OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

D01886

United Nations Industrial Development Organization

Distr.
LIMITED
ID/WG.62/49
20 October 1970
ORIGINAL: ENGLISH

Symposium on Maintenance and Repair in Developing Countries

Duisburg, Federal Republic of Germany, 10-17 November 1970

DEVELOPMENTS IN PREDICTIVE MAINTENANCE

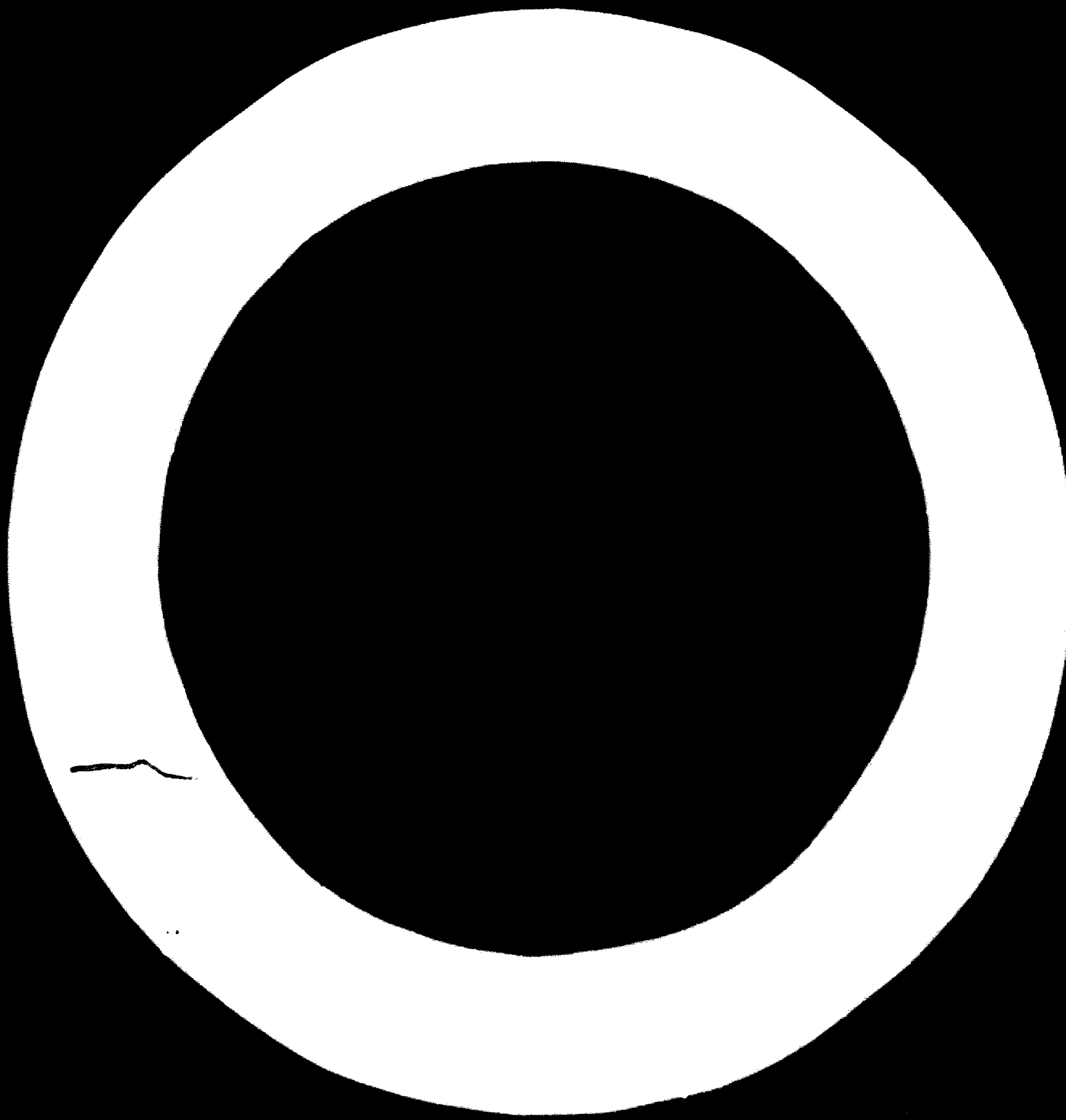
by

J. D. Quinn
E. I. du Pont de Nemours and Company
U. S. A.

Organised in co-operation with the German Foundation for Developing Countries and the German Association of Machinery Manufacturers (VDMA).

---

id.70-5867



The proposition of establishing how much maintenance is actually required is very interesting and very complex. Logically, we cannot reach decisions on "how much maintenance" without first establishing the reasons why we have maintenance.

I would like to review some thoughts on "reasons for maintenance" that are pertinent to my subject "Predictive Maintenance".

In the past few years there has been considerably more discussion about competition. Many companies have recognized a vital need to decrease operating labor cost and at the same time do this with less capital investment. In a sense, this statement is paradoxical, but it must be recognized that the effort to meet both objectives has resulted in many significant changes in the design of our plants and consequently the maintenance requirements. There has been a very definite transition from independent positions and unit operations to integrated continuous systems. "Pipeline" systems that are not new to refineries or some chemical plants have been adopted for many other operations. Other changes have included more extensive use of materials handling facilities, control systems, and other labor-saving devices. While some of these changes have reduced the operating labor requirements, they have changed both the maintenance requirements and maintenance objectives.

Other design changes made to minimize capital investment have also changed maintenance requirements. In the past it was not unusual to have spare units and storage facilities installed in systems to allow some shutdown of some units without production loss. At this point in time they may be considered but not included.

These changes in plant design have introduced a need for both high component reliability and high system availability to meet production requirements and the predicted unit cost of the product. Therefore, maintenance objectives must be closely related to a company's objective which, to state it simply, is to earn a profit.

This profit objective has far reaching effects. The business decisions that relate to manufacture of a product at a profit, along with plant design, establish the initial maintenance requirements.

While we may have a high regard for management and engineering decisions, we also know that when a large number of decisions are involved in the design of a large facility they are based on poor to good data, past experience, and opinions. We have to accept the maintenance requirements that result, but we should establish that we have to accept them indefinitely as requirements.

We inherit some maintenance; in other cases, maintenance is created. It can be created by preventive maintenance programs, which have been described as "the hallmark of modern progressive management". Many years ago, we concluded that we should recognise the value and cost of "an ounce of prevention" but we should also know how often preventive maintenance is necessary - or if it is necessary at all.

So, we have two conditions to consider - the maintenance that is inherited and the maintenance that it is assumed is required. Logically, if we can establish the cause and justify the cost of corrective action, elimination of maintenance work should be the initial step. However, because of the cost involved this may not be feasible so the next step in the logic should be to establish what other courses of action should be considered. The question at this point is "how can this be established?"

In review of preventive maintenance programs, we have found that the frequency of overhauls or reconditioning of equipment has often been based on:

(1) Random failures that occurred. Random failures alone could be small samples on which to base decisions to do a considerable amount of work year after year.

(2) Decisions based on visual, external inspection and opinions regarding internal conditions. This, in some cases, could result in dismantling of equipment that did not require attention.

(3) Decisions based on the very simple proposition that something should be done periodically -- usually with the intervals neatly arranged - three months, six months, one year, two years, three years.

Decisions on when maintenance should be undertaken have become more difficult to reach as changes from unit operation to integrated systems have occurred in the design of manufacturing facilities. With this change, any maintenance - planned or unplanned - could have considerably more impact on both the volume produced and product cost.

Even overhauls planned for, say, every year do not eliminate the probability of a problem occurring during the next week, month or year. Even more important, through dismantling and reassembly of equipment, we risk introducing problems through replacement of components or poor workmanship.

With this background, I will now discuss predictive maintenance - and, to define predictive maintenance simply, it is the sensing, measuring, or monitoring of equipment to determine whether there have been changes in the physical condition of the equipment. Through this approach, we have the prospect of reducing the frequency of overhauls or periodic repairs without increasing the risk of equipment failures and to substantially reduce both equipment downtime and maintenance cost.

The approach, in a way, is similar to that taken by medical doctors. In many cases, periodical physical measurements are made -- weight, blood pressure, blood cell count and levels of vision and hearing. Their objective - and the predictive maintenance objective - is not necessarily to establish precise numbers but to establish whether there have been any important changes in physical conditions. In the plant situation, the use of sensing equipment and other devices, along with a well-considered approach, will allow us to express physical changes as numbers rather than opinions or other terms that are not conclusive. (Refer to Figure 1) It will allow us to establish more certainly when maintenance is required; reduce the volume of unnecessary preventive maintenance work; minimize the amount of unplanned or emergency situations by providing "lead time" for the work; extend equipment and component service life by establishing that the equipment is operating within acceptable limits. Increased availability of process equipment can result from less equipment downtime for either emergency repairs or planned preventive maintenance. All these, to different degrees, can reduce the maintenance cost for the product.

In most manufacturing situations, as in the medical situation, attention is necessary when there is a significant change in physical conditions - beyond an acceptable limit. To determine when changes have occurred there is a wide selection of commercially available sensing and measuring devices, but their use has not been exploited -- to any great extent -- for this purpose. (Refer to Figure 2) For vibration measurements, you may be familiar with equipment available such as analyzers and amplitude meters. For continuous monitoring of critical equipment vibration levels there now is a wide selection of equipment with the capability of providing an alarm at a preset level of amplitude and to shut the monitored equipment down at a higher level.

For determining temperature change, there are low cost heat-sensitive labels and crayons that change color at different temperature levels, contact-type electrical thermometers for periodic readings, or infrared radiation thermometers to measure surface temperature of rotating units or surfaces at inaccessible points.

For pressure or load measurements there is an array of strain gages, load cells and similar devices.

Instruments are available to sense or measure internal wear. Air jet gages and noncontact electronic sensors are being used to measure or monitor axial displacement resulting from wear, to measure changes in clearance, or configuration of internal components. Magnetic plugs that can be retracted for examination with equipment in operation can provide information about separation of magnetic particles from components such as might result from spalling of gear teeth. Recently, similar units for collection and monitoring of nonmagnetic particles have been developed and are available. For other conditions where the particles may not be contained, either magnetic or nonmagnetic components can be exposed to a radioactive source and the particles traced.

External changes in alignment or relationship of components can be established with optical alignment equipment,noncontacting pick-ups, air jet gages, dial indicators and other devices.

Rate of corrosion can be established with coupons, but there are available Corrosometers, Corraters for continuous monitoring of corrosion rates, ultrasonic gages, portable x-ray,cobalt capsules and other radioactive sources.

A change in physical conditions is the principal reason for maintenance being required. When we examine these reasons we find a "cause and effect" situation. A change in conditions occurs and -- too frequently -- efforts are directed towards correcting the effects.

As I mentioned previously, a more satisfactory solution would be to take care of the cause through corrective action, or corrective maintenance, if the cost of doing it can be justified. When this action cannot be justified then there are only two alternatives. (Refer to Figure 3)

Repairs maintenance - doing the work as it is required - or preventive maintenance to overhaul units or replace components before the need occurs. If data are not available, decisions for one course or the other, whether the equipment is critical or non-critical, must be based on past experience or opinion. Either decision on this basis could adversely affect both equipment availability and maintenance cost.

Figure 4 shows what I consider to be the relationship of predictive maintenance to the present practices. If corrective maintenance cannot be justified, then there is a good prospect that predictive maintenance can establish when maintenance should be undertaken. While we know what can be done to identify changes in physical conditions, it is necessary to establish what conditions to measure, select the most suitable equipment, develop criteria, and evaluate results.

In 1962, I discussed this concept with one of our works engineers. There was interest in evaluating this approach as there was the prospect that the techniques developed could have application at many other plants in their department - and throughout our Company. Arrangements were made for one of our engineers to work full time with plant personnel on a comprehensive study.

To date, we have collected considerable reference material and have evaluated many sensing, measuring and monitoring devices.

In addition to development work within the Company, I have been following an approach that can be classified as predictive maintenance that is being done by a large midwest utility company. At one of their generating stations their newer turbogenerators have been in continuous operation for six to seven years, without increased risk, under monitored and controlled conditions. They tell me that,without risk, they can predict when overhauls or even minor maintenance work will be necessary. Optical tooling, used during installation of the equipment, is now for alignment checks; all bearing temperatures are sensed and recorded, load and vibration amplitude is measured at strategic points; internal wear, clearance and axial displacement are measured continuously. In addition, the usual efficiency tests are performed periodically. Alarms are provided to alert the operators if conditions should change significantly. If there should be radical changes, provisions have been made to shut the units down automatically.

In the future, it is not unrealistic to visualise the same approach for identifying changes in the physical condition of critical equipment that we now have to indicate changes in process conditions. Graphic panels in the manufacturing areas or central control rooms could, and, I am quite sure, will be considered for indication or measurement of changes in physical conditions.

In the meantime, we must know about how to sense and measure changes -- to take care of the present situation and provide knowledge for future developments. Predicting when maintenance is needed, either through periodic measurements or monitoring, can become a very important part of any company's maintenance operation. Properly organised, it can be one more important way to reduce maintenance cost and contribute substantially to the profit objective.

PREDICTIVE MAINTENANCE OBJECTIVES

ESTABLISH WHEN MAINTENANCE IS REQUIRED

REDUCE VOLUME OF PREVENTIVE MAINTENANCE WORK

MINIMIZE UNPLANNED OR EMERGENCY WORK

EXTEND EQUIPMENT AND COMPONENT SERVICE LIFE

INCREASE PROCESS EQUIPMENT AVAILABILITY

REDUCE MAINTENANCE UNIT COST

FIGURE 1.

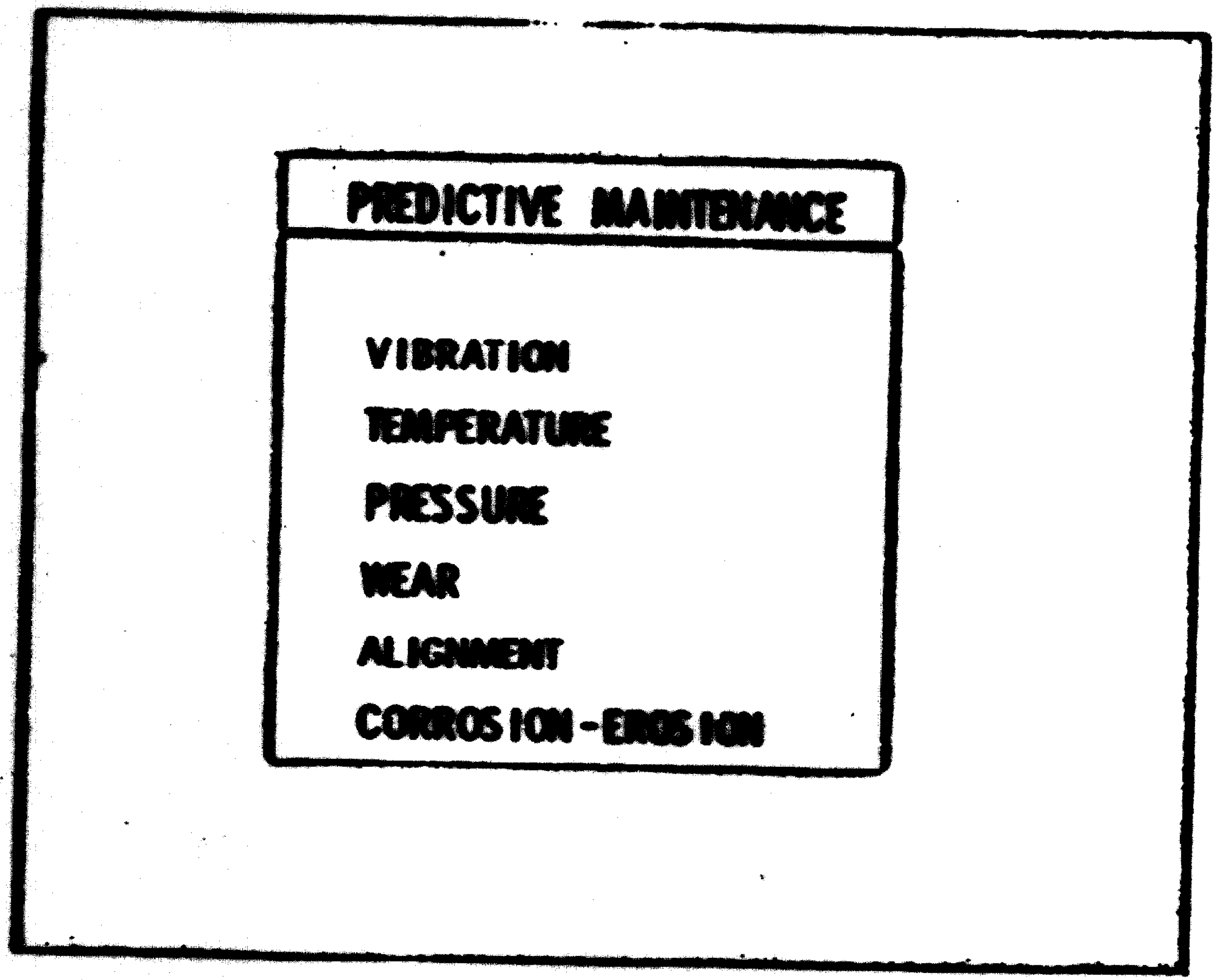

PREDICTIVE MAINTENANCE
VIBRATION
TEMPERATURE
PRESSURE
WEAR
ALIGNMENT
CORROSION-EROSION

FIGURE 2.

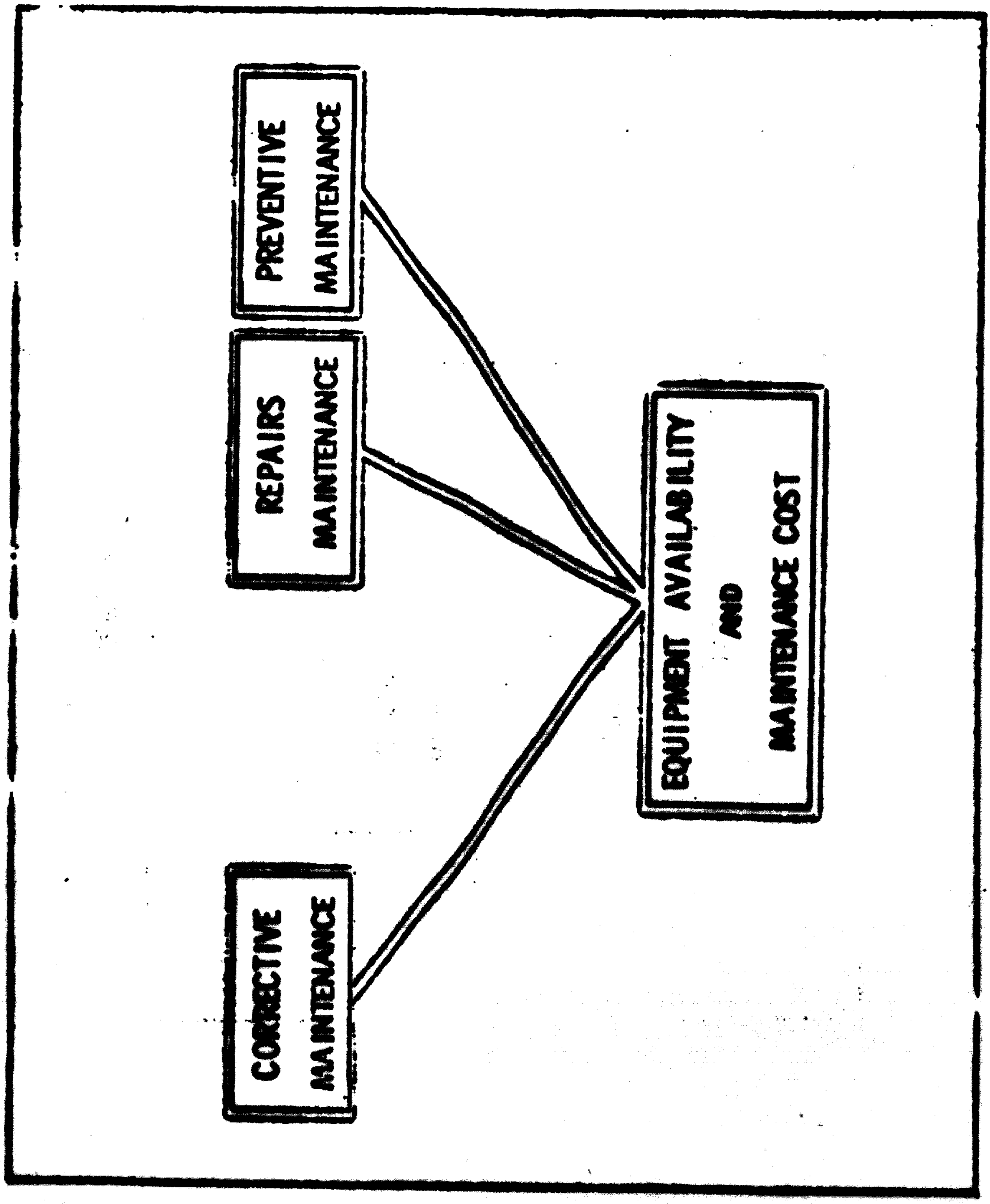

PREVENTIVE MAINTENANCE
REPAIRS MAINTENANCE
CORRECTIVE MAINTENANCE
EQUIPMENT AVAILABILITY AND MAINTENANCE COST

FIGURE 3.

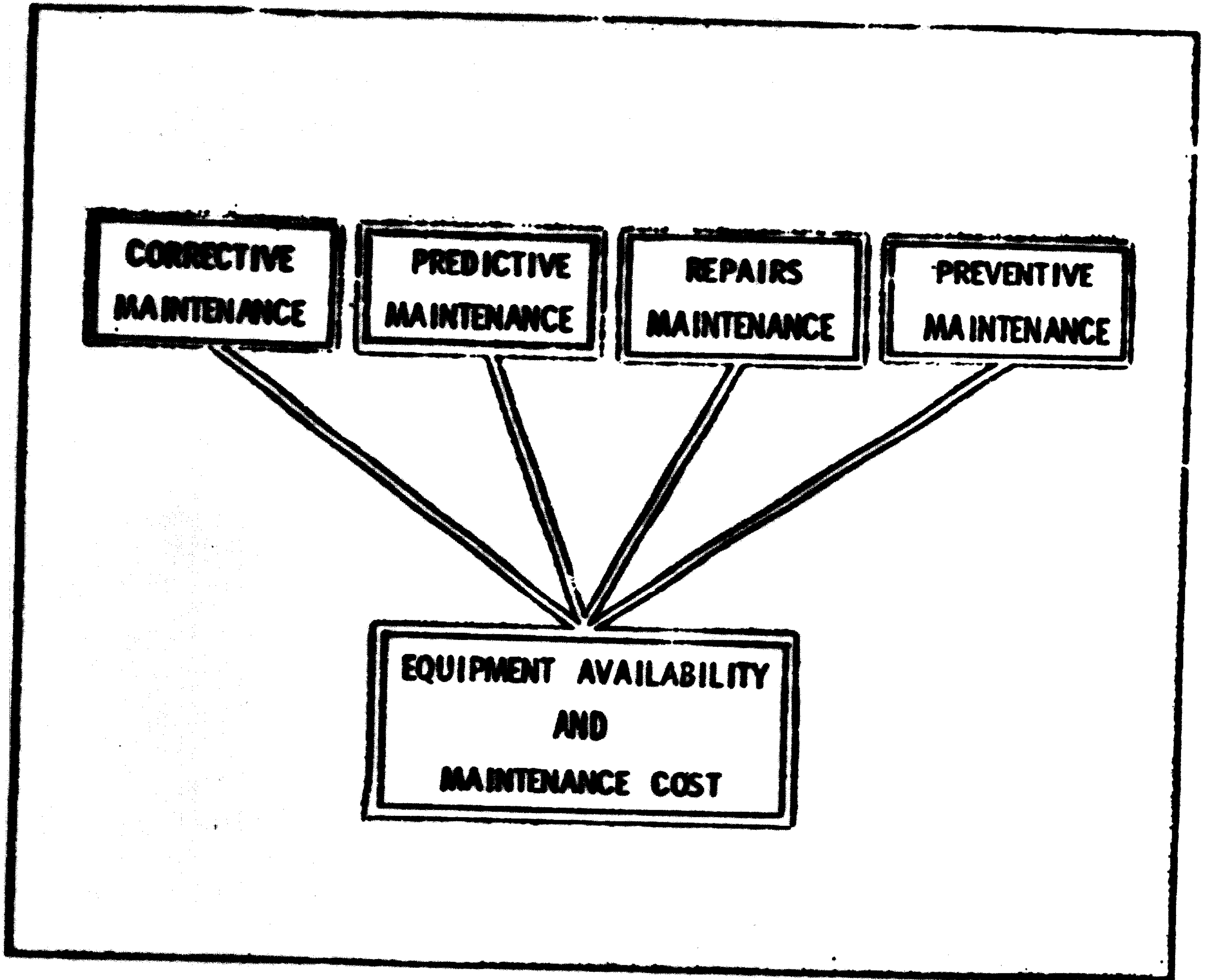

CORRECTIVE MAINTENANCE
PREDICTIVE MAINTENANCE
REPAIRS MAINTENANCE
PREVENTIVE MAINTENANCE
EQUIPMENT AVAILABILITY AND MAINTENANCE COST

FIGURE 4

6. 10. 71