Journal of Solar Energy Research (JSER)

Journal homepage: jser.ut.ac.ir

The Influence of the Geographical Location on the Preventive Replacement of Renewable Energy Devices

Ali Ezzedine [a], Abdolhamid Rezaei Roknabadi [a], Gholam Reza Mohtashami Borzadaran [a,*]

[a]*Department of Statistics, Faculty of Mathematical Sciences, Ferdowsi University of Mashhad, Iran*
Received: 2020-12-19
Accepted: 2021-08-14

Abstract

In this article- we study devices that derive energy from natural process (sun, wind, winter, soil, etc.) and that are replenished constantly such as fans generating electric power and solar energy devices. However, all devices are exposed to damage over time resulting in the accumulation of the damage caused by climatic fluctuations (Every geographical area is characterized by bad weather characteristics that leave damage to the device; like wind, rain and humidity) that lead to the failure of the device. These devices receive energy directly from nature in order to supply it to other systems (mechanical, electrical, etc.). A failure of the device reduces electrical-mechanical production. The companies manufacture renewable energy devices and export them to other countries in various geographical locations. The devices are used to provide electrical current in these countries. These companies seek to develop long-term protection plans against the device failure. A failed device becomes ineligible even for recycling in these companies. Therefore, the cost of the device failure and forced replacement becomes too expensive for these companies. Because of this, companies tend to find the optimal time to replace the device shortly before failure to reduce the cost of failure. In this experiment we study a device that is subject to shocks and calculate the optimal time for preventive replacement of a said device. As an example a solar energy device exposed to shocks resulting from climate fluctuations. We place this device in three different geographical locations (desert, tropical, and temperate), and calculate the optimal time for preventive replacement of the device. Finally, the results from these three locations are compared.

Keywords: Preventive replacement, compulsory replacement, solar energy devices, tolerance limit, climate fluctuations.

Introduction

Renewable energy devices are used to supply electrical current or other tasks like heating water. But since they are expensive, manufacturers work hard on developing maintenance plans or preventive replacements in order to avoid sudden failure, lack of electrical production and mandatory replacement cost after failure which is considerably high.

All climatic fluctuations cause damage to the device over time. The damage accumulates and exceeds the limit of the device tolerance, so the device fails. One of the significant problems the companies are faced is that these devices are manufactured in one country and are exported to another country with a different climate. Climate fluctuations vary from one country to another. Taking this into account, our goal is to determine a preventive replacement time for the

* *Corresponding author: grmohtashami@um.ac.ir*

device and its relationship to the geographical location of it.

Some investigators including Cox [1], Esary et al. [2], Nakagawa and Osaki [3], Savits [4], Gotlieb [5], Ross [6], Qian et al. [7] and Nakagawa and Ito [8] calculated the best time for preventive replacement in machines subjected to shocks. However, some other investigators such as Satow and Osaki [9], Sheu et al. [10] studied a machine consisting of more than one part subjected to shocks and calculated the optimal time for the preventive replacement. In recent years, Sheu et al. [13] and Gregory et al. [14] studied the extended optimal replacement policies with random working cycle.

* Corresponding author:
grmohtashami@um.ac.ir

We have examined a device that has been subject to random shocks, every shock causes damage to the device. When the total damage reaches the tolerance level K the device fails. In order to keep the device failure from occurring we have calculated the optimal time for preventive replacement of the device. Then we have placed three solar energy devices having the same industrial specifications in three different geographical locations calculating the optimal time for the preventive replacement of the device. The effect of the geographical location on the optimal time for preventive replacement of the device has clearly been established.

Several studies have investigated the repair plan, life span of a device, and the time to replace a system with a new system. In these studies, researchers investigate specific device types, and they monitor the times of failure of the system, repair time, and time of replacement depending on experimental observations. That is why for each new type of industrial device researchers shall wait years while observing the device until it reaches its life span, so that they can develop useful life plans and evaluate the best time for replacement.

As for the model we have studied, it's a model that connects two parameters: the first one is the device's endurance and the average damage that the device suffers from when any climate shock occurs, and the second one is the device's useful life. This model facilitates our ability to determine the useful life of the device and its ability to withstand. Through this model, we can develop the device's bearing capacity and calculate directly the useful life of the device of through the equations.

2. Renewable energy device

The world is currently moving towards renewable energy because it is less harmful to the environment. It is also known that the devices are affected by climate fluctuations due to geographical location. As these devices are highly expensive, the manufacturers of the devices are prompted to develop plans and programs in order to protect the devices. The most commonly used devices are turbines (machines that convert wind into electricity), solar energy devices and tidal devices. Mathaios and Pierluigi [11] and David and Miguel [12] studied the impact of climatic fluctuations on the devices. Figure 1,2 and 3 shows renewable energy devices.

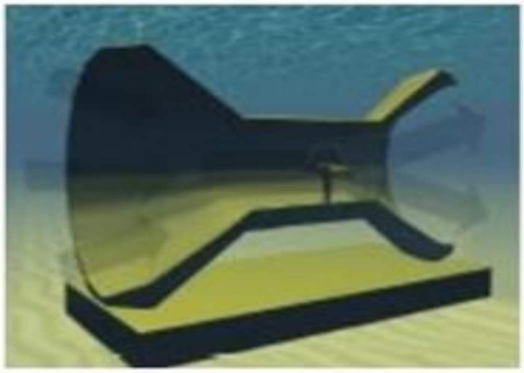

Figure 1. Tidal devices

Figure 2. Solar energy devices

Figure 3. Turbines

(Source first figure 1: European marine energy centre. Source second figure 2: Solar Projects-Arduino Project hub creat.Arduino.cc. Source third figure 3: National Geographic Society).

As time passes and due to climate-related damage, the device usually ages and its functioning deteriorates. During the aging process, the production and maintenance costs increase until they reach a stage that they outweigh the costs of buying a new device. That is why it is considered one of the maintenance forms to replace the device before it reaches this stage of expensive old age.

The lifecycle of the device is divided into three stages. In the first stage, "the start-up stage", failure rates decrease and costs decrease, it's abbreviated by (DFR). In the second stage, "the production stage", failure rates are constant (CFR). And in the third stage, "old age", the device deteriorates, its production decreases, and the costs increase (IFR). Therefore, choosing the suitable time to replace the device with a new one allows us to save money. That is the aim of our model: to use mathematical equations to calculate the time of preventive device replacement that leads to the least money costs.

3. Model

Every geographical area has its specific weather characteristics that may sometimes cause damage to devices. Climate fluctuations on these devices leave harm to the device, so each climate change is a random shock that strikes the device and leaves damage. Let X_1 a random variable be the time of the first shock to the device, but X_j is the time interval between the occurrence of the $(j-1)^{th}$ shock and the occurrence of the $(j)^{th}$shock, and also S_n is the time of $(n)^{th}$shock occurrence. Therefore, $S_n = \sum_{j=1}^{n} X_j$ that has a distribution function $F_n(t) = \Pr(S_n \leq t)$, while B (t) is the number of shocks that occurred until time t. The equation (1) was used in a book (Shock and Damage Models in Reliability Theory) on page 10 Writer Nakagawa [15], in equation (1) we made use of it to see the potential number of shocks until time t,

$$\Pr\{B(t) = n\} = P\{B(t) \geq n\} - P\{B(t) \geq n+1\}.$$
$$= P\{S_n \leq t\} - P\{S_{n+1} \leq t\}$$
$$= F_n(t) - F_{n+1}(t). \quad (1)$$

Every shock leaves damage to the device. Let W_j be a random variable describing the amount of damage to the device resulting from the $(j)^{th}$ shock (j=1, 2, 3…), but $Z(t)$ is the total of damage due to shocks up to the time t, so $Z(t) = \sum_{j=1}^{B(t)} W_j$. Shock damage in device has an identical distribution $G(x) = P\{W_j \leq x\}$ with mean μ, when B (t) =j the distribution is $G_j(x) = P\{Z(t) \leq x\} = P\{\sum_{i=1}^{j} W_i \leq x\}$.

As for the different geographical location of the device, which is a difference in the rate of climate fluctuations, the mean of time the shocks enter the device differs from one geographical location to another. Therefore, we code each geographic location (i) with a mean time occurring shock of device $E_i(X_j) = \frac{1}{\lambda_i}$.

$$E_{Tropical}(X_j) \neq E_{Mediterranean}(X_j) \neq E_{Desert}(X_j) \ldots\ldots\ldots\ldots \neq E_{geographical\ location}(X_j).$$ In this form $E_1(X_j) \neq E_2(X_j) \neq E_3(X_j) \ldots\ldots\ldots\ldots \neq E_n(X_j)$.

3.1. Costs

Every climate change causes shock to the device resulting damage to it. When the total damage on the device reaches the endurance level K, the device fails, so we have to replace it. This is called a compulsory replacement. Sudden failure of the device stops production in these devices, as a result, the failed device is unable to work again, keeping this in mind that compulsory replacement is expensive.

Implementing a preventive replacement of a device in a planned time will reduce costs, it also prevent a sudden failure in the device ensuring continuity in production. There are two types of costs:

C_K: Compulsory replacement cost for devices,

C_T: Preventive replacement cost for devices.
With $C_K > C_T$.

3.2. Probabilities of replacement

There are two types of preventive and compulsory replacements. The probability of performing a protective replacement of the device in the planned time T before the total damage on the device reaches the tolerance limit K is P_T. Then we used Equation (1) in Equation (2) and calculated the probability that the total damages in time T were less than the device's bearing limit.

$$P_T = \Pr\{Z(T) \le K\} = \Pr\left\{\sum_{i=1}^{B(T)} W_i \le K\right\}$$

$$= \sum_{j=0}^{\infty} \Pr\left\{\sum_{i=1}^{B(T)} W_i \le K \middle| B(T) = j\right\} \Pr\{B(T) = j\}$$

$$= \sum_{j=0}^{\infty} G_j(K)\left[F_j(T) - F_{j+1}(T)\right].$$

(2)

As for the probability when the total damage reaching the tolerance limit K before reaching the planned time T for preventive replacement is P_K:

$$P_T + P_K = 1 \quad \Rightarrow$$

$$P_K = 1 - P_T.$$

3.3. Expected cost rate

The time interval between the first replacement and the next replacement is called a cycle. Time and cost for each cycle are independent, we calculate the expected cost per unit of time which is called the expected cost rate:

$$C(T) = \frac{\text{Expected cost of one cycle}}{\text{Mean time of one cycle}}$$

Calculating the mean time of one cycle, we need replacement times and their condition.

$$\begin{cases} T & \text{if } B(T) = j \text{ and } \sum_{i=0}^{j} W_i \le K \quad j = 1,2 \ldots\ldots \infty \\ S_{j+1} & \text{if } S_{j+1} < T \text{ and } \sum_{i=0}^{j} W_i < K \le \sum_{i=0}^{j+1} W_i \quad j = 1,2 \ldots\ldots \infty \end{cases}$$

(3)

T is the time for the preventive replacement of the device, while S_{j+1} is the time for compulsory replacement.

The mean time of one cycle is equal to

$$\sum_{j=0}^{\infty} G_j(K) \int_0^T (F_j(t) - F_{j+1}(t))dt.$$

(4)

To calculate (4) we use (3) describing how we calculate it in the appendix.

Calculating the expected cost of one cycle, we need cost of replacement and their probability,

$$\begin{cases} C_T & \text{with probability} \quad P_T \\ C_K & \text{with probability} \quad P_K \end{cases}$$

The expected cost of one cycle is equal to

$$C_T \times P_T + C_K \times P_K$$

$$= C_K + (C_T - C_K)\, P_T$$

(5)

So,

$$C(T) = \frac{C_K + (C_T - C_K)\sum_{j=0}^{\infty} G_j(K)\left[F_j(T) - F_{j+1}(T)\right]}{\sum_{j=0}^{\infty} G_j(K) \int_0^T (F_j(t) - F_{j+1}(t))dt}.$$

(6)

3.4. Optimum time

To calculate the best time for a preventive replacement of a device, we have to know the time at which $C(T)$ becomes in the minimum, so we will derive $C(T)$ and equate it with zero. T^* Is the optimum time for preventive replacement for the device.

$\frac{d\,C(T)}{dT} = 0$, we will explain how to calculate (7) in the appendix,

$$\sum_{j=0}^{\infty} G_j(K)\left[F_j(T) - F_{j+1}(T)\right] - \frac{\left[\sum_{j=0}^{\infty} G_j(K)\left[f_j(T) - f_{j+1}(T)\right]\right] \times \left[\sum_{j=0}^{\infty}\left(G_j(K)\right) \int_0^T (F_j(t) - F_{j+1}(t))dt\right]}{\sum_{j=0}^{\infty} G_j(K)\left[F_j(T) - F_{j+1}(T)\right]} = \frac{1}{1 - \frac{C_T}{C_K}}$$

(7)

To get T^* we put all the values in Equation (7).

3.5. Device repair

Some companies carry out repair programs during the life cycle of the device leading to an increase in its life span. C_R Is the cost of repairing the device. Let the random variable Y be time to repair the device, has a distribution $H(t) = \Pr(Y \le t)$.

We increase the cost of repairing the device multiplied by the probability of repairing the device before performing a preventive replacement of the device over the expected life cycle cost of the device. The expected life cycle cost of the device becomes the following:

$$C_K + (C_T - C_K)\sum_{j=0}^{\infty} G_j(K)\left[F_j(T) - F_{j+1}(T)\right] + C_R H(T)$$

As for the expected cost rate $C(T)$, it becomes as follows:

$$C(T) = \frac{C_K + (C_T - C_K)\sum_{j=0}^{\infty} G_j(K)\left[F_j(T) - F_{j+1}(T)\right] + C_R H(T)}{\sum_{j=0}^{\infty} G_j(K)\int_0^T (F_j(t) - F_{j+1}(t))dt}.$$

As for the calculation of the optimal time to preventive replacement of the device, it becomes as follows,

$$\frac{d\,C(T)}{dT} = 0$$

$$\sum_{j=0}^{\infty} G_j(K)\left[F_j(T) - F_{j+1}(T)\right] - \frac{\left[\sum_{j=0}^{\infty} G_j(K)\left[f_j(T) - f_{j+1}(T)\right] - \frac{C_R}{C_K - C_T} h(T)\right] \times \left[\sum_{j=0}^{\infty}\left(G_j(K)\right)\int_0^T (F_j(t) - F_{j+1}(t))dt\right]}{\sum_{j=0}^{\infty} G_j(K)\left[F_j(T) - F_{j+1}(T)\right]} = \frac{1}{1 - \frac{C_T}{C_K}} + \frac{C_R}{C_K - C_T} H(T). \quad (8)$$

In order to get the optimal time for preventive replacement of a device, we use equation (8).

4. Geographical location and climate change

There are various climates related to geographical locations. There are tropical, desert, coastal, polar and temperate climates, each geographical location has a specific climate which means the average climate fluctuation varies from one geographical location to another. This is due to the fact that the average time to enter climate shocks on renewable energy devices varies from site to another. We will distinguish each geographical location (i) by an average of climate shocks on energy devices $E_i(X_j)$. Then we study the optimal time for the protective replacement of the device in each geographical location. In figures 4 and 5 we observe a device placed in two different geographical locations. In the first geographical location, we observe that the time between the occurrence of a climatic shock and the subsequent shock is greater than it is in the second geographical location (i.e. $E_1(X_j) > E_2(X_j)$. We noticed that the device in the first geographical location took more time than the one in the second geographical location to reach the point of bearing K.

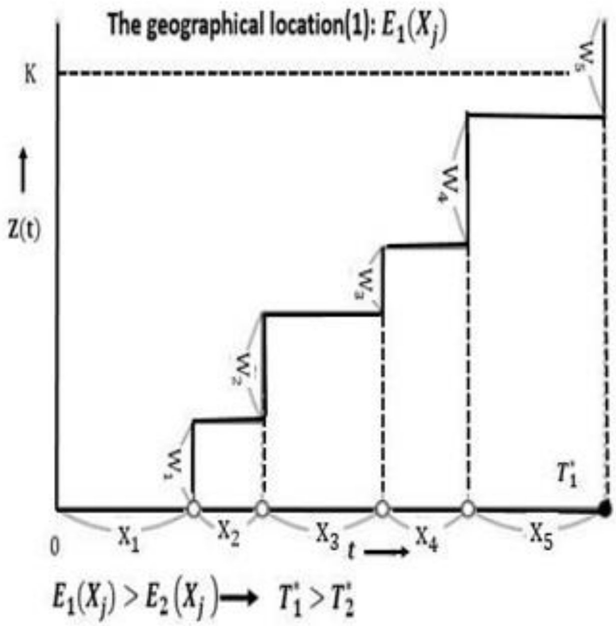

Figure 4. The geographical location (1)

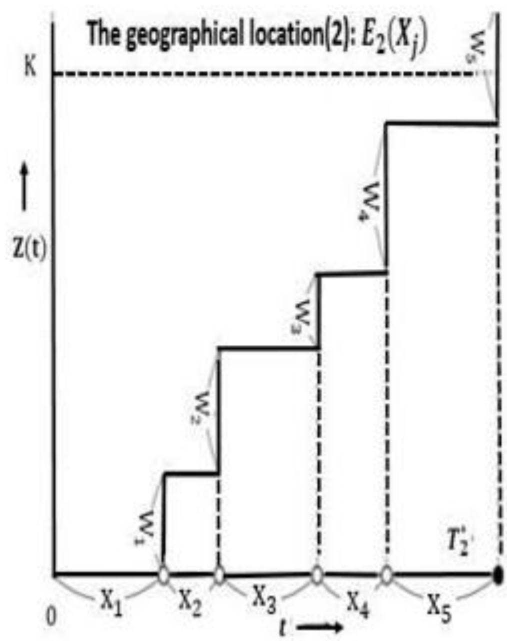

Figure 5. The geographical location (2)

5. Numerical example

Companies manufacture solar energy devices and export them to many countries with different climates, supplying electrical current. The contract between these companies and the countries is a long-term protection plan as the failure of the device becomes ineligible even for recycling in these companies, so the cost of failure of the device and its forced replacement becomes costly to these companies. Regarding these facts, the related companies are looking for a time to replace the device shortly before its failure in order to reduce the costs to the companies.

This is a company that exported devices to the regions of Western Asia, Mediterranean region and also African countries around the equator. The average climate fluctuation in the equatorial, the Mediterranean region and the desert region is 2, 2.5 and 3 days respectively. These rates are the mean time to enter climate shocks on solar energy devices, so $E_1(X_j)=\frac{1}{\lambda_1}=2$, $E_2(X_j)=\frac{1}{\lambda_2}=2.6$ and $E_3(X_j)=\frac{1}{\lambda_3}=3$. Figure 3 represents projects implemented by Ezzedine Solar Energy Factory in Lebanon.

Figure 6. Device in a topical area in Cote d’ivoir

Figure 7. Device in the Mediterranean in Beirut

Figure 8. Device in a desert region in Riyadh

The devices have a tolerance limit $k=15$ with every shock caused by fluctuation in the weather leaves damage to the device. The mean of the damage is $\mu = \frac{1}{100}$, when the total damage reaches the tolerance limit k, the device fails and we have to replace it. This replacement is mandatory and expensive, $C_K = 10000$ USD. In order to prevent the failure before it actually occurs, we carry out a preventive replacement in the device that costs $C_T = 1000$ USD.

Suppose that $F(t)=1-e^{-\lambda_i t}$, shocks occur in a Poisson process with rate $\frac{1}{\lambda_i}$ $(i = 1,2,3)$ and Z_j has Erlanger distribution, so

$$G_j(x) = 1 - \sum_{i=0}^{j-1} e^{-\frac{x}{\mu}} \frac{(\frac{x}{\mu})^i}{i!}.$$

To calculate the optimum time T^* for a preventive replacement of the device, we put all the values in the equation (7). We will repeat these accounts for each geographic location. The optimum time for preventive replacement for the device in equatorial region, Mediterranean region, and desert region is T_1^* , T_2^* and T_3^* respectively. The figure 4 is the result of our use of the equation (7) in a program maple.

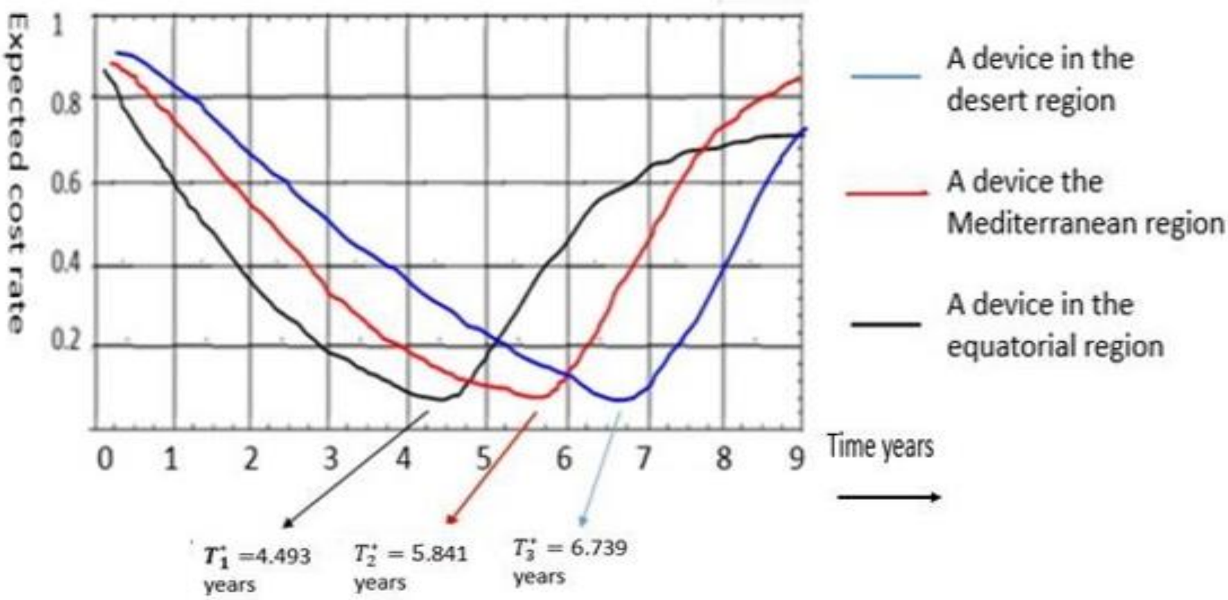

Figure 8. Diagram showing the expected cost rate of three devices in three different regions over time.

In Figure 8, the result of the optimum time for preventive replacement for the solar energy device in the desert region, the Mediterranean region, and the equatorial region is 6.739, 5.841, and 4.493 years respectively. Through equation (5), we were able to calculate the expected costs during the life cycle of the solar device in three different regions. In the desert it was expected to be 1326 USD, in the Mediterranean regions 1523 USD, whereas in equatorial region 1763 USD.

In Table 1, the mean climate fluctuations are changed and the optimum time change for the preventive replacement of the solar energy device is determined K is the endurance limit of the device, $E_i(X_j)$ is the mean time of shock occurrence in a geographical location (i), $E_1(X_j)$ is the average climate fluctuation in the equatorial region and is equal to 2 days, $E_2(X_j)$ is the average climate fluctuation in the Mediterranean region and is equal to 2.6 days, $E_3(X_j)$ is the average climate fluctuation in the desert region and is equal to 3 days. For number 4, we added it as the average incidence of shocks for a given geographic location, this is to show us in the table the effect of the high time of shock occurrence on the life of the device.

Table 1. The optimal time for preventive replacement for device after changed the mean climate fluctuations.

K	$E_i(X_i)=2$ T^*	$E_i(X_i)=2.6$ T^*
K=5	1.205	1.56 years
K=10	3.232	4.20 years
K=15	4.493	5.841 years
K=20	6.684	8.69 years

K	$E_i(X_i)=3$ T^*	$E_i(X_i)=4$ T^*
K=5	1.80	2.41 years
K=10	4.84	6.46 years
K=15	6.73	8.9 years
K=20	10.02	13.36 years

Table 1 indicated that the higher the average climate fluctuation, the greater the optimum time for a preventive replacement of a device. It is also shown that the better the industrial specifications (that is, the greater the tolerance limit of the device), the greater the optimum time for the preventive replacement of the device.

6. **Conclusions**

The optimum time for a preventive replacement of renewable energy devices varies from one geographical location to another due to the fact that each geographical location has its own climatic fluctuations. The higher the occurrence of climatic fluctuations in a geographical location, the shorter the optimal time for a preventive replacement of the device.

Using equations (5) and (7) we found that the useful life of a solar device in a desert is 6.739 years with an expected cost of 1326 USD, 5.841 years in the Mediterranean region with 1523 USD as expected costs, and 4.493 years with 1763 USD cost in the equatorial region.

The higher the average occurrence of climatic fluctuations, and as a result, the greater the optimal time for the protective replacement of the device. It was also indicated that the better the industrial qualifications (that is, a greater tolerance limit for the device), the greater the optimal time for a preventive replacement for the device. Therefore, companies that export these devices must study the geographical location where the device is exported and the climate in which it is distinguished in order to develop plans and programs to protect the device.

The main value of the article is that it allowed us to know the exact useful life of a device in addition to its expected costs in its life cycle, depending on the climate variability in a specific geographical locations and the tolerance limit of the device. The study of the geographical location and the related climatic shocks does not require a long time, and this is the main difference that this study achieved compared to its predecessors (who relied on monitoring the whole life of the device to determine its age and expected cost in its life cycle). Moreover, a new mathematical model that links climate fluctuations to the device's useful life and projected costs is now in action.

7. Appendix

How to calculate (4):

Use (4) for Calculate (4)

The mean time of one cycle is equal to

$$T\sum_{j=0}^{\infty}G_j(K)\left[F_j(T)-F_{j+1}(T)\right]+\sum_{j=0}^{\infty}(G_j(K)-G_{j+1}(K))\int_0^T t dF_{j+1}(t)=$$

$$=T\sum_{j=0}^{\infty}G_j(K)\left[F_j(T)-F_{j+1}(T)\right]+\sum_{j=0}^{\infty}(G_j(K)-G_{j+1}(K))(TF_{j+1}(T)-\int_0^T F_{j+1}(t)dt)=$$

$$=T\sum_{j=0}^{\infty}G_j(K)\left[F_j(T)-F_{j+1}(T)\right]+\sum_{j=0}^{\infty}(G_j(K)-G_{j+1}(K))\int_0^T F_{j+1}(t)dt=$$

$$=\sum_{j=0}^{\infty}G_j(K)\int_0^T(F_j(t)-F_{j+1}(t))dt.$$

How to calculate (7):

$$\frac{d\,C(T)}{dT}=0.$$

$$\frac{\left[(C_T-C_K)\sum_{j=0}^{\infty}G_j(K)[f_j(T)-f_{j+1}(T)]\times\sum_{j=0}^{\infty}\left(G_j(K)\right)\int_0^T(F_j(t)-F_{j+1}(t))dt\right]-\left[(C_T-C_K)\left(\sum_{j=0}^{\infty}G_j(K)[F_j(T)-F_{j+1}(T)]\right)^2+C_K\sum_{j=0}^{\infty}G_j(K)[F_j(T)-F_{j+1}(T)]\right]}{\left(\sum_{j=0}^{\infty}(G_j(K))\int_0^T(F_j(t)-F_{j+1}(t))dt\right)^2}=0$$

$$\frac{\left[(C_T-C_K)\sum_{j=0}^{\infty}G_j(K)[f_j(T)-f_{j+1}(T)]\times\sum_{j=0}^{\infty}\left(G_j(K)\right)\int_0^T(F_j(t)-F_{j+1}(t))dt\right]-\left[(C_T-C_K)\left(\sum_{j=0}^{\infty}G_j(K)[F_j(T)-F_{j+1}(T)]\right)^2\right]}{\sum_{j=0}^{\infty}G_j(K)[F_j(T)-F_{j+1}(T)]}=C_K$$

$$\frac{-\left[(C_K-C_T)\sum_{j=0}^{\infty}G_j(K)[f_j(T)-f_{j+1}(T)]\times\sum_{j=0}^{\infty}\left(G_j(K)\right)\int_0^T(F_j(t)-F_{j+1}(t))dt\right]+\left[(C_K-C_T)\left(\sum_{j=0}^{\infty}G_j(K)[F_j(T)-F_{j+1}(T)]\right)^2\right]}{\sum_{j=0}^{\infty}G_j(K)[F_j(T)-F_{j+1}(T)]}=C_K$$

$$\frac{-\left[(C_K-C_T)\sum_{j=0}^{\infty}G_j(K)[f_j(T)-f_{j+1}(T)]\right]\times\sum_{j=0}^{\infty}\left(G_j(K)\right)\int_0^T(F_j(t)-F_{j+1}(t))dt}{\sum_{j=0}^{\infty}G_j(K)[F_j(T)-F_{j+1}(T)]}+(C_K-C_T)\sum_{j=0}^{\infty}G_j(K)[F_j(T)-F_{j+1}(T)]=C_K$$

$$\frac{-\left[\sum_{j=0}^{\infty} G_j(K)\left[f_j(T)-f_{j+1}(T)\right]\right] \times \sum_{j=0}^{\infty}\left(G_j(K)\right)\int_0^T (F_j(t)-F_{j+1}(t))dt}{\sum_{j=0}^{\infty} G_j(K)\left[F_j(T)-F_{j+1}(T)\right]}+\sum_{j=0}^{\infty} G_j(K)\left[F_j(T)-F_{j+1}(T)\right]=\frac{C_K}{C_K-C_T}$$

$$\sum_{j=0}^{\infty} G_j(K)\left[F_j(T)-F_{j+1}(T)\right]-\frac{\left[\sum_{j=0}^{\infty} G_j(K)\left[f_j(T)-f_{j+1}(T)\right]\right] \times \left[\sum_{j=0}^{\infty}\left(G_j(K)\right)\int_0^T (F_j(t)-F_{j+1}(t))dt\right]}{\sum_{j=0}^{\infty} G_j(K)\left[F_j(T)-F_{j+1}(T)\right]}=\frac{1}{1-\frac{C_T}{C_K}}$$

Acknowledgements

The author thanks Ferdowsi University of Mashhad for his support.

Nomenclature

X_j: is the time interval between the occurrence of the $(j-1)^{th}$ shock and the occurrence of the $(j)^{th}$ shock

S_n: Is the time of $(n)^{th}$ shock occurrence

B (t): is the number of shocks that occurred until t

$Z(t)$: Is the total of damage due to shocks up to the Time t

C_K: Compulsory replacement cost for devices

$E_i(X_j)$: The mean time of shock occurrence in a geographical Location (i)

T^* Is the optimum time for preventive replacement for the device

$\frac{1}{\lambda_i}$ is the rate of shocks occur in a Poisson process in a geographical location (i).

References

1. Cox, D. R., *Renewal Theory*. Methuen, London,1962. United Kingdom.
2. Esary, J.D., Marshall, A.W. and Proschan, F., *Shock models and wear processes*. Annals of Probability,1973. **1**: p. 627-257.
3. Nakagawa,T. and Osaki, S., *Some aspects of damage model*. Microelectronics Reliability,1974. **13**: p. 253-257.
4. Savits, T.H., *Some multivariate distribution derived from a non-fatal shock model*. Journal of Applied Probability,1988. **25**: p. 283-390.
5. Gotlieb, G., *Failure distributions of shock models*. Appl. Probab., 1980. **17**: p. 745-752.
6. Ross, S.M., *Stochastic Processes*. John Wiley and Sons, 1983. New York.
7. Qian, C.H., Ito, K., and Nakagewa, T., *Optimal preventive maintenance policies for a shock model with given damage level*. J. Qual. Maint., 2005. **11**: p. 216-277.
8. Nakagewa, T. and Ito, K., *Comparison of three cumulative damage models*. Quality Technology and Quantitative Management, 2011. **8**: p. 57-66.
9. Satow, T. and Osaki, S., *Optimal replacement policies for a two-unit system with shock damage interactio*. Comput. Math, 2003. **46**: p. 1129-1138.
10. Sheu, S.H., et al., *Extended optimal replacement policy for a two-unit system with shock damage interaction*. IEEE Transactions on reliability, 2015. **64**: p. 998-1014.
11. Mathaios, P. and Pierluigi, M., *Influence of extreme weather and climate change on the resilience of power systems:Impacts and possible mitigation strategies*. Electric Power Systems Research, 2015.3: p.259-270.

12. David, L and Miguel, E., *Climate Change and Renewable Energy from the Ocean and Tides: Calming the Sea of Regulatory Uncertainty*. the International Journal of Marine and Coastal Law. 2009.4:p. 617- 651.
13. Sheu, S.H., Liu, T.H. and Zhang, Z.G., *Extended optimal replacement policies with random working cycle.* Reliability Engineering & System Safety. 2019.3:p. 398- 415.
14. Gregory, L., Maxim, F. and Yuanshun, D., *Optimal preventive replacement policy for homogeneous cold standby systems with reusable elements.* Reliability Engineering & System Safety. 2020.3:p.107- 135.
15. Nakagawa, T., *Shock and Damage Models in Reliability Theory.* Springer Science & Business Media, 2007.