MAINTENANCE CRITICAL ANALYSIS AND PRIORITY INDEX: A NEW MODEL FOR MAINTENANCE POLICY

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ABSTRACT
Industrial processes are realized according to production levels established in the design phase.

Proper maintenance of machines involved in the process guarantees the compliance of these levels over time, ensuring adequate availability standards of plant and machinery. Conversely, inadequate maintenance can affect a decrease of production levels. In this case, the company may not respect the demands of customers, resulting in economic losses, which may affect its survival.

In this paper, a new procedure is proposed, in order to develop a useful tool to support the design of maintenance.

The proposed procedure is based on the identification of the main factors influencing availability and maintenance of industrial plants, then summarized through appropriate indices.

Indices analysis allows the identification of the guidelines, to optimize the maintenance of the units.

This tool allows an appropriate allocation of budgets to maintenance activities, right for machines or units that are strategic to ensure production.

Keywords: design of maintenance, budgets allocation

1. INTRODUCTION

The maintenance plan of a plant is primarily designed to ensure a high level of availability, so as to complete a given production.

The overall availability of an industrial plant depends itself from the wards or by machines that constitute it, and how the machines are linked together. From this point of view, the plant is similar to a complex system, whose target of reliability results from those of its components. In fact, it is possible to establish a plant target value of availability, according to the elements composing it.

In this case the target depends on the quantities set out in the master production schedule and the service level established in supply contracts (Falcone *et al.*, 2011).

Units or machines have different criticalities depending on many factors that identify their importance in the production process.

The proposed methodology is the result of a careful bibliographical study about the main research areas in the field of maintenance.

The development of a maintenance program must be based on information collected by monitoring the condition of a system or a production process, which can be classified into two categories: direct information, and indirect information.

In direct information, the parameter measures the fault of the process or wear condition (for example, the thickness of brake pads). On the other hand, indirect information give indications on the dynamics of failure, but they are not a direct measure. Example of indirect information can be an analysis of the characteristics of refrigerant oil (Christer and Wang, 1995), (Raheja *et al.*, 2006).

The works of applied research can be divided into three groups as follows.

The first group of research is only focused on the determination of the optimal inspection times or intervals (Chen and Trivedi, 2002), (Wang, 2003), (Falcone *et al.*, 2004), (Kalleh and Van Noortwijk, 2006), (Wang and Jia, 2007).

A common assumption is that the used information are direct; for this reason, the wear condition of the system can be identified by monitoring it and then, after an inspection, it is possible to provide appropriate maintenance action. The aim is to determine the best time of inspection, depending on the optimization of a parameter such as the maximum availability or the minimum cost per unit of time.

The second group of research concerns the dynamic determination of the inspection time and the time of maintenance or replacement (Castanier *et al.*, 2003), (Chen and Trivedi, 2005), (Ghasemi *et al.*, 2007), (Wang *et al.* 2009). Future inspections and the best maintenance actions are scheduled in this case, according to several performance criteria, such as the "long run system availability" and "long-run expected maintenance cost". For this purpose, information on the wear level of the system result from non-periodic inspections.

The third group is focused on the determination of the optimal level maintenance or replacement (Banjevic *et al.*, 2001), (Chen and Wu, 2007), (Lu *et al.*, 2007). A common assumption is that the information obtained from monitoring the conditions are indirect. The inspections are carried out periodically and aperiodically but with a predetermined schedule. The aim is to determine a level that optimizes a given performance criterion.

Makis and Jardine (1992), propose the definition of the limit level of a system, for a random fault. In their approach, the checks are carried out at fixed interval, determined for each. The equipment is replaced each time it fails. In addition, after each inspection and according to the results of the inspection, if the fault cost reaches or exceeds a predetermined limit, a preventive replacement is provided.

The main techniques in literature are based on the assumption, (implicit but real) you have an unlimited budget and always sufficient to ensure the operations that each methodology identifies.

This hypothesis is often in conflict with the increasing difficulty that companies have to dispose of adequate capital for the ideal maintenance of their plants.

The above considerations suggest the development of a method, in order to quantify units criticalities, identifying the most relevant to ensure the production. The basic hypothesis is that a greater strategic importance of the unit or machine, must signify greater efforts in terms of maintenance activity.

For this purpose we introduce some indices, to take into account factors that can quantify the importance of each unit in a manufacturing process.

2. FACTORS DETERMINING THE AVAILABILITY OF MACHINES

For the application of the proposed methodology, factors considered critical to the maintenance of the machines were analyzed.

2.1. Level of Use

Not all the units have the same relevance, in a plant. This essentially depends on how one unit or machine is involved in the production process. It is clear that units more "stressed" by the process have a greater influence, showing for this reason, the highest levels of criticality.

In terms of availability, higher performance is required to most involved units. The unavailability of a highly used machine, in fact, risks to compromise the whole process. The level of use depends on:

- working time of machine or unit, compared to running time of the plant;
- flow of material crossing the unit, compared to the overall flow of the plant.

2.2. Maintainability

The operational availability of a working system, when uptime and downtime are known, can be precisely calculated as the ratio between the real working time and the theoretical one and depends on the mean values of the distributions of faults and repairs in time. Therefore maintainability greatly influences the availability of the plant (Falcone *et al.*, 2014).

Maintainability characterizes the simplicity of maintenance activities. For the same number of faults and theoretical working time, the greater will be the time required to restore the system in working condition, the lower will be the availability.

These concepts are also analytically reflected, as is well known, in the operational availability A(t):

$$A(t) = \frac{MUT}{MUT+MDT} \tag{1}$$

where the Mean Up Time (MUT) and the Mean Down Time (MDT) are average values in a time range, typically one year.

A poor maintainability of the system corresponds to high values of the MDT and consequently a reduction of the system availability, for equal MUT.

The maintenance times (MDT) are therefore an indirect measure of the availability.

Units or machines with a high mean down time, are the critical issues in terms of overall availability of the system, with consequences also in terms of safety (Falcone *et al.*, 2007), (Di Bona *et al.*, 2014).

2.3. Working time

Another way to evaluate the importance of the unit in the process, is to estimate how much time it is used for producing a single unit of product, compared to its takt time.

More work times in fact, generally correspond to complex and relevant operations. In case of multi-product companies, the assessment must be repeated for all products which the unit is involved for.

2.4. Maintenance cost

In the economic sphere, maintenance is similar to a particular type of investment, depending on production volumes and on the importance of the machine in the production cycle.

The costs related to maintenance activities are numerous and different. The main types of cost are:

- Cost of spare parts and equipment;
- Cost of internal labor;
- Cost of external labor;
- Non-profit due to break of production;
- Costs of image.

Investment in maintenance, which are often very large in modern in company, must be weighed and focus on those departments whose unavailability can compromise the whole production process.

2.5. Variety of faults

To make more complex the maintenance operations, influencing the availability of a beam, is not only the quantity (measured in terms of time) of failure events that occurs, but also their variety. Different faults are generally synonym of a high complexity in maintenance operations, as well as a structural complexity of unit or machine.

3. STRUCTURE OF INDICES

The influencing factors and critical issues, analyzed so far, have been formalized through appropriate technical and economic indicators, used to measure the criticality of units in terms of maintenance and consequently production.

The mathematical structure of the indices is as follows.

3.1. Flow index

Flow Index (FL_i) for the machine i-th is equal to the ratio between the flow processed by the unit (F_i) and the total materials flow of the plant (F_{tot}).

$$Fl_i = \frac{F_i}{F_{tot}} \quad (2)$$

This technical indicator is intended as a measure of the importance that the unit or the machine covers in the production process.

It always takes positive values between 0 and 1; in particular take values close to one, in case of indispensable units for production.

The flow index takes into account, even if indirectly, the production process and the functional connections between the machines.

For companies with a single product line layout, the flow rate will be the same for each machine with value always equal to 1 (unless by-pass along the process).

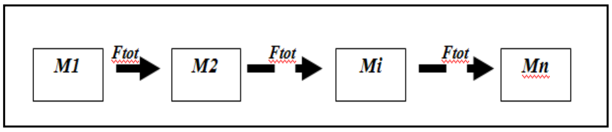

Figure 1: Line layout flow

In case of more complex layout configurations, with more production lines or machines in parallel, the flow index can be calculated as in the example shown in Figure 2.

Being Fi the flow of materials in the machine i-th, and assuming that the takt times are equal, is possible to assume values of flow as follows:

- $F_1 = F_7 = F_{tot}$;
- $F_2 + F_3 = F_1$
- $F_3 = 2F_2$
- $F_4 = F_5$
- $F_2 = F_6 = F_4 + F_5$

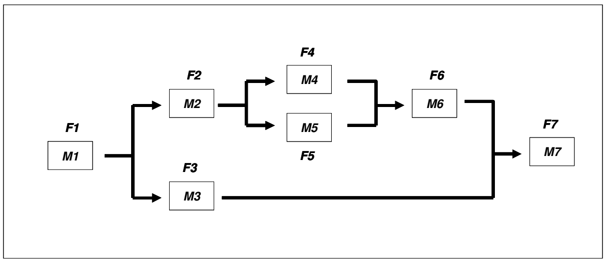

Figure 2: Example of complex layout

It will result for example, the following values of the flow index:

- $Fl_1 = 1$
- $Fl_3 = 2/3$
- $Fl_4 = 1/6$

In calculating the index, it is necessary to measure the flow of materials in a way suited to the specific production process (number of pieces, weight, capacity, MAG).

3.2. Time index

Time Index (T_i) for the unit or machine i-th is the ratio between the working time of the machine for a unit of product and the takt time of the product.

In case of multi-product company, where the same machine is used for the production of different products, the index formula is different.

P_1.....P_n are the products made by the company. If we denote TC_1 ..... TC_n as the takt times for each product and T_{ij} as the time in which the i-th machine works the product j-th; the machine time index will be:

$$T_i = \frac{\sum_{j=1}^{n} T_{ij}}{\sum_{j=1}^{n} TC_j} \quad (3)$$

Because of its formulation, time index value is between 0 and 1.

3.3. Maintenance Index

Maintenance Index (M_i) is given by the ratio between the average number of hours spent in maintenance in the i-th station (TM_i) and the average number of hours of maintenance time, calculated for the unit with the highest maintenance time (TM_{max}) .

$$M_i = \frac{TM_i}{TM_{max}} \quad (4)$$

The introduced index can take only positive values up to 1, in the case of a unit with the highest maintenance time.

3.4. Cost Index

Cost Index (C_i) is the ratio between the annual cost of maintenance for the i-th unit (CM_i) and total cost of maintenance of the system (CM_{tot}) in a year.

$$C_i = \frac{CM_i}{CM_{tot}} \quad (5)$$

Differently from the previous, it is a purely economic indicator, to estimate the importance of the unit in terms of cost in maintenance.

Also in this case the index takes values greater than 0 and can be 1 if the entire cost of maintenance of the company is used for the analyzed unit. The index only takes into account the costs for industrial maintenance.

3.5. Failure Index

Failure Index (Fa_i) is the ratio between the failure modes occurring in the i-th machine (Fm_i) and all the different failure modes (Fm_{tot}) of the plant (in a year).

$$Fa_i = \frac{Fm_i}{Fm_{tot}} \quad (6)$$

The term "failure mode" refers to the diversity of faults and not to their number. In fact, if the same fault occurs again, in the index it should be counted as one.

4. MCA (MAINTENANCE CRITICAL ANALYSIS)

The proposed indices, are the base in a method of analysis, able to constitute a real tool for maintenance management of an industrial plant.

The introduced methodology, called **Maintenance Critical Analysis (MCA)**, aims to identify units or machines that have the most critical maintenance and require major investments. The MCA method can be summarized in some stages.

4.1. Plant breakdown

It is necessary preliminary to define what are the units or machines that break down the system to be analyzed. At this stage of breaking down, some basic rules must be observed:

- The number of components has to be such as to adequately describe the specifics of the system, however, does not create problems of data management, due to a too detailed breakdown;
- For chosen parts, the parameters used for the analysis must be uniquely and easily identified.

4.2. Data collection

For the selected units, the data needed to calculate the indicators for MCA, should be collected. This operation may require, in some cases, an extended period of time.

4.3. Indices calculation

Once the necessary data are been collected, the indices for the analyzed units are calculated.

4.4. Maintenance Priority Index (M.P.I.) calculation

The calculated parameters are summarized in a single index, called the Maintenance Priority Index (MPI) to be calculated for each machine.

The mathematical formulation of MPI is as follows:

$$MPI_i = Fl_i \times T_i \times M_i \times Fa_i \times C_i \quad (7)$$

The introduced index can take values between 0 and 1, directly proportional to the criticality related to the unit or the machine.

4.5. Analysis of results

By ordering the units according to a decreasing value of MPI, you can get the list of priority maintenance priorities.

According to these priorities, maintenance must be designed and budgets must be allocated.

Units with higher values of MPI are the ones who more resources should be used in terms of maintenance activities. Their unavailability may in fact seriously undermine the success of the production process.

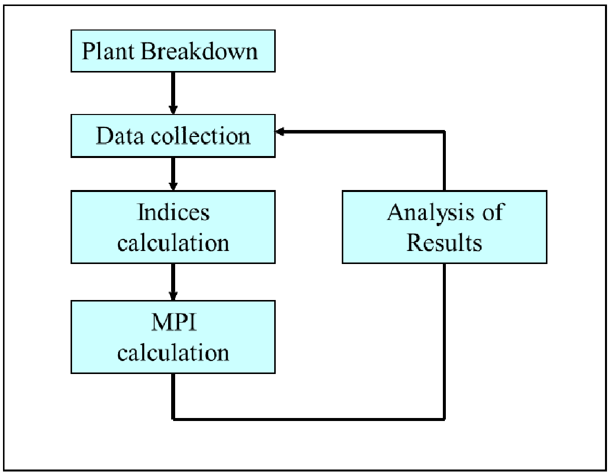

Figure 3: MCA flowchart

4.6. Design of the maintenance plan

Once defined which production units are prioritized in terms of maintenance and the overall budget to be allocated, the obtained results can be used to design the maintenance plan.

For each unit, all maintenance operations necessary for its survival must be defined; these operations constitute the minimum level of maintenance. Calculating the corresponding cost for each unit you get the minimum cost of maintenance for the overall plant.

In order to apply the methodology in a profitable way, the budget that the company has set aside for maintenance, has to be greater than the minimum cost previously defined. In this case, by subtracting the second to the first, it gets the remaining budget that can be allocated, according to the MPI values.

4.7. Results Checking

The nature of the proposed methodology is iterative, since the analysis must be periodically repeated with two different purposes.

The first one is to check the results. The MPI values of those units, which the remaining budget was allocated to, will be reduced in comparison to those previously calculated.

The second reason is to monitor any changes in terms of the importance of the departments, due to possible changes in production.

A further verification of the results, can be done by comparing the break down times of the system before and after the application of the method, expecting a decrease.

5. CONCLUSIONS

After explaining the phases of the proposed method, it is appropriate to highlight some important features.

It should first be pointed out that since this is a tool for preliminary analysis, it favors simplicity, both in the mathematical treatment, as in the application. This allows a profitable use, without excessive use of resources.

The generality of the indicators determines the MCA applicability to any type of industrial plant, regardless of its peculiarities.

By repeating the maintenance analysis on selected units after the first application, the method can be also used as comparison and to check the results.

Finally, it is important to note the similarities between MCA and FMECA. The two methods have a very similar logic, although using different indicators.

While FMECA is focused on the analysis of failure modes, MCA takes into account a larger number of factors and is aimed to the analysis of units and machines in general. It should also be highlighted that the introduced tool, can be used as a preliminary stage of more specific analysis on the machines.

Currently the method is tested in two different production systems. The results of the testing phase will be processed in order to identify possible criticalities or improvements.

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