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Industrial Systems Maintenance under the Light of Reliability

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Abstract: The continuous development of industry with the automation of production and the increasing of commercial competition the last decades, impose the direct upgrade role of maintenance that is as important as the production. In this manuscript we present a simple expression of reliability in industrial systems that affect the maintenance activity in order to contribute productively (effectively and efficiently). Effective and efficient maintenance is always a burden to the production process in industry. Then we give a modern definition of maintenance activity and his application in industry. Convincing proof is given towards this line of thought as well as practical guidelines to achieve it.

Key words: Reliability, industrial systems, practical management, maintenance

INTRODUCTION

The mass production materializes in the last four decades with industrial equipment, which is marked continuously with an increased grade of automation. Thus, through automation, the task of the direct production work relieves, the task of the indirect production work (quality assurance, corrective or preventive maintenance) upgrades in importance, especially concerning the value of the final product and production quantity.

The gradually increasing of automation in the industry leads to the "painful" realization that the repercussions of failures, due to automated equipment, increased and as a result the need for Maintenance emerged. There are heavy losses in industry when the equipment is not in full operational mode. For example, in open cut mining, the loss in revenue resulting from a typical dragline being out of action is \$0.5-1.0 million per day. In the case of airline operations, the loss in revenue from a 747 plane being out of action is roughly \$0.5 million per day[1].

The expensive equipment must remain available at any time during the operation. The industrial systems maintenance, which is in fact a dominant tenement, must be invisibly present, safeguarding the desired availability but not intervening in the production schedule.

Production and manufacturing problems received tremendous interest from operations research and management science researchers. Some books with a collection of papers dealing with various aspects on maintenance and summarises the latest results and the current status have been written[2].

Collaterally the increased competition between quantity and quality of products (large volumes of production with high quality) dictated that the maintenance activity must be not only effective but also provident. There the outset of demand of invisible presence of Maintenance is placed, which contains by nature Reliability elements[3].

The relationship between equipment maintenance and production has also received increasing attention in the literature[4,5]. Equipment maintenance (corrective or preventive) has a direct impact on the reliability of the equipment. Therefore, maintenance has a direct impact on the performance of the equipment. If this equipment is used to manufacture products, then it is obvious that improving equipment performance would also enhance product quality[6, 7].

The main purpose of this study was to give a simple expression of the reliability of industrial systems that affect the maintenance function in order to contribute productively (effectively and efficiently) and we addresses some practical guidelines to achieve it.

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THE QUANTITATIVE APPROACH OF RELIABILITY

Reliability is the probability that a piece of equipment will function without failure for a certain period of time within an environment for which it has been designed to operate[8]. The operational state of the industrial equipment will be "operational" (up) or "non- operational" (down). Theory of probability and its applications has a very important role in the definition of reliability and reliability analysis. We define as[9, 10]:

R(t): the probability that the system will not fail during the stated period of the operating time t, under stated operating conditions, R(t)=P{the system does not fail during [0,t]}

F(t): the probability that an part will fail before or at the moment of operating time t, F(t)=P(failure will occur before or at time t)

Then the equipment status at the point of operating time t will be determined by:

$$R(t) + F(t) = 1 \tag{1}$$

Relation (1) describes the fact that it is certain that the part of equipment in a future moment of operating time t will be either operative or non-operative.

Relation (1) can be written as:

$$R(t) = 1 - F(t) \tag{2}$$

Relation (2) describes the fact that it is certain that an part of equipment in a future operating time t can be calculated if it's unreliability is known, something which sometimes is found to be easier to calculate. For example, proposes unreliability calculations to be used in stock control forecasting of repair parts.

At this point we consider it necessary to proceed in the following clarifying remarks:

- The terminologies operational, and non- operational, refer to the ability of the equipment (or system) to operate according to its specifications. We adopt the convention that the term operation is describing to the user's while the term operational describes in a probabilistic manner the status of the equipment (i.e.,it's ability to operate).
- The function R(t) is practically a time function of the equipment's operation and/or the calendar time, which starts at a given point of time. It can also be a function of equivalent quantities as for example operation cycles (e.g., flight hours, mileage of a car, burn-in of electronic circuits, etc).

The notion of reliability is equivalent to quality over time. It is the quality of performance for durable goods, and what more durable good from the industrial equipment. When we refer to the industrial equipment and even more when this equipment is interrelated with automated functions, the highly automated production systems render themselves to analytical procedures and make possible the quantitative expression of deviations from the specifications' standards. This fact contributes to more effectively control the production function, making it possible to express quantity, quality and product's cost parameters.

The notion and meaning of reliability is more perceptible when we think of it from the user's side. That is how we can construct more reliable products. In the maintenance function, however, we anticipate the reverse problem. That is how a product which we have already bought and use, we can exercise productive maintenance. We consider the simple case of the series configuration that is the most commonly encountered reliability block diagram in engineering practice. In a series configuration, all the consisting parts of the system should be available or functional to maintain the required function of the system. Thus, failure of any one part of the system will cause failure of the system as whole. Let $R_i(t)$ denote the reliability function of the part I, and we suppose that the system consist of n parts. Then the reliability function of the system for t hours of operation is given by:

$$R(t) = R_1(t)^* R_2(t)^* \ldots {}^* R_i(t), = \prod_{i=1}^{n} Ri(t), \; I = 1,2,3 \ldots n \tag{3}$$

In Fig. 1 we present the system's reliability for series configuration as a function of reliability of each part. We observed that for a system which is comprised of ten parts with 99% reliability each, the whole system's reliability turns out to be 90.43%, whilst a system which comprises of 100 parts with 99% reliability each, presents a whole system's reliability of 36.6%. Examining closely at a further level the notion of reliability we shall come upon the notion of operational efficiency. Operational efficiency brings us to very important maintenance parameters as time to failure (TTF) and time to repair (TTR). The TTF of a particular equipment (of the system) is defined as the time that elapses from the moment the equipment goes up and starts operating after a failure, until the moment it goes down again and stops operating due to a new failure. The TTR of failed equipment is the time that elapses from the moment the equipment goes down and stops until the moment it goes up and starts operating again. If we know the performance of a equipment or in general of a industrial system (e.g., the layout of the production machines) it is possible to forecast the consequences of the TTR over the whole production system.

The product of maintenance activity is to keep available and in operative status the industrial equipment. That is to keep it able to operate according to each specification - when and whenever it is required. Thus,

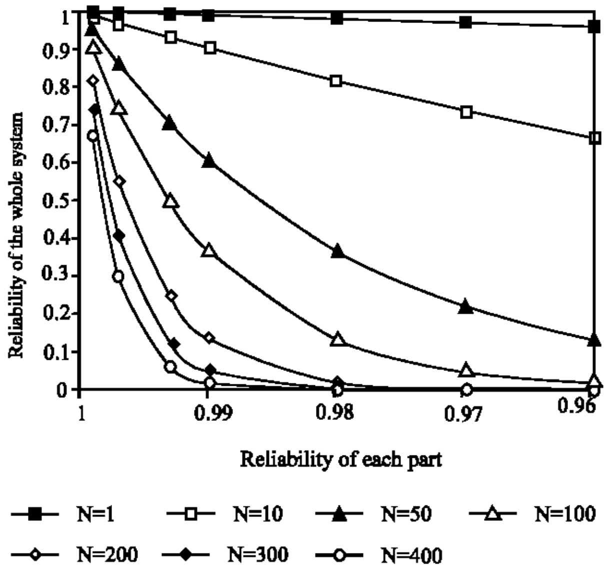

Fig.1: Reliability of the whole system for series configuration in terms of reliability of each part

the product of the maintenance activity can be defined as availability of the equipment. Availability is the umbilicus court between maintenance and system's reliability. Our target is to minimize the down times of the system, reducing the TTR. This can be diminished in a system from: a) the designed and manufacturing phase following proper specifications that will provide for backup units and sub-systems, b) the user applied the appropriate maintenance policy and c) undertaking a suitably programmed training continuous effort of the maintenance personnel.

THE QUALITATIVE APPROACH OF RELIABILITY

The manufacturer is the only one who knows the reliability of the product he designed, manufactured and sold to the users and even has the primary initiative in editing and issuing the maintenance requirements, cannot control neither of the following factors:

- The environment in which the user will operate his product. We mean that the physical environment e.g., climate: imagine a grader walking in desert or arctic conditions.
- The specific range of operations pertinent to the user specific operations. That is the specific sub-set of the whole range of permissible operation, which the product can be performed and that subject buyer will use for his purposes.
- The management/administrative conditions prevailing in the user environment. That is the professional and technical level of the maintenance personnel of the operators and of the whole management structure of production and maintenance.

The above argument can rather easily drive us to the conclusion that reliability has in practice three levels of expression:

Inherent reliability: Is what stems out of the designed and manufacture data of the product (that is level of technology, selection of material, manufacturing methods, etc.). For this wholly responsible is the manufacturer. This parameter can be calculated nowadays with satisfactory accuracy as it stems out of a wide bibliographical range.

Induced reliability: Is what the user inflicts for the machine and which stems out of its environment peculiarities and specific range of his operations. For these parameters the only responsible contributor is the user. This parameter includes sub-elements of the user physical operating environment, technical training and dexterity level of his operation and maintenance personnel, the effectiveness of his supply and support function and his adequacy in tools, equipment, etc. The expression of reliability acts in a corrosive way to the inherent reliability. This can only diminish inherent reliability and never improve it. Thus the expression of reliability stresses the fact that the user of the equipment can only act in a way that may be deteriorating to the building reliability of the equipment.

We must clarify that induced reliability cannot be calculated with the same level of mathematical accuracy with the inherent one, because we enlarge the system under consideration. That is while in the inherent reliability we have the structure of the product only and on it, we perform our calculations (the product we know and we control its design) in the induced reliability the system is enlarged by exogenous factors to the product some of them are not easily quantified (physical environment, training level, administrative efficiency, supply line efficiency, etc.).

Phenomenal reliability: Is a function of at first glance undetermined functional relation of the above two expressions. If we symbolize with R_h the inherent reliability, with R_d the induced reliability and R_{ph} the phenomenal reliability, then what the user perceives as equipment reliability is the phenomenal reliability:

$$R_{ph} = f(R_h, R_d) \quad (4)$$

The function "f (·)" is not easily formulated and requires the exact expression of both R_h and R_d and the permanent awareness that the first stems out of the hardware and the latter stems out of the conditions of exploiting the machinery – some of which are not easily quantified and that R_d acts only negatively to R_h. In other words when we refer in the reliability of the industrial equipment, in practice we denote the phenomenal than the inherent reliability.

This is a very important because leads us to very useful suggestions in reference with the way we must practice the maintenance activity. Recognizing this triple phased structure of reliability means that if we bought poor inherent reliability equipment we can only maintain its reliability in the highest level only and only if we can secure the highest possible induced reliability that in the best case must have zero effect in diminishing inherent reliability. On the other hand - this proves very easily in practice–its usual to enjoy less inherent reliability than the one we bought if we operate in a negative maintenance environment or with poor maintenance.

INDUSTRIAL SYSTEMS MAINTENANCE - DEFINITION

It is necessary to provide a standard definition of the modern maintenance function and to interrelate it with the notions of availability and reliability that we dealt with: Maintenance is the undertaking actions in order to secure that a given industrial equipment will maintain for a certain period of time its specified performance.

Four are the elements which interweave in the above definition by which we don't only know what modern maintenance is but also we are given instructions how to perform it efficiently and effectively:

- Maintenance is undertaking actions. It's following on action, which is dictated by the operation of the equipment. This means that even without the operation of the equipment calendar time may impose requirements of maintenance action. Thus, maintenance is a doer's job. This doesn't mean necessarily that does not render itself to scheduling. On the contrary, it needs programming and scheduling but is not a staff function. It's a line function, usually subordinate to production.
- The industrial equipment upon which we exercise maintenance actions is known to us (which means that we know it by model ¯ part/No., and even by serial number ¯ s/n). Also we have been equipped by its bibliography which means operation manual, maintenance manual, etc. It goes without saying that the personnel who will undertake and carry out the necessary maintenance actions should be qualified with the general and specific knowledge of his specialty and the equipment. Training is a must and it plays a very active role in the whole maintenance activity.
- We maintain only for a certain period of time. That is whatever maintenance activity we undertake these actions have a due date after which we must repeating the same or a variance of the original maintenance action. Under this light maintenance can be considered as the legal term dominant tenement.
- Our aim is to enjoy the services of the equipment that we have paid and bought. The services of which we evidently need in order to exercise our business. In other words, we need the specified performance of the equipment over time. At this point we could be mentioning a series of generic problems relating with the criteria we employ when we buy industrial equipment. That is how we evaluate our suppliers, their products and their services after sale, etc.

This definition does not only inform us what modern maintenance is but also, at the same time, it suggests what we must do, in order to implement effective maintenance. In order to enjoy modern effective maintenance we must:

- Document the subject equipment with all the pertinent manuals, blueprints, service bulletins, etc of the manufacturer. In case the manufacturer cannot provide these, we must substitute with some kind of information what we are going to use as documented information about the industrial equipment we use. For example, specifications, operations instructions, parts catalogue, etc. may constitute the nucleus of the required technical documentation.
- Plan and execute a schedule of programmed maintenance with the objective of preserving the original specifications performance of the equipment. This will help us maintain diaxronika the quality of the equipment we bought. The maintenance programme, in combination with the maintenance procedures, comprises the maintenance system. The user must operate his equipment with computerized maintenance management systems (CMMSs). Our general objective is according to relation[4] to enjoy R_h which we bought instead of an R_{ph} which will be $R_{ph} < R_h$ because induced reliability will act negatively on the inherent reliability. In general, we don't want $R_{ph} \# R_h$, on the contrary we pursue with every available mean $R_{ph} = R_h$. Thus, all the factors that comprise the induced reliability – and there are a lot and important – they must be treated in such a way as to be always present during the maintenance actions and to act positively.

- Collected by the user information data of the equipment if he recalls in a systematic way the operational characteristics of the equipment (such as failure modes, frequency of failures, findings during the repair activities or scheduled maintenance inspections, TTR, TTF, etc.) under his own particular operational experiences and within his own working environment. Thus, it becomes necessary the creation of a sub-system collecting and processing of maintenance statistical data which will be considered an essential part of the maintenance system.

The information data of such a system when processed and analyzed will render useful information which will lead to suggestions about the objectives and the expected performance of the maintenance function and then to the production function. Only with such a way the user of the equipment can be secured that he uses valid data for the critical calculations which are required for an effective production schedule and only in this manner he can be sure that every time he proceeds to the renewal of his industrial equipment he will be contributing to a better and more reliable production system as a whole.

CONCLUSIONS

It is clear that if the already established knowledge of reliability theory is in a potential position to help the firm enlighten some dark cost sectors; this can be done only with a control system that will be operating constantly within the firm and which:

- It will secure that the reliability and maintainability standards that the firm is pursuing must be incorporated effectively in the already accepted firm procedures and that these standards express themselves when and where needed in the every day practice from everybody involved, with the scope to maintain $R_{ph} = R_h$.
- It will provide a method of recording, storing and analyzing the functional characteristics of the equipment, as these are expressed in the daily operation. It is absolutely necessary for an established procedure to be available and which will rule the anticipation of failures in correlation with the losses of production. Part of this procedure must comprise the evaluation of the maintenance effectiveness.
- It will permit easy research in connection with who is responsible for keeping the provisions of these procedures in a way that will make directly and clearly visible the compliance responsibility, either this concerns departments or persons (no gray areas of responsibility overlapping or obscure personal responsibility).

If the firm decides that its products reliability will contribute to its profitability, then it must anticipate reliability under the concept that the reliability is a duty and a responsibility of everyone working in the firm and must be organized upon on the three above directive lines. In modern management there is analogous development of the fundamental concept of quality that the last decade or so has been transformed as total quality. If we want reliability to play an active role in firms' profitability, we must proceed to analogous movement. Reliability must break the tightness of departmental lines and become a common term of reference between technical, engineering, financial and administrative personnel of the firm, get out the designed desks and find a seat on the table of the board of directors.

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