

STUDY ON THE ESTIMATION OF THE DEMAND OF SPARE PARTS BY USING THE RENEWAL PROCESS

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ABSTRACT: The purpose of this paper is to estimate the amount of spare parts, for a specified operation period of a machine or equipment considering the renewal process, in order to forecast the need for spare parts, which is based on the renewal theory implying the explicit expression of the renewal function, the degree of failure also called the renewal rate function.

Keywords: spare parts, reliability, Weibull distribution, estimation, renewal.

1. GENERAL CONSIDERATIONS

In specialized literature there are a large number of references in the field of spare part supplies, especially in logistics.

Quantitative methods based on the theory of reliability, enable the estimation of the degree or the rate of failure for the items supplied (purchased) and/or stored, which is used for much more accurate determination of the rates of application.

The availability of the systems means that spare parts are always available upon request. However, estimating and calculating the amount of spare parts in order to ensure the availability of required taking into account the technical and economic requirements (reliability, maintainability, cost of operating time, etc.) have been taken into account and investigated very rarely.

Estimates are not precise enough, because in real situations, it has been demonstrated that there are a multitude of factors other than time, which have considerable influence on the characteristics of reliability of components and systems.

The environmental conditions in which a piece of equipment operates, such as temperature, humidity, dust, etc., often have a considerable influence on the reliability

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characteristics of the product, conditions which must be taken into consideration when sizing the logistics support, as well as when adopting a strategy of maintenance.

The most significant examples of environmental conditions in which the product works are:

- climatic conditions, such as temperature, pressure and humidity;
- environmental physical factors, such as dust, smoke, mist, corrosive agents and others similar to them;
- characteristics of the user such as operator skill, education, culture and language;
- the place of operation or location, which refers to the place and the space in which the equipment operates, in open or closed spaces, the branch of industry and/or other characteristics of the field, such as mining, underground or on the surface;
- the level of application, which refers to the importance of the system be it of a major, minor or auxiliary importance, or a waiting one;
- working time and length of operation, which refers to the fact that a product may be up and running, or only partially running.

2. THE RENEWAL MODEL FOR FORECASTING THE NEED FOR SPARE PARTS

The renewal theory is used to examine the functionality of equipment after the occurrence of failures, in order to establish the distribution of the number of spare parts, as well as their average number. This theory is the most appropriate means of forecasting the need for spare parts.

A process of renewal is characterized, for an entity, by the distribution time between renewal periods (number of failures), denoted by $F(t)$.

Considering $N(t)$ the number of renewals, i.e. the number of failures that occur at time t , and also considering the time of failure as a random variable X , $i \geq 1$, independent, characterized by the distribution function $F(t)$, then the probability distribution of the number of failures is given by the relation

$$P[N(t) = n] = F^n(t) - F^{n+1}(t), \quad (1)$$

where $F^n(t)$ represents the probability that the n -th malfunction should occur at time t , which is expressed by the relation

$$F^n(t) = \int_0^t F^{n-1}(t-x) dF(x). \quad (2)$$

The number of failures, $M(t)$, during the period of time t , is given by the relation

$$M(t) = \sum_{n=1}^{\infty} F^n(t). \quad (3)$$

This relation is known as *the renewal function*, which expresses the number of renewals on the interval $(0, t]$, and which can be written in the following form

$$M(t) = F(t) + \int_0^t M(t-x)f(x)dx. \quad (4)$$

It is well known that for an exponential distribution of failure time, the distribution function is $F(t)=1-\exp(-\lambda t)$, while for the Weibull reliability model, which is the most appropriate model for characterizing the length of service of mechanical components (mechanical systems), it is $F(t)=1-\exp[-(t/\eta)^\beta]$.

The following conditions shall be met:

- the average time of failure of the components replaced is $E[t]$, MTTF;
- the standard deviation of the time failure is $\sigma(t)$;
- the variation coefficient of the time of failure is $(CV) = \sigma(t)/E[t]$;
- the operating time, t , of the system or machinery which contains replaced elements is long enough and there is the need for more replacements during this period.

Under these conditions the average number of failures during the time $(0, t]$, $E[N(t)] = M(t)$, could stabilize around the asymptotic value of the renewal function,

$$N(t) = M(t) = E[N(t)] = \frac{t}{E[t]} + \frac{(CV)^2 - 1}{2}. \quad (5)$$

Accordingly, the degree of failure or the renewal rate function is

$$m(t) = \frac{dM(t)}{dt} = \frac{dE[N(t)]}{dt} = \frac{1}{E[t]}. \quad (6)$$

The standard deviation of the number of failures during $(0, t]$ period of time is

$$\sigma[N(t)] = (CV) \sqrt{\frac{t}{E[t]}}. \quad (7)$$

If the period of time is sufficiently long, then the number of failures, $N(t)$ is distributed according to an approximately normal value (according to the central limit theorem) with the help of an average $\bar{N}(t)$. Under the circumstances, the approximate number of spare parts, N_t , needed for the length of service $(0, t]$, with a confidence level p , is given by the relation:

$$N_t = \frac{t}{E[t]} + \frac{(CV)^2 - 1}{2} + (CV) \sqrt{\frac{t}{E[t]}} \Phi^{-1}(p), \quad (7)$$

where $\Phi^{-1}(p)$ represents the reverse rated normal distribution function.

The graphics in figures 1...5 show the dependencies between the number of spare parts required for the maintenance of a product according to the ratio of the cumulative and average running time, $t/E(t)$ or $t/MTTF$, in the case of Weibull distribution, for different values of the shape parameter β (1; 1; 1; 2; 3; 4; 5; 6) and different levels of reliability.

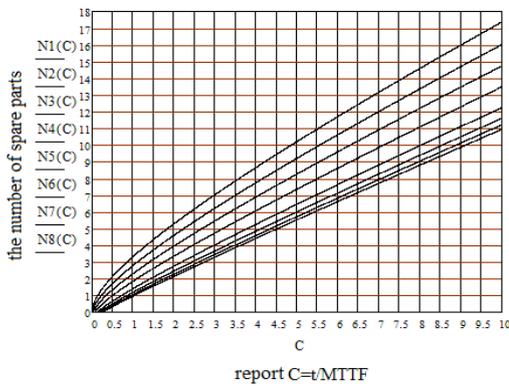


Fig. 1. The number of spare parts related to the mean failure period, 2-parameter Weibull distribution with the following parameter 1; 1,2; 1,5; 2; 3; 4; 5; 6, the level of reliability of 0,99, the renewal process model

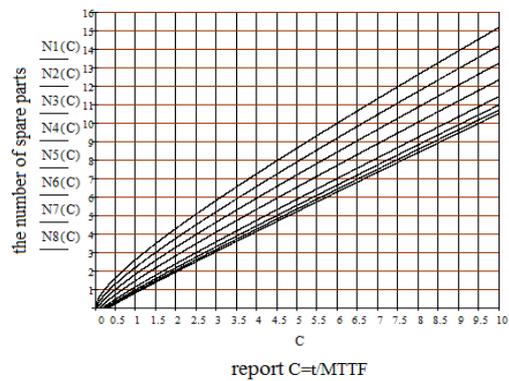


Fig. 2. The number of spare parts related to the mean failure period, 2-parameter Weibull distribution with the following parameter 1; 1,2; 1,5; 2; 3; 4; 5; 6, the level of reliability of 0,95, , the renewal process model

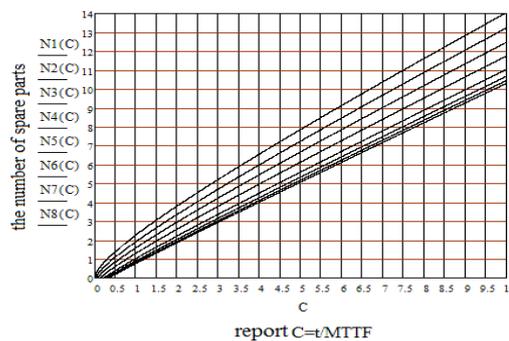


Fig. 3. The number of spare parts related to the mean failure period, 2-parameter Weibull distribution with the following parameter 1; 1,2; 1,5; 2; 3; 4; 5; 6, the level of reliability of 0,90, , the renewal process model

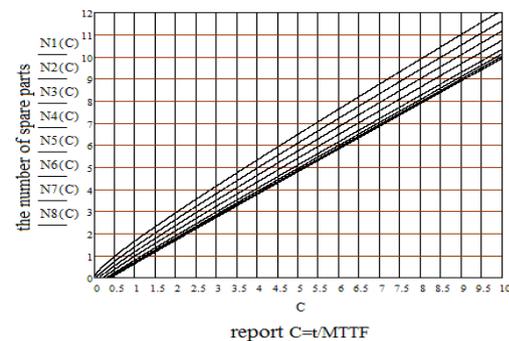


Fig. 4. The number of spare parts related to the mean failure period, 2-parameter Weibull distribution with the following parameter 1; 1,2; 1,5; 2; 3; 4; 5; 6, the level of reliability of 0,75, , the renewal process model

The graphics in figures 1... 5 represent monograms of a general nature which can determine the necessary spare parts, for any machinery the operation of which, including the distribution of the number of spare parts, is governed by the Weibull distribution law. Knowing the shape parameter β and the mean operating time until failure, MTTF, allows direct reading of the provision of spare parts, for an imposed cumulative period of time.

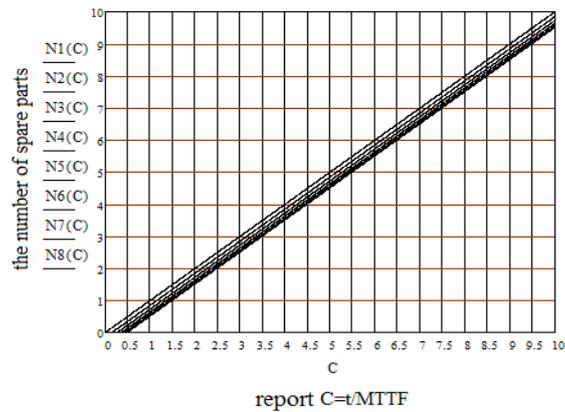


Fig. 5. The number of spare parts related to the mean failure period, 2-parameter Weibull distribution with the following parameter 1; 1,2; 1,5; 2; 3; 4; 5; 6, the level of reliability of 0,50, , the renewal process model

3. CASE STUDY

In the case of the three components of the machineries used for loading, transportation and storage, i.e. the linear hydraulic engine for handling the bucket, the hydraulic piston pump of the brake circuit and the brake pads within the same braking system, the issue of estimating the need for spare parts arises, using the renewal process model for forecasting the demand, for a length of service of 10,000 hours of operation, which means a period of approximately four years.

Table 1. The demand of spare parts for an operating length of 4 years

Nr. crt.	Analyzed product, spare part	β	MTTF, h	t, h	Report t/MTTF	Number of spare parts, n				
						Approximate method				
						Level of reliability, γ				
						0,99	0,95	0,90	0,75	0,50
1	Linear hydraulic engine	2,065	2171	10000	4,60	6	6	5	5	4
2	Hydraulic pump	5,005	6834		1,46	1	1	1	1	1
3	Brake pads	6,543	1512		6,61	7	6	6	6	6

Table 1 reveals the sizes necessary for the implementation of the renewal process model for the three products, namely the shape parameter β and the mean operating time until failure, MTTR, together with values for the number of spare parts required for a period of four years, estimated using monograms characteristic to the approximate method, database diagrams, figs. 1 ... 5.

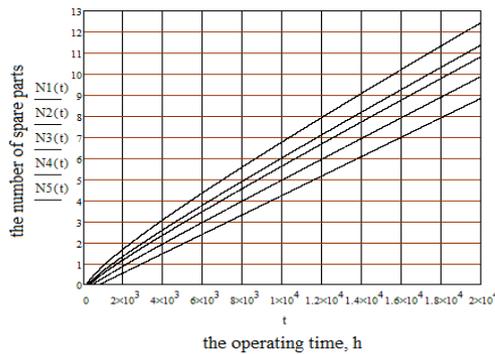


Fig. 6. The number of spare parts depending on the cumulative operating time for linear hydraulic engine, levels of reliability 0.99; 0.95; 0.90; 0.75; 0.50, renewal process model

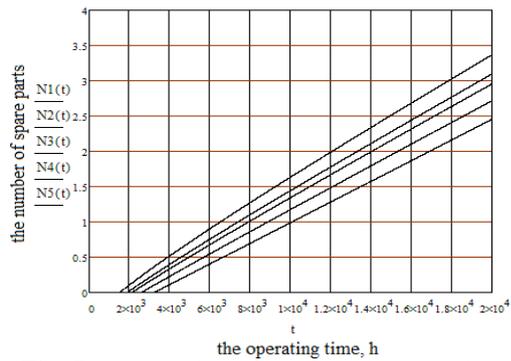


Fig. 7. The number of spare parts depending on the cumulative operating time for the hydraulic pump of the brake circuit, levels of reliability 0.99; 0.95; 0.90; 0.75; 0.50, renewal process model

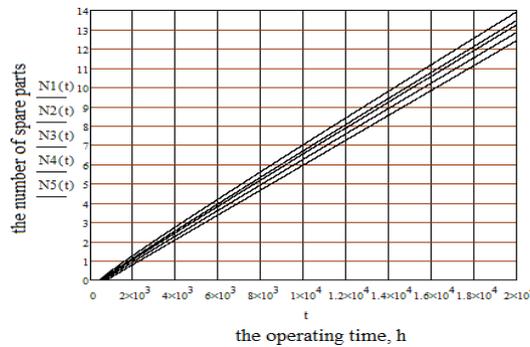


Fig. 8. The number of spare parts depending on the cumulative operating time for brake pads, levels of reliability 0.99; 0.95; 0.90; 0.75; 0.50, renewal process model

In figures 6, 7 and 8 there are given the necessary spare parts depending on the operating time of the three components of the loading, transportation and storage machineries under study. The graphics are obtained by using the relation (7) and the parameters included in table 1. The levels of reliability are distributed on the graphical representation from top to bottom with decreasing values specified in the field of representation.

Comparing the two methods of estimating the amount of spare parts, that is to say the centralized supply model and that of the renewal process, respectively one can notice that the values are significant; those obtained for the levels of reliability taken into account are almost identical, with the remark that for the renewal process model, for large values of the levels of reliability, especially for 0.99, one unit lower values are obtained for the number of spare parts, which shows, overall, the viability of both methods of stock estimation.

4. CONCLUSIONS

The study shows that the number of spare parts required for a period of four years, is quite large and that demonstrates the low level of reliability of the products reviewed.

Considering the Weibullian character of the products, the entire theoretical reasoning, combined with practical technical aspects is materialized by an explicit mathematical relation the approximate solving of which translates into a set of charts that enable the estimation of the demand for spare parts, according to the ratio of the length of time taken into account and the average operating time until failure.

The model also allows direct expression, for a particular product the functioning of which is governed by the Weibull distribution, of the number of spare parts required for a specific period of time.

The renewal process can be transposed, through a case study into the products analyzed using the model shown above. The result of the analysis leads to overlapping the results almost entirely, except for the reliability level of 99%, for which the values are lower, usually by a unit.

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