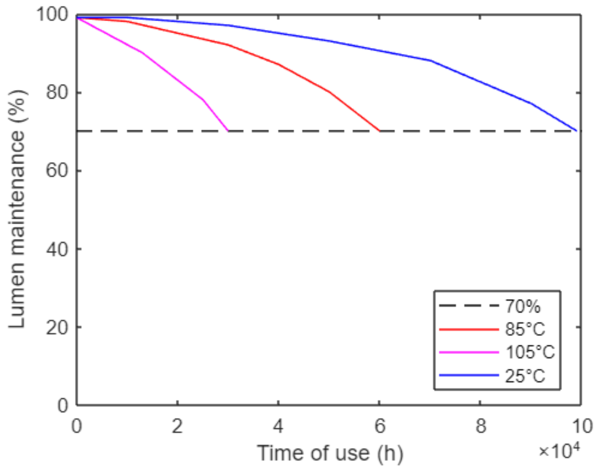

Figure 5. Lumen depreciation curve of the manufacturer

This process is performed by all LED luminaire manufacturers in order to estimate the useful life of their luminaires based on lumen degradation.
The luminaires described are installed in the city of Manta, Province of Manabí, Ecuador. In 2019, the process of integrating the Public Lighting service to the concept of smart cities began. Through the management of the National Electricity Corporation CNEL EP Manabí Business Unit and Street Lighting Department, a considerable number of LED luminaires with remote management systems have been installed in the main roads of the city. The first batch of installed luminaires has been operational since May 2020, while the last batch of installed luminaires has been operational since October 2021.
In order to predict the RUL of the luminaires and to establish maintenance tasks before the luminaires fail, the data provided by the manufacturer is verified to determine whether the lumens degradation as a function of the hours of use is satisfied. Thus, measurements of the luminous flux projected on the public road are obtained with a luxmeter, with the data a modeling of the exponential degradation is performed by means of engineering software.

*B.2. Energy consumption of luminaries*

The telemanagement system is able to dim the power of the luminaires, optimizing the electrical energy consumption, helping the group of luminaires to maintain a useful life of about ten years. Using the power attenuation parameters in Table 2, the luminaires reach 60% of their normal performance in 12 hours of operation.

Table 2. Daily luminarie perfomance details

| Dimming | | | |
|---|---|---|---|
| POWER (W) | DIMMING (%) | TIME OF USE (h) | CONSUMPTION(Wh) |
| 210 | 0% | 3 | 630 |
| 147 | 30% | 3 | 441 |
| 84 | 60% | 3 | 252 |
| 63 | 70% | 3 | 189 |
| | | Total | 2520 |
| No Dimming | | | |
| POWER (W) | DIMMING (%) | TIME OF USE (h) | CONSUMPTION(Wh) |
| 210 | 0% | 12 | 2520 |

*C. Predictive model development*

*C.1. Lumen degradation.*

Considering two batches of the same luminaire model installed 17 months apart, it is possible to assess the luminous flux degradation in this period. Also, following the same LM-80 and TM-21 methodology, the data are extrapolated to estimate the degradation in the coming years, as shown in Figure 6. The data belong to 210 W LED luminaires, for which measurements were taken in five units installed in 2020 and in another five installed in 2021 at an average temperature of 25°C, thus obtaining the luminous degradation values for one year. All luminaires are of the same model and from the same manufacturer.

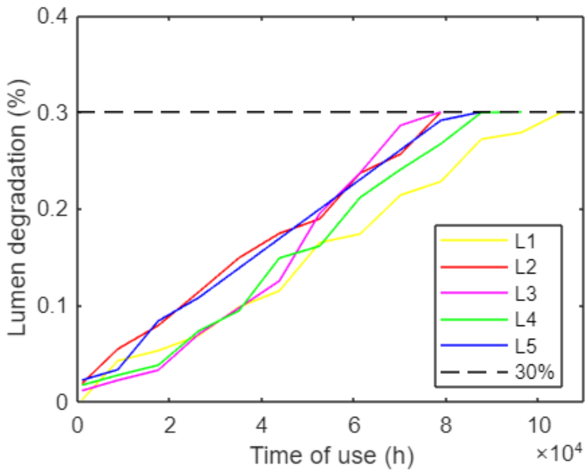

Figure 6. Projected lumen degradation of installed luminaires

*C.2. RUL estimation by exponential lumen degradation*

The effect on the useful life of the luminaires evaluated in this study is mainly influenced by the geographical conditions where they are installed. In the area there is a high salinity due to the proximity to the sea, the ambient temperature during the day has an average of 28°C, industrial areas and a sandy soil that provides a contamination that cumulatively affects any device that is exposed to these conditions. Bresle test patches are used to determine the concentration of soluble salts on a surface using the ISO 8502-6 test method. These conditions affect the different electrical equipment connected to the network. When the surfaces are dry, the effect is not significant. However, when the weather is wet and rainy, contaminants reduce the efficiency of the insulating material of any equipment installed outdoors, and the risk of failure increases. [18]. Therefore, the temperature to which they are exposed, environmental pollution and humidity conditions are important issues for the reliability of an electrical system and the proper functioning of its components. For this paper, the exponential lumen degradation method was chosen, which is applied in an engineering software tool in order to predict the RUL of luminaires, based on data collected using techniques recommended by international organizations. As recommended in the TM-21 method, the data collected from lumen maintenance using the LM-80 report is fitted to a curve, and then this curve is extrapolated to obtain the data at a future time. As discussed in [19], all collected lumen flux data are first normalized to a value of 1 (with an initial value set to 100%) for each test unit. The lumen maintenance "LM" is defined as the percentage of luminous flux that is maintained over time, as shown in Equation (1) presented in [19]:

$$LM(t) = \frac{\Phi(t)}{\Phi(0)} \times 100\% \tag{1}$$

Where Φ(0) is the initial luminous flux, and Φ(t) is the luminous flux at time t. A threshold value of 70% degradation was considered as a threshold in the exponential degradation model.
Then, a curve fitting based on the exponential least squares regression method is performed using Equation (2) presented in [19] :

$$LM(t) = \beta * \exp(-\alpha * t) \tag{2}$$

Where β is the projected initial constant, α is the decompensation rate constant, and t is the operating time.
Finally, an extrapolation of curves based on the previously obtained data is performed in order to calculate the projected lifetime. Equation (3) presented in [7] is used to perform this extrapolation:

$$L_{70} = \ln(\beta / 0.7) / \alpha \tag{3}$$

This equation allows extrapolating the data into the future up to a degradation of 70% of the initial value.
The exponential degradation model estimates the remaining useful life (RUL) by predicting when a monitored signal crosses a predefined threshold. This degradation model is very useful when the device suffers wear and tear that has accumulated over time, and is given by the Equation (4) presented in [11]:

$$h(t) = \phi + \theta(t) e^{\left(\beta(t) + \xi(t) - \frac{\sigma^2}{2}\right)} \tag{4}$$

Where h(t) is the health indicator, $\theta$(t) and β(t) are characteristic stochastic variables, $\theta$(t) is a lognormal distribution and β(t) is a Gaussian distribution. At each time period t, the distribution of $\theta$(t) and β(t) are updated based on the last observation of S(t). $\varepsilon$(t) is a Gaussian additive noise and is modeled as a normal noise distribution with zero mean and variance [11].

In Matlab, "exponentialDegradationModel" is used to estimate the remaining lifetime of a piece of equipment as shown in Figure 7. This function complies with the model in Equation 4. Thus, once the historical data is imported, "exponentialDegradationModel" is used to obtain the variance data of the stochastic variables $\theta$(t) and β(t).

```
mdl = exponentialDegradationModel('LifeTimeUnit',"TIEMPO");
fit(mdl,datos2,"TIEMPO","LUX")
mdl.Prior
threshold = 11;

N=height(datos1)
for t = 1:N
 update(mdl,datos1(t,:))
end
estRUL = predictRUL(mdl,threshold)
           Theta: -5.6439
   ThetaVariance: 15.2055
            Beta: 0.2085
    BetaVariance: 0.0213
             Rho: 0.9581
```

Figure 7. Use of "exponentialDegradationModel"

## 3. Results

Based on the characteristics of the manufacturer, the luminaires have a useful life of 100,000 hours equivalent to 11 years of operation without interruption. This value provided by the manufacturer can be used as a reference for the calculation of the lifetime of the luminaires that is performed with Matlab. Then the "predictRUL" function is used to obtain the result of the RUL of the luminaires taking as a reference the collected and extrapolated data, and the value provided by the manufacturer. To use this Matlab function, the estimation model is configured using historical data showing the status of a set of the LED luminaires. Figure 8 shows the entry of the threshold value provided by the manufacturer and the calculation of the RUL in years, the result in this case is 9.9381 years or 86724 hours. It should be clarified that these 9.9381 years are calculated as if the luminaire operated continuously throughout the day, it is equivalent to almost 20 years of operation when operating 12 hours per day.

```
threshold = 11;

N=height(datos1)
for t = 1:N
 update(mdl,datos1(t,:))
end
estRUL = predictRUL(mdl,threshold)
     estRUL = 9.9381
```

Figure 8. Use of "predictRUL"

As discussed in [20], since these approaches are based on statistical supervision techniques that directly predict future degradation from the collected data, even larger installations can be analyzed and the results used to enhance maintenance planning.
Figure 9 shows the difference between the lifetime indicated by the manufacturer and that calculated by the algorithm based on the collected data. The difference between the calculated RUL and the RUL provided by the manufacturer is 13.27%.

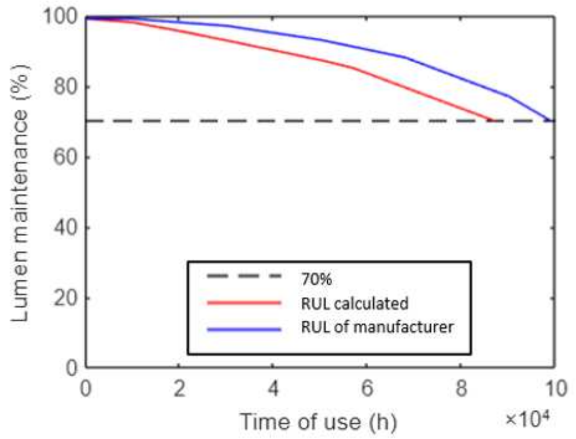


Figure 9. RUL curves calculated and provided by the manufacturer

Figure 10 shows how this dimming technique can influences directly to the useful life of the luminaries, optimizing their performance and operation according to the needs. That is, if the dimming technique is applied, their useful life would only be reduced by approximately 6%.

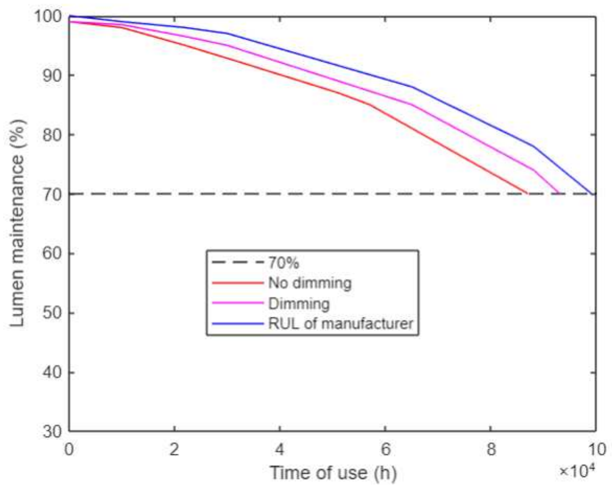


Figure 10. Lifetime of luminaries with dimming and no dimming

## 4. Results analysis

Using the same LM-80 and TM-21 methods exposed in [9] and with the manufacturer's data, it was possible to obtain the lumen degradation over a period of time. Thus, it was possible to obtain a degradation curve similar to Figure 11 where 30% degradation is taken as the threshold value for failure.

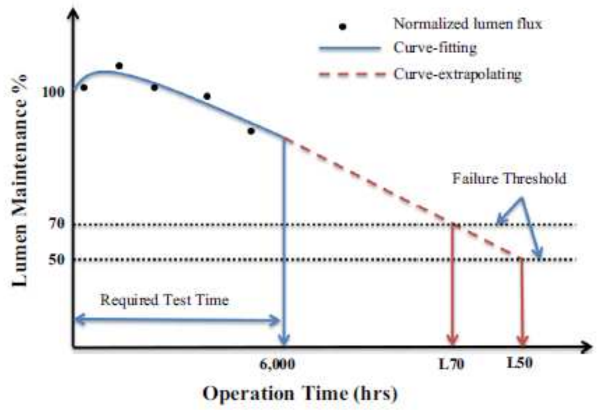


Figure 11. Projection approach TM-21 [20]

To obtain accurate results using Matlab, an algorithm was developed with functions that are based on exponential degradation, just as in [11]. This formulation was used to calculate the lifetime of the luminaires from the data collected and entered into the algorithm. The result obtained with this algorithm helps to plan actions that help to maintain a long useful life before the equipment fails.
It was found that the main maintenance activities carried out by the technical personnel in charge of the public lighting system studied in this article are the same as those indicated in [21]. The main maintenance activities carried out by the technical personnel in charge of the public lighting system studied in this paper are the same as those indicated in this article, which are: determining the energy consumption of the luminaires, checking their condition and replacing those that are inactive.
The main disadvantage of this type of activity is that residential areas and roads with high vehicular traffic are affected by the absence of lighting due to the damage of luminaires that could not be intervened in advance. This is due to the fact that there is no storage of historical measurement data that could contribute to predict the useful life of this equipment.

### *A. Proposed Predictive Maintenance Plan*

Based on the remaining life prediction by lumen degradation and the dimming option provided by the remote management system, a predictive maintenance plan is proposed to improve the current failure detection procedures (see Figure 12).
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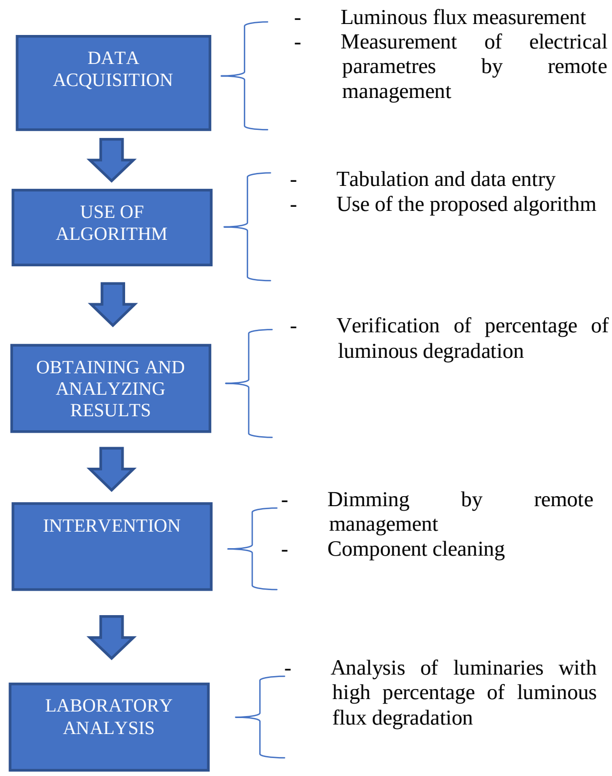


Figure 12. Proposed predictive maintenance plan

#### *A.1. Data acquisition*

The measurement and recording of the luminous flux of all the groups of luminaires installed with their power at 100% must be carried out. The measurement of the luminous flux must be carried out with a properly calibrated luxmeter. This task must be carried out monthly, with this it is possible to have a historical database which, when analyzed, can provide information if a specific site is experiencing greater degradation of the luminous flux. Likewise, the parameters such as electrical power, consumption and energy saving must be obtained every month with the help of the telemanagement tool to be able to carry out consumption patterns, as [22] tells us, these patterns are useful in many areas, such as in demand forecasting and forecasting, energy management, implementation of efficiency and smart energy policies, improvement of tariff supply, etc. Also [23] tells us that electricity consumption patterns review the behavior of energy demand and allow implementing a strategy to increase efficiency using monitoring systems.

#### A.1. *Use of the Algorithm*

The data obtained should be entered in a matrix that allows visualizing which luminaire it belongs to, location, date of data collection, type of data, measured value of the luminous flux. Once this data is sorted, it can be entered into Matlab software and the functions described in this study can be used to estimate the RUL of the luminaires. This process should be done for each of the luminaires separately.

*A.2. Obtaining and analyzing results*

The results obtained will be much more accurate as long as the database is updated every month. These results make it possible to predict the lifetime of the luminaires and to see the percentage of degradation that exists in their luminous flux.

*A.4. Intervention*

Once the results are analyzed, cleaning activities should be coordinated, readjustment of components, and if necessary the removal of luminaires in which a greater degradation of lumens has been detected in a shorter period. Due to the high degree of contamination and salinity, a general cleaning and readjustment of all elements is recommended. In addition, the option of dimming by remote management must be adjusted as the percentage of flux degradation increases. This technique also has a direct influence on the lifetime of the luminaires. The installation of vehicle traffic intensity sensors (TIS) can also be an alternative option.
Figure 13 shows a simulation exercise, where it is assumed that these maintenance tasks are performed once the luminous flux degradation exceeds 10%, thus reaching a useful life similar to that predicted by the manufacturer.

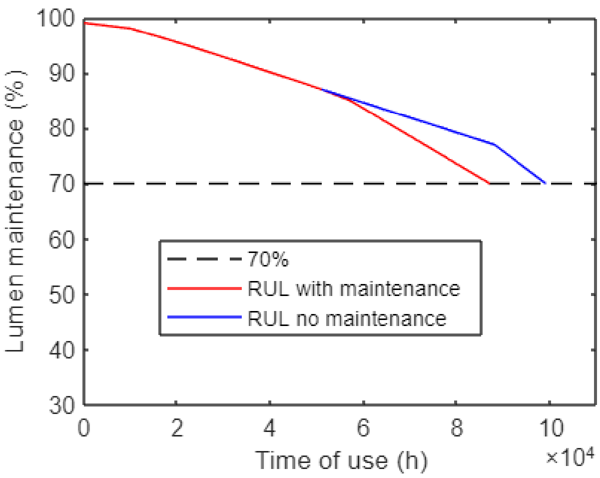

Figure 13. RUL with maintenance and no maintenance

*A.5. Laboratory analysis*

As temperature is one of the main parameters affecting luminous flux degradation and luminaire lifetime, it is recommended once measurement records are taken, and if the percentage of luminous flux degradation is close to 30% in a short period of operation, for example 10000 hours, this luminaire should be uninstalled to perform the same process as performed by the manufacturer based on the LM-80 and TM-2 methods. That is, perform tests at different degrees of temperature and take lumen measurements in a laboratory, and compare the results with those measured while the luminaire was installed to verify if the degradation is indeed due to temperature. A similar process is described in [9] in order to verify the degradation suffered by the element that is exposed to a temperature variation as shown in Figure 14.

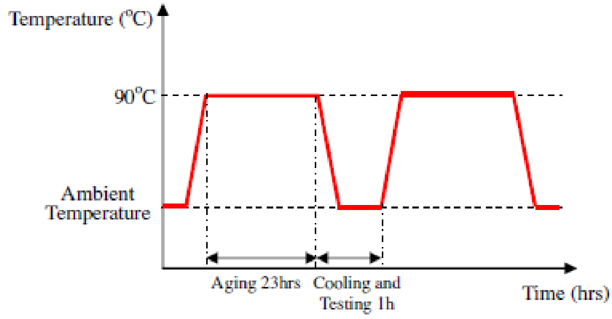

Figure 14. Operating curve of an accelerated degradation test for led luminaires

The same process can be applied to verify if the degradation is due to the accumulation of contamination. That is, uninstall the luminaire that is affected by a degradation in its luminous flux, perform tests in a laboratory under stable conditions, take measurements and compare the results that were available when the luminaire was installed.

## 4. Conclutions

This paper has made it possible to establish specific tasks to carry out predictive maintenance using an algorithm designed in an engineering software, based on the degradation of lumens, and whose accuracy depends on the amount of historical data that are entered. Temperature and luminous flux were identified as the main variables that allow predicting the useful life of the luminaires. The control of power dimming by remote management is a key element to obtain a longer useful life of LED luminaires with this type of technology. With the results obtained, it is possible to establish actions that allow predictive maintenance of the LED street lighting system with remote management, and to achieve a longer useful life.


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