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MAINTENANCE MANAGEMENT*

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* The views expressed in this paper are those of the author and do not necessarily reflect the views of the Secretariat of UNIDO. This document has not been edited.

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INTRODUCTION

The economic development in many developing countries has undergone considerable changes during the past ten years. On the one hand, there have been technological innovations, and a continuous decrease in the use of installed plant capacity on the other hand. As a result, average capacity utilization of industrial enterprises is below 40 per cent. One of the main reasons is the low priority plant managers have been given to maintenance of equipment and maintenance management.

At the Second Consultation on the Training of Industrial Manpower and the Regional Consultation on Industrial Rehabilitation/Restructuring with Special Focus on the Food-Processing Subsector in Africa, the importance of maintenance was underlined as one of the tools to increase the profitability of industrial enterprises.

The United Nations Industrial Development Organization (UNIDO) and the International Labour Organisation (ILO) are increasingly aware of the importance of maintenance and have jointly provided funds for the preparation of a manual with wide focus on the problems of maintenance management in developing countries. The manual, which is about to be completed, has been prepared by Mr. P. de Groot, a well-known consultant, and is intended for both executives and maintenance managers.

The manual aims at:

- Making top management aware of the importance and benefits of good maintenance as well as the problems and costs of neglecting maintenance work;
- Presenting a professional guide for maintenance managers of medium-scale enterprises for organizing maintenance departments and implementing effective maintenance management systems.

The paper presented at the Workshop is based on that manual.

COMMON MAINTENANCE PROBLEMS IN INDUSTRY

In reviewing the facts which affect maintenance of industrial plants both in developed as well as in developing countries, 5 common problem areas are distinguished :

- (1) the plant and its operation;
- (2) maintenance organization and management;
- (3) material resources with special emphasis on technical documentation and spare parts control;
- (4) human resources;
- (5) financial constraints

We shall discuss each of these problem areas in the following sections.

1. The plant and its operation

The origin of many maintenance problems can be found at the design stage long before the start-up of installations.

These problems concern essentially the correct adaptation of the equipment to local conditions, the timely supply of all operation and maintenance documentation, the supply and installation of machines, spare parts, training of personnel, technical assistance and after-sales service.

In pre-investment studies, the maintenance factor (budgets, human and material resources) is rarely considered.

The terms of reference and technical specifications deal particularly with the production machines. They never deal in detail with factors such as standardisation, maintainability, technical documentation, spare parts, training of maintenance personnel and maintenance organisation.

During contractual negotiations, maintenance specialists are usually absent. The requirements of maintenance are rarely taken into consideration, on the one hand because of the lack of consciousness of this problem and on the other for reasons of increase in price. The extra cost that maintenance requirements entail is in no relation to the benefit- financial and moral- of a good functioning plant.

Regarding the design of the factory, too little attention is paid to the factors which determine its success, such as location, size, detailed design of the installations and adaptation of the equipment to the environment (human and climatic). This is often due to the fact that the designer is not a plant operator himself.

Regarding the choice of adequate technology for developing countries, this does not mean outdated technology- not enough attention is paid to the following factors which have a direct influence upon maintenance : distance between the plant and the suppliers, communication deficiencies, severe climatic conditions, lack of qualified work force, operational errors occurring more frequently than in the traditional industrial context, etc.

Regarding the strategy of construction of a plant it has been found that the auxiliary services (workshop, stores, offices, ...) are built after the installation of the production machines. So precious time is lost for training and for organizing maintenance.

From the organizational point of view, the various maintenance sections are planned too late (in many cases just before start-up), leading to insurmountable problems during the start-up period.

The supervision of plant construction by the customer concentrates almost only on the erection, commissioning and start-up of the production machines and buildings. The control of services rendered by the supplier in the field of technical documentation, spare parts or training for maintenance for instance is often neglected.

Finally, the construction planning being rarely respected, the contractor tries to make-up for the delay by accelerating the remaining work at the end of the construction. This concerns mainly electricity and instrumentation. It has been found that these measures lead to points of neglect and error in vulnerable installations where Maintenance will have to face most of the problems after start-up.

2. Maintenance organization and management

The lack of organisation and management of maintenance concerns particularly following topics :

- maintenance is generally under-estimated and its productive function is not recognised. This has the following consequences :
 - the maintenance department is placed in a minor position on the organisation chart,
 - the maintenance department is placed hierarchically in an inferior position to that of the production department,
 - Insufficient financial means are allocated to maintenance,
 - under-qualified personnel is allocated to the maintenance department,
 - insufficient attention is paid to the requirements of maintenance in the pre-investment and engineering phases, as well as during the purchase of equipment,
 - there is a belated preparation of the maintenance function when implementing new projects (human, material and financial means);

- the maintenance organisation chart is unclear or ill-defined; the job descriptions are non-existent;
- the following functions are non-existent or under-estimated :
 - methods,
 - programming.
 - job-preparation,
 - scheduling,
 - maintenance management,
 - stock administration;
- data collection is insufficient, information flow is not defined and there is no feed-back nor evaluation of data;
- the internal organisation is neither established nor registered;
- the aspect "maintenance management" is practically non-existent :
 - establishment of a management steering-chart,
 - management of maintenance ratios,
 - establishment of availability statistics of the production machines,
 - calculations of reliability,
 - analysis of breakdowns (nature, frequency, direct or indirect effect),
 - assessment of maintenance costs and outlook,
 - life-cycle costs,
 - dosage of periodic, condition-based and corrective maintenance in maintenance planning;
- maintenance methods are under-developed; the consequence is :
 - no maintenance planning,
 - incomplete lubrication planning,
 - no job preparation, - no work analysis,
 - no machine history files,
 - no selection of parts or raw material to be stocked,
 - impossibility of making correct estimates,
 - impossibility of indicating or respecting a delay; training in maintenance organisation, methods and management intended for engineers and foremen is under-developed and often far from reality.

3. *Material resources*

The material resources which are necessary for maintenance practice are the technical documentation, spare parts, tools, measuring instruments, machine-tools and workshop equipment. Hereafter we will limit our presentation to the 2 most important ones : technical documentation and spare parts.

Technical documentation

During surveys carried out in industry in various countries, it was noted that only about 5 % of the factories have a complete documentation; 15 % possess sufficient documentation permitting correct maintenance; 55% have an incomplete documentation often in a language other than their own, while 25 % of the plants have no documentation at all.

When purchasing equipment for plants, technical documentation is generally neglected both by the supplier and by the customer.

The lack of documentation is one of the major problems which maintenance services have to face. Maintenance without a comprehensive technical documentation is almost impossible. It is necessary to ensure repair work, manufacturing of spare parts, quick trouble shooting, a thorough work safety of personnel, a better maintenance management, a correct choice and administration of spare parts and an efficient training of maintenance personnel.

In the process of technology transfer, technical documentation is a priority link without which efficient transfer is possible.

Spare parts

Spare parts cause major headaches to the operators of industrial installations. In developing countries for instance it has been found that at least 50 % of unavailability of production equipment is due to a lack of spare parts.

Problems which have been noted at plant level are as follows :

- an important variety of equipment manufacturers and little effort made to standardize machinery and components, resulting in a large investment in spare parts stock;
- poor selection of stored spares. This is due to on the one hand a lack of information in technical documentation given by the manufacturer and on the other hand to a lack of experience in plant operation from those who make the choice;
- incorrect designation of spare parts. The designations are mainly done, based on the information supplied by the manufacturer. In most cases, they only give the designation of the machine manufacturer and not of the spare part manufacturer. The use of designations in conformity with international standards hardly exists because manufacturers think they can protect the spare parts market by doing so. The problem exists even more for the spare parts of sub-assemblies or individual components (from which the manufacturers are sub-contractors of the machine manufacturer, often to the third degree);

- **non-existent in-plant codification of parts. The reasons are :**
 - non-existent internal coding system (codification grids),
 - ill-identified spare parts,
 - poor application of codification grid, if it exists;

- **insufficient or non-existent stock administration, due to a lack of stock administration systems or to a lack of information concerning the administration parameters (average monthly consumption, price, delay, mini-maxi stocklevels, ordering point). A poor data collection (issuing or entering quantities, repairability, etc.) or a belated treatment (manual or by computer) jeopardizes reliable data. Moreover, unreliable information about frequency of part-replacement or priorities for planned overhauling, do not allow for the determination of consumption parameters;**

- **lengthy re-ordering delays, due to protracted internal delays in the plant, delivery delays by the supplier, delays in payment or in the setting-up of financing (mainly for imported parts in countries with non-convertible currency), custom delays (heavy administration, work overload of custom services, ...) and finally due to transport delays between place of arrival and destination;**

- **lack of hard currency for imported spare parts which has obliged plant management to reduce their stock. This reduction is done indiscriminately, which leads to stock-outs of vital parts;**

- **random allocation of import quotas in certain countries;**

- **poor storage due to insufficient storage and handling facilities or due to a lack of part conservation arrangements (cleaning, anti-choc or anti-corrosion, protection and coating). In certain countries, it has been found that approximately 15% in the value of the stored spare parts is useless when they are needed due to storage conditions;**

- **poor knowledge of stock. There is an important percentage of dead stock (often between 15 and 20% of the items). Stock analysis (i.e. method of Pareto) is not carried out and therefore spare parts for machines after demolition continue to be stored.**

Apart from the above problems, it must be stressed that detailed contractual clauses concerning spare parts are missing or are unclear when purchasing equipment. Separate terms of reference rarely exist in this case.

As to developing countries, there is a lack of facilities and capabilities for local manufacturing of spare parts. The industrial network around the factories in Third World countries is very limited. This often forces the factories to become self-sufficient in this field. But this is still not enough to encourage adequate investment to meet these needs. In order to be able to manufacture spare parts locally the following conditions should be fulfilled :

- knowledge of technical information for manufacturing (workshop drawings, material, tolerances, heat treatment, etc.);
- availability of machine-tools;
- availability of cutting tools and measuring instruments;
- availability of raw material;
- availability of qualified workforce.

Techniques for reconditioning of spare parts (protective coating through welding techniques, metallisation, application of antifriction metal, adhesives, Metalloc system, etc.) are little known and almost no effort has been made to develop them.

Nevertheless they represent a cheap way to make up for the lack of spare parts in many cases.

Finally very little action is taken in the field of HRD for :

- the choice, codification and designation of parts
- stock administration.

4. Human resources

The problems which are found in the field of training for maintenance, can be summarized as follows :

- poor knowledge of training needs leading to inadequate programmes;
- poor knowledge of training facilities (centres, schools, institutes, ...), existing at national and international level;
- incoherence and poor coordination between training programmes of the various training institutes (national and international);
- absence of a maintenance discipline in high school education;
- appropriate training methods (too far removed from daily practice);
- insufficiency or absence of training programmes and facilities for technicians in the following fields :
 - maintenance methods,
 - methods for machine-tooling,
 - stock administration,
 - maintenance management,
 - maintenance organization,
 - instrumentation
 - hydraulics/pneumatics,
 - foundry (modelling, moulding, melting).
- inadequate training programmes for maintenance engineers;

- poor supervision and control of results of fellowships, mainly abroad;
- poor or insufficient qualification and experience of trainers;
- insufficient budgets for maintenance training
 - in plant construction projects,
 - in plants in operation,
 - in industrial projects with international financing.

5. *Financial constraints*

Generally, maintenance budgets are set too low, or they do not exist at all. There is hardly any cost control, and cost data, as far as they can be obtained from the manufacturer, are not appropriate for a developing country. The scarcity of hard currency makes the re-ordering of necessary spare parts in sufficient quantities nearly impossible.

CONCLUSIONS

Operating and maintaining industrial equipment is a difficult task especially when it concerns difficult environments. Too often the interdependency of all the problems mentioned above is neglected. Solving only one of these problems will not even have a palliative effect. Only the reconsideration and emphasis of the maintenance function will help to solve the crucial maintenance problem in many industries. A maintenance strategy, directed at improved maintenance practice in the plants, including rigorous and thorough training plus complete and efficient documentation, are all factors which will contribute to the availability and long life of production facilities.

The launching of an industrial plant is no longer the supply of the equipment plus a number of other services only. It is more than that. It is an integrated process in which production - operation and maintenance- must play a major role from the very start.

**CHAPTER 1
ECONOMIC CONSIDERATIONS ABOUT
MAINTENANCE**

1.1 SOME FIGURES

The expenditure which a manufacturing plant, a company or a country has to make in order to ensure an "acceptable" level of maintenance of its production equipment is in general underrated. Clear and objective data are hard to give, for a common terminology and a standard accounting system do not exist. On the basis of several surveys which have been made in this field during the past 20 years and on the basis of our research and experience one can nevertheless conclude that this expenditure is tremendous.

Maintenance of production equipment has obviously an impact on both macro- and micro-economic levels. Following figures highlight this impact.

In a study of "Factory" in the early seventies, maintenance cost of 687 American industrial enterprises, representing 53,8% of American industrial production, have been analyzed. Following figures have been obtained :

- yearly maintenance cost in relation to turn-over : average 4,12% with a maximum of 17,5%
- maintenance cost in relation to fixed assets : average ranging from 2,73% to 13,8% with a maximum of 17,13%
- maintenance cost in relation to production cost : average ranging from 1,38% to 12,15% with a maximum of 15,86%.

Studies made in Japan in the mid seventies gave 4 to 6% for the ratio maintenance cost/fixed assets.

As to the maintenance cost compared to the production cost, most surveys give a range between 6 and 12%.

A survey made in 50 industrial enterprises from the metal-working, food, chemicals, textiles and paper sectors, by the Centre for Interenterprise Comparison in the U.K. in 1977 resulted in following interesting figures :

- maintenance costs/fixed assets : 5,3 to 26,7%
- maintenance costs/turn-over : 2,5 to 9,8%
- maintenance costs/added value : 3,8 to 16,2 %
- maintenance staff/total plant workforce : 4,7 to 16,9%
- hours worked on preventive maintenance/
total hours worked by maintenance department : 19%.

A survey made by DGS International in 1987 in 3 industrial sectors in Europe (cement, mechanical construction, petrochemicals) resulted in following figures :

- maintenance cost/fixed assets 7,98 to 16,4%
- maintenance cost/added value 10,44 to 12,9%
- maintenance manpower cost/
total maintenance cost 41,75 to 58,35%
- cost for spare parts/
total maintenance cost 17,02 to 44,64%
- maintenance staff/
total plant workforce 5,6 to 65,7%

Following chapters are based on the contribution of Prof. R. LEENAERTS (Catholic University of Leuven - UCL) to the "Maintenance Management Manual" written by Patrick DE GROOTE for UNIDO/ILO. This contribution has been adapted for reasons of the present seminar.

1.2 MACRO-ECONOMIC CONSIDERATIONS

As to the macro-economic level in industrializing countries, following figures highlight the importance of money spent :

- in France, maintenance of production equipment costs 15% of the GNP
- West-Germany spend every year 23 billion US\$ for the maintenance of production equipment
- 165 of the most important industrial companies in the U.S. spend each year in average 5% of their turn-over to maintain their production equipment.
- in 1982, the 9 countries of the EEC of that time spent 86 billion US\$ to maintain their production equipment. This figure corresponds to the GNP of a country like Belgium.

In less-industrialized countries the economical development has been hindered by the imbalance between the purchasing of appropriate technology including modern technology and equipment and its rapid premature deterioration. This imbalance is found at all levels (industry, transport, communications, infrastructures, roads, rail,

etc.) which indicates that it deals with a mechanism which has not been mastered, even partially, by political parties and governments of the countries concerned. The result is, on macro-economic level, that the ratio profit/investment is not only inferior to what it should be but will become close to zero very soon.

The inevitable consequence of this state of affairs -one which has aggravated the situation even more in the developing countries- is that, over the last 20 years, Third World countries have had recourse to huge loans with international financing organizations. Many of them are now burdened by foreign debts. The inference therefore is the imperative necessity to drastically reduce investment and, for future borrowers, to demand a concrete proposition regarding objectives and profitability.

Maintenance can be used at management level as a means to improve the economic performance thus helping to solve, if only partially, the problem of foreign debts. Undoubtedly this is a most optimistic conclusion if one takes into account the gloomy prognostications that are made concerning the subject of development policy.

1.3 MICRO-ECONOMIC CONSIDERATIONS

Because of the indivisible link between the economic health of a country and its activities of production and services - however small - the preceding macro-economic considerations can be applied, in general terms, to these activities.

However, from the moment that production or service equipment is involved and whatever the nature of this equipment, be it a technical unit, a machine, an instrument, a building, roads, etc. the micro-economic logic must come into effect, so that maintenance is considered as the essential contributory factor for company management.

To be able to understand the place maintenance occupies in management, reference should be made to the life-cycle and investment curve relative to the equipment.

a) Life-cycle of an equipment

It has become usual to compare production equipment with a living organism. For each item there is the phase of design followed by manufacturing or construction. Then comes the period of use which is limited of necessity because of the progressive deterioration, and finally after a certain time, total break-down and ruin.

Thus the proposed analogy is strict and must be observed throughout all practical applications from beginning to end. Of equal importance is its economic evaluation.

So whatever the equipment, the same "life-cycle" as represented in Fig. 1 is used as a base. It clearly shows the quantity of goods or services produced annually.

The two areas in the diagram can be explained as follows: AC corresponds with the design (AB) and manufacturing (BC) phase of equipment and CF is in relation to the operation phase (exploitation).

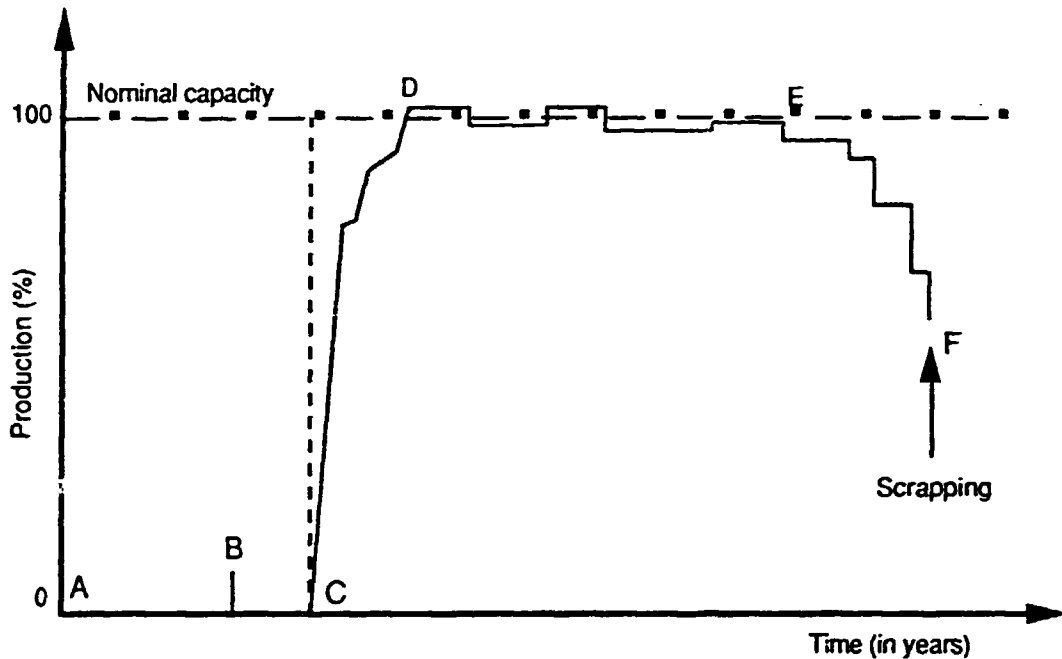


Figure 1 : Life-cycle of a production equipment (goods or services)

AC is often confused with the time scale whereas CF starts with a section CD (which corresponds with the start up of the equipment) DE represents the operation phase and EF is descending in relation with gradual obsolescence. Final scrapping is in point F.

It is essential for the economist to understand that a life-cycle of the equipment generally follows the same pattern. To ease understanding, the failure rate has been introduced. This shows the number of break-downs that occur during a certain period of time e.g. weekly or monthly.

This failure rate obviously depends on the age of the equipment. This can be seen in Fig. 2 , the "bath tub curve".

Classically, curves of this sort can be divided into 3 zones. Zone 1 : during the start-up a decreasing number of hidden construction failures, errors of assembly and running-in problems cause break-downs.

Zone 2 : exploitation; the failure rate is stabilized by controlling wear and tear but this inevitably will increase.

Zone 3 is characterized by an accelerated failure rate due to age followed by obsolescence of the equipment.

Of course any curve of that type will stop suddenly if the equipment is scrapped or re-built.

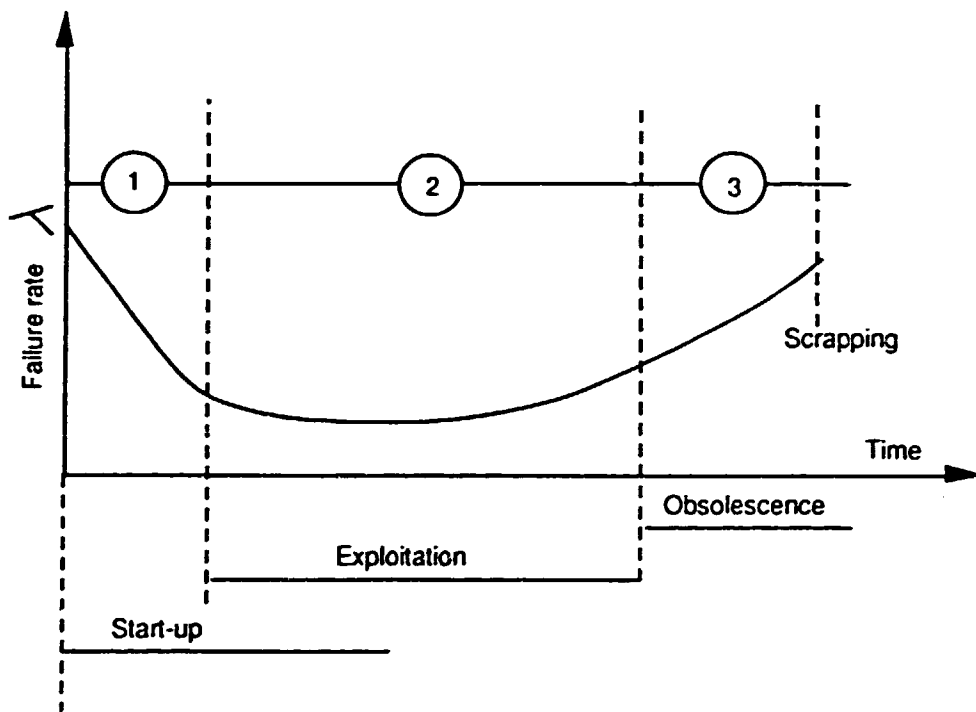


Figure 2 : Failure rate in relation to age of equipment.

b) *Investment curve*

Considering the close relationship between the life-cycle of the equipment and the financial resources involved for the design, construction (or acquisition) and exploitation, it is of the first importance to examine how these financial resources will evolve with time and how the generalization of the notion of investment will allow basic considerations.

At the design stage, the following are grouped under the heading "pre-investment": cost for research, development, in short all activities involved before construction such as project feasibility studies, marketing studies, etc.

In absolute value, the pre-investment is often modest and its evolution is shown in the first part of Fig. 3 .

As to the actual investment, this is the capital needed to acquire or construct, not only the equipment, but also all resources necessary for its exploitation.

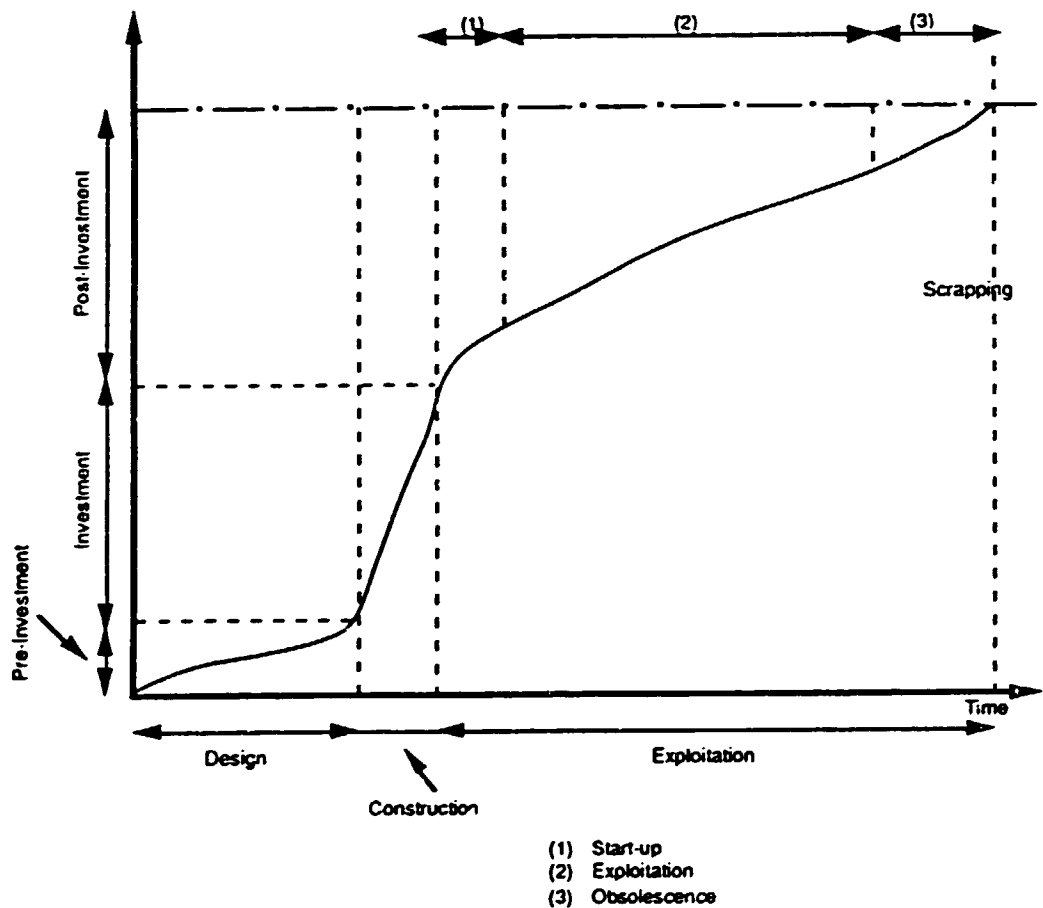


Figure 3 : Investment curve for production equipment (for goods or services)

Compared to the pre-investment, the investment is of a completely different nature: much bigger. Because of this, once the decision to invest has been taken, it is in the interest of everyone to start-up the equipment as soon as possible. This is the part close to the vertical as shown in Fig. 3.

A logical consequence of this approach is to define post-investment as the invested amount during exploitation, which is necessary to ensure correct running of the equipment.

Obviously post-investment includes not only all maintenance costs but also those incurred for improvements or modifications (small engineering and construction work) carried out on the equipment in order to assure technological updating. In Fig. 3 the post-investment occupies a place stretching over a normally long period. The curve shows, at first, a rapid increase in relation to the start-up of the equipment. This increase then attains a more or less constant rate which means an efficient use of the equipment in practice. The final increase of the curve is due to the obsolescence of the equipment which progressive evolution results finally in the stoppage of exploitation and post-investment.

It should be noted that, because of the period post-investment covers in total a considerable financial value is represented, sometimes exceeding that of the actual investment.

c) The economic role of maintenance

The aim of the brief review of "life of the equipment," and the general ideas on investment that have been expounded, is to illustrate explicitly the role of maintenance in the production process.

It is evident that the exploitation of equipment is influenced by a number of things. First of all quality of the design and construction, respect for the rules of correct usage and above all the actions of maintenance undertaken in order to keep the equipment in good running order.

These actions are to be defined every day, year after year and in relation to the programmed life time. It is a difficult definition. There is a way to assess this difficulty by imagining two extreme situations. One where maintenance reduced to a minimum, would shorten, in an exaggerated way, life time (and consequently lead to a halt in activity) and the other, on the contrary, where supplementary maintenance (thus a supplementary post-investment) would extend the use of the equipment for longer than was originally planned.

This establishes (if necessary) that the choice of the life-time and its corresponding prerequisites of maintenance can only be decided by judging the criteria which are obtained from the economy and profitability of exploitation.

Consequently, in order to put maintenance in the context of economy, its management should be promoted, the necessary resources available and a strategy defined.

1.4 ANALYSIS OF MAINTENANCE COSTS

Given that the results obtained from the exploitation of equipment can be appreciated on the basis of the criteria of economical profitability, these same criteria must be used to appreciate the performance of maintenance. The analysis of maintenance costs is consequently a priority.

There are two sorts of costs : direct and indirect. The indirect costs are also called failure costs. The former are those which determine the actual maintenance practice and are all quantifiable. The latter correspond to production losses (and their harmful consequences) resulting in the unavailability of equipment due to insufficient maintenance. This explains why they are called failure costs. Certain of them can be quantified, others not.

a) Direct maintenance costs

The list below represents an overview of current direct maintenance costs :

- Regular maintenance costs
- Labour costs
- Equipment costs
- Consumables, spare parts and stock management costs
- Training costs
- Sub-contracting costs
- Costs for technological updating

These are the major elements which make up the inventory of direct maintenance costs. Each of them are quantifiable and, in a well-run business, are quantified. They are the basis for an erroneous and widespread presumption that maintenance is cost-making, unprofitable and in the end, a luxury.

b) Failure costs

Failure costs, already introduced at the beginning of this chapter, and which are caused by a deficiency or lack of maintenance, are a financial loss to be sustained by the company. A complete analysis of them is almost impossible to do with great precision because the majority are not directly measurable. This is not a reason though to ignore them. The following nomenclature does not pretend to be

exhaustive. It merely brings to light the most important causes of failure costs and illustrates the way they should be approached.

- Reduction of production or service
- Alteration in the quality of production or service
- Delivery delays
- Depreciation costs
- Work accidents
- Alteration in the work place and environment
- Demotivation of personnel
- Company Image

These are the principal indirect maintenance costs. They are not all of equal importance nor measurable but must all be given close attention by management. Certain (e.g. loss of production) are perfectly measurable whereas others can only be evaluated by estimated imprecise factors.

Whatever the case, the evaluation of failure costs (however approximate) is highly recommended and should always be part of management thinking.

1.5 ECONOMIC MANAGEMENT OF MAINTENANCE

Maintenance management involves establishing the objectives and determining and controlling the resources to carry them out. There are principle aspects relevant to the economy :

- by combining direct and failure costs in order to obtain the best financial result possible - the following paragraph shows that it is, in fact, a minimalization problem
- by integrating direct and failure costs in the economical calculation of depreciation so that the life-cycle cost of the equipment also produces the best possible financial result. The reasoning below shows that this calculation is a maximalization.

Concerning the resources to be foreseen, short term and long term management should be considered separately. The former involves the setting up of a maintenance policy whereas the latter is concerned with actual strategy.

a) Economic Objectives

Minimalization of direct costs and failure costs.

Imagine that maintenance activity could be measured by a "rate of maintenance" indexed from 0 to 1 - 0 corresponds to no maintenance at all and 1 to a rate of maintenance which keeps the equipment in perfect working order with a perfect remedy always on hand to deal with eventual break-downs. These extreme situations are utopian but allow one to place the problem in its economical environment.

Concerning the direct costs, it is easy to see that an increasing "rate of maintenance" results in increasing expenses.

Figures which illustrate this function do not exist but it has been established that the growth is more than linear, especially when the rate of maintenance approaches the unit.

In Fig. 4 the evolution of direct costs is represented by a constant growth curve identified by index (1).

Likewise the rate of maintenance has an effect on the failures thus on the indirect costs. Failure costs appear as high as the maintenance rate is weak, which means they should be considered as a decreasing function of the rate.

In Fig. 4 this evolution is represented by the decreasing curve (2).

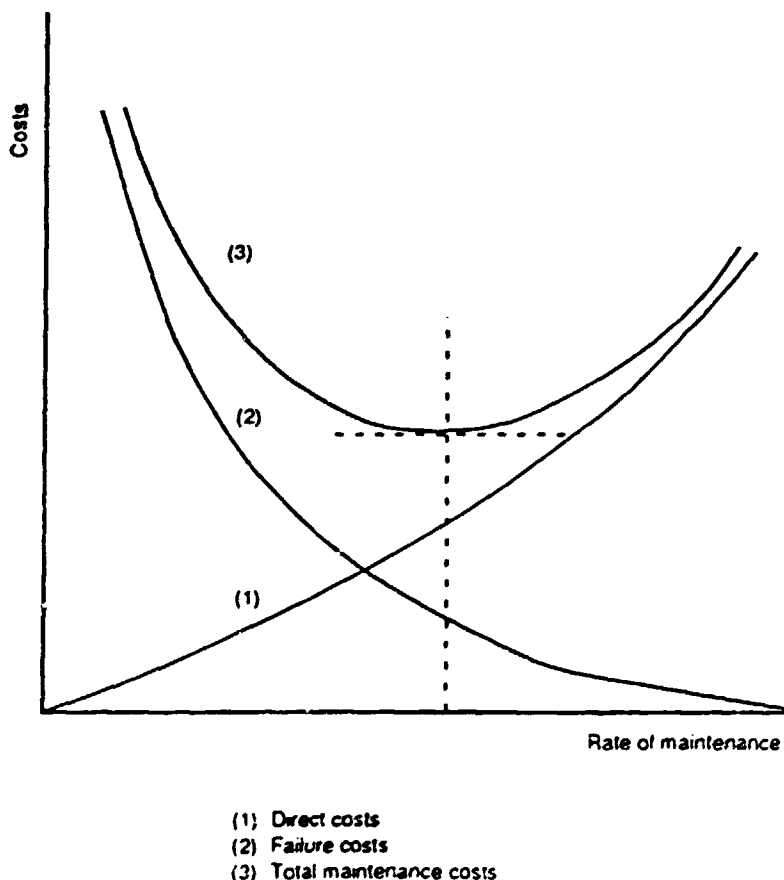


Figure 4 : Evolution of maintenance costs.

Taking direct costs and failure costs together is a new approach of management as it is obvious that a better financial result cannot be obtained by only reducing the direct costs to a minimum. Both costs must be dealt with together. The sum total of both costs can be easily determined by the combination of curves 1 and 2 in Fig. 4. The result is shown in (3). The latter curve denotes that the management of maintenance and of post-investment is not a question of reduction but of minimalization which is shown in the diagram as a minimum of total maintenance costs.

In other words, an optimal rate of maintenance exists which suggests, fundamentally a new approach. Maintenance is no longer carried out to keep the equipment running at any cost, but so that the highest profit can be obtained at minimal cost.

A final remark is that, in the preceding text the rate of maintenance was introduced more or less instinctively and even now, the definition and particularly the purpose are still ill-defined notions. Nevertheless the important point is to be conscious of the existence of a minimal cost of maintenance and to manage accordingly. Pareto's law, well known by maintenance people, shown in Fig. 5 shows that 75% of the maintenance budget is necessary for only 25% of the operations. This means also that 75% of direct costs of maintenance correspond to 25% of failures.

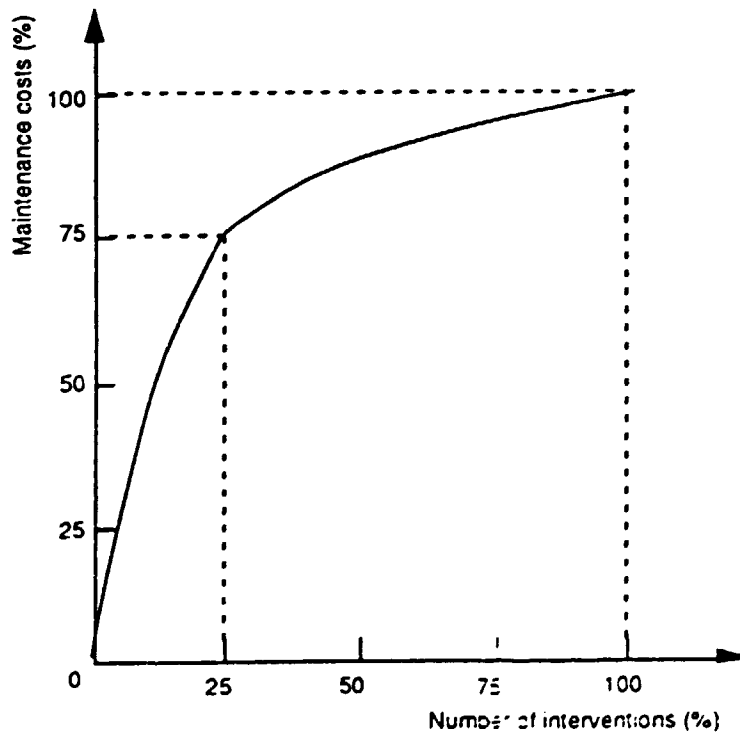


Figure 5

Evolution of direct maintenance costs according to number of interventions

Optimalization of the life-cycle of equipment.

The determining of the life-time of production equipment is a key question for management. In simple terms the question is : at which moment should the equipment be scrapped and replaced so that production can continue in the most economical way.

There are several methods of calculation, and probably the simplest is to make a yearly evaluation of the decrease (ΔI) in the inventory value of the equipment, and the total costs (C) of maintenance. By dividing the figure ($\Delta I + C$) by the cumulated running hours (H) a value is obtained which, after having decreased to a minimum over the first few years, will increase due to the progressive and rapid acceleration of maintenance costs. See Fig. 6.

In theory, the optimal life-time is fixed by the value of the abscissa which is to the right of minimum. This conclusion, -rigorously theoretical- has to be judged with a certain flexibility because it is influenced by the more or less ease with which the inventory value can be negotiated and worked out. Equally, it can be modified by the financial conditions governing the economic situation. In any case, the determination of the optimal life-time must be obtained by calculating the financial up-dating taking into account rates of interest and inflation.

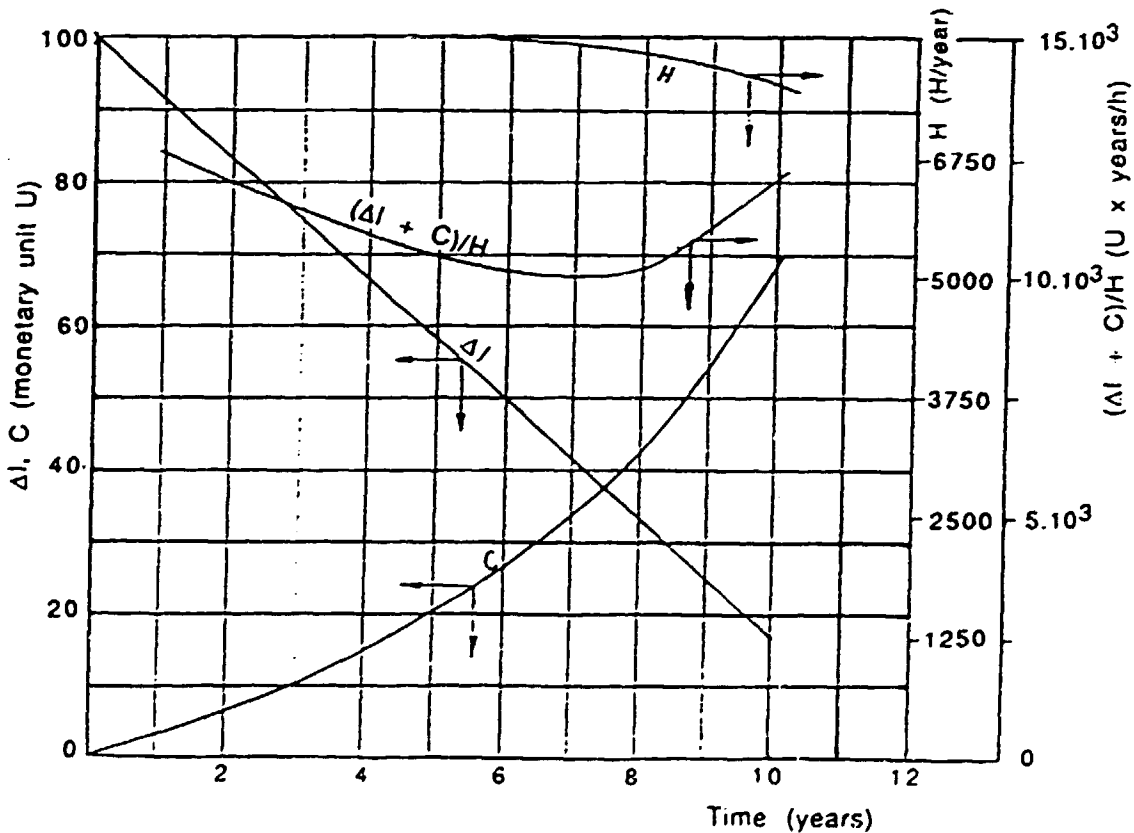


Figure 6 : Graphical determining of optimal life-time of the equipment

b) Management methods

The importance of the economic stakes of maintenance are such that a manager will ask the following question : which actions must be undertaken to ensure that maintenance of the equipment is carried out in the most efficient way ?

As mentioned above the answer to this question can be analysed more easily by considering two types of management. One is short term, e.g. from year to year, and is defined as maintenance policy; the other is long term, sufficiently long to cover the period of exploitation foreseen, is defined as "post-investment strategy". Both management types are part of a so called Maintenance Management Master Plan.

Maintenance policy.

A maintenance policy governs, above all, the technical aspects (knowledge of equipment, foreseeing and prevention of break-downs, carrying out of work, selection of types of maintenance, etc.) aspects of organization (definition of organization chart, administration of operations, planning of studies and work, sub-contracting etc.), accountancy procedures and financial evaluation.

It is not the aim of this chapter to deal in-depth with these questions but only to draw attention to the fact that a maintenance policy is a system of organization and management which allows for the coordination of actions in such a way that, year after year, the efficiency of the exploitation of the equipment is optimized. This can be expressed through the following ratio :

$$\frac{\text{total cost of maintenance}}{\text{profit withdrawn from equipment}}$$

Post-investment strategy

Once the management methods are defined, their evolution must be in line with the level of obsolescence of the equipment. This often results in a modification of the maintenance policy, for instance by selecting different types of interventions or deciding upon partial or total rehabilitation or technological updating. It is obvious that these preoccupations are done in the framework of optimizing the life cycle of the equipment, as has been discussed before.

Under these conditions, the final objective during the whole life cycle is to optimize the ratio :

$$\frac{\text{Total post-investment cost}}{\text{Profit withdrawn from equipment}}$$

This procedure is part of a real strategy which turns post investment -thus maintenance- into an actual profit centre for the manager.

<p style="text-align: center;">CHAPTER 2 WHAT MAINTENANCE REALLY IS</p>

2.1 DEFINITION OF MAINTENANCE FUNCTION

2.1.1 Introduction

The objective of the maintenance function is to ensure the fullest availability of production equipment, utilities and related facilities at optimal cost and under satisfactory conditions of quality, safety and protection for the environment.

Maintenance was long considered to be a subordinate function, entailing an inevitable waste of money. There was a tendency to lump it together with troubleshooting and repairing machinery that was subject to wear and obsolescence.

In actual fact, the maintenance function involves far more than that: it has become an unceasing effort to achieve a compromise between "technical-economic" and "technical-financial" considerations. Yet there is still a long way to go before its productive function is fully understood. For that to happen, people have to realize that maintenance is not merely the function of a "partner" of production : it is quite simply one of the sine qua non requirements for producing.

To do its job successfully, maintenance calls for sizeable and appropriate human and material resources. It cannot become a dumping-ground for personnel who do not have, for instance, the necessary skills for manufacturing, and it must receive an operating budget so that it can perform as more than just an emergency repair service. Planning, organization, and a methodical work approach are essential for managing maintenance activities. Appropriate programmes are required in vocational training, as well as in research and development in the field of maintenance, to enable the quality of work to be continually enhanced. Only then will the maintenance function be able to play its prime role fully in productivity, quality insurance of production, personnel safety and environmental protection.

2.1.2 Objectives of maintenance

The main objectives of maintenance are as follows :

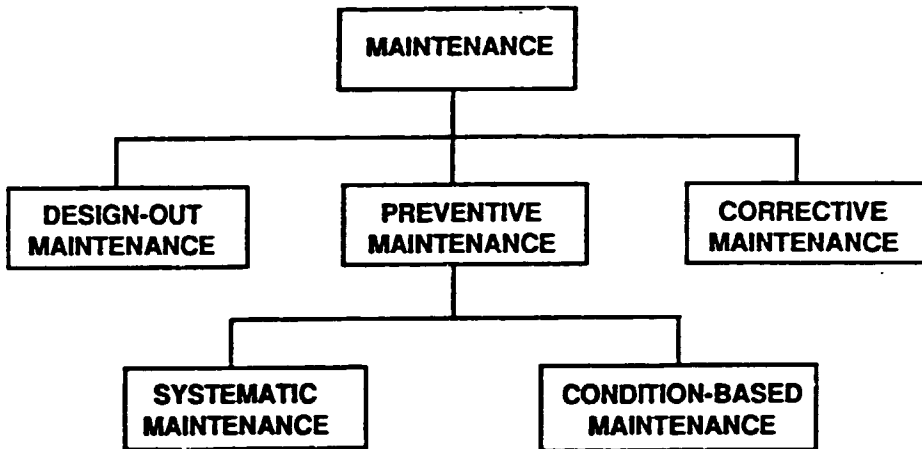
- to optimize the reliability of equipment and infrastructure;
- to see, on an on-going basis, that equipment and infrastructure are maintained in good condition;
- to ensure prompt emergency repair of equipment and infrastructure so as to secure the best possible availability for production;
- to enhance, through the study of modifications, extensions, or new low-cost equipment, the productivity of existing equipment or production capacity
- to ensure that the equipment for production and for the distribution of energy and fluids is in an operable condition;
- to improve works safety;
- to train personnel in specific maintenance skills;
- to advise plant management as well as the production, purchasing, engineering and R & D departments in the fields of acquisition, installation and operation of machinery;
- to play an on-going role in guaranteeing finished product quality;
- to ensure environmental protection.

2.1.3 Terminology

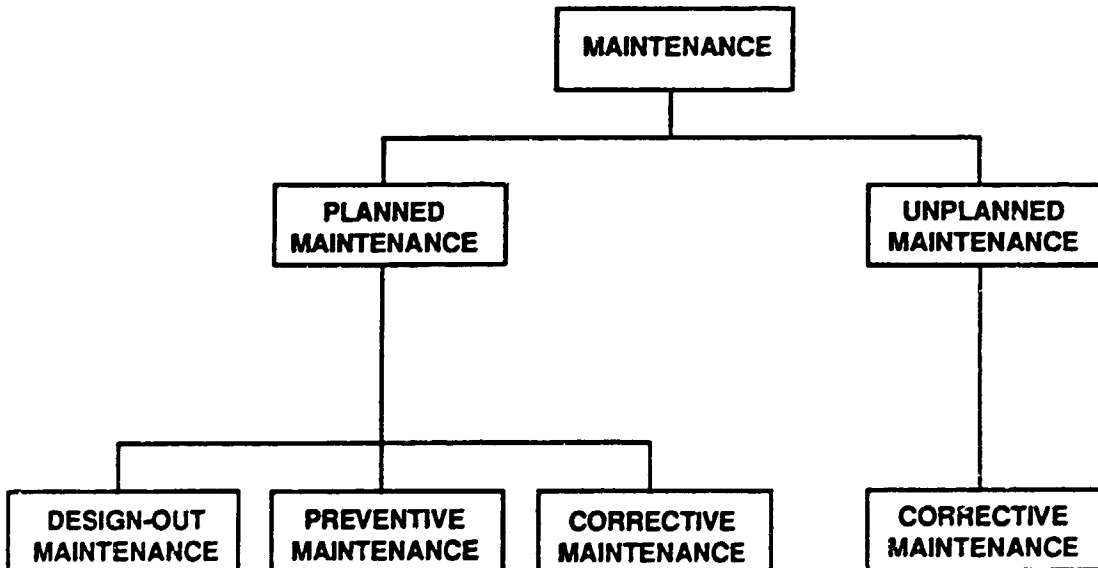
Maintenance is put into practice through 3 forms, namely :

- a) design-out maintenance
- b) preventive maintenance, which includes systematic (periodic) maintenance and condition-based maintenance
- c) corrective maintenance

In chart form, the layout is as follows :



Maintenance can also be divided into planned and unplanned maintenance (or scheduled and unscheduled). The following chart highlights the relation to the previous chart :



a) *Design-out maintenance*

This is also known as plant improvement maintenance or as adaptive maintenance, and its object is to improve the operation, reliability or capacity of the equipment .

This sort of work usually involves studies, engineering, construction, installation, start-up and tuning.

The improvements which are brought about must always contribute towards reducing equipment downtime and operating costs, including maintenance costs in particular.

Moreover, it has been demonstrated that the principle of design-out maintenance must come into action on the drawing board: from the moment equipment design starts, thought needs to be given to various maintenance-related considerations, namely :

- maintainability (capability of being easily maintained and protected against failure);
- local repairability (e.g. ability to be welded, recharged);
- ability to be dismantled easily;
- accessibility;
- selection of low-maintenance materials;
- etc.

b) *Preventive maintenance*

The principle of preventive maintenance is always based on thinking ahead. It is put into practice in two forms : systematic maintenance and condition-based maintenance.

Systematic maintenance

This consists of servicing the equipment at regular intervals, either according to a time schedule or on the basis of predetermined units of use (hours in operation or kilometres travelled) with a view to detecting failures or premature wear and eliminating them before a break-down occurs. The servicing schedule is usually based on the manufacturers' forecasts, revised and adjusted according to actual experience in previous servicing. This type of maintenance is also called periodic maintenance.

Condition-based maintenance

This type of maintenance, also called predictive or auscultative maintenance, is a break-down prevention technique requiring no dismantling, and based on inspection by auscultation of the equipment involved.

It enables the state of wear of the equipment to be analysed while it is running. The advantage is that it makes it possible to get an idea of the condition of the equipment without down-time and/or dismantling .

It calls, however, for rather sophisticated equipment and specialized personnel, and mainly makes use of techniques such as sound analysis, vibration analysis, thermography and thermoscopy, shock-wave analysis, ultrasound analysis, the frequency spectrum and spectrographic oil analysis (SOAP).

Failures are detected by comparing the measurements thus taken with the original data, and by analysing graphs that demonstrate the trend in the various measurements in relation to elapsed running time.

The failures observed, complemented by the findings of the programmed inspections and checks, are then dealt with through occasional corrective action which enables break-down to be avoided.

The implementation of a preventive maintenance programme requires a good maintenance department organization, with particular emphasis placed on the following areas :

- inspection of equipment in operation, on the basis of a pre-established programme of periodic inspections so that working conditions can be checked;
- systematic servicing after inspection of the shut-down equipment and programmed parts replacement. The first step in devising this programme will be forecasting the life-time of parts subject to wear and components (study of reliability models). The programme will subsequently be refined and adjusted according to the experience acquired from inspections, in order to optimize the replacement intervals. This activity emphasizes the capital importance of proper mastery of the statistics in the machine-files and keeping the latter up to date. Indeed, too long a replacement interval increases the risk of a break-down, while too short an interval results in the replacement of parts and components that have not completed their optimal life-time;
- overhauls, which often require considerable work, can be carried out during programmed shut-downs or during low production periods (holidays or weekends);

- routine maintenance, such as greasing, tuning, cleaning, running-in new or overhauled machines, painting, etc.

Setting up a preventive maintenance programme, carefully researched and specially designed to deal with the problems specific to each item, continues to be one of the most effective ways of reducing break-downs and keeping equipment in good condition. It is important to implement the preventive maintenance programme as soon as new equipment is put into service.

c) Corrective maintenance

Also called break-down maintenance, palliative or curative maintenance, this consists of :

- troubleshooting on machines whose poor condition results either in total or partial stoppage of the equipment, or in its operation under intolerable conditions;
- machine repairs.

It is therefore indispensable to work methodically to keep the time of repair as short as possible. Good work preparation and the gathering and processing of all the data relevant to the repairs will enable :

- downtime to be avoided;
- mistakes in assembly or dismantling to be eliminated;
- improvements to be made in the conditions under which the work has to be performed.

2.2. ACTIVITIES OF A MAINTENANCE DEPARTMENT

The activities of a maintenance department embody the functions listed below.

2.2.1 Methods

The Methods function consists of thinking through and making the best possible preparation for maintenance department work through the use of suitable techniques and appropriate resources.

This function can be applied either to a single well-defined job, in which case it involves "work preparation" as discussed later in Chapter 2.2.3, or to a whole maintenance programme on a machine.

The way to proceed is to assemble as many factors as possible which can enable maintenance work to be properly carried out, by especially :

- establishing machine record cards and machine history cards;
- establishing machine files and keeping them up to date;
- defining work studies, a.o. for repetitive and important jobs;
- designing preventive maintenance programmes;
- cooperating in the establishment of in-plant standards and standardization of equipment;
- taking part in shop-floor diagnostics in the event of critical break-downs;
- analysing and evaluating on a continuous basis all the information gathered, with a view to improving methods for all the important jobs and updating and correcting the existing programmes and procedures;
- analysing repetitive failures and advising the engineering section of the resulting proposals for modifications;
- cooperating with the stock management department in selecting the spare parts, tools, and materials to be kept in stock and in deciding on the relevant management parameters;
- developing forms and documents for use by the various services of the Maintenance Department and determining their flow (Management Information System).

2.2.2 Engineering

The Engineering function concerns the study and design of modifications or minor extensions to existing equipment and machinery, with a view to improving :

- capacity or output
- quality of production
- personnel safety
- maintainability or accessibility
- environmental impact

The work of the Engineering Section is thus characterized as much by the wide diversity of work studied as by the variety of techniques used to execute it.

The Engineering Section, as designer, will act as a monitoring body of the work executed by the relevant maintenance services. In this capacity, it will be responsible not only for the studies but also for the erection, installation, start-up and fine tuning of the machinery concerned.

2.2.3 Job Preparation

The job preparation function determines work studies (operating procedures), job specifications, material resources, requirements, time allocation, and workload.

Job preparation results directly from the methods function, but centres on a given individual job.

Good job preparation involves studying and defining two facets : describing the job and breaking it down into separate operations.

The *job description* is also a guide for the person responsible for monitoring safety, quality, and cost.

Break-down into separate operations provides the required timelines for the job scheduling.

It is not necessary to prepare for every one of the maintenance jobs, firstly because the staff used are qualified to perform them, and therefore expensive, and secondly because it is a good thing to let the foremen or the persons responsible for a job take some initiative in carrying them out.

Discernment must be used, therefore, in deciding which jobs do need preparation. In maintenance work, job analyses demonstrate that preparing for the work pays off in at least 25 percent of cases, even if for the sole reason that better use is made of personnel.

2.2.4 Programming - Work scheduling - Follow-up

a) The *Programming* function is responsible for assembling the required material and human resources, drawing up a programme and setting time limits. The job includes, in particular :

- planning the overall programme to be tackled by the department (long term planning);
- assessing work request priorities;

- making sure that orders for subcontracting and supplies required for programmed work are followed through, in liaison with the work preparation staff;
 - supervising the respect of instructions and timelines.
- b) *Work Scheduling* is the function closest to job execution (short term planning). It deals with workload planning in accordance with the plan laid down in relation to team and machine workloads. In this context, it is a necessity if rational use is to be made of manpower.
- c) *Follow-up of work in progress* is usually taken care of by the team responsible for work scheduling. It is continually monitoring the workload of the personnel executing the work and of the machine-tools, and correcting both under-utilization and over-utilization. The schedule must allow for contingency work-time in which to deal with unexpected, emergency or delayed jobs. A special plan for preventive maintenance enables progress on jobs scheduled according to agreed timelines to be monitored easily.

2.2.5 Job execution

Job execution is facilitated and optimized by good preparation and efficient planning, provided that those responsible for job execution keep strictly to doing quality work while also observing the agreed timelines.

Without job preparation and planning, time will be wasted during execution, and that will result in a low rate of utilization of maintenance personnel, and consequently in :

- poor synchronisation in the timing of the work done by the various teams;
- a large number of unsolved problems emerging during execution;
- the use of tools that are unsuitable for the job;
- poor use of skilled personnel.

Needless to say, wasted time raises both maintenance costs and equipment downtime.

In other respects, with a new project, a lot of time wasting can be avoided by making the right choices of location, in designing the factory, for strategic maintenance points such as workshops, central stores, subsidiary stores, the maintenance planning office, etc.

Generally speaking, decentralizing the various sections reduces trips between the stores and the workshops and work sites, but on the other hand, centralizing often permits better organization, which leads to cost reduction.

2.2.6 Quality Control

The Quality Control function for maintenance work is very important in that it guarantees quality of execution. The degree to which it is effective constitutes the hallmark of maintenance.

The essential nature of its role is full justification for the necessary investments, in both personnel and in tools and measuring instruments. For manufacturing workshops, and in particular for machine-tooling, it is therefore worthwhile training some staff to specialize in quality control. Concerning action on the shop-floor, the foreman-level staff will often be made responsible for controlling the work of their crews.

The instructions describing in detail both the inspection procedures and the tools expected to be needed for controlling, on the job site and in the workshops and also for subcontracted work, must be drawn up clearly in the course of job preparation.

2.2.7 Spare Parts Management and Maintenance Stores

The *Spare Parts Management and Maintenance Stores* function should be fulfilled by the Maintenance Department rather than by the Purchasing Department. The tasks must be shared out between the two departments as follows :

- Maintenance will be responsible for establishing the purchase or reordering request, concerning technical decisions, coding, and description of the item;
- The Purchasing Department will take care of commercial decisions, preparing the purchasing orders and following up on them.

It stands to reason that harmonious cooperation between the two departments will ensure optimal selection in purchasing spare parts.

The prime task of stock management is to anticipate, at all times, the factory's needs as regards :

- consumables and current maintenance store items
- standard parts

Next, these requirements must be managed and the quantities to be reordered must be determined in terms of stock levels and various other parameters, such as consumption, delivery delay, safety stock; the requirements peculiar to certain markets for products that need to be reordered, etc.

This important function ought really to involve everyone. But what actually happens is that conflicts frequently arise because the various users all see the stock situation from their own standpoint.

To avoid conflicts of this sort, it is indispensable to establish a sound stock management policy with coding and correct designation of all the parts. Coding and designation, applied at all levels of ordering, manufacturing, maintenance and industrial accounting, will avoid any ambiguity in the exchange of information.

2.2.8 Management of maintenance personnel

Personnel management is one of the essential aspects of running a Maintenance Department. On it, indeed, depend the rational use, the selection and the motivation of personnel.

These criteria have a direct impact on the quality and quantity of work delivered by the department, hence on its efficiency and its cost-effectiveness.

In view of the above, managers will take particular note of the following points :

- personnel qualifications : maintenance jobs, which are often complex and varied, call for highly qualified staff;
- staff who have received training in a variety of fields will be much appreciated in view of the various disciplines with which they will be confronted;
- close attention should be paid to foreman-level personnel, who is often undervalued. In addition to their hierarchical role, they also have to take on a task of fundamental importance, namely personnel training;
- function and job descriptions must cover all maintenance positions;
- recruiting maintenance personnel calls for particular care;
- training and up-grading maintenance personnel;
- salary policy : care must be taken that average maintenance salary rates are the same as those for production, when qualifications are equal. Output-linked wage structures must be applied with caution; for instance, by judging the worth of personnel in money terms on the basis of efficiency and quality of service rather than on quantity.

2.2.9 Cost control and maintenance management

By decreasing its own costs, any maintenance department enhances the profitability of an enterprise. To be able to control the costs, one has to know what they are and be able to interpret them.

For this purpose, it is justifiable to have a "maintenance management" unit, reporting to the Maintenance Manager and working in close cooperation with the factory accounting department, with the assignment of :

- supplying the maintenance department on a continuous basis with all the data relating to its own expenditures, and thus enabling it to react promptly to any discrepancy or error;
- ensuring better monitoring of allocations [to cost centres] and thus limiting the number of errors;
- facilitating the drawing up of estimates;
- enabling the expenditures relative to a single job to be compiled more easily;
- more closely defining and keeping track of the allocation of overheads

2.2.10 Exploitation of utilities

The utilities, or facilities for the production and distribution of energy and fluids, include

- electricity production and distribution
- water treatment, distribution and sewerage
- compressed air production and distribution
- the vacuum network
- heating and steam production and distribution
- storage and distribution of various gases
- storage and distribution of fuels

Exploitation of utilities, includes not only the maintenance but also the operation of these facilities.

Maintenance is the most appropriate department to carry out this task, since it requires qualified personnel who can act as operators and service technicians, rather than as operators only.

Indeed, these facilities can be looked upon as ancillaries to production, the operation of which does not call for personnel with a one-machine speciality, but rather for good

electromechanics trained in both fields. Especially since their job will consist, to a much greater extent, of routine inspections and maintenance than of operating a one-process machine.

2.3 MAINTENANCE LEVELS

Five levels of maintenance can be discerned, according to the complexity of the work and the urgency of action to be taken. AFNOR Standard X60-011 gives the following definitions :

2.3.1 Level 1

Simple adjustments anticipated by the manufacturer, by means of accessible components, requiring no disassembling or opening of the equipment, or completely safe replacement of accessible consumable components, such as signal lights or some types of fuse.

Remarks:

Servicing of this type can be performed by the equipment operator on site, without tools and by following the instructions for use. The stock of consumable parts required is very small.

2.3.2 Level 2

Troubleshooting by means of exchange units designed for this purpose, and minor preventive maintenance operations such as greasing or checking for proper functioning.

Remarks :

Servicing of this type can be performed by an authorized technician with average qualifications, on site, with the portable tools specified in the maintenance instructions, with the help of the afore-mentioned instructions. The transportable spare parts required can be easily procured without delay in the immediate neighbourhood of the place of use.

Note :

A technician is authorized when he has received training enabling him to work safely on a machine presenting certain potential dangers, and with full awareness of the problems.

CHAPTER 3 MAINTENANCE PLANNING AND IMPLEMENTATION

3.1 ABOUT MAINTENANCE STRATEGIES

The development of maintenance in a company must fit into a framework of a Corporate strategy which deals with the following topics :

- management of human resources;
- renewal of production equipment;
- acquisition of new equipment;
- introduction of computerized systems;
- financial management;
- marketing;
- maintenance;
- production processes;
- raw materials;
- social and cultural environment of the company.

Each above topic should ensue its own Corporate Management Master Plan.

The Maintenance Management Master Plan should deal with the following topics :

- the hierarchical position of maintenance in the company organization chart;
- the development of human resources in maintenance;
- the introduction of an analytic accounting system which details maintenance expenditure per cost centre, per machine and per nature;
- the setting up of a separate maintenance budget;
- the acquisition and renewal of equipment (choice of technology, terms of reference, participation of maintenance specialists during negotiations, introduction of the life-cycle cost approach, taking into account the indirect costs);
- the structure of maintenance : centralized, de-centralized or mixed;
- computer-assisted maintenance and computerized maintenance management systems;
- the sub-contracting of maintenance work;
- the definition of priority equipment and dosage of the various sorts of maintenance: periodic, condition-based, corrective and design-out maintenance;
- the relation with the QC department

- the safety of personnel and safety in general;
- the protection of the environment.

Even though all the above fields are important, emphasis will only be put here upon certain among them, with the risk of being incomplete. The following chapters allow the further completion of this position and particularly to define it more clearly.

The hierarchical position of maintenance in a company must be very high; at the same level as that of manufacturing/production, the commercial department, administration and finance. In other words the maintenance manager must be a member of the Board of Directors.

The structure that gave us the most efficient results in all types of environments is that of a centralized maintenance. The following chapter will deal with this theme in more detail.

In Development of Human Resources, there are two urgent priorities: motivation and training. One of the problems is to attract highly qualified personnel to a field which traditionally offers very poor career prospects. This is certainly true in the case of the engineers level. It is the duty of the company to adjust this neglect by setting up a career plan for the whole of the maintenance personnel, especially for the engineers.

Computerization of maintenance must not be looked upon as separate from the rest of the company computerization. The choice of computer programmes and hardware must match those which already exist in other departments such as accountancy, production, management of raw materials.

In the acquisition of equipment, either for reasons of renewal, extension or modernization, maintenance must play an important role in the choice of the adequate technology, in the design of equipment and infrastructures and in all the arrangements to be made necessary to ensure maintenance. This is the reason why it is imperative for maintenance specialists to take part in all contract negotiations.

A sub-contracting policy is a factor which contributes greatly to the performance of the service. The inevitable question is : should the work be done by the company workforce or should it be done by outsiders ? In the latter case, which are the jobs that should be sub-contracted and which ones should be kept within the maintenance department so the loss of know-how can be avoided, even if an investment in specialized personnel is necessary ?

In the choice of the optimal maintenance type, a well-balanced dosage between the various forms of maintenance must be introduced (see previous chapter). This

dosage must be decided on the basis of a thorough study of the importance of the reliability of the machines in relation to production, quality, costs of repairs, safety and environment. The search for zero-defect is out-of-date : it has become more a question of mastering the break-downs and learning to know where failures can be accepted or where they are absolutely unacceptable.

Thus, it can be seen that when setting up a maintenance service, the options to be taken must form part of a well-thought out strategy.

The following chapters will give some suggestions to company and maintenance managers in order to help them make their choice.

3.2 ORGANIZATIONAL STRUCTURE OF THE MAINTENANCE DEPARTMENT

3.2.1 Basic principles of maintenance organization

The solution to problems related to the organization of maintenance departments both in industrialized as well as in countries with a difficult environment is not an easy one. Let us discuss here some principles.

The most efficient form of organization is not one which is perfect from the beginning but one that is applied correctly. This means in the first place a simple organization, eliminating as much paperwork as possible. Clear, concise explanation is necessary for the personnel on the various mechanisms and on the information routings so that they fully understand the interdependencies. After the introduction period, the chosen organization is adapted step by step so that it may be improved and completed.

The principles which should be considered as fundamental for the organization of maintenance in small and medium enterprises can be summarized as follows :

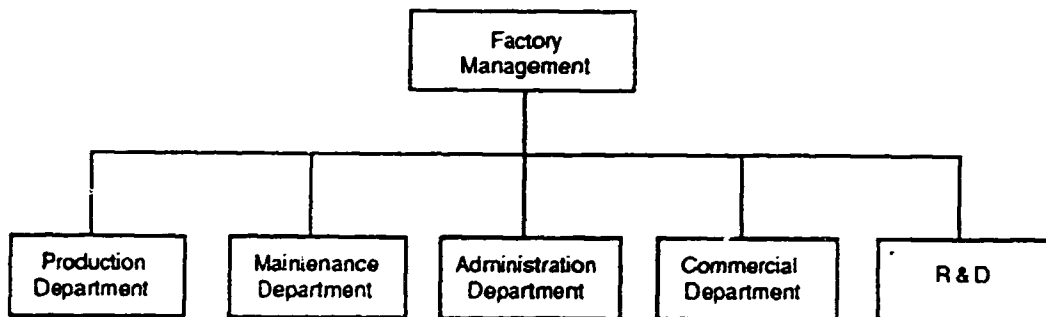
- centralize all maintenance activity in one department under one head;
- place the maintenance department high on the factory organization chart;
- avoid that maintenance is headed hierarchically by production. Ensure that both are on the same level;
- assign fully qualified personnel to the maintenance department;
- allocate sufficient financial resources;
- devise an organization which suits the particular needs of each factory and allow it to evolve accordingly;

- avoid trying to set-up a perfect organization from the start. Find flexible structures and ensure that the personnel understand the system thoroughly before the definite implementation;
- avoid useless paperwork but fill-in carefully any forms necessary to ensure an efficient flow of information.

3.2.2 Position of the maintenance department in the organizational structure of the plant

It is important to establish a direct link between the head of maintenance and the factory or company manager. The responsibilities of the former encompass every function explained in the chapter "what maintenance really is".

The hierarchical position which should be assigned to the maintenance department is illustrated in the following general organization chart.



As the objective for the production and maintenance departments is the same, i.e. production at a minimum cost under good quality and safety conditions, it is indispensable that both departments are placed on the same hierarchical level in order to allow inter-relations, based on an equivalent decision-making power.

Positive experience with the Total Productive Maintenance (T.P.M.) approach has been gained in certain industrialized countries, where both maintenance and production are carried out by the same personnel. Nevertheless especially in DC's and other difficult industrial environments it is to recommend that -at least for the moment- maintenance should be independent and must not be placed hierarchically under production. A head of maintenance has to be able to use his authority to stop production for urgent interventions, even before a break-down has occurred. This is not always understood when maintenance depends on the production. The latter often aims only at achieving a record output no matter what it costs, while totally under-estimating the rapid deterioration of equipment. In fact, a clear relationship

formulated in detailed procedures between maintenance and production should be established as far as possible before actual start-up. This relationship should be at the basis of yearly production plannings and should be reviewed during monthly or 3-monthly meetings, in order to ensure a satisfactory system of consultation between the two departments

The role of maintenance during the acquisition of new equipment or plant extensions is of the utmost importance. During the preparation of a project or contractual negotiations the company must not only be represented by production or commercial managers but also by Maintenance, whose opinion must be a deciding factor.

The centralization of maintenance has a number of advantages. The most important are :

- keeping the Board of Directors advised by means of one source of information
- an efficient use of personnel and a sound job preparation
- avoidance of non-respect of procedures due to personnel turn-over, by means of written procedures and a central storage of information
- a better supervision and optimalization of maintenance costs through a clear separation between "clients" and "suppliers"
- a better use of specialists, machine-tools and specific tools
- an optimalization and a better follow-up of sub-contracted work
- the possibility of reducing down time for yearly overhauls and major repairs through the concentration of all available resources
- the improvement of quality and efficiency of maintenance work through the centralization of experience gained in repair and trouble-shooting for the whole plant
- an easier set-up of adequate technical specifications for the purchase of new equipment taking into account better maintainability and measures to ensure proper maintenance (such as technical documentation, training, spare parts, etc.).

3.2.3 Maintenance organization chart

a) Introduction

A maintenance organization chart (organigram) which can be used as a discussion base for different types and sizes of factories implies an approach in terms of the necessary functions which must be assured. For that purpose, it should be understood that a function on the charts hereafter can be carried out by one or several people or conversely one person can assure several functions. It all depends on the size of the plant.

In order to explain the organization charts for maintenance we have chosen to approach this in successive stages of complexity.

The first stage of complexity is a simple organization chart for a small factory showing the basic functions indispensable for an efficient maintenance operation.

The second stage concerns a bigger factory with one single production area and working 8 hours a day.

The third stage of complexity is for a new factory with several production areas and working on a continuous basis (24 hours a day).

Finally, the fourth stage concerns the evolution of the preceding organization chart towards alternatives depending on various particularities of plants.

The functions are explained step by step which allows the reader to find all the elements enabling him to adapt the given advice to his particular situation.

b) About maintenance organization charts

Before dealing with the organization charts in detail, it is important that emphasis be put upon some principles :

- in a maintenance department 5 groups of functions should be present in order to cover all the tasks as described in chapter 2. They are :
 - a function of reflection : methods, job preparation, planning
 - an execution function
 - a control function
 - a logistic function : workshops, laboratories, garage, stores
 - an evaluation and management function.

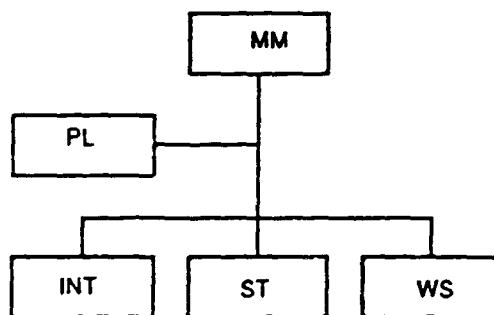
These functions must always be part of an organization chart, however small.

- maintenance activities should be split up into preventive and corrective maintenance. Job descriptions should be defined accordingly. In medium or large-size factories, this results in one (or several) team(s) working a normal day and carrying out preventive tasks exclusively. As to the team(s) in shift they should take care of break-downs and minor repairs. This latter case is only relevant when the factory is working around the clock. For a factory which only works 8 hours a day, the above teams in shift will do the normal time-table, but will still be in charge of corrective maintenance exclusively;
- logistic supports should be centralized : central workshop, spare parts store, planning office. Independent decentralization in the production areas should be avoided especially for small plants. For bigger plants, the setting up of antennae of each of the above services in the main production area could be helpful, particularly for the planning office. Nevertheless workshops in this case should only be equipped with basic equipment, as it would not be efficient to have the double of all equipment from the central workshop located in the production area.

c) *Basic organization charts*

c.1) **First stage**

The simplest organization chart (first stage) for a maintenance department is composed of 5 boxes which correspond to the 5 principle functions mentioned above. It is presented below.



MM : Maintenance Management
PL : Planning
INT : Interventions
ST : Stores for spare parts
WS : Workshop

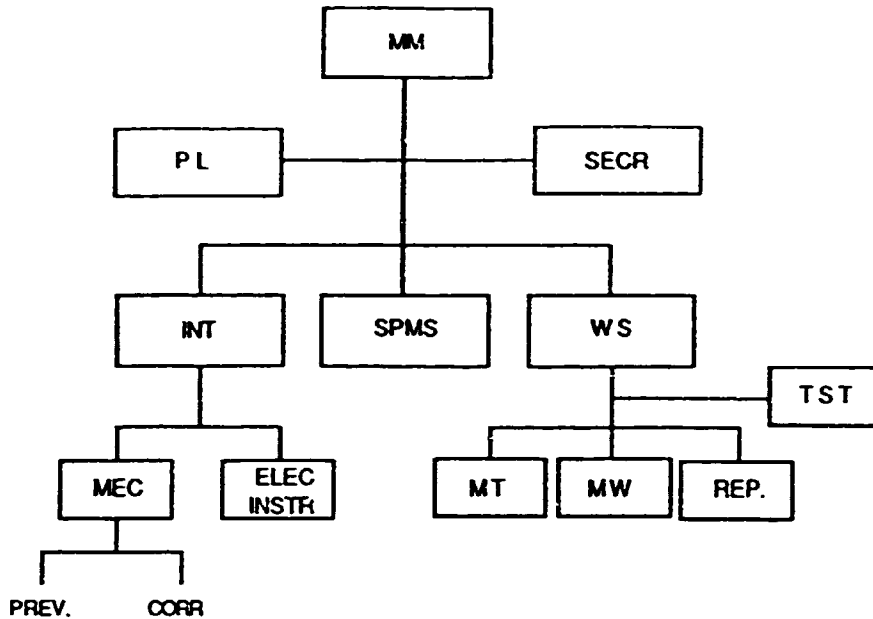
- MM : Maintenance Management. Responsible for technical and administrative management. This particularly concerns the supervision of various work, the establishing of a budget, the follow-up of expenditure, the interpretation of technical

failures, the instructions for maintenance programmes, the recruitment of personnel, taking part in the board meetings and advice in the field of renewal and purchasing of equipment;

- PL : Planning. Responsible for methods (programmes, work preparation), work planning (programming - scheduling) as well as for the technical documentation. This function will in this case also be in charge of the choice of parts to be stored and their administration;
- INT : Interventions. Responsible for all mechanical, electrical and other interventions, for preventive as well as corrective maintenance;
- ST : Spare Parts Storing. This function is responsible for stockkeeping of spare parts (registration, filing, conservation, storage) and issuing
- WS : mechanical and electrical repair Responsible for minor welding jobs, metalwork and small electrical repairs.

In fact, for very small factories these functions could actually be carried out by one single person (e.g. a plant with a total workforce of 10) or by 4 or 5 people for larger ones (e.g. total workforce 20 to 30). For still larger factories (workforce 50 to 100) maintenance departments will have a staff of 10 to 20 people.

This organization chart could develop, always for small factories, into the following chart :



MM	: Maintenance Management	CORR	: Corrective Maintenance
SECR	: Secretariat	SPMS	: Spare parts Management
PL	: Planning		: and Stores
INT	: Interventions	WS	: Workshop
MEC	: Mechanics	MT	: Machine-Tools
ELEC/INSTR	: Electricians / Instrumentists	MW	: Metalworking
PREV	: Preventive Maintenance	REP	: Repair
		TST	: Toolstore

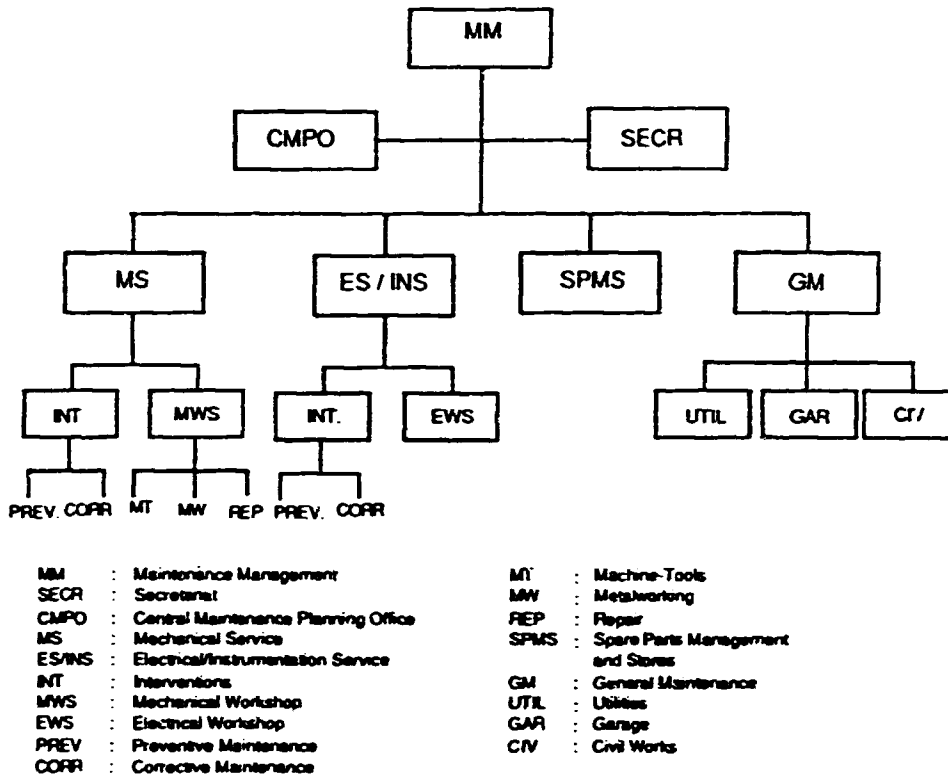
The same functions as in the first organization chart above are found here but with some developments :

- INT has been split up into 2 sections : one for mechanics (MEC), the other electricians and instrumentation (ELEC/INSTR). Moreover, the mechanical section is composed of 2 teams : one for preventive work (PREV), the other for break-downs and minor repairs (CORR).
- the WORKSHOP (WS) has also been reinforced by a section M.T. (machine-tools), a section REP (mechanical and electrical repairs) and a small store for raw material and tools (TST).

In this case, we are speaking of a factory workforce 80 to 130 and a maintenance department of 20 to 25 people.

c.2) Second stage

A second stage in the design of organization charts concerns a larger factory with one production area working 8 hours a day. The preceding organization charts could evolve as follows :



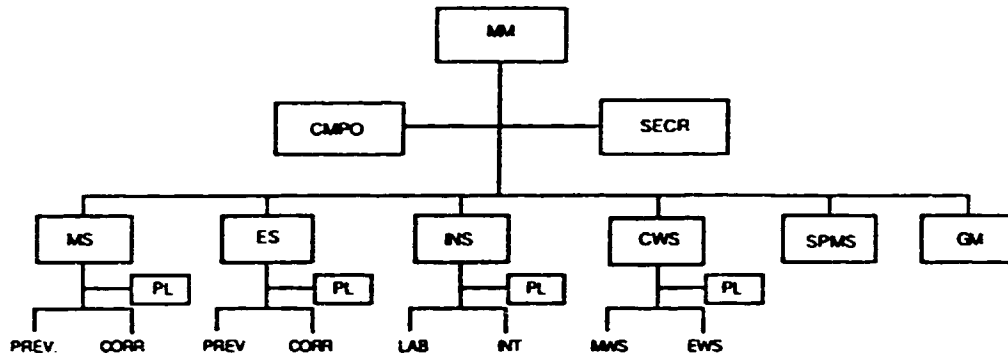
The maintenance department is composed of 4 line services (MS - ES - SPMS - GM) and 1 staff service (CMPO). The various functions put forward in the preceding organization charts appear again but for certain amongst them, the implementing services have been adapted slightly.

This is the case with the mechanical and electrical services which have now grouped together not only the interventions but their respective workshops (MWS : Mechanical Workshop/EWS : Electrical Workshop). In other words, the mechanical and electrical services are big enough to host their own workshops. On the contrary, a central workshop would probably be too small to exist as a separate service.

A new service has been added : GM (General Maintenance) This service is responsible for the exploitation of utilities (production and distribution of energy and fluids), maintenance of rolling stock (GAR : garage) and civil works (CW).

If a plant has a lot of control and regulation equipment it is wise to create a separate service "Instrumentation". Moreover in case of a plant with mechanical and electrical

equipment which necessitates a continuous follow-up (for instance plants with a high break-down cost such as a power plant), creating a heavy workload on the 2 services, then it would be wise to group the workshops MWS and EWS into a CWS (Central Workshop). The organization chart below shows the possible organization for such a hypothesis.



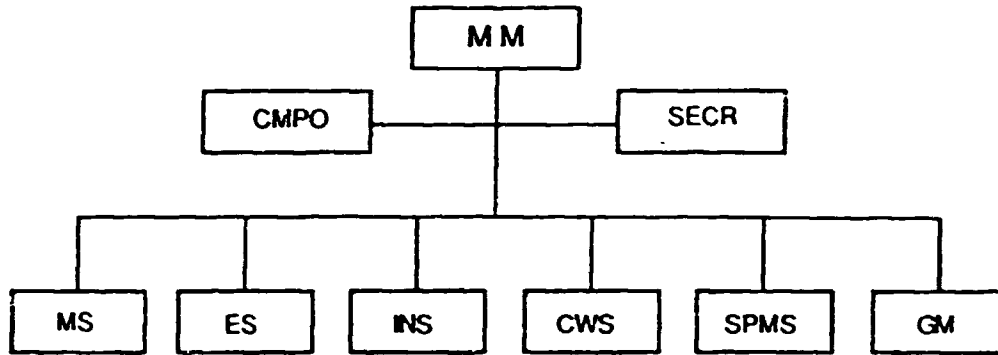
- | | |
|--|--------------------------------------|
| MM : Maintenance Management | GM : General Maintenance |
| CMPO : Central Maintenance Planning Office | PL : Planning |
| SECR : Secretariat | PREV : Preventive Maintenance |
| MS : Mechanical Service | CORR : Corrective Maintenance |
| ES : Electrical Service | LAB : Laboratory for instrumentation |
| INS : Instrumentation Service | INT : Interventions |
| CWS : Central Workshop | MWS : Mechanical Workshop |
| SPMS : Spare Parts Management and Stores | EWS : Electrical Workshop |

The function PL (programming - preparation - scheduling) has been decentralized as a staff function in each of the services concerned. Taking into consideration the amount of work the mechanical, electrical and instrumentation services have to do, the centralization of PL within Central Maintenance Planning Office (CMPO) would not give the necessary flexibility. The Central Maintenance Planning Office will then mainly focus on methods, technical documentation and minor engineering work.

The workforce and size of the factory for this organization chart are not so different from the preceding one. Above all, it is the nature of the work and urgency of the interventions which justifies a more extensive organization chart.

c.3) Third stage

A *third stage* in the design of maintenance organization charts applies to a factory with several production areas and working 24 hours on 24. It is the most complete organization chart for a maintenance department. If considering the various services as functions, we find exactly the same ones as described above. Thus, even though this organization chart can be considered more or less as a standard one, it has to be adapted to each factory. Therefore, it can only be used as a guide, not as a master-key.



- MM : Maintenance Management
- CMPO : Central Maintenance Planning Office
- MS : Mechanical Service
- ES : Electrical Service
- INS : Instrumentation Service
- CWS : Central Workshop
- SPMS : Spare Parts Management and Stores Service
- GM : General Maintenance Service
- SECR : Secretariat

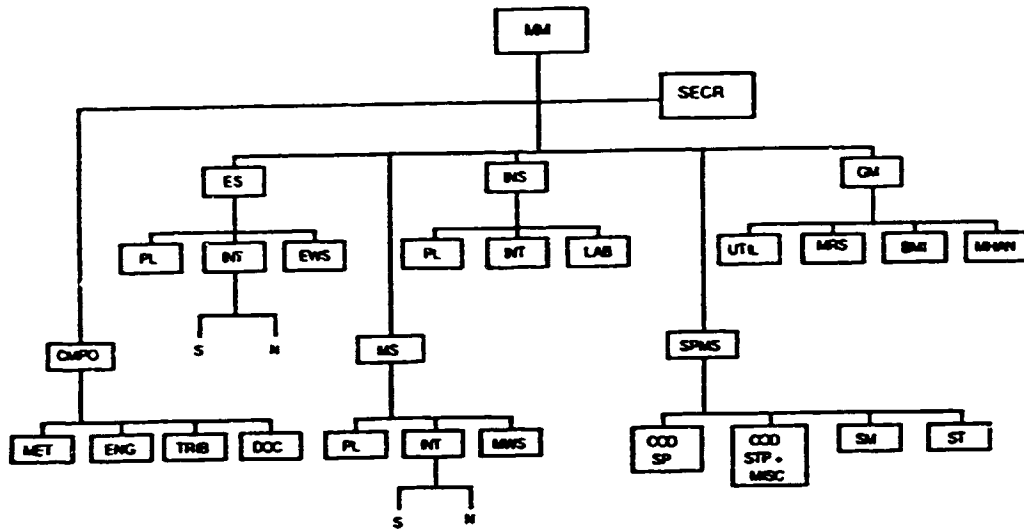
The standard organization-chart is composed of 7 centralized services, each reporting to a service head : Central Maintenance Planning Office, Mechanical Service, Electrical Service, Instrumentation Service, the Central Workshops, Spare-parts Management and Stores, and General Maintenance Services.

All the heads of services report to the maintenance manager. In large plants, some of the services may be decentralized in each production area (assigned maintenance), under the authority of the maintenance manager. This is especially the case for CMPO, MS and ES.

Many modifications of the standard organization-chart are possible and may be justified in some cases. The chart represents a general organization for which the principles may be applied in any plant.

c.4) Fourth stage

Finally, in a fourth stage an application of the above organization chart for a medium-sized plant (actual workforce 900) is given below.



- | | | | |
|------|---|------|---|
| MM | Maintenance Management | INS | Instrumentation service |
| SECR | Secretary | LAB | Workshop for Instrumentation |
| MMPO | Central Maintenance Planning Office | SPMS | Spares Parts Management and Stores |
| MET | Methods | SP | Specific Spares Parts |
| ENG | Engineering/Drawing office | COD | Certification |
| TRB | Tribology | STP | Standard spare parts |
| DOC | Technical Documentation | MSC | Miscellaneous |
| ES | Electrical Service | SM | Stock Management |
| PL | Planning | ST | Stores |
| INT | Instruments | GM | General Maintenance |
| S | Shift (3 x 8 hours) | UTL | Utilities |
| N | Normal time-table (8 hours/day) | MRS | Maintenance of Rolling Stock |
| EWS | Electrical Workshop | MWH | Material Handling |
| MS | Mechanical Service | BM | Building and Infrastructure Maintenance |
| MWS | Mechanical Workshop | | |

Remark

The above organization charts concern a centralized maintenance department. The reasons for a centralized structure have been listed previously. Nevertheless we have attached in appendix 1 and 2 the organization charts of a decentralized structure, and 1 of a mixed structure. In addition, and for reasons of comparison, a centralized structure for the same type of plant has been included in appendix 3

3.3 MAINTENANCE MANAGEMENT INFORMATION SYSTEM (MMIS)

Setting up an efficient MMIS requires the definition of all relevant data to be collected and the clear fixing of information routings from shop floor up to management and vice versa.

The data which the maintenance department will require in order to carry out its job efficiently are of various types :

- basic data regarding written procedures on the internal relations and organization of the maintenance department;
- detailed inventory of machines, apparatus, installations, including technical characteristics;
- technical data contained in the technical documentation;
- instructions and information regarding work-execution;
- historical data of machines,
- information regarding spare-parts;
- necessary data for cost control and maintenance management.

In order to avoid incoherence and discontinuity of work due to turn-over of personnel, it is necessary to record all instructions regarding the organization, work-methods, the information systems, etc. By keeping *written records*, poor application of verbal instructions can be avoided.

A complete inventory of all items to be maintained with indication of their location and main characteristics is the starting point for maintenance strategy and planning.

The *technical documentation* contains all the drawings and documents, which are or have been necessary for the design and construction of the plant, as well as for the sound operation of the equipment. It contains all the information regarding operation, maintenance or possible future extension of the plant.

The information regarding the *maintenance work-execution* concerns :

- the job request;
- gathering all the supports for job-preparation, incl. work-specifications (work-study);
- the job-order;
- the work-planning (maintenance programming and scheduling);
- the feed-back of information to the various sections (methods, stock-management, accountancy, machine-files).

The data regarding the *history of machines* are collected on a History Record Card after each maintenance intervention on the machine, and also during the operation of the machine. These data form the basis for the cost and productivity analyses of the machine on the one hand, and for the preventive maintenance programmes as well as the preparation of capital overhauls on the other hand.

The documents regarding *spare-parts* constitute, together with the technical documentation, the main information support between the Purchasing Department, the spare-parts store and the user. These documents concern the codification of the parts, the spare-parts' management, procurement/reordering and stock movement.

The data which are required for *cost-control and maintenance management*, should permit the calculation of the cost for each maintenance job. This cost should include the following components : labour, materials, sub-contracting services (internal and external), overheads.

The labour cost covers the actual wages paid to the personnel, as well as incentives and social advantages.

The material cost contains all charges for spare-parts, raw materials and other maintenance materials.

The external sub-contracting services may concern the carrying out of an actual maintenance job, or the payment of technical assistance or part-time personnel. Internal sub-contracting occurs when the maintenance department receives services from other departments of the plant.

The maintenance overheads concern in the first place the charges for rent (i.e. occupied surface, energy), as well as the depreciation of the machines used by the maintenance department, insurance and other constituents of the operating costs of the department.

3.4 MAINTENANCE PLANNING

3.4.1 Introduction

The planning of maintenance work in general concerns daily maintenance, repair schedule, preventive and design-out maintenance, periodic overhauls, planned replacements and the activities of the central workshops.

Daily maintenance concerns cleaning of the equipment, routine maintenance (i.e. tuning, adjustment, alignment, greasing, etc.) and the various checks to be made (abnormal heating and sounds, vibrations, leaks, normal operation in general). The daily maintenance also concerns break-down maintenance, i.e. unscheduled interventions which are often urgent. Emergency work should on the average not exceed 5 % of the total work-load of a well-run maintenance department. It should be stressed here that the maintenance department in small and medium scale enterprises faces often 40% of unscheduled work in industrialized countries and in most of the developing countries about 60 to 70 %. A substantial reduction of these unscheduled interventions can be achieved by implementing a sound, planned maintenance system.

The repair schedule consists of :

- repairs on site : repairs on the machine will take place when the defective sub-assembly cannot be transported into the workshop;
- repairs in the electro-mechanical workshop concern the repair of assemblies or sub-assemblies, such as pumps, compressors, fans, electrical and pneumatical equipment, electro-motors, control-equipment, etc.

Workload planning should be fixed by taking into account the priorities put forward by the production department.

The planning of *design-out maintenance* is in general a long-range planning, due to the fact that modification or extension work to the equipment require detailed preliminary studies. In practice these plans are made on the basis of the data received from the Central Maintenance Planning Office.

As to the planning of *preventive maintenance* and lubrication (periodic and condition-based maintenance), a distinction should be made between activities with a high frequency (daily and weekly), which often interfere with the activities of routine maintenance, and activities with a low frequency. Activities with a high frequency seldom require the shut-down of the machine, whereas interventions with a low frequency (monthly, three-monthly, half-yearly or yearly) involve more important work

so it is generally necessary to stop the machine for some time (partial overhauls, exchange of parts, changing oil, etc.).

Periodic overhauls are planned on the basis of the manufacturer's instructions and on the analysis of the history of the machine; they generally take a long time. It may be interesting to plan these periodic machine overhauls at a period of the year of general plant shut-down. During this annual overhaul, any problems with the machines, which have not been solved during the current year, should be dealt with. The planning of an annual overhaul requires long and detailed preparation. Nevertheless, it should be mentioned that the principle of annual overhaul is not always ideal. Regular shut-down of a part of the installation (for example during week-ends) for overhaul or repair is a new trend in many factories.

Planned replacements are necessary due to the wearing of parts or sub-assemblies after a certain time of operation. For instance, bearings, seals, sleeves, drive chains, etc. are replaced systematically after a number of operational hours or according to condition-based parameters. The planning of these replacements is based on the history of the machine, on site experience or on instructions of the manufacturer. The use of condition-based methods should be stressed. By monitoring the equipment, the intervals between replacements are increased thus reducing the high cost of systematic replacement. A condition-based philosophy should be part of a maintenance strategy under consideration of the risks which can be taken in relation to safety, reliability and quality.

The *central workshop* is concerned mainly with the repairs as mentioned above plus the manufacturing of spare parts, or renovation of sub-assemblies and equipment. The planning of this work will depend on the priorities of the production department, and the availability of skilled personnel as well as on appropriate machinery.

3.4.2 Planning of preventive maintenance

The preventive maintenance file contains all the information necessary for the execution of preventive maintenance work. This information concerns the work study (work specifications), the parts of the machine to be inspected, as well as the job planning, inspection schedules and check-lists.

A distinction is made between the following types of information :

- job instructions : the preventive maintenance card;
- programming of preventive maintenance : work programming;
- scheduling of preventive maintenance jobs : workload planning;
- inspection of the work.

The implementation of the preventive maintenance card is done by separating the preventive work into mechanical, electrical and instrumentation work. A card is made for each machine, assembly or sub-assembly. The instructions are given for each periodicity, starting with the highest one. These instructions should be clear, precise and in simple language.

Based on the preventive maintenance programme per machine, a detailed planning will be made for all the machines. This preventive maintenance planning will take into consideration the time which is necessary to carry out all the jobs for each sub-assembly indicated in the programme. It will also consider the periodicity of the inspections. For coordination and practical purposes, the plan will make a distinction between the preventive mechanical maintenance and the preventive electrical maintenance and will contain also the planning for lubrication. This lubrication planning should be added to the mechanical planning because in most cases, the lubrication job is done at the same time.

Inspections are included in the foreman's work-load planning or are done by specialized inspectors from the CMPO or PL section. An inspection report is made after each inspection.

3.4.3 Planning of lubrication

The lubrication file contains all the information necessary for carrying out lubrication. This information concerns work specifications and lubricating points, as well as planning and inspection of the work.

A distinction should be made between the following elements :

- work instructions : the lubrication card;
- lubrication planning : work programming;
- the lubrication workload schedule : workload planning.

A lubrication planning is made for lubrication which exceeds two weeks. It is based on the lubrication programme and is in line with the preventive maintenance planning, because most lubrication activities which exceed two weeks coincide with those of periodic maintenance.

3.4.4 Planning of overhauls and major repairs

The various operations which are necessary for the implementation of maintenance work can consist of a number of complex tasks. This is especially the case for overhauls and major repairs.

These tasks must be carried out respecting a certain sequence and interdependency. This means that certain tasks are consecutive, others can be done at the same time.

Several methods exist for the planning of overhauls and repairs. One of them is the PERT method (Programme Evaluation and Review Technique). The methods are based on the calculation of the critical path of all tasks to be executed. The method can be implemented very easily today by using existing micro-computer programmes.

3.4.5 Work programming and scheduling

a) Programming

The programming function is responsible for making available the human and material resources needed to carry out a work programme :

- drawings and technical documentation;
- spare parts and supplies;
- tools;
- measuring instruments;
- machines, machine-tools, accessories and miscellaneous devices;
- transport and lifting equipment;
- manpower.

The programming function is thus responsible for the definition and editing of the work programme. Consequently it has a mid and long-term planning mission.

b) Work scheduling

The job scheduling function has a short-term planning function. It is in fact the planning function which is the closest to execution : it is responsible for the work distribution according to a plan (work-load planning) which is established taking into consideration the work-load of the teams and machines. It shows the necessity for the efficient utilization of manpower and equipment.

The job scheduling should take into account a buffer for unforeseen work, emergency or delayed jobs.

3.5 MANAGEMENT TOOLS FOR MAINTENANCE

3.5.1 What are they and how can they be used ?

For the efficient management of a maintenance service, it is advisable to have condensed, easy and quickly accessible information at hand. Maintenance managers have long known of the necessity to have points of reference which give an idea of performance of their departments. Therefore indicators must be found that can, on the one hand situate maintenance in relation to the other services in the factory and on the other compare it with active maintenance service in other similar and equally important sectors.

These performance indicators, and related information are generally presented in the form of coefficients or of a relation of two absolute values and are called "RATIOS". These ratios become, in fact, real maintenance management tools.

Comparing the ratios of one plant to those of another in the same industrial field can be dangerous, particularly for plants in varied situations: different countries, or a different industrial environment.

The deviations in relation to these "foreign" averages do not necessarily imply good or bad maintenance. The results are based on particular situations in the plants concerned and on their own system of data gathering. This can seriously influence the results.

During comparison of ratios, experience has shown that the following principles must be respected :

- each user must choose his own ratios: the maintenance manager of a factory is not necessarily interested in the same ratios as a manager of another factory or production sector would be;
- the number of ratios on the monitoring chart (steering chart) must be limited. A dozen is considered as sufficient;
- the ratios must be based on data easily available in the factory. A reliable system of data gathering is thus, indispensable;
- up-dating of the values which make up the ratios must be carried out on a continuous basis;
- the results must be carefully interpreted, so that they can be compared to the previous results. For example, the variations in the exchange currencies will have a marked influence on the value of spare parts used or on the production cost of a product. Differences in production equipment or maintenance resources will also have an influence.

3.5.2 Performance indicators

There are two categories of ratios under which the performance indicators can be presented :

- economic ratios which allow the follow up of the evolution of internal results and certain comparisons between maintenance services of similar plants
- technical ratios which give the maintenance manager the means of following the technical performance of his installations.

3.5.2.1 Economic ratios

a) *Ratios linked to maintenance costs*

Amongst the economic ratios that exist, we have chosen those which seemed to us to be the most representative. Understandably this list must be completed by a "customizing" per company.

Direct cost of maintenance

Added value of products

The direct cost of maintenance comprises :

- cost of manpower;
- cost of materials (spares, parts subject to wear, miscellaneous);
- cost of sub-contracting work;
- overheads.

The added value of the product constitutes the total cost of production less the cost of raw materials. This ratio situates the importance of maintenance in a plant. The fact of using the added value and not the total cost of production eliminates the important fluctuations in the plant itself as well as between enterprises due to the fluctuation in the price of raw materials.

$$\frac{\text{Direct cost of maintenance + failure costs}}{\text{Added value of products}}$$

Even though it is theoretically possible to calculate this ratio by type of product, it is easier and just as efficient to calculate it for the whole plant or production unit. Particular attention must be paid when calculating the failure costs.

As already mentioned under chapter 1, this takes into account ad hoc circumstances such as profit loss through use of a substitution product, intermediate stock of product in the process of manufacturing, the possibility of overcoming the loss in production by overtime, loss of company image, indirect overheads of the equipment,.... It is an actual cost because it can be calculated immediately after failure has occurred.

This ratio is important for the maintenance manager because he tends to think that the failure costs are low and do not influence total costs of maintenance. As the two vary inversely to each other - care must be taken to keep this ratio as small as possible.

$$\frac{\text{Cumulative costs of maintenance of a unit since start-up}}{\text{Number of running hours since start-up}}$$

This ratio links the total direct costs of maintenance to a time unit (apparatus, equipment, etc.).

Two precautions are necessary :

- the costs must be calculated in constant francs
 - the interest on money spent must not be added to the costs of previous years.
- If the entity shows a low rate of utilization, the penalization produced by the valorization of interest will be serious and will give an erroneous idea of the cost of the entity.

This ratio allows an efficient comparison of similar entities. The number of definable ratios is unlimited; it is up to the maintenance manager to decide upon those which appear the most suitable to help him in his task.

b) Ratios in relation to spare parts

$$\frac{\text{Average stock value}}{\text{Replacement value of production equipment}}$$

This ratio takes into account the components of maintenance costs in relation to exterior ones. This ratio is significant for indicating the degree of ageing of the equipment.

Likewise it has a comparative value for similar plants or for a developing enterprise.

$$\frac{\text{Cumulated value of issued spares over 12 months}}{\text{Average stock value over 12 months}}$$

This ratio measures the stock level of spares or stock rotation. This means the number of times the value of the stock is issued per year.

The value of the yearly issues is clearly defined. The average stock value is the average value during the period of issues. This eliminates any ad hoc variations in the stock value. This precaution is necessary because if the stock value was taken at the end of the exercise by a company which amortizes regularly at the end of every exercise a considerable stock of spares, non-representative stock rotations would be obtained.

$$\frac{\text{Cumulated value of issues over 12 months - cumulated value of issues of safety parts over 12 months}}{\text{Average stock value without safety parts}}$$

This ratio eliminates the safety parts issues on the ratio of stock rotation. These parts are generally supplied together with the production equipment. From the accountancy point of view, they are considered together with the fixed assets.

A substantial reduction in the stock value then arises without decreasing the value of the issues. Here too the stock rotation would not reflect the real situation.

Even if it is sometimes difficult to define and classify with precision the safety parts, the last ratio will be more precise than the previous one. When considering 2 types of classifications, it can be seen that the last ratio is hardly influenced by variations, whereas the previous ratio is very sensitive. In other words any error in classification of safety pieces will have a limited impact on the last ratio and a strong impact on the previous one.

c) *Ratios in relation to manpower*

$$\frac{\text{Cost of sub-contracting}}{\text{Direct cost of maintenance}}$$

This ratio follows the evolution of the policy adopted for sub-contracting.

Sub-contracting is defined as the total amount of maintenance operations which are given to outside companies.

A value between 0,10 and 0,20 is quite frequent.

$$\frac{\text{Cost of maintenance personnel}}{\text{Direct cost of maintenance}}$$

This ratio gives an idea of the impact on fixed or temporary personnel.

The temporary workforce is described as follows : ad hoc personnel supervised by the company personnel and placed under the orders of the foreman of this company. The work carried out by the temporary manpower is added to that of the maintenance department.

3.5.2.2 Technical ratios

The technical ratios, far more numerous than the economical ratios, are also much more varied. This is why only those considered to be fundamental and applicable to all companies are described on the condition that the principles of preventive and organized maintenance can be applied.

Contrary to the economic ratios which are often in relation to the whole plant maintenance, the technical ratios concern mainly apparatus, measures or installations. They can be placed under 2 categories :

- those which interest the users of the equipment and are a measure of the efficiency of maintenance;
- those which interest more directly the maintenance manager in measuring the efficiency of maintenance policy.

$$\frac{\text{Hours theoretically available} - \text{Hours of maintenance}}{\text{Hours theoretically available}}$$

By hours theoretically available in a period is meant the hours during which, if the machine is technically in working condition, it can really be used. For a 30 day month in a factory running at full capacity, this corresponds to 720 hours.

The hours of maintenance are considered as hours of break-down, of preventive maintenance, of repairs, inspection, lead-time awaiting spares and waiting around for maintenance personnel during micro-stops. In certain companies the hours of down-time for accidents are considered as hours of break-down or repairs. This depends on the agreement between maintenance departments and production. In any case, the details of causes of down time will highlight certain stoppages that necessitate particular analysis.

This ratio indicates the time during which the equipment would have been in production. It is one of the principal performance ratios of maintenance. It also allows calculation of the degree of utilization of equipment.

$$\frac{\text{Number of running hours}}{\text{Number of running hours} + \text{down-time for maintenance}}$$

It is the ratio of operational availability.

The number of running hours is clearly defined.

Down-time for maintenance includes : repairs, preventive and corrective maintenance, overhauls, micro-failures.

$$\frac{\text{Number of hours of down-time for unscheduled maintenance}}{\text{Number of running hours}}$$

The denominator is calculated based on total down-time for maintenance reasons, less the hours for scheduled inspection and maintenance.

This ratio represents the lost production hours due to break-down for maintenance reasons, during which the production manager could not use his personnel for other jobs.

$$\frac{\text{Number of stoppages}}{\text{Number of running or usage hours}}$$

This ratio characterizes the number of failures in the system per unit of time and is a measure of the failure or break-down rate. It is generally preferred to the previous one wherever production of wastes at the time of shut-down or start-up is important and expensive. This is the case for paper-mills, spinning units, rolling mills and also when re-start up takes a long time.

The unit of use chosen should be large enough so that it is representative, for example 1000 hours, or 1000 kms., 10.000 cubic metres, etc.

The ratio allow to judge the evolution of the reliability of the equipment, during its life cycle. Under normal conditions of operation and maintenance, this ratio evolves following the so-called "bath tub curve". For new machines, during the initial working hours, break-downs which are called "teething troubles" will give a higher ratio. Later this will decrease and stabilize to a lower value. If operation is "normal" and the maintenance well done, this ratio will stay low during a good part of the life of the equipment.

A sudden variation of this ratio, calculated periodically, indicates that something abnormal is taking place either during maintenance or operation of the equipment. If the ratio increases progressively even though conditions are normal, it is time to think about re-conditioning or scrapping of the material.

This ratio also represents the opposite of MTBF when the units of time are used in the denomination.

$$\frac{\text{Number of maintenance hours}}{\text{Number of running hours}}$$

This ratio measures the evolution of the state of material. It can predetermine by material group, the maintenance workload for the personnel.

This ratio is applied to heavy rolling stock (bulls, cranes, graders) as well as to industrial production machines.

$$\frac{\text{Number of man hours for trouble shooting}}{\text{Number of man hours for scheduled maintenance}}$$

This ratio measures the efficiency of the applied maintenance policy.

By trouble shooting is meant the urgent interventions carried out because of the danger of serious accident or stoppage of production as well as those necessary to re-start up an apparatus under satisfactory conditions. Trouble shooting always causes an immediate disruption in the production programme and maintenance personnel.

Scheduled maintenance includes all maintenance work except that which involves major overhauling work which can immobilize the material during a long time.

Man hours spent on prepared work

Total man hours spent by maintenance personnel

This ratio measures the level of work preparation. It is a sign of an efficient maintenance organization.

Sum total of time allocated

Sum total of time actually worked for these jobs

This ratio gives an indication concerning the performance of interventions.

From the reflections developed above two aspects are apparent and must be considered:

1. The interdependence of the ratios in general. A ratio on its own rarely signifies anything specific. It must always be backed up or confirmed by examining others in relation to the same topic;
2. The need for a precise terminology which is part of the numerators and denominators.

It is obvious that one must be extremely careful when examining published ratios in international literature without further explanation. Care should also be taken when comparing ratios of maintenance departments from different enterprises.

3.5.3 Management monitoring chart (steering chart)

a) Setting-up the monitoring chart

It has been shown in the preceding paragraphs that the ratios, both economic and technical, permit the maintenance manager to follow the evolution of maintenance performance. The results allow him to knowingly make any decision necessary in order to correct his management. All the ratios are gathered on a "monitoring chart", also called "steering chart".

The principal objectives of this monitoring chart are :

- to serve as an alarm bell or flashing light if something goes wrong in maintenance practice;
- to allow systematic comparisons with preceding results and so establish the evolution of parameters and deduce the trends;

- to judge the performance of different maintenance services, as far as is possible within limits of the ratios.

The frequency of data outputs that influences the calculation of these ratios must correspond to the fixed objectives. It serves no purpose to produce them too often, but they must be sufficiently close together so that action can be taken in time.

The data allows :

- the taking of any immediate necessary action to face emergencies;
- the request for analysis reports and detailed studies on certain topics;
- the correction of deviations, by specific actions, or to verify the effects of any previous corrections;
- the preparation, in detail and with justification, of budgets for operation and investment;
- the informing of management and other services of the technical and economical progress of maintenance in the plant;
- the justification of reorganization or reconstructing and follow up of the results of these modifications by using existing ratios or by new ratios created for this purpose.

An efficient and well-designed monitoring chart with satisfactory follow-up not only gives a precise idea of the performance of maintenance but also allows for the making of strategic decisions which directly influence profitability.

b) Users of the monitoring chart

In general there are 2 types of users :

- the staff in charge in the production areas (operators and maintenance people)
- the maintenance manager.

Both will compile monitoring charts but the degree of detail will be different. In the production areas, the following points will be of most interest :

- number of break-downs per installation/machine/apparatus;
- analysis of break-downs (origin, repetitivity, corrective measures, bottle-necks);
- manning tables by qualification and sector;
- analysis of work (time spent per machine, or per kind of work, parts used);
- maintenance costs per installation or machine.

For the collection of data, job order, daily job reports from the shifts, the analysis of work carried out, production reports etc. will be available. If necessary, specific reports will be made, either to analyse in detail certain situations or to establish budgets for his sector, to make forecasts for material or personnel.

Of most interest to the maintenance manager will be the overall view supplied by the data collected from the various sectors. The ratios that interest him concern the whole of his service. They could be those presented in the previous chapter.

A centralized system for data collection allowing rapid access must be installed. A manual processing of these data is possible for small enterprises, but for large ones computerization is necessary. In any case, with the progress of micro-computerization, it would be advisable that a computerized system be introduced either partially or gradually for certain data bases, even for small enterprises.

c) The monitoring chart as a tool for maintenance management

This monitoring chart will allow the maintenance manager to establish company standards for each ratio after a certain time of implementation. Moreover, he will be able to set objectives for each ratio. By following up the evolution for instance per week, he will be able to take necessary measures. These objectives can then be split-up for each production sector or even installation. Each section head or maintenance master will have his objectives which is expected and the obtained results can then easily be controlled and the measures discussed. A principal topic in this management system is the reporting procedures between the different sections and the maintenance management. Experience proves that a good maintenance management is only possible if the maintenance manager is correctly informed. A

reporting system should consequently be installed to assure the transmission of the necessary information based on an efficient repartition for each level of responsibility.