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O&M efficiency model: A dependability approach

D Galar^{1,3}, U Kumar¹, P Sandborn² and A Morant¹

¹ Division of Operation and Maintenance Engineering, Lulea University of Technology, Lulea, Sweden;

² CALCE, Center for Advanced Life Cycle Engineering, University of Maryland, College Park, MD, USA;

E-mail: diego.galar@ltu.se, uday.kumar@ltu.se, sandborn@calce.umd.edu, amparo.morant@ltu.se

Abstract. The occurrence of equipment failures is one of the main causes of inefficiency. These events increase the operational costs and give rise to a loss of revenues or in the worst case they can even produce an accident with significant damages to people and the environment. The efficiency of the operation of an industrial installation in a given period of time has been defined use the ratio of the Dependability level achieved by the installation in a specified period of time and the sum of the corresponding Dependability and Undependability costs. The aim of this paper is the development of a methodology for the calculation of operating costs in industrial facilities that addresses the difficulty of performing a simple, homogeneous and objective evaluation of the operational efficiency of the industrial facility. The main obstacle to this evaluation is the lack of a method for quantifying Dependability, which to date has always been considered a purely qualitative characteristic.

1. Introduction

The mission of device is to satisfy, throughout its operative life, its operational demand in suitable technical conditions and security with minimum cost. Its use during a certain period of operation T generates a benefit for the user (B^T) that can be expressed, conceptually as the difference between the “value” obtained with its operation (V^T) and the associated total cost of its use in the period (C^T),

$$B^T = V^T - C^T \quad (1)$$

In order to satisfy consumer’s expectations, the manufacturer must respond by guaranteeing sufficient levels of dependability of the products that it makes and that it sells. Also, the manufacturer would wish to have high levels of dependability in their facilities in order to minimize disruptions in production that could cause the appearance of unavailability in its equipment and thus, to maximize their potential benefits.

³ Diego Galar; diego.galar@ltu.se

Dependability or safety in the operation of a device can be defined as the quality which characterizes its capacity to take care of its demand of operation in adapted technical conditions and security, within operative environment and considered period of time. It constitutes the overall and integral vision of the following interrelated capacities of a device (figure 1) ([1], [2], [3], [4]):

- Reliability: Capacity of a device to operate continuously in suitable operative conditions.
- Maintainability: Capacity of a device so that their suitable operative conditions are recovered before it appears a failure or when this already it has happened.
- Availability: Capacity of a device to work at a certain moment.
- Safety: Capacity of a device to operate without producing damage to itself or damage to the system it is in.

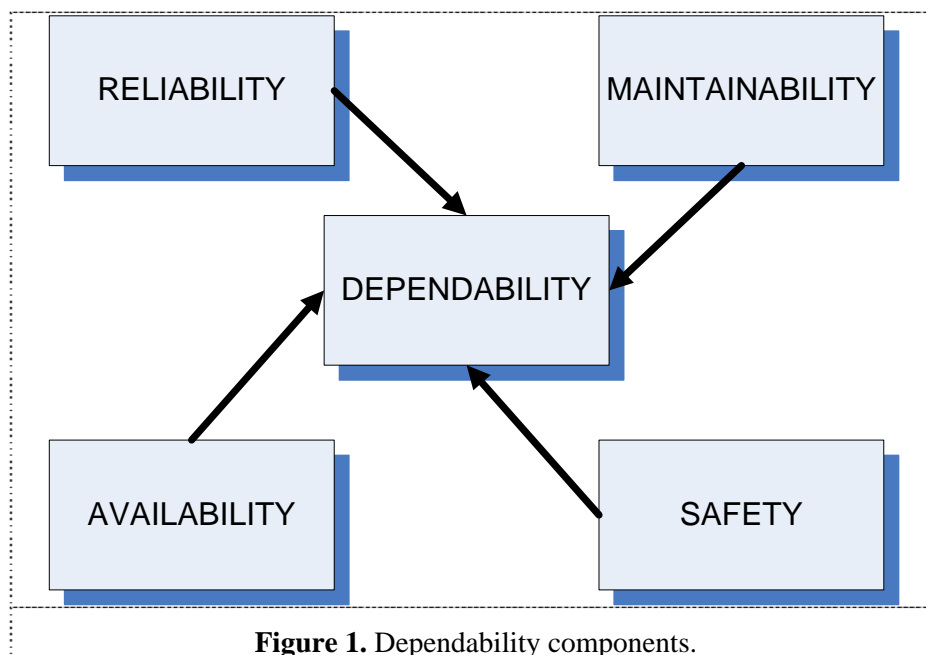


Figure 1. Dependability components.

In order to diminish the frequency of appearance of unavailability in the devices or their consequences, certain measures are usually adopted in the phases of design, construction and operation. In the phases of design and construction, modular designs can be conceived to facilitate the fast repair of the device if this it is damaged and be used materials and components with great resistance to the wearing down, redundancies can be implanted or to define protection measures, among others possibilities. All these actions entail a certain cost that is considered at the time of establishing the sale price of the device on the part of the manufacturer and who, from the point of view of the consumer or user will be included in the acquisition cost.

2. The operating cost of a device

During the operation of a device, the most common action that is adopted is the execution of an efficient program of preventive maintenance that tries to resist the negative effects that bring about the wear out processes. The design and the execution of this plan of preventive maintenance would carry a certain cost in the considered period of operation (C_{PM}^T).

Also and depending on technical-economic viability, in some cases different additional actions are taken from the considered ones in the design phase in order to improve the Reliability, Availability and Safety of the devices in their specific operative environment. Evidently, the inclusion of these measures also will result in a cost for the user (C_{RAS}^T).

The overall costs incurred during the period of operation under analysis of a device for the conservation or improvement of its dependability will be hereafter denominated cost of dependability (C_{DEP}^T). i.e.:

$$C_{DEP}^T = C_{PM}^T + C_{RAS}^T = C_{PM}^T + (C_R^T + C_A^T + C_S^T) \quad (2)$$

Where C_R^T , C_A^T and C_S^T are, respectively, the costs of the improvements of Reliability, Availability and Safety conducted in the considered operative period. However, one should be very careful in the cost assignation since “in the period” does not directly apply to some of these cost contributions. For example, “costs of the improvements of reliability” should be calculated for one particular time period in function of the total investment done. If one pays money to improve reliability, a single investment provides benefit for all periods of time, so just a portion of the cost of reliability improvement should be charged to that particular period of time

The sum of the cost of dependability and all those others required for the use of the device (costs of electricity and other raw materials, labour force, regulations and authorizations, etc.) in the selected period of operation, C_U^T , will constitute the denominated cost of operation and maintenance ($C_{O\&M}^T$) in this period, ([5],[6],[7],[8]).

$$C_{O\&M}^T = C_{DEP}^T + C_U^T \quad (3)$$

In spite of all the indicated measures, unavailability of the devices happen, since its probability of appearance never can become null. This unavailability generates negative consequences that, in economic terms, will be quantified by the cost of unavailability (C_{UNA}^T) ([9], [10], [11]). The cost of unavailability of a device in a certain period of operation T considers the cost of the conducted corrective maintenance in this period (C_{CM}^T) and the penalty cost which it has been incurred (C_{PEN}^T).

Corrective maintenance cost represents all those activities that have been realized to recover the functionality of the damaged device. On the other hand, the penalty cost (C_{PEN}^T) constitutes economic assessment of the tangible damages brought by unavailability happened in the device during the period under analysis. These damages can be of very diverse kind. Most important ones in this category are as follows:

- Personal or material damages, whether internal or external to the facility.
- Deterioration or contamination of the environment.
- Lost production caused in other productive processes and the cost of providing the service via alternative means.

Therefore, one would verify that:

$$C_{UNA}^T = C_{CM}^T + C_{PEN}^T \quad (4)$$

The sum of the cost of operation and maintenance and the cost of unavailability corresponding to the period of time under analysis constitutes the cost of operation of the device in this period (C_{OP}^T). i.e.

$$C_{OP}^T = C_{O\&M}^T + C_{UNA}^T \quad (5)$$

In order to determine the associate total cost to the use of a device in a certain period of time T or global cost of operation in this period (C^T), it will be necessary to add the costs of amortization (C_{AM}^T) and of disposal of device (C_{DIS}^T) applicable to this period to the cost of corresponding operation. Therefore:

$$C^T = C_{OP}^T + C_{AM}^T + C_{DIS}^T \quad (6)$$

3. Economic performance in operation

In a conceptual framework, the economic assessment of the functionality of a device in a certain period of operation (V^T) can consider the difference between the associate economic value to the total satisfaction of the demand of operation required to the device during the considered period of time (VE^T), and lost value or the cost of lost production associated to unavailability present in this period (C_{LP}^T). i.e.:

$$V^T = VE^T - C_{LP}^T \quad (7)$$

The cost of lost production represents the economic estimation of the diminution of income or value that, for the user, take place due to unavoidable or programmed unavailability that undergoes the device and that originates the lost of its functionality, preventing that can take care of a certain demand of operation. The sum of the costs of lost production and unavailability, and cost of non dependability of the device will be denominated (C_{NDEP}^T). It can be expressed mathematically as:

$$C_{NDEP}^T = C_{LP}^T + C_{UNA}^T = C_{LP}^T + (C_{CM}^T + C_{PEN}^T) \quad (8)$$

Due to the previously mentioned unavailability and costs the operation management of a device must be based on the control of the efficiency of its operation throughout its entire operative life. Therefore, the benefit obtained with the operation of a device in a certain period of time T can be able to be expressed as follows:

$$\begin{aligned} B^T &= V^T - C^T = V^T - (C_{OP}^T + C_{AM}^T + C_{DIS}^T) = (VE^T - C_{LP}^T) - (C_{OP}^T + C_{AM}^T + C_{DIS}^T) = \\ &= (VE^T - C_{LP}^T) - ((C_{OP}^T + C_{UNA}^T) + C_{AM}^T + C_{DIS}^T) = \\ &= (VE^T - C_{LP}^T) - (((C_{PM}^T + C_{RAS}^T + C_{O\&M}^T) + (C_{CM}^T + C_{PEN}^T)) + C_{AM}^T + C_{DIS}^T) = \\ &= VE^T - (C_{LP}^T + C_{PM}^T + C_{RAS}^T + C_{O\&M}^T + C_{CM}^T + C_{PEN}^T + C_{AM}^T + C_{DIS}^T) = \\ &= VE^T - ((C_{LP}^T + C_{CM}^T + C_{PEN}^T) + (C_{PM}^T + C_{RAS}^T) + C_{O\&M}^T + C_{AM}^T + C_{DIS}^T) = \\ &= VE^T - (C_{NDEP}^T + C_{DEP}^T + C_{OP}^T + C_{AM}^T + C_{DIS}^T) = \end{aligned} \quad (9)$$

In Figure 2, the existing relations between the benefit obtained in the operation of a device during a period of time determined and its associate costs, are represented.

Given a determined demand of operation for a device in a certain period of time T , the economic performance of its operation ($\eta(t)$) will come defined by the ratio of the benefit obtained in this period (B^T) to the maximum benefit that had been able to obtain (B_{MAX}^T). i.e.:

$$\eta^T = \frac{B^T}{B_{MAX}^T} \quad (10)$$

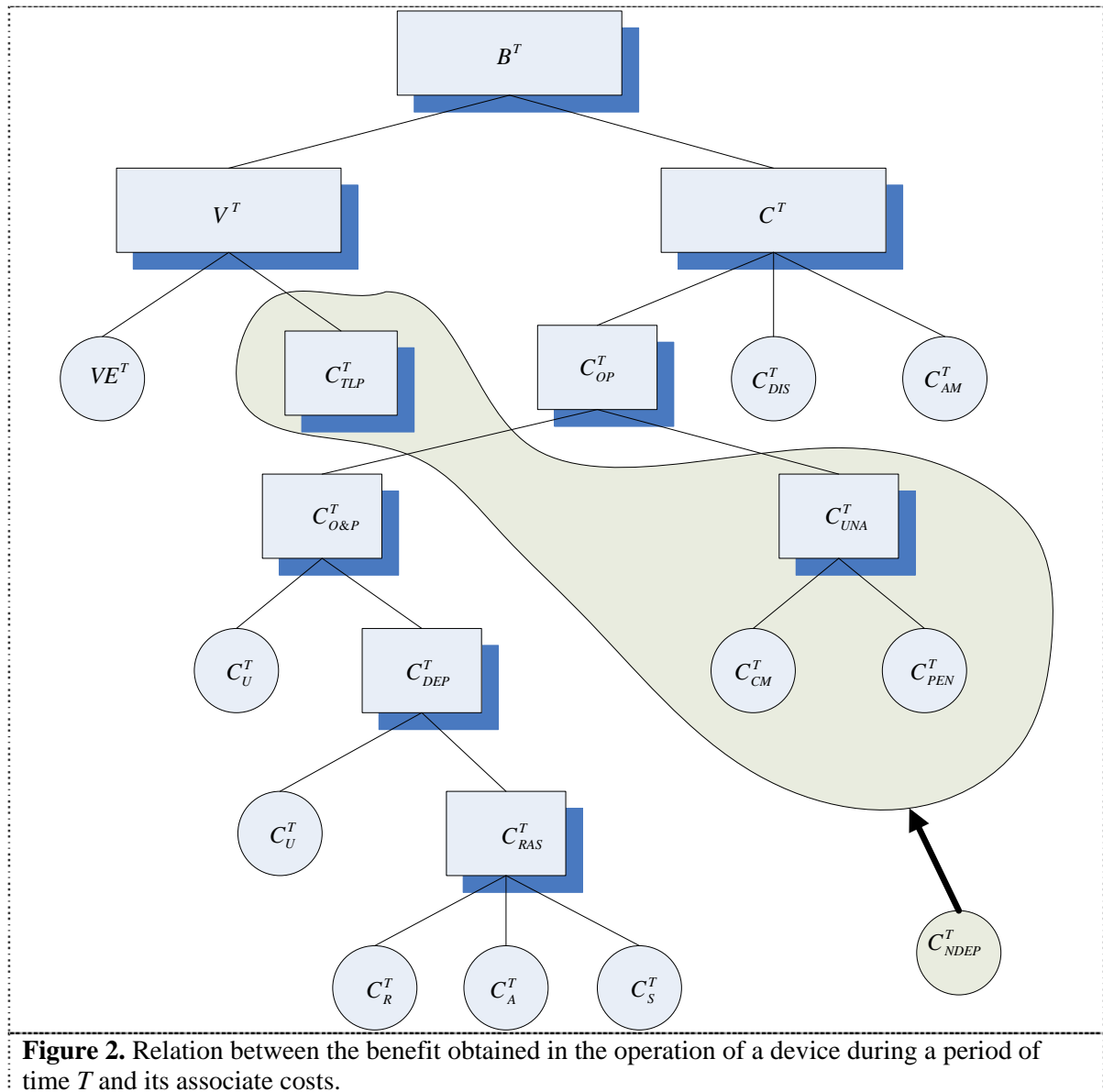


Figure 2. Relation between the benefit obtained in the operation of a device during a period of time T and its associate costs.

The maximum possible benefit would correspond to a hypothetical situation in which $C^T = 0$ and $C_{LP}^T = 0$, verifying then that $B_{MAX}^T = VE^T$ and, therefore, the economic performance of the operation of the device in the considered period can be expressed in the following way:

$$\eta^T = \frac{B^T}{B_{MAX}^T} = \frac{V^T - C^T}{VE^T} = \frac{(VE^T - C_{LP}^T) - C^T}{VE^T} = \frac{VE^T - (C_{LP}^T + C^T)}{VE^T} = \quad (11)$$

$$= 1 - \frac{C_{LP}^T + C^T}{VE^T} = 1 - \frac{(C_{DEP}^T + C_{NDEP}^T) + (C_{OP}^T + C_{AM}^T + C_{DIS}^T)}{VE^T}$$

One can observe that the economic performance corresponding to the operation of a device in a certain period of time always be less than or equal to one, and will become negative if $C^T \geq V^T$.

Generally, one will assume that the costs of dependability and non-dependability corresponding to the operation of a device during a certain period of time vary with the dependability reached in the period, whereas the costs of use, amortization and disposal are not affected by it.

The maximum economic performance will be obtained in a process of operation characterized by a level of dependability (DEP_{OPT}^T), denominated optimum level:

$$\left. \frac{d\eta^T}{dDEP^T} \right|_{DEP_{OPT}^T} = \left. \frac{d(C_{DEP}^T + C_{NDEP}^T)}{dDEP^T} \right|_{DEP_{OPT}^T} = 0 \quad (12)$$

$$\left. \frac{d^2\eta^T}{dDEP^{T2}} \right|_{DEP_{OPT}^T} \leq 0$$

4. The efficiency in operation

It is assumed that the costs of non-dependability of the operation of a device fall as dependability increases. In Figure 4, the theoretical curves of the costs of dependability and non-dependability of a device are represented under these assumptions. In this case, it is possible to observe that the optimum level of dependability of the device (DEP_{OPT}^T) corresponds to that where the minimum sum of associated costs is a minimum.

Once, the demand for operation for a device is defined for a certain period of time whose associated economic value to its total satisfaction is VE^t , different alternatives can appear to obtain a particular economic performance, as shown in Figure 5.

The point A marks one situation on a map of null economic performance that this characterized by the level of dependability DEP_A^T . This situation corresponds to the case where the appearance of a problematic situation of unavailability due to a low level of dependability that results in costs associated with non-dependability. Point B marks another possible situation on a map of null economic performance, characterized by the level of dependability DEP_B^T . This situation is the result of actions of conservation and improvement of the dependability of the device oriented to the minimization of the frequency of appearance of unavailability in the equipment and their associated high costs.

For both alternatives,

$$(C_{DEP}^T + C_{NDEP}^T)|_{(A)} = (C_{DEP}^T + C_{NDEP}^T)|_{(B)} = VE^T - (C_{OP}^T + C_{AM}^T + C_{DIS}^T) \quad (13)$$

It is possible to observe that the maximum benefit will be obtained with a process of operation represented by the point O in which the sum of the costs of dependability and non-dependability is minimized.

The efficiency of the operation of a device in a certain period of time T is determined by the ratio of the dependability reached in this period (DEP^T) and the sum from the costs of dependability and non-dependability which it has been incurred ([12], [13]), which can be expressed as

$$\xi^T = \frac{DEP^T}{C_{DEP}^T + C_{NDEP}^T} \quad (14)$$

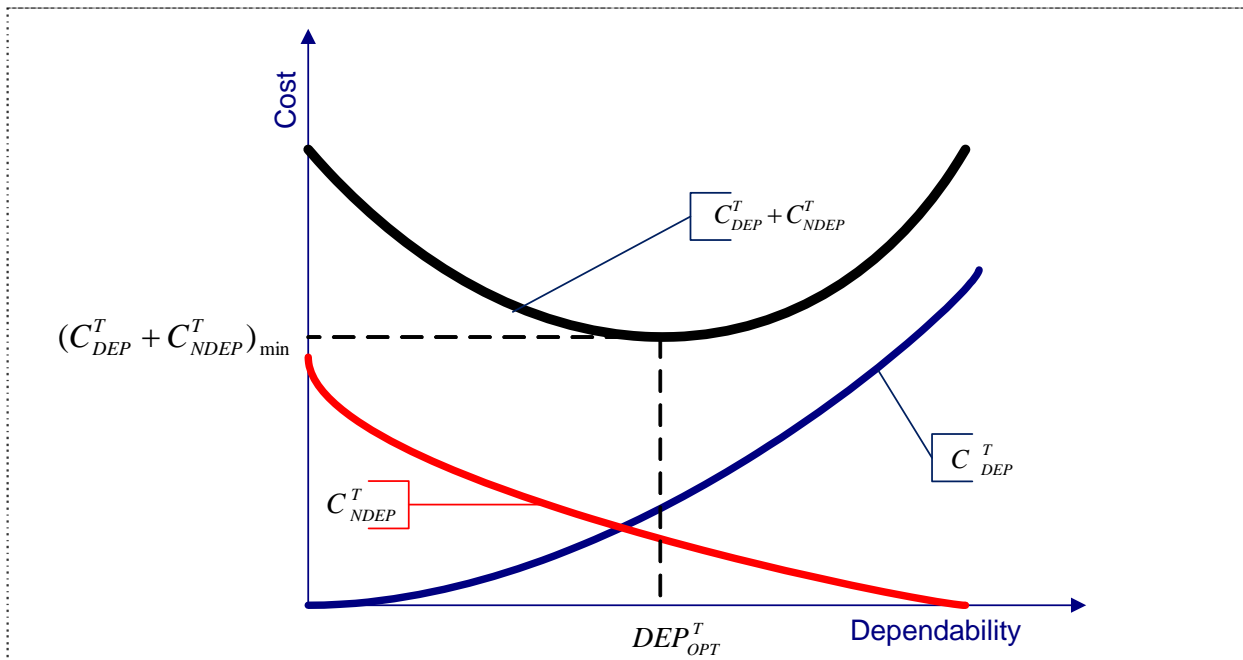


Figure 4. Theoretical curves of the costs of dependability and non dependability of a device.

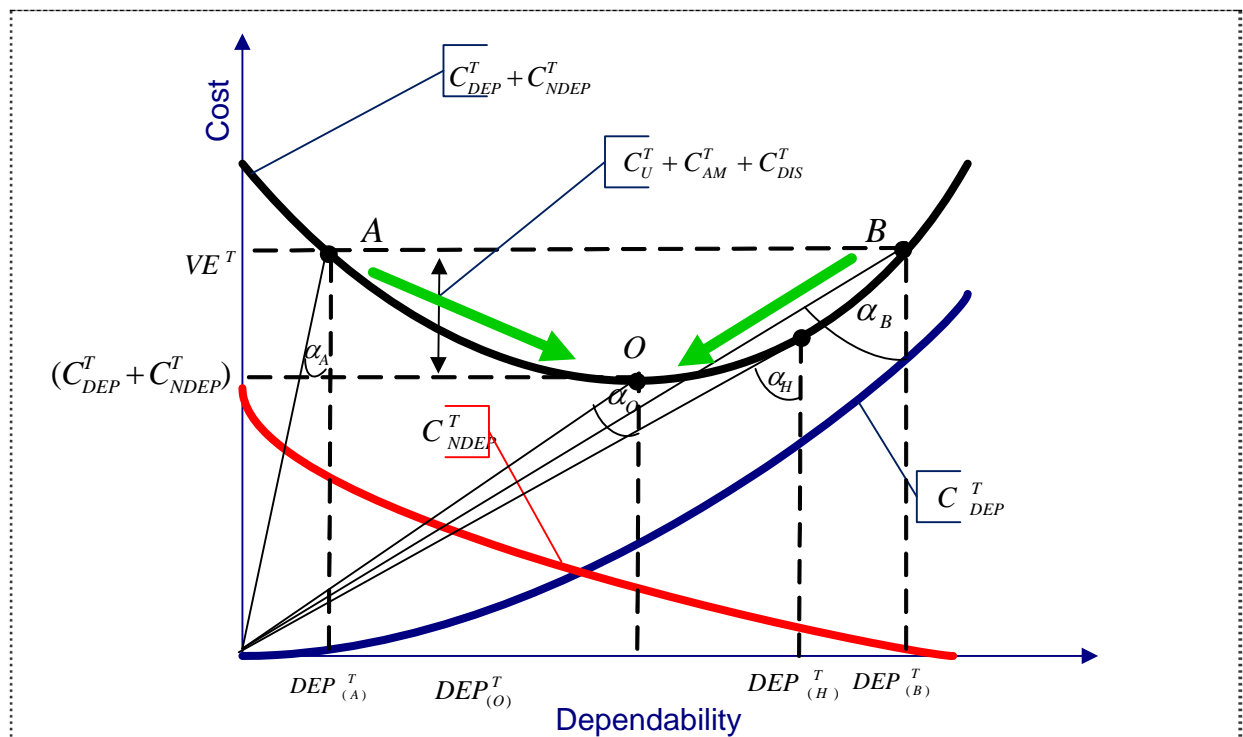


Figure 5. Alternatives of action in an industrial facility with respect to its level of dependability.

In Figure 5, it can be observed that ξ^T is the tangent of the angle α . ξ^T is greater for the alternative B than for the alternative A, although both processes present/display the same economic performance. The process of operation represented by point O corresponds to the situation of maximum economic performance, being its efficiency: $\xi^T_{(O)} = \tan(\alpha(0))$.

The processes of operation with dependability greater than DEP_{OPT}^T have an efficiency greater than $\xi^T_{(0)}$; they are characterized by an excess of economic resources used for the improvement of the dependability of the installation. On the other hand, the processes of operation with dependability smaller than DEP_{OPT}^T will have a smaller efficiency than $\xi^T_{(0)}$; they have little allocation of economic resources to the improvement of the dependability of the installation in the period under analysis.

The maximum efficiency will be obtained in a process of operation characterized by point H , since at this point the first derivate of ξ^T equals 0, i.e. the curve $(C_{DEP}^T + C_{NDEP}^T)$ as a function of dependability meet the tangent of angle α_H . The point H is defined by,

$$\left. \frac{d\xi^T}{dDEP^T} \right|_H = \frac{(C_{DEP}^T + C_{NDEP}^T)_H - DEP_H^T \cdot \left. \frac{d(C_{DEP}^T + C_{NDEP}^T)}{dDEP^T} \right|_H}{[(C_{DEP}^T + C_{NDEP}^T)_H]^2} = 0$$

$$(C_{DEP}^T + C_{NDEP}^T)_H = DEP_H^T \cdot \left. \frac{d(C_{DEP}^T + C_{NDEP}^T)}{dDEP^T} \right|_H \quad (15)$$

$$\frac{(C_{DEP}^T + C_{NDEP}^T)_H}{DEP_H^T} = \tan(\alpha)_H = \left. \frac{d(C_{DEP}^T + C_{NDEP}^T)}{dDEP^T} \right|_H$$

The point of maximum efficiency will agree with the point of maximum performance only when the evolution of the sum of the costs of dependability and non-dependability based on the dependability reached by the facility takes place according to the following linear relationship,

$$(C_{DEP}^T + C_{NDEP}^T) = \frac{DEP^T}{\xi^T_{(0)}} \quad (16)$$

for values $DEP^T \geq DEP_{OPT}^T$

where $(C_{DEP}^T + C_{NDEP}^T) > (C_{DEP}^T + C_{NDEP}^T)_{(0)}$ for values $DEP^T < DEP_{OPT}^T$.

5. Conclusions

Good management of the operation of a device must be based on the control efficiency of its operation over its entire operating life. Therefore, it is highly desirable to have appropriate mechanisms for control and monitoring costs incurred in making use of the device. These mechanisms should cover effectiveness and efficiency aspects.

The most integrating effectiveness measurement of functional safety is the dependability of a device, meaning the quality or characteristic that integrates globally the concepts of Reliability, Availability, Maintainability and Safety and its more or less value in a given period of operation determines the effectiveness of production process achieved in that period.

The efficiency of the operation of any device in a certain period of time T is defined as the ratio of the dependability reached in this period (DEP^T) and the sum from the costs of dependability and non-dependability that have been incurred:

$$\xi^T = \frac{DEP^T}{C_{DEP}^T + C_{NDEP}^T}$$

With these parameters, a graphical method to maximize the economic performance and efficiency has been proposed in order to balance the allocation of resources as a function of the expected goals to be achieved in the operation. Actually, the search process for the optimum situation of operation for a certain industrial installation entails the allocation or distribution of the resources available between the minimization of the occurrence of unavailability (Costs of Dependability) and the assumption of its consequences (Costs of Non-Dependability), assuming considering that the approach to the minimal value of the sum of the costs of dependability and non-dependability will not give rise to the attainment of the greater benefit. From maintainability point of view, this question is translated in carrying out an optimum allocation of the resources available between preventive or corrective activities and deciding how and when that equipment must be preventively maintained.

References

- [1] European Committee for Electro technical Standardization. "Railway applications. The specification and demonstration of dependability, availability, maintainability and safety (RAMS)". Draft European Standard pr EN 50126. November 1.995.
- [2] International Electrotechnical Commission, "Dependability Management. Part 3: Application Guide - Section 1 : Analysis techniques for dependability : Guide on methodology". IEC 300-3-1. First edition. 1.991.
- [3] International Electrotechnical Commission, "Dependability Management. Part 3: Application Guide - Section 4: Guide to the specification of dependability requirements". IEC 300-3-4. International Standard. August 1.996.
- [4] Villemeur, A., "Reliability, Availability, Maintainability and Safety Assessment". John Wiley & Sons. 1.991
- [5] Drago A, Pezzo T, Zuccare U, F y Diamantidis D, "Experienced gained from availability analysis of existing steel plants". European Conference on Safety and Reliability. ESREL'93. 1.993.
- [6] International Electro technical Commission, "Dependability Management. Part 3 : Application Guide - Section 3 : Life Cycle Costing". IEC 300-3-3. Committee Draft. May 1.999
- [7] Jones C, "Life-cycle costs become focus of standard designs". Power. Págs. 126-128. September-October 1.996.
- [8] Suokas J, Heikkilá J, Kortelainen H, Reunanen M y Whetton C, "Extending the economic lifetime of ageing plants". European Conference on Safety and Reliability. ESREL'98. June 1.998.
- [9] Douglas J, "The Maintenance revolution". EPRI Journal. Págs.7-15. Mayo- Junio 1.995.
- [10] Douglas J, "The value of Reliability". EPRI Journal. Págs.4-11. Marzo 1.986.
- [11] Electric Power Research Institute. "Power Plant Availability Engineering : Methods of Analysis, Program Planning and Applications". EPRI NP-2168. May 1.982.
- [12] Despujols A, Delbos J P y Beaudouin F, "Aid in the selection of preventive maintenance actions and their frequency". 12th International ESReDA Seminar on Decision Analysis and its applications in Safety and Reliability. May 1.997.
- [13] Vanneste S G. y Van Wassenhove L N, "An integrated and structured approach to improve maintenance". European Journal of Operational Research. Vol. 82. Pp. 241-257. 1.995