UNIVERSITÀ DEGLI STUDI DI TRIESTE

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INDUSTRIAL PLANTS II

Chapter two ï part 5

Maintenance of Industrial Plants

Spare Parts Management

DOUBLE DEGREE MASTER IN

ñPRODUCTION ENGINEERING AND MANAGEMENTò

CAMPUS OF PORDENONE

UNIVERSITY OF TRIESTE

SPARE PARTS MANAGEMENT

Introduction

In order to obtain an acceptable **level of availability of the machinery** installed in an industrial plant, it is necessary to maintain an adequate stock of spare parts resulting in a substantial economic weight. The problem is the determination of the various stock levels to minimize the **overall maintenance costs of spare parts and the lack of production due to unavailability of the same.**

The achievement of this objective is complex, as the **management of the spare parts warehouse** is different from other material management (raw materials, semi-finished products, finished products, etc.), due to the fact that the fixed assets are very high and the rotation index of materials is very low.

Spare parts are vitally important because they influence a lot the parameter **availability A**:

$$A = \frac{MTBF}{(MTBF + MTTR + MTWS)} = \frac{MTBF}{(MTBF + MDT)}$$

where:

MTBF = mean time between failures (reliability index);

MTTR = mean time for repair (maintainability index);

MTWS = mean waiting time of spare parts;

MDT = mean down time

SPARE PARTS MANAGEMENT

main characteristics of spare parts

materials consumed in small quantities

materials to be used in the medium or long term

materials with different, specific and exclusive uses

high storage costs
- **High stock**
- **Low turnover**

SPARE PARTS MANAGEMENT

Spare parts coding

The correct coding of technical materials is very important for their management; operationally the problem is not as simple as it may seem from a theoretical point of view.

Coding allows to :

- Å **identify** clearly and unambiguously the spare parts
- Å **facilitate** the immediate localization in the warehouse
- Å **provide** useful indications on the possible functional interchangeability with other similar parts
- Å **standardize** materials and machinery,
- Å **manage** them by an IT system.

SPARE PARTS MANAGEMENT

Spare parts coding

Progressive code

Functional code

Speaking with keys code

Mixed type code

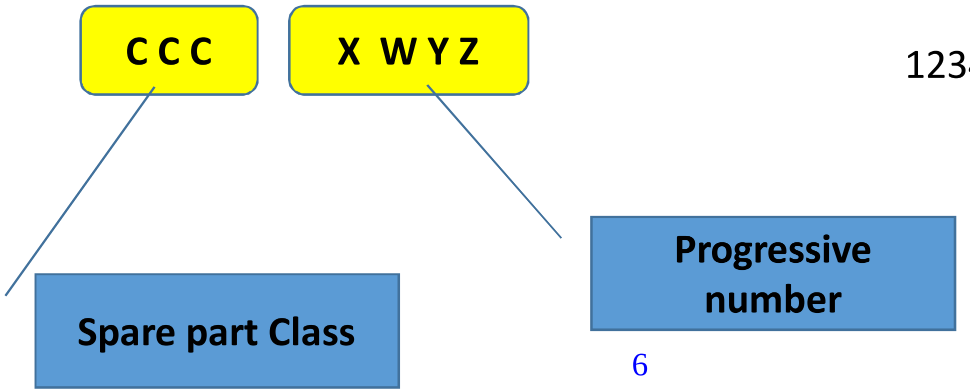
SPARE PARTS MANAGEMENT

Spare parts coding

a) Progressive or chronological code

Once the class of the spare part has been determined, its code is characterized by **two or three digits** which allow it to be identified in progressive order. This coding is easy and inexpensive to do, but it has to be managed carefully due to the consequences it can bring, namely:

- assigning multiple codes to the same object;
- difficulty/impossibility in detecting interchangeability;
- impossibility to characterize similar materials and to make both technical and economic comparisons;



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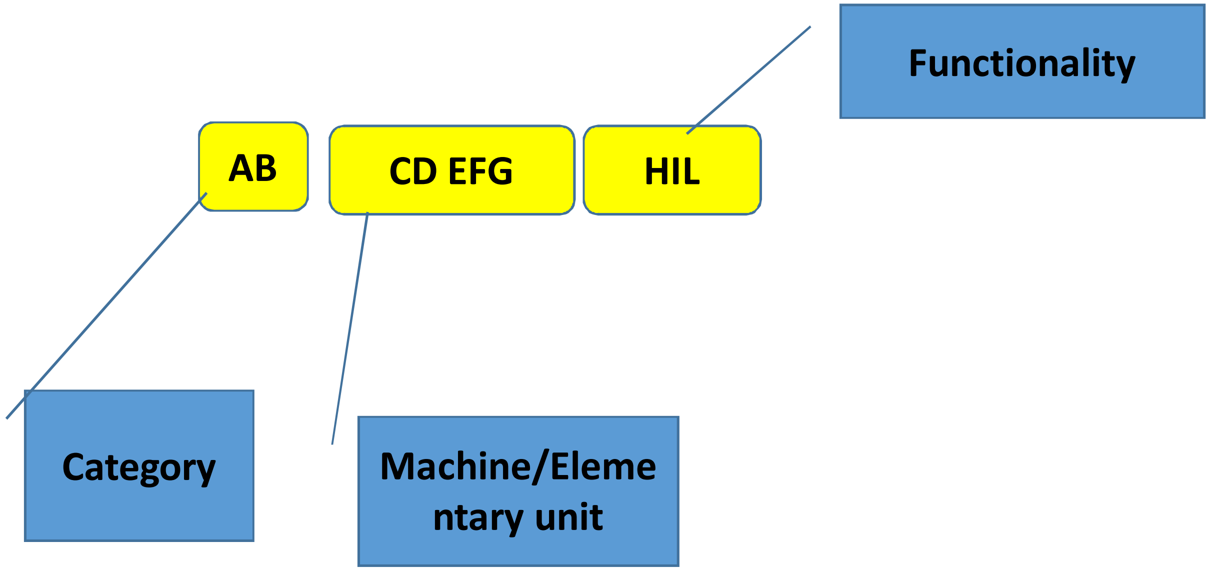
SPARE PARTS MANAGEMENT

Spare parts coding

b) functional code

The code is constructed so as to be able to locate a certain component within the system without adding anything regarding the type and characteristics of the component. It consists of **three groups of digits or letters**, which are used to identify the category to which they belong, the machine and the elementary unit on which the spare is mounted and, finally, the relative functionality. The code is simple to interpret, allowing for easy localization of the piece, but has the disadvantage of not being able to uniquely identify the type of spare part, with the danger of creating multiple stocks, and not allowing the standardization of the same in any way;



SPARE PARTS MANAGEMENT

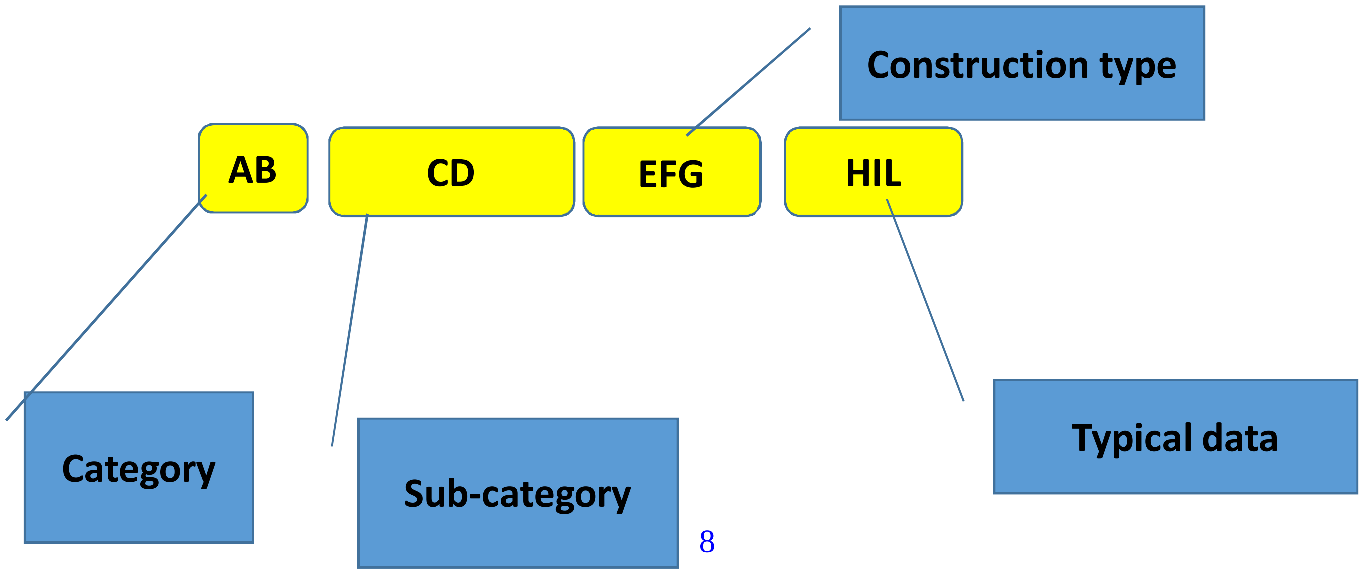
Spare parts coding

c) structural descriptive code (speaking with key)

This code contains more information than the previous two, but it is more difficult to implement and more expensive, both to generate and to manage..

The descriptive structural type code consists of **four groups of letters or numbers** to identify, in the order, the category to which the spare part belongs, the subcategory, the construction type and the typical data of the component under examination (dimensions, technical characteristics etc.).

Eg:



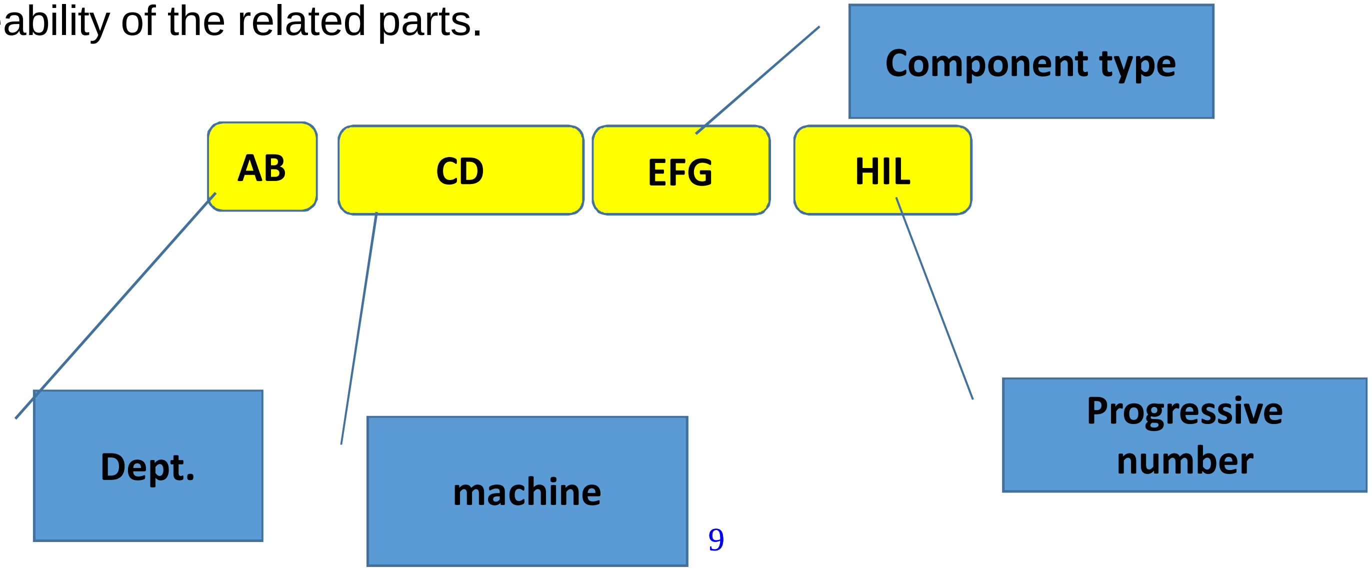
SPARE PARTS MANAGEMENT

Spare parts coding

d) mixed type code (functional, descriptive, enumerative)

Defined as a synthesis of the codes previously seen, it is the most difficult to create and the most expensive to implement even if it combines the advantages of the previous ones.

It generally consists of **four groups of letters or digits**, which are used to define, in order, the department, the machine or the operating unit on which the piece is mounted, the type of component and, finally, the enumerative type code. . This code lends itself to an excellent location of the spare part, but, although possible, it does not lend itself to easily provide data on the standardization and interchangeability of the related parts.



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SPARE PARTS MANAGEMENT

Spare parts classification

Operating characteristics

- **criticality of use (risk and costs)**
- **type of physical failure process, which generates the request for the spare part (failure due to wear or fatigue, accidental failure, induced failure etc.);**
- **average consumption per unit of time**
- **Purchasing unit cost**

SPARE PARTS MANAGEMENT

Spare parts classification

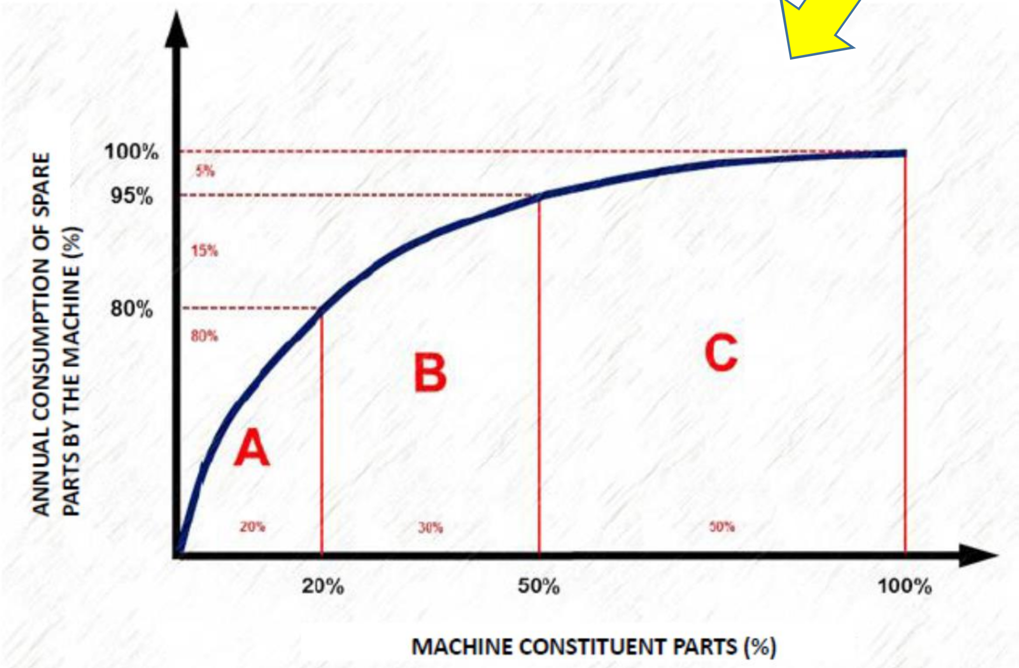
Failure process

purely accidental faults: the request is sudden and completely unpredictable. They are described by a negative exponential probability density function

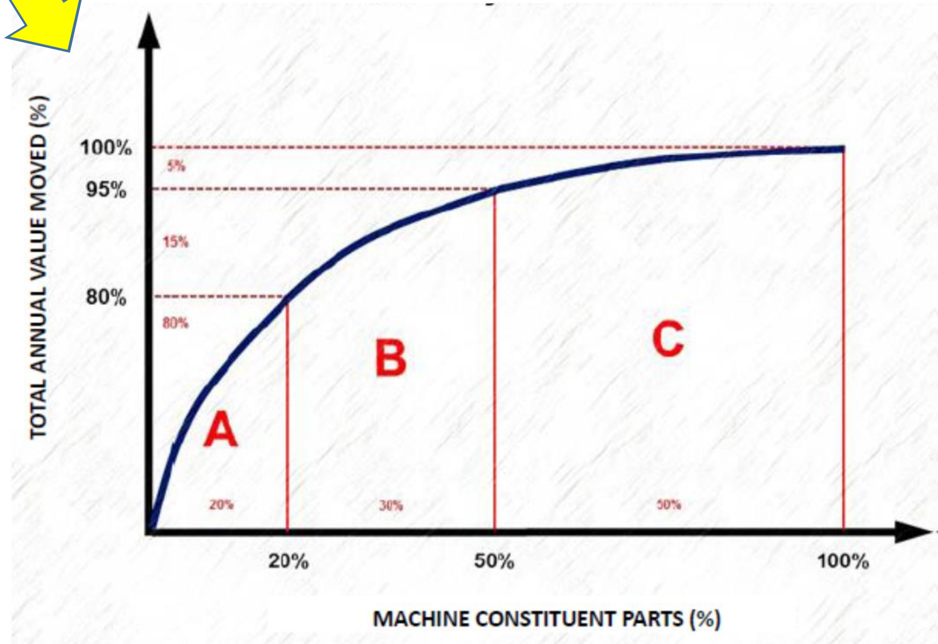
more or less foreseeable faults in statistical terms (faults due to wear, fatigue, corrosion etc.): there is an interval between the requests for pieces in the warehouse, which tends to be distributed around a more probable value. The fault law can be expressed by the Weibull law or by a normal or Gauss distribution.

SPARE PARTS MANAGEMENT

Spare parts classification
Request and value



Annual intensity of request for spare parts according to the parts making up the machine



Total annual value moved according to the parts making up the machine

SPARE PARTS MANAGEMENT

Spare parts classification
Rotation index

spare parts with low rotation index

They present a low annual consumption, due to an high unit value, a high criticality of use, an unpredictable demand (accidental breakdowns), poor or no repairability, high risks of obsolescence related to the specific use and, from a point of economic-managerial view, long supply times and fixed assets; **s**

Spare parts with normal rotation index

They have complementary characteristics to those set out for low rotation index spare parts.

a) **vital pieces**, the failure of which determines the stop of the production process with consequent high cost of absence;
b) **essential pieces**, the failure of which can be tolerated for short periods with consequent moderate cost of absence;
c) **auxiliary parts**, the failure of which does not have consequences on production in short times with consequences of low cost of absence.

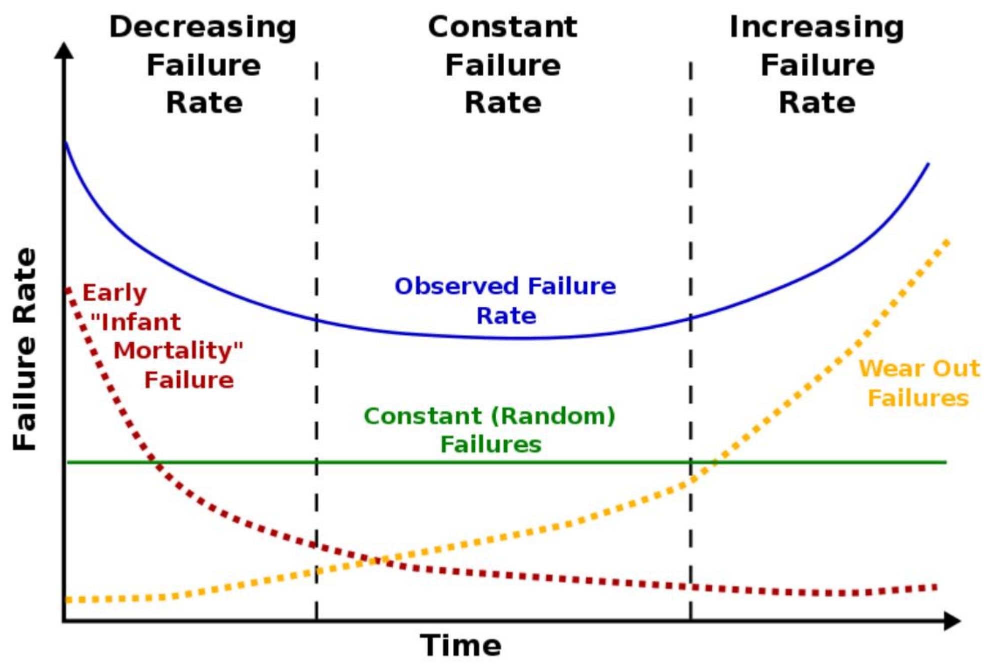
SPARE PARTS MANAGEMENT

Assessment of needs

The problem to be solved is to predict the consumption of the parts in advance, in order to determine the stock levels.

During the start-up phase of a new plant, the estimation of needs is difficult, as there is no possibility to rely on historical data: in these cases, evaluations are carried out by **machine manufacturers,** which are not always accurate for commercial reasons. It is not possible to evaluate the initial stock levels on the basis of quantitative criteria: it must be entrusted to qualitative and subjective elements such as **experience**, **trust of suppliers, financial availability and sensitivity of the designers.**

Immediate **verification and updating of the initial estimates** is necessary in order to correct any errors. This verification can be carried out by detecting the operating data (location form, withdrawal form and spare part form) and comparing them with the initial estimates, in order to update and correct them.

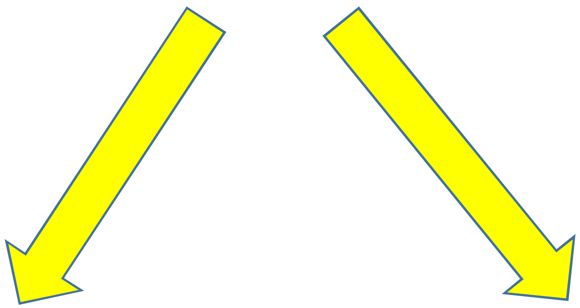


SPARE PARTS MANAGEMENT

Assessment of needs

Due to the fact we do not want to have an overstock of parts normally with low rotation index or very low rotation index, it is necessary to carefully evaluate the possible consumption per period of time. The considerations differ according to the rotation index value.

Criteria



Normally low rotation index

Very low rotation index

SPARE PARTS MANAGEMENT

Assessment of needs

Low rotation index spare parts mounted on a machine

For these materials mounted on a single machine, the assessment of needs of spare parts can be defined by applying the **Bayesian technique,** where we update the probability of an hypothesis as soon as we have the availability of more evidence or information.

The current estimate of spare parts requests is equal to the **initial estimate multiplied by a corrective factor taken from the operating data** and, in particular, from the average consumption of spare parts.

Therefore, there will be an average consumption in the unit of time C_f, updated according to the actual requests, defined by the relationship:

$$C_f = C_i \cdot \frac{(Y+1)}{(T \cdot C_i + 1)}$$

where:

C_i = average consumption in the unit of time estimated initially;

Y = consumption of spare parts ascertained at time T;

T = time elapsed since the initial estimate.

This C_f relationship allows you to update, by correcting them, the initial estimates which, according to the requests for exercise, make them tend to "**likely**" consumption values.

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SPARE PARTS MANAGEMENT

Assessment of needs

Low rotation index spare parts mounted on several machines

In industrial plants it often happens that the **same component is mounted simultaneously on several identical or similar machines** and therefore the request for the corresponding spare part is due to the request for several machines involved.

The problem is to calculate the total requirement, known that the requests relating to the individual machines are detectable on the basis of the average value and the variance in the consumption of pieces expected.

The Poisson distribution

The number of such events that occur during a fixed time interval is, under the right circumstances, a random number with a Poisson distribution that can be applied to these systems because it presents **a large number of possible events, each of them rare.**

The equation can be adapted if, instead of the average number of events ῎Ἀ̣ , we are given the average rate at which events occur.

In probability theory and statistics, the Poisson distribution is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time if these events occur with a known constant mean rate and independently of the time since the last event.

SPARE PARTS MANAGEMENT

Assessment of needs

Low rotation index spare parts mounted on several machines

We can assume that the result of the requests of all the machines follows a Poisson distribution law having the average ʺẠof the distribution equal to the sum of the C_{gi} consumption per period relating to each of the n machines on which the spare is mounted. Therefore:

$$\lambda = \sum_{i=1}^{n} C_{gi}$$

The probability that the overall needs for n machines of that spare part in a certain period of time T is equal to a certain value N will be expressed by the relationship given by the Poisson formula:

$$P(\wedge, T, N) = \frac{(\lambda \cdot T)^N \cdot e^{-\lambda T}}{N!}$$

By recursively evaluating the requests of each of the n machines, applying the Bayes formula and adding them, it is possible to obtain the average consumption of a low rotation index spare part mounted on several machines.

SPARE PARTS MANAGEMENT

Assessment of needs

Spare parts with normal rotation index

With regard to this type of spare parts, the "**exponential smoothing**" can be used as a forecasting technique. Its application requires the knowledge of two quantities:

- consumption forecasts for the previous period (A_i);
- actual consumption of pieces (B_i) occurred in the same time period

The **error** made between the forecast of consumption and actual consumption results :

$$E_i = B_i - A_i$$

therefore, having to reformulate the forecast of consumption in the subsequent period i+1 will occur:

$$A_{i+1} = A_i + \alpha \cdot E_i = A_i + \alpha \cdot (B_i - A_i) = \alpha \cdot B_i + (1 - \alpha) \cdot A_i$$

with α = coefficient variable between 0 and 1.

SPARE PARTS MANAGEMENT

Assessment of needs

Spare parts with normal rotation index

If the value 1 is attributed to α, i.e. all the error committed is added to the expected consumption, no account will be taken of the previous forecast, while, if it α is assumed to be less than 1, i.e. the previous forecast is trusted, it will be held account to some extent of the error committed to arrive at a new estimate of consumption.

It can be noted that in the forecast of consumption in the period before A_i all the information on past consumption is condensed. So you can write:

$$A_i = \alpha \cdot B_{i-1} + (1-\alpha) \cdot A_{i-1}$$
$$A_{i-1} = \alpha \cdot B_{i-2} + (1-\alpha) \cdot A_{i-2}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$

from which it will be possible to go back to the final report on the estimate, which consists of the previous estimates multiplied by a coefficient, which decreases as the age of the data increases:

$$A_i = \alpha \cdot [B_{i-1} + (1-\alpha) \cdot B_{i-2} + (1-\alpha)^2 \cdot B_{i-3} + \ldots\ldots + (1-\alpha)^{n-1} \cdot B_{i-n}]$$

The exponential damping induced indicates that the weight of demand decreases over time with exponential law.

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Low rotation index spare parts almost always have the following characteristics:

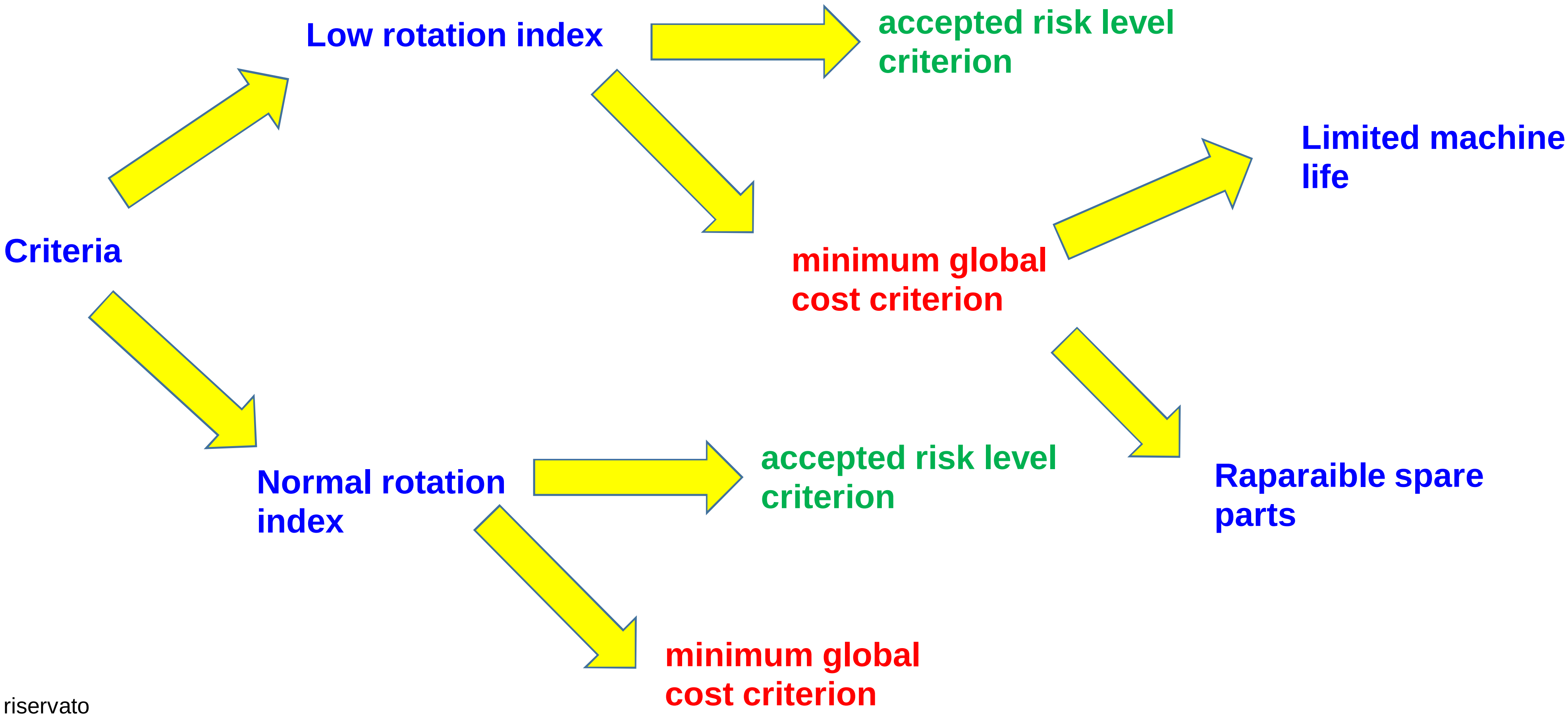
- **low annual consumption** (maximum 1 piece per year);
- **high criticality of use to ensure business continuity**;
- **accidental breakdowns** (unpredictable);
- **high unit cost of purchase**.

Usually, the rules followed for the determination of the quantity of reordering require to acquire no more than one piece at a time, since together with the high unit cost there are risks deriving from obsolescence, due to stocks higher than the unit one.

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

The management policy, in this case, consists in constantly keeping the stock at the same level of pre-established availability (physical stock plus pending orders).



SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Accepted risk level criterion

This method is used when the low value of the capital immobilized by the replacement or other difficulties allows us avoiding an out-of-stock and the pertinent costs.

The phenomenon in question (accidental failure and rarity of the event) is described by Poisson's law, which allows to calculate the **probability of not going below stock in a supply time T (Service Level)**, having fixed the average consumption λ expected in the unit of time and the level of stock N. You will therefore have:

$$P_{T,\lambda,N} = \sum_{X=0}^{N} e^{-\lambda T} \cdot \frac{(\lambda \cdot T)^X}{X!}$$

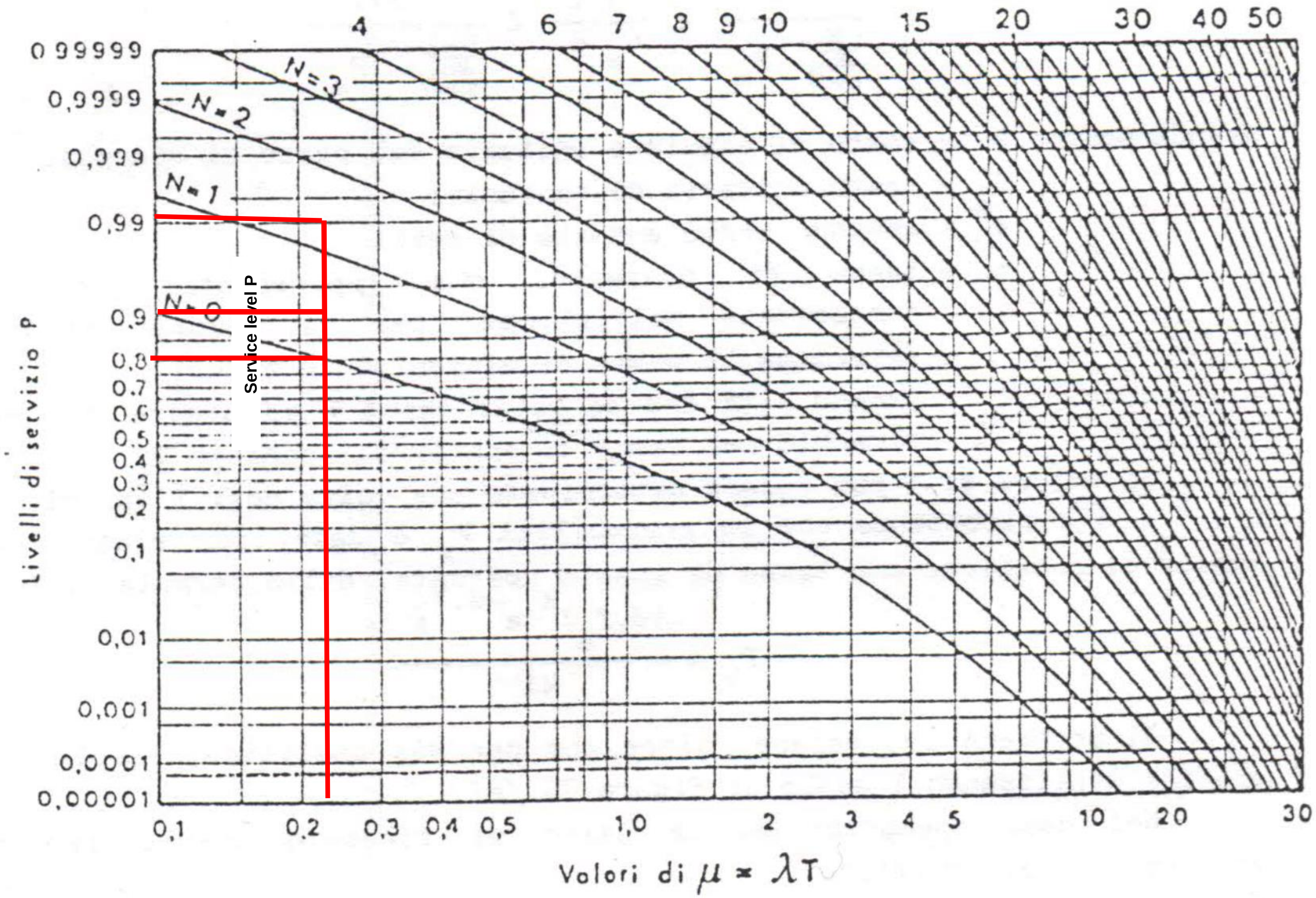
Operationally, the level of service or the probability of not going under stock is fixed a priori and the value of reordering N is known, known the value of λ and T

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Accepted risk level criterion

The problem can be solved graphically by using, for example, the schedule shown in the figure where, in correspondence with the chosen service level and knowledge of the expected average consumption in the unit of time λ and the supply time T, it is possible to determine the spare N level for the spare part considered



SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Accepted risk level criterion

Referring to an expected consumption λ of 0.9 pieces / year and a supply time T of 3 months, corresponding to a product value λ·T of:

$$\mu = \lambda \cdot T = \frac{0,9}{12} \cdot 3 = 0,225 \quad \text{pieces}$$

and having previously selected 3 service levels (P = 0.8, 0.9 and 0.99) from the schedule in figure, it is possible to determine the 3 values of the corresponding stock level N:

- Service level P = 0,8 Stock level N = 0
- Service level P = 0,9 Stock level N = 0.3 rounded to 1
- Service level P = 0,99 Stock level N = 1,25 rounded to 2

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion

According to this methodology, it is necessary to research that **cost that minimizes the sum of the cost of absence**, resulting from the plant shutdown and the consequent lack of production, and the **cost of ownership**, resulting from the maintenance of spare parts of high economic value in the warehouse.

It can be shown that the optimal stock level N, relative to the minimum cost, is that which verifies the double inequality:

$$\frac{P_N}{\sum_{m=0}^{N} P_m} < \frac{R \cdot t}{C_m \cdot d} < \frac{P_{N-1}}{\sum_{m=0}^{N-1} P_m}$$

where:

R = unit purchase cost of the spare part;

C_m = unit cost of absence;

d = average annual consumption of pieces;

t = rate of ownership representing the percentage factor multiplied by the unit value that determines the annual maintenance cost;

P_m = probability that m requests of the same spare part occur in the supply time T_a.

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion

The N value can be determined once the values of R, T, C_m, T_a and d are known, and remembering that the probability P_k is given, for low rotation index spare parts with constant failure rate, by the Poisson formula:

$$P_k = \frac{(d \cdot T_a)^k \cdot e^{-d \cdot T_a}}{k!}$$

In the specific case of a spare part having the following characteristic sizes:

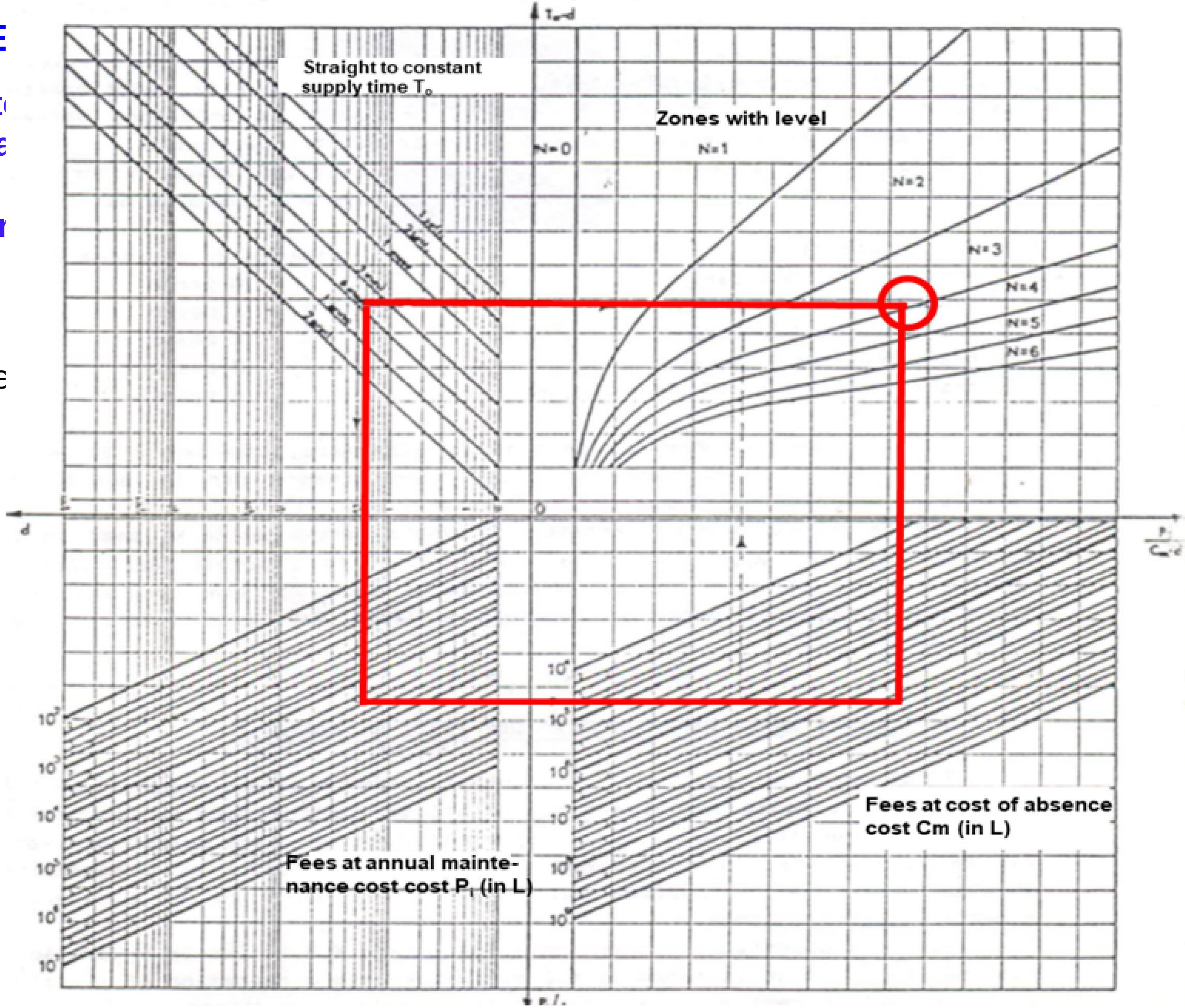
- average annual consumption d = 1 piece / year;
- unit purchase cost of the spare part $R = 2 \cdot 10^5$ ú;
- possession rate t = 10%;
- procurement time T_a = 3 months;
- constant annual maintenance cost $P_i = R \cdot t = 2 \cdot 10^4$ ú;
- unit cost of absence $C_m = 10^6$ ú;
- an optimal level N equal to 3 pieces is obtained, which represent the total between physical stock and ordered pieces.

SPARE PARTS MANAGE

Methods and management crit low rotation index spare pa

Minimum overall cost criter

The problem can also be solved graphically by using the schedule abacus of figure



Abacus relating to the minimum global cost management criterion

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion

Among all the quantities considered, the most difficult parameter to estimate is the unit cost of failure C_m, which can be expressed by means of the relationship:

$$C_m = C \cdot (t_2 - t_1)$$

where:

C = cost of absence in the unit of time of the machine to which the spare part refers;

t_1 = total repair time when the fault occurs with stock greater than zero;

t_2 = total repair time when the failure occurs and the spare part is not present in the warehouse.

The determination of the values of C, t_1 e t_2 is quite difficult, but for the purpose of determining the level of reordering N, the exact quantification of these parameters is not critical, as the optimal solution does not change even for fairly large variations of the three parameters.

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion

Considering the example above and having the same values (d = 1 piece / hour, $R = 2 \cdot 10^5$ ú, t = 10% e T_a = 3 months), based on the schedule shown, we have:

Cost of absence C_m	Reorder level N
Less than 20.000 €	0 pieces
Between 20.000 and 70.000 €	1 piece
Between 70.000 and 1.000.000 €	2 pieces
Between 1.000.000 and 15.000.000 €	3 pieces
Between 15.000.000 and 150.000.000 €	4 pieces

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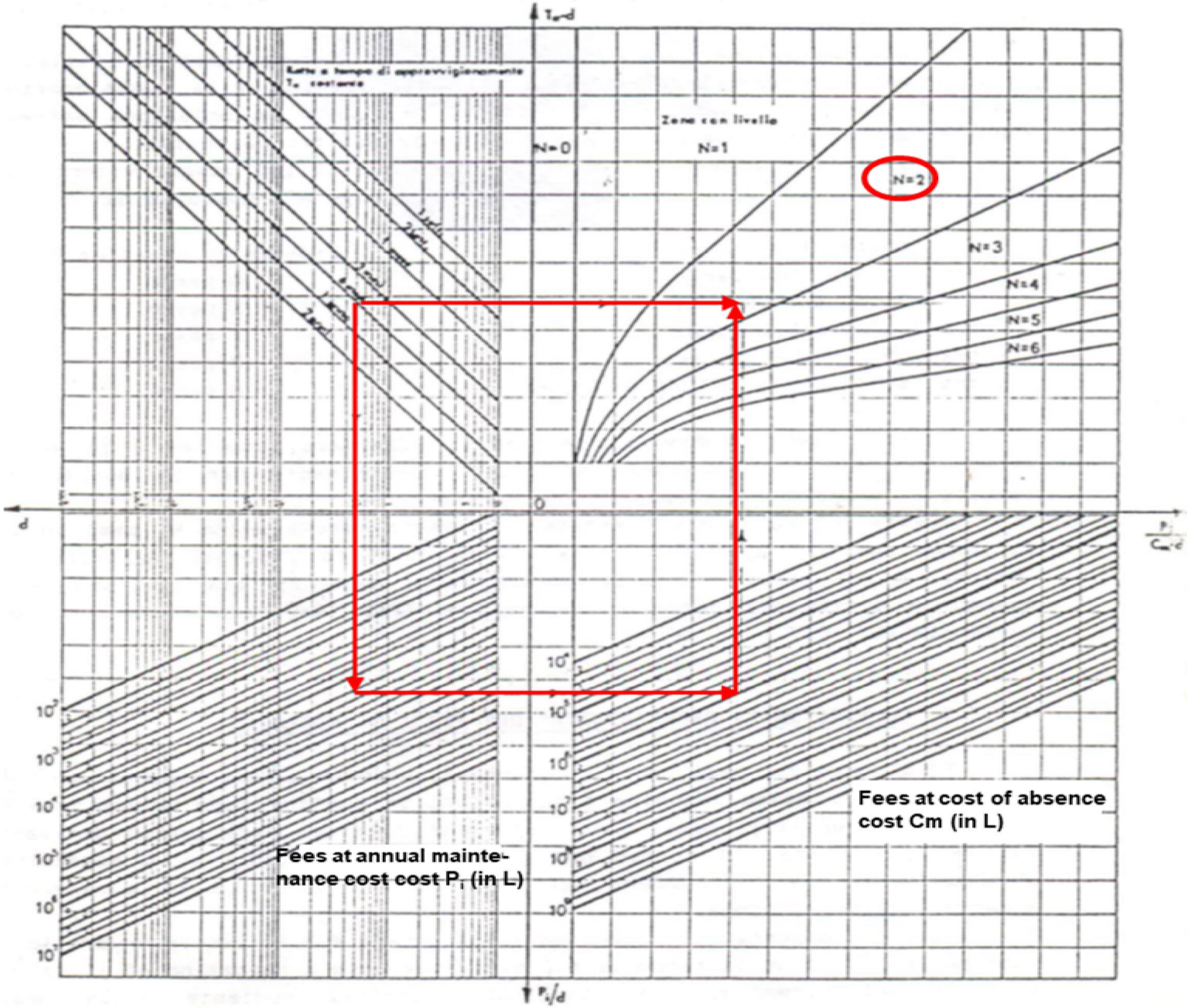
SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion



Materiale riservato
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SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion - Effects of reparability of spare parts

This happens when the **parts can be repaired with/without dismantling them** from the machine or adjusting them, while awaiting replacement with other new parts. The relative cost will equal up to the downtime, as there is no request of material from the warehouse. The consequence is minor cost of absence and a production increase.

In this management model the consumption is unchanged, but changes the time of supply in the warehouse and the unit value of the spare part, which are calculated by means of weight averages.

The weighted average value of the repairable spare part R* is:

$$R^* = \frac{(R + r \cdot R_1)}{(1 + r)}$$

Where:

R = unit purchasing cost of the spare part

R_1 = average repair cost

r = percentage of possible repairs in the workshop

T_a^* = weighted average supply time

T_a = supply time

T'_a = average repair time

$$T_a^* = \frac{(T_a + r \cdot T'_a)}{(1 + r)}$$

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion – limited machine life

In case of machines close to their replacement, their residual life is often comparable with the average stay of the part in the warehouse. In this case, the interest and usefulness of purchasing spare parts is lower, unlike the spare parts with normal rotation index where it is sufficient to reduce the stock of spare parts in the warehouse in the last months of life.

The question is **to keep a certain vital part in stock or not**. It can be answered through a global economic management budget for the period of T years, at the end of which the machine will be replaced. In the event that the spare parts are 0 or 1, the most convenient solution will be chosen.

If we consider:

j: the unitary depreciation rate in T years

$$j = \frac{i \cdot (1+i)^T}{(1+i)^T - 1}$$

i: annual discounting rate

t: ownership (allocation) rate

$t' = t + j$: new ownership rate which takes over the useful life of the machine,

R = unit cost of purchasing the spare part;

C_m = cost of absence;

d = average annual consumption

In case the reordering level is N = 0, the resulting relationship is:

$$\frac{R \cdot t'}{C_m \cdot d} > 1$$

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion ï limited machine life

In case of inequality as below, it is not convenient to keep spare parts in stock:

$$\frac{R \cdot t'}{C_m \cdot d} > 1$$

That is:

$$R \cdot t' > C_m \cdot d$$

It means that the overall cost of keeping the part in stock is greater than the cost of absence. In the other case, it is convenient to have spare parts in stock and the level N will be determined with the general equation, after introducing the ownership rate tó

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts accepted degree of riskï Spare parts case for multiple machines

This is the case where there is the possibility of having **identical spare parts mounted on several identical machines**, operating in the same ambient and service conditions that is a case quite normal in many factories.

The stock levels of the spare parts are obtained, in the same way of all low rotation index spare parts, following the criteria of the **accepted degree of risk** or that of the **minimum overall cost.** In the first case taking into account the value of the average Ạ̏of the distribution equal to the sum of the C_{gi} consumption per period relating to each of the n machines on which the spare part is assembled.

$$\lambda = \sum_{i=1}^{N} C_{gi}$$

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion ï Spare parts case for multiple machines

In the second case, the value of the average annual consumption of all the machines should be assigned:

$$d = \sum_{i=1}^{N} C_{gi}$$

In both cases, the value of the unit cost of failure (C_m) must be suitably modified (for example, taking the minimum value of the cost of failure among all the machines on which the spare part is mounted).

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts

Minimum overall cost criterion ï Spare parts case for multiple machines

For example, if you consider that the same piece is mounted on 5 machines with the following spare parts requests:

machine 1: expected consumption C_1 = 1 piece/year

machine 2: expected consumption C_2 = 2 pieces/year

machine 3: expected consumption C_3 = 2 pieces/year

machine 4: expected consumption C_4 = 3 pieces/year

machine 5: expected consumption C_5 = 4 pieces/year

The total consumption is:

$$\lambda = C_1 + C_2 + C_3 + C_4 + C_5 = 12 \text{ pieces/year } = 1 \text{ piece/month}$$

SPARE PARTS MANAGEMENT

Methods and management criteria for low rotation index spare parts
Minimum overall cost criterion / accepted degree of risk
Spare parts case for multiple machines

In case of a supply time of 3 months, you will have:

$$\mu = \lambda \cdot T = \frac{12}{12} \cdot 3 = 3 \text{ pieces}$$

If you want to evaluate the level or reordering N with the accepted degree of risk method, and having previously chosen three service levels (P= 0,8 ï 0,9 ï 0,99) from the nomogram you can get:

Service level P = 0.8 N = 3.95 rounded to 4
Service level P = 0.9 N = 4.8 rounded to 5
Service level P = 0.99 N = 7.1 rounded to 8

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

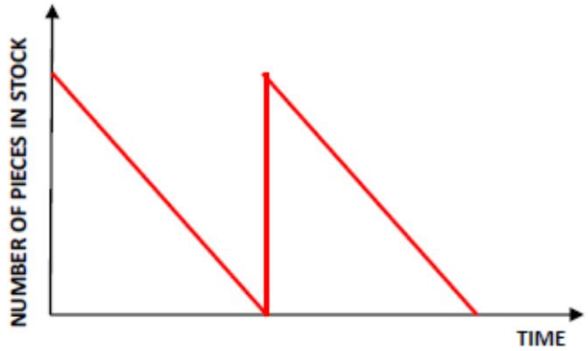
Given the different management characteristics (intensity of consumption, criticality of use, etc.) of **the spare parts with normal rotation index**, the management methods refer to probability distributions of demand, downtime costs and mathematical models, different from those determined for low rotation index spare parts. Also in this case, the **criteria with the degree of risk accepted** and **minimum overall cost** will be used with appropriate clarifications.

Before applying them, the average needed stock, relating to pieces with considerable annual movement has to be determined. In this case, the choice, between high inventory costs or frequent purchase orders with the risk of stockout has to be done.

SPARE PARTS MANAGEMENT
Methods and management criteria for normal rotation index spare parts

Following initial factor should be considered:

a) **the quantity stored in the warehouse at any time**. It generally has a saw tooth type trend (shown in figure), if the demand is constant;



Level of spare parts warehouse stocks

b) **the request for spare parts over time**;

c) **the replenishment lead time**.

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

The latter parameter is very important in the management of stocks, as it determines the level of reordering (Lr). It represents the stock level quantity, which has to be obtained when replenishing :

$$L_r = \lambda \cdot T_a + S_s$$

where:

λ = average consumption per unit of time;

T_a = supply lead time;

S_S = safety stock quantity, which compensate the variability in the system (demand variability, replenishment lead time variability,é)

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

In the event that the replenishment lead time and the safety stock are set to zero, due to economic reasons, the reordering level is zero. In this case, it is possible to increase supplies over the year as a consequence of consumed quantity, by decreasing the reordering lot, reducing the average value of the stock and the pertinent capital as there are fewer parts in stock. This involves a frequent issue of purchase orders, which increases the overall costs (costs of issuing the order, unit prices that decrease with the growth of the ordered pieces, different payment conditions depending on the quantity to be purchased, quantities bound to standard packages etc.).

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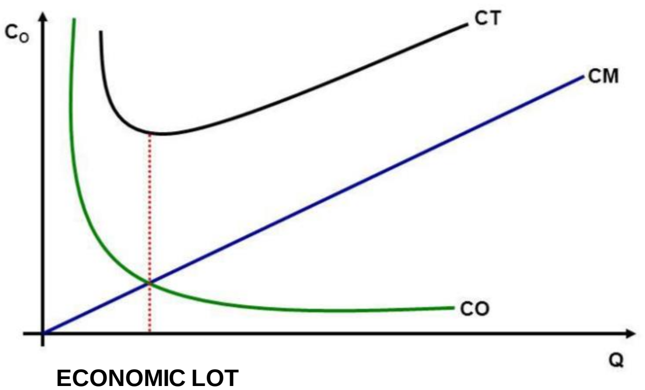
The **optimal quantity of replenishment** is the quantity that minimizes the total management costs, consisting of the cost of purchase order and the cost of inventory (figure).



Total spare parts management costs
CO = cost of launching orders as the ordinary quantity changes - CM = cost of inventory when the quantity in the warehouse changes - CT = total cost - Q = quantity of spare parts

SPARE PARTS MANAGEMENT

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The **total cost for launching orders for a spare part CO** is defined by:

$$CO = \frac{\lambda \cdot C_{Lo}}{L}$$

where:

λ = consumption of pieces in the unit of time;

C_{Lo} = cost of launching an order;

L = lot size quantity of spare parts to be purchased;

while the **annual fixed cost of a spare part CM** is defined by:

$$CM = \frac{L \cdot V_u \cdot I}{2}$$

Where:

V_u = purchase price of spare parts;

I = fixed asset rate to be calculated as cost or loss of income on the average capital stock fixed in the warehouse (expressed as a fraction of V_u).

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The quantity that minimizes the total management costs of the Spare parts with normal rotation index is the **economic purchase lot L_{EA}**, which is expressed by Wilson's formula:

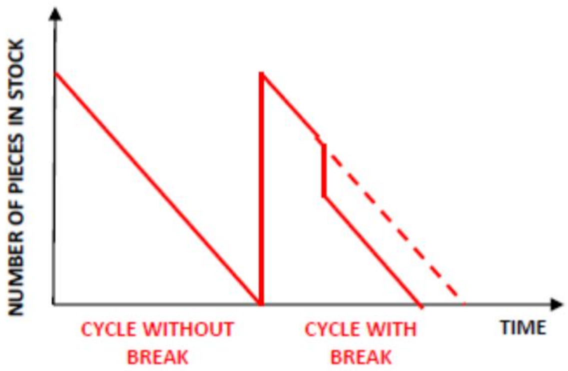
$$L_{EA} = \sqrt{\frac{2 \cdot C_{Lo}}{V_u \cdot I}} \lambda \qquad (4.22)$$

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

Accepted risk criterion

It is a question of choosing a probability of downtime due to lack of spare parts and consequently of sizing the stocks in the warehouse. The choice of a degree of risk of A% means that you agree to be in a situation of stockout of spare parts every A supply cycles out of 100 and the consequent physical storage assumes the trend shown in the figure.



Physical stock in the warehouse of spare parts in cases with and without stockout

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

Accepted risk criterion

To size the stock, it is necessary to know **the probability distribution of the demand over the supply time**, which follows a normal Gauss distribution defined by the mean xbar and the standard deviation ů determined by the relation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n}}$$

Where:
Xbar = average demand value
Xi= generic demand value

The standard deviation defines the dispersion of the values around the average, so the greater the ů the more flattened the curve is and the more dispersed around the average are the distribution values. It is shown the 67% of the values fall in an interval ů with respect to the average, about 95% of the values values fall in an interval +/-2ů with respect to the average, about 99% of the values values fall within +/- 3ů.

SPARE PARTS MANAGEMENT

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Accepted risk criterion

Once the average and standard deviation of the spare parts consumptions have been calculated, it is possible to determine **the reordering point of the stock**, after establishing a certain degree of safety , in order to foresee possible lack of spare parts stock in the warehouse. Infact, if we have an average consumption M of spare parts pieces per month with standard deviation ů, keeping in stock the quantity M + ů, there is the probability of not going out of stock equal 50 +34 = 84%.

Therefore the level of reordering M + ů garantees a degree of risk of out of stock not higher than 84%. If this risk is consider acceptable, the spare part must be supplied when its availability falls below the reordering level M + ů .

In general, the reordering level can be determined by using the standard normal curve defined as the normal curve where:

Xbar = 0 **ů = 1**

SPARE PARTS MANAGEMENT
Methods and management criteria for normal rotation index spare parts
Accepted risk criterion

The standardized variable is defined by:

$$k = \frac{(x - \overline{x})}{\sigma}$$

Or:

$$x = \overline{x} + k \cdot \sigma$$

In this way the ordinates can be calculated knowing those of the standard curve, as well as the area included in a certain range of values of x.
If the average value of the demand xbar, the standard deviation **σ** and the probability that the actual consumption during the supply period is covered by the stock, it is possible to determine the standardized variable k, detectable from the tabulation of the cumulative normal curve and the maximum value that x must assume.

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Accepted risk criterion

Values of the standardized variable k

k	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5834	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6227	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6925	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7703	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.91973	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97745	.97778	.97831	.97882	.97934	.97982	.98030	.98077	.98124	.98169
2.1	.98204	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.990097	.990358	.990613	.990803	.991106	.991344	.991576
2.4	.991802	.992024	.992240	.992451	.992656	.992857	.992857	.993053	.993431	.993613
2.5	.993790	.993963	.994132	.994297	.994457	.994614	.994766	.994915	.995060	.995201
2.6	.995339	.995473	.995604	.995731	.995855	.995975	.996093	.996207	.996319	.996427
2.7	.996533	.996636	.996736	.996833	.996928	.997020	.997110	.997197	.997282	.997365
2.8	.997445	.997523	.997599	.997673	.997744	.997814	.997882	.997948	.998012	.998074
2.9	.998134	.998193	.998250	.998305	.998359	.998411	.998462	.998511	.998559	.998605
3.0	.998650	.998694	.998736	.998777	.998817	.998856	.998893	.998930	.998965	.998999
3.1	$.9^{3}0324$	$.9^{3}0646$	$.9^{3}0957$	$.9^{3}1260$	$.9^{3}1553$	$.9^{3}1836$	$.9^{3}2112$	$.9^{3}2378$	$.9^{3}2636$	$.9^{3}2886$
3.2	$.9^{3}3129$	$.9^{3}3363$	$.9^{3}3590$	$.9^{3}3810$	$.9^{3}4024$	$.9^{3}4230$	$.9^{3}4429$	$.9^{3}4623$	$.9^{3}4810$	$.9^{3}4991$
3.3	$.9^{3}5166$	$.9^{3}5335$	$.9^{3}5499$	$.9^{3}5658$	$.9^{3}5811$	$.9^{3}5959$	$.9^{3}6103$	$.9^{3}6242$	$.9^{3}6376$	$.9^{3}6505$
3.4	$.9^{3}6631$	$.9^{3}6752$	$.9^{3}6869$	$.9^{3}6982$	$.9^{3}7091$	$.9^{3}7197$	$.9^{3}7299$	$.9^{3}7398$	$.9^{3}7493$	$.9^{3}7585$

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

Accepted risk criterion

Accepted risk criterion

The standardized variable is defined by:

If for a spare part there is an average consumption of 20 pieces/month and a standard deviation of 5 pieces/month, if a 93% probability is considered that the actual consumption during the supply period does not cancel the stock, from table it is possible to detect the value of the standardized variable k, equal to 1.48 which allows to determine the maximum value of the reordering level which is:

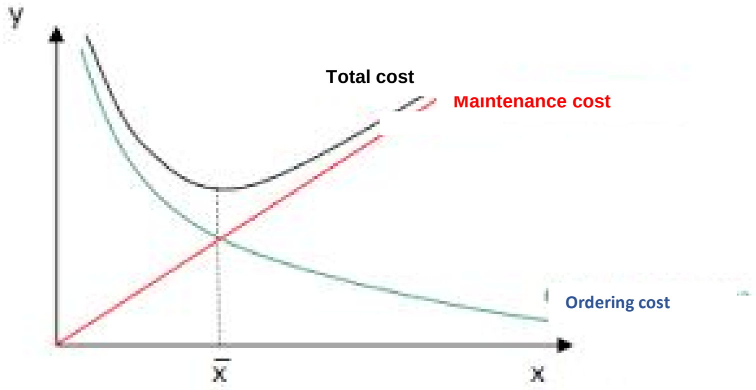
$$x = \overline{x} + k \cdot \sigma = 20 + 1{,}48 \cdot 5 = 27{,}4\ pieces \qquad rounded\ to\ 28\ pieces$$

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

Minimum global cost criterion

In case that the costs of spare parts purchasing and shortages are significant, it is convenient to manage these materials with the method that provides for the **minimum overall cost** (storage costs plus shortage costs). As the number of spare parts in the warehouse increases, the probability of stops due to lack of spare parts decreases, but the financial costs related to the cost of storage increase (figure). The optimum will be the value that minimizes the overall cost.



Total spare parts management costs - X = quantity of spare parts - Y = costs

Minimum global cost criterion

Indicating with:

C_e = cost of missing spare parts;

C_m = maintenance cost as a percentage per year;

P = unit value of the spare part;

d = annual demand for spare parts;

$\overline{x}$ = economic lot of spare parts;

σ_{Ta}= standard deviation in case of the supply time T_a defined:

$$\sigma_{Ta} = \sigma(T_a)^{\frac{1}{2}} \quad (4.26)$$

σ = standard deviation in case is referred to the unit of time;

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

Minimum global cost criterion

it is possible to determine the function of probability to reach out of stocks f(k) which, in the hypothesis of a Gaussian distribution of demand, is:

$$f(k) = \frac{\sigma \cdot (T_a)^{1/2} \cdot C_m \cdot P \cdot \overline{x}}{C_e \cdot d}$$

Once the value of f(k) is known, it is possible to obtain the value of the standardized variable k through the table x which considers the f(k) expressed according to Gaussian distribution. The level of reordering L_r is calculated according to the relation:

$$L_r = d \cdot T_a + k \cdot \sigma \cdot (T_a)^{1/2}$$

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

Minimum global cost criterion

The function of probability to reach out of stocks f(k) is:

$$f(k) = \frac{\sigma \cdot (T_a)^{1/2} \cdot C_m \cdot P \cdot \overline{x}}{C_e \cdot d}$$

Where:

d: annual demand for spare parts = 60 pcs/year

xbar: economic lot = 15 pcs

ů: standard deviation = 4 pcs/month

Ta: Lead time for replenishment = 4 months

Ce: cost of missing parts = 2000 ú

Cm : maintenance cost per year in percentage = 40%

P: Unit value: 100 ú

$$f(k) = \frac{\sigma \cdot (T_a)^{1/2} \cdot C_m \cdot P \cdot \overline{x}}{C_e \cdot d} = \frac{4 \cdot (4)^{1/2} \cdot 0{,}4 \cdot 100 \cdot 15}{2000 \cdot 60} = 0{,}04$$

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Minimum global cost criterion

Values of the standardized variable k

k	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.3989	.3989	.3989	.3988	.3986	.3984	.3982	.3980	.3977	.3973
.1	.3970	.3965	.3961	.3956	.3951	.3945	.3939	.3932	.3925	.3918
.2	.3910	.3902	.3894	.3885	.3876	.3867	.3857	.3847	.3836	.3825
.3	.3814	.3802	.3790	.3778	.3765	.3752	.3739	.3725	.3712	.3697
.4	.3683	.3668	.3653	.3637	.3621	.3605	.3589	.3572	.3555	.3538
.5	.3521	.3503	.3485	.3467	.3448	.3429	.3410	.3391	.3372	.3352
.6	.3334	.3314	.3292	.3271	.3251	.3230	.3209	.3187	.3166	.3144
.7	.3123	.3101	.3079	.3056	.3034	.3011	.2989	.2966	.2943	.2920
.8	.2897	.2874	.2850	.2827	.2803	.2780	.2756	.2732	.2709	.2685
.9	.2661	.2637	.2613	.2589	.2565	.2541	.2516	.2492	.2468	.2444
1.0	.2420	.2396	.2371	.2347	.2323	.2299	.2275	.2251	.2227	.2203
1.1	.2179	.2155	.2131	.2107	.2083	.2059	.2036	.2012	.1989	.1965
1.2	.1942	.1919	.1895	.1872	.1849	.1826	.1804	.1781	.1758	.1736
1.3	.1714	.1691	.1669	.1647	.1626	.1604	.1582	.1561	.1539	.1518
1.4	.1497	.1476	.1456	.1435	.1415	.1394	.1374	.1354	.1334	.1315
1.5	.1295	.1276	.1257	.1238	.1219	.1200	.1182	.1163	.1145	.1127
1.6	.1109	.1092	.1074	.1057	.1040	.1023	.1006	.09893	.09728	.09566
1.7	.09405	.09246	.09089	.08933	.08780	.08628	.08478	.08329	.08183	.08038
1.8	.07895	.07754	.07614	.07477	.07341	.07206	.07074	.06943	.06814	.06687
1.9	.06502	.06438	.06316	.06195	.06077	.05959	.05844	.05730	.05618	.05508
2.0	.05399	.05292	.05186	.05082	.04980	.04879	.04780	.04682	.04586	.04491
2.1	.04398	.04327	.04217	.0418	.04041	.03955	.03871	.03788	.03706	.03626
2.2	.03547	.03470	.03394	.03319	[illegible]	.03174	.03103	.03034	.02965	.02898
2.3	.02833	.02708	.02705	.02643	.02582	.02522	.02463	.02406	.02349	.02294
2.4	.02239	.02186	.02134	.02083	.02033	.01984	.01936	.01888	.01842	.01797
2.5	.01753	.01705	.01667	.01625	.01585	.01545	.01506	.01468	.01431	.01394
2.6	.01358	.01343	.01289	.01256	.01223	.01191	.01160	.01130	.01100	.01071
2.7	.01044	.01014	$.0^{2}9871$	$.0^{2}9606$	$.0^{2}9317$	$.0^{2}9094$	$.0^{2}8846$	$.0^{2}8605$	$.0^{2}8370$	$.0^{2}8140$
2.8	$.0^{2}7915$	$.0^{2}7697$	$.0^{2}7483$	$.0^{2}7274$	$0^{2}7071$	$0^{2}6873$	$0^{2}6679$	$0^{2}6491$	$0^{2}6307$	$0^{2}6127$
2.9	$.0^{2}5953$	$.0^{2}5782$	$.0^{2}5616$	$.0^{2}5454$	$.0^{2}5296$	$.0^{2}5143$	$.0^{2}4993$	$.0^{2}4847$	$.0^{2}4705$	$.0^{2}4567$
3.0	$.0^{2}4132$	$.0^{2}4302$	$.0^{2}4173$	$.0^{2}4049$	$.0^{2}3928$	$.0^{2}3810$	$.0^{2}3695$	$.0^{2}3584$	$.0^{2}3475$	$.0^{2}3370$
3.1	$.0^{2}3267$	$.0^{2}3167$	$.0^{2}3070$	$.0^{2}2975$	$.0^{2}2884$	$.0^{2}2794$	$.0^{2}2707$	$.0^{2}2623$	$.0^{2}2541$	$.0^{2}2461$
3.2	$.0^{2}2384$	$.0^{2}2309$	$.0^{2}2236$	$.0^{2}2165$	$.0^{2}2096$	$.0^{2}2029$	$.0^{2}1964$	$.0^{2}1901$	$.0^{2}1840$	$.0^{2}1780$
3.3	$.0^{2}1743$	$.0^{2}1667$	$.0^{2}1612$	$.0^{2}1560$	$.0^{2}1508$	$.0^{2}1459$	$.0^{2}1411$	$.0^{2}1364$	$.0^{2}1319$	$.0^{2}1275$
3.4	$.0^{2}1232$	$.0^{2}1191$	$.0^{2}1151$	$.0^{2}1112$	$.0^{2}1075$	$.0^{2}1038$	$.0^{2}1003$	$.0^{3}9689$	$.0^{3}9358$	$.0^{3}9037$

SPARE PARTS MANAGEMENT

Methods and management criteria for normal rotation index spare parts

Minimum global cost criterion

Minimum global cost criterion

From table it is possible to detect the value of the standardized variable k which is equal to 2.14, which allows to determine the value of the reordering level that results:

$$L_r = d \cdot T_a + k \cdot \sigma \cdot (T_a)^{\frac{1}{2}} = 60 \cdot \frac{4}{12} + 2{,}14 \cdot 4 \cdot (4)^{\frac{1}{2}} =$$ 37,12 pieces, rounded to 38 pieces

Quantity in stock (physical stock plus pending orders) must be kept above the level of 38 pieces, which ensures the minimum of the overall management cost.