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

FAIR USE POLICY

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

D01632

United Nations Industrial Development Organization

Distr.
LIMITED
ID/WG.62/29
17 September 1970

ORIGINAL: ENGLISH

Symposium on Maintenance and Repair in Developing Countries

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

MAINTENANCE OR RENEWAL

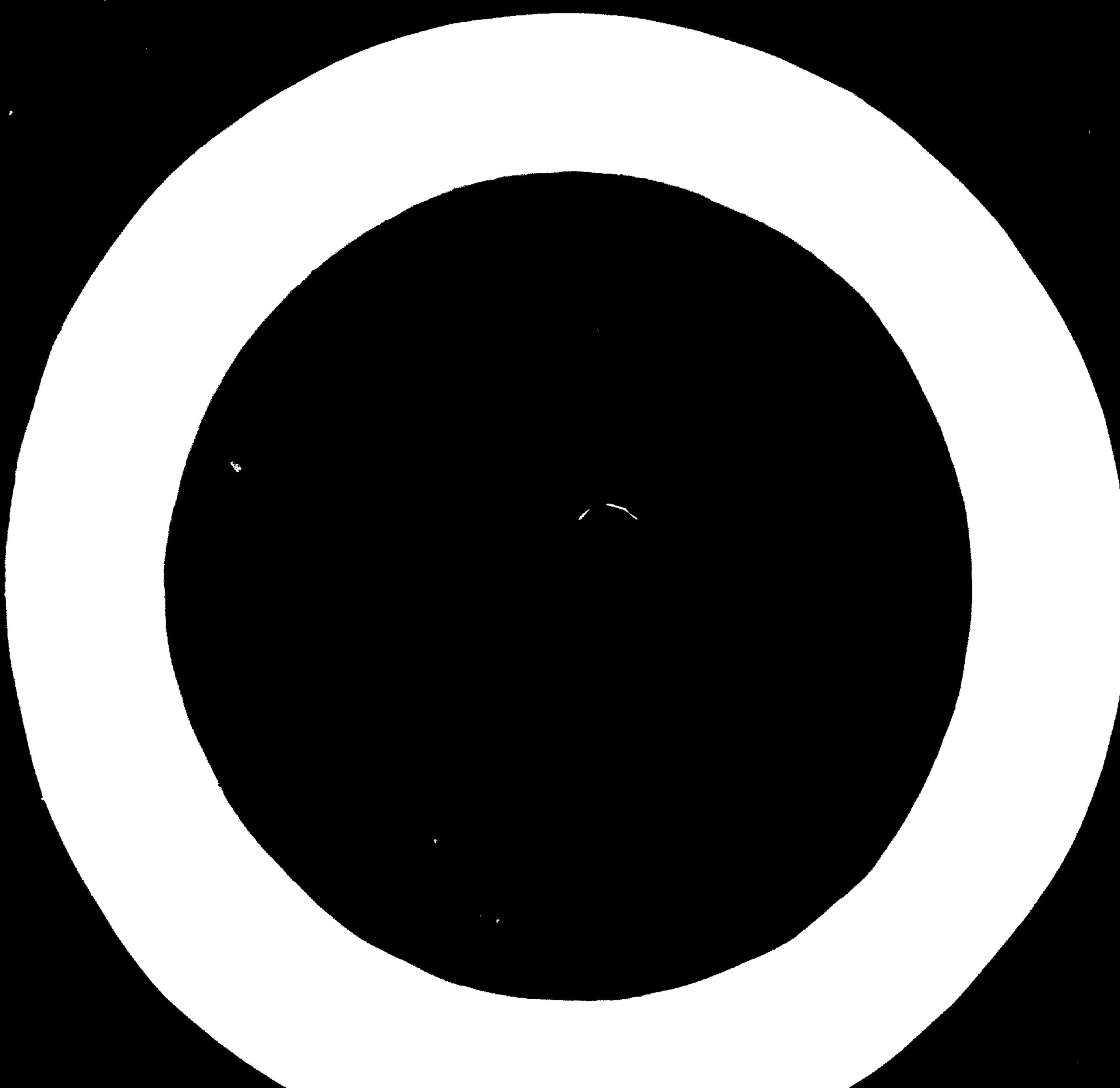
by

A. Ullman
Sweden

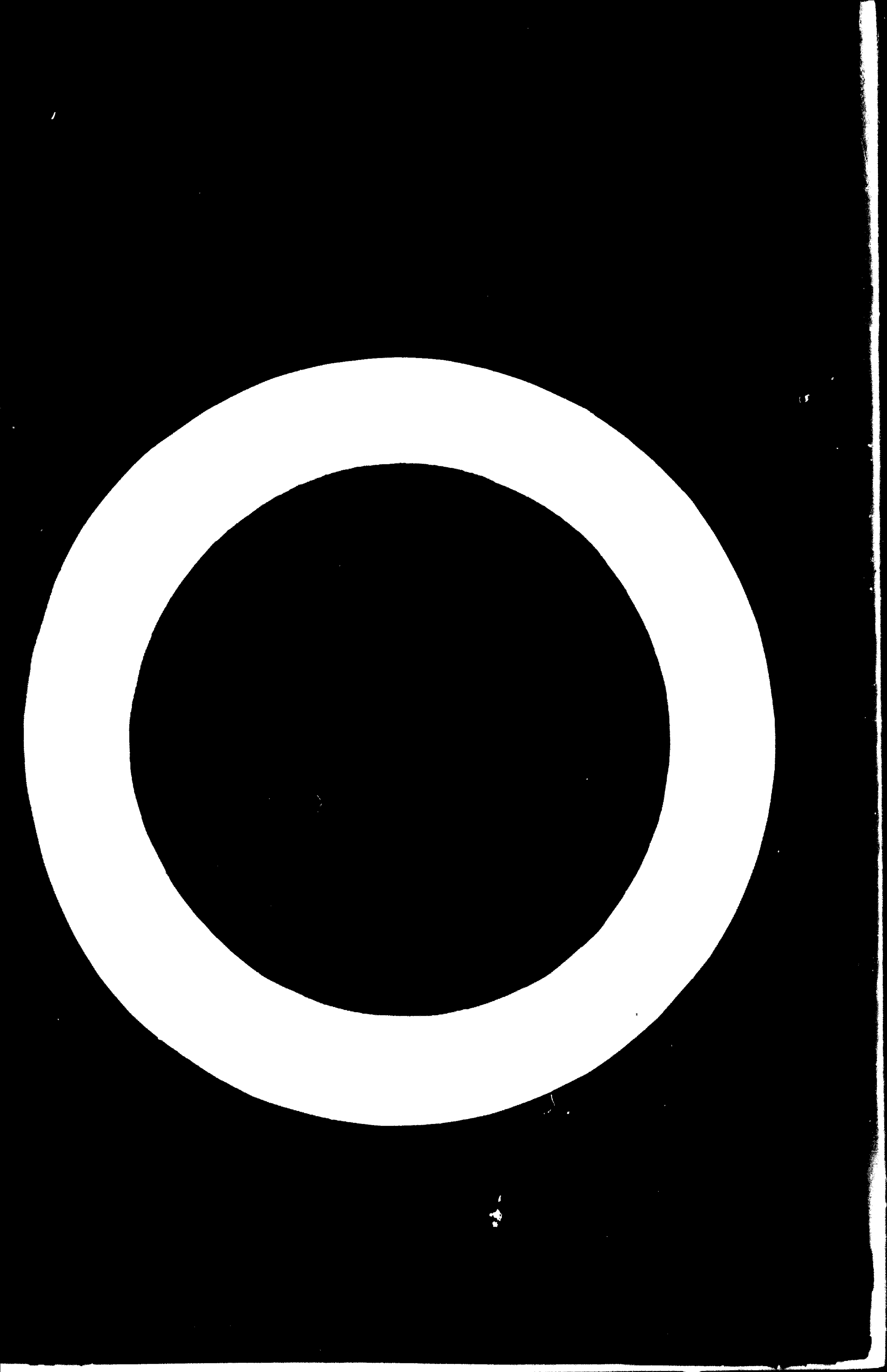
Organized in co-operation with the German Foundation for Developing Countries and the German Association of Machinery Manufacturers (VDMA).

---

id.70-5228



Content



MAINTENANCE OR RENEWAL

I Introduction

The aim of this paper is to describe the problem of finding the correct moment to cease from maintenance and instead renew machinery and equipment in the manufacturing industry .

The environment in which to decide will be the market economy and the decision is meant to fall upon the factory management, which principally has to base all its decisions on profitableness as the main criteria.

It should be noted, though, that in the factory we have two levels for work of this type. The decision to renew a process machinery or a piece of equipment involves an investment. Investments are decided upon by the board, which , when choosing between continued maintenance or renewal, has to consider other questions than just the profitableness of two or more competing suggestions. Such questions are: Do we dispose of the money necessary for the investment? If so, are there other urgent objects for investment to compete for the money either at the moment or later on, for which the money then should be saved? Are possibly available investment credits limited to the use of certain types of production?

The production manager or chief engineer of that certain department , in which the machinery rather should be renewed, has no possibilities to survey the investment situation. He should just find out the straight forward profitableness of possible alternative ways of action of maintenance or renewal and present them to the management, which then very well could decide because of such reason as mentioned, that for the time being a less profitable suggestion should be chosen.

Another of such motives could be the question of tax. Investments are generally exposed to regulations by law. There could be tax on investments above a certain limit, or for certain types of installations or equipment. Or there can be tax relief on investments in certain areas where governments see a need for raised employment.

The paper will generally deal with the problem of the production manager or chief engineer, but will also touch on finance and tax problems.

II Factors determining the decision of maintenance or renewal.

A Normal profit calculation

The total cost for operating a processing machinery, a set of machines, or any piece of equipment, comprises the costs for

a. invested capital in machines, buildings, installations, necessary new training, running in time, when production is limited etc. the depreciation of which has to be charged to the production by piece, by amount per timeunit, by time unit or otherwise suitable in each case,

b. material, such as raw material and semimanufactures used in the process,

c. manpower, operators, watch keepers, other forms of direct labour,

d. operation, electrical power, workshop administration, lubrication oil and other consumed articles, other than b) above, indirect labour for all necessary services to facilitate the operation such as workshop cleaning and transports etc. , all being such costs, which cannot always be added as a certain addition to direct labour, but is rather related to production,

e. maintenance, maintainers'wages, raw material for maintenance, spare parts, costs for maintenance workshops, including administration costs for these, transport, lifting, disassembling and reassembling equipment, test rigs etc.

All costs under these headings build up the total cost, that has to be charged to the products. They must be determined for all interesting alternatives under consideration, such as

a. Preventive maintenance and necessary corrective maintenance of existing equipment, continously carried out in slack production periods.

b. Renovation to bring existing equipment into condition as new and after that preventive and corrective maintenance, which then will be cheaper. (Decide whether the renovation is radical enough to motivate that it from finance and tax aspects could be considered as investment).

c. Modernization as well as renovation to bring the equipment not only into condition as new but to raise productivity or to improve precision to raise product quality, and thus attain a higher technical level. The result will be a cheaper maintenance. (The same investment consideration as under b) will be necessary)

d. Replace the equipment by similar with same productivity and precision, which will be an investment, that should correspond to the depreciation of the old equipment (including what is gained by selling this) and will bring down maintenance costs.

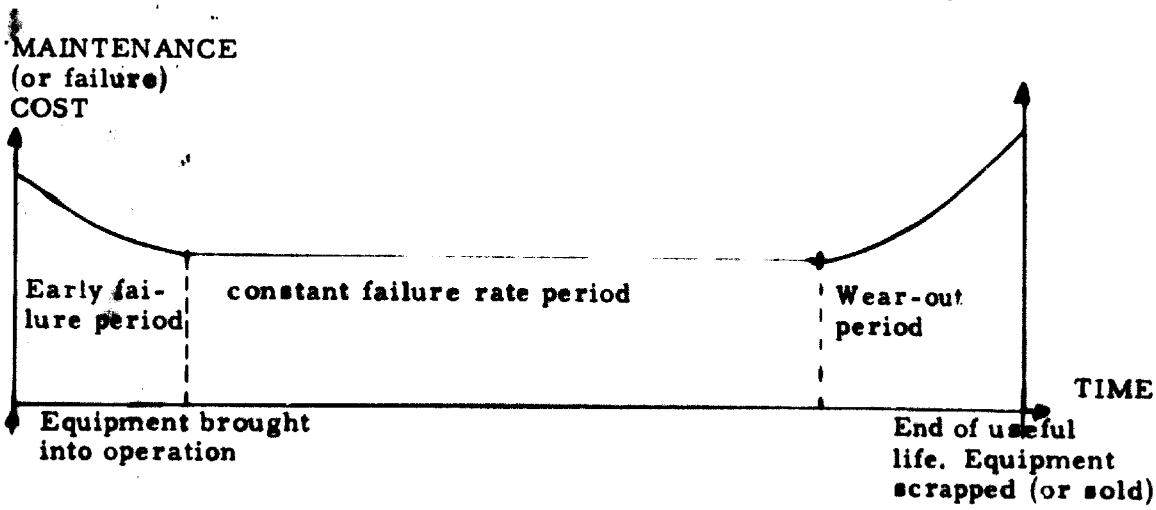
e. Replace the equipment by similar with higher productivity and higher precision, probably also easier operation where as well precision as operation are improved not only by precision manufacturing but also by modern control equipment.

It should be noted that investment costs are spent in alternatives c) and e) not only to maintain the same production in quantity and quality as before but as well to raise the production as to improve the quality. It is of interest to keep apart these two parts of the investment.

Summing up these total costs for each of the alternatives, which seem to be interesting to compare and charging them to the expected production by unit or by some other usable measure will make it possible to rank the alternatives after profitableness from the production engineer's point of view.

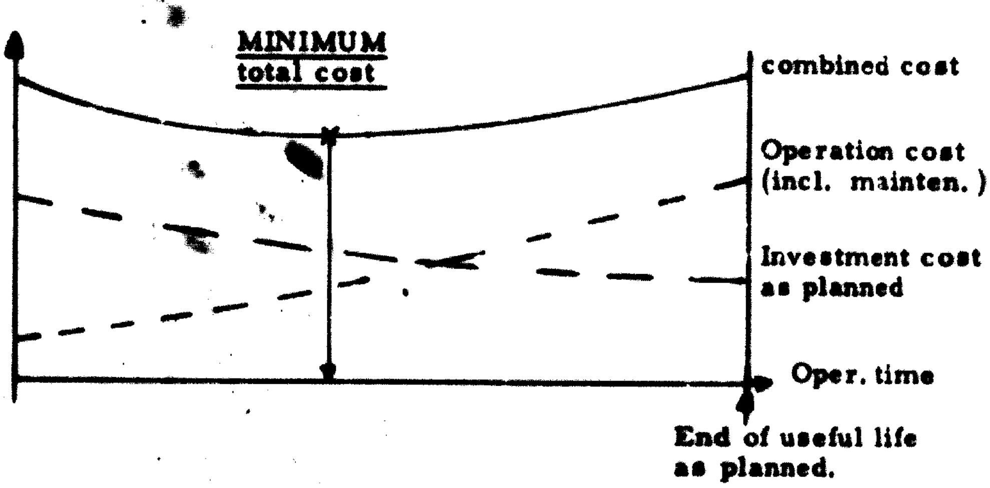
Apart from the fact that the management might choose an alternative that does not top the list, there are a few considerations, which will make the decision a bit more complicated than it might seem from what is said as yet.

First, a look at this diagram shows that we have to deal with an aspect of time.



When does the failure rate or preventive maintenance cost raise to an unacceptable measure? This form of the so called "bath tub curve" is principally general.

If we for the "wear out period" draw a curve showing total operating cost including maintenance and combine it with a curve showing the cost (in same unit as maintenance cost per product unit, per year etc) for the actual, still not depreciated, investment, we might get a diagram like this:



Somewhere, depending on expected total operation cost year by year and on the rate of cost year by year for spent investment capital, we can get a minimum total cost at a certain point of time. If we take that as a point of interest where renewal should be considered, we might not have utilised the invested capital. The capital cost curve presupposes a certain operative useful life. If equipment is scrapped earlier, the curve should have been different and the point of minimum total cost probably displaced. Obviously it is necessary not only to look at profitableness at a certain point of time but to survey a period of time ahead and find out not <u>if</u> the equipment should be replaced but <u>when</u> this must be done.

Considering this it is further obvious, that the different cost items as given above under a) to c) should be found out not only at the present actual time but at successive points of time ahead. This makes heavy demands on judgement and foresight upon those involved. Many of the important factors in the calculation are uncertain. For instance:

What is the future demand for produced quantity? As each product unit has to bear its part of fixed costs this figure has a great influence on the investment decision. It is necessary that the management decides as a question of policy for what productivity (or what possible alternative productivities), during the time to come, the calculation should be carried out.

How about the technical development? When will there be a demand for a product of higher technical quality or of different design or generally with different qualities or caracteristics? This will have effect on the useful life of our equipment, which obviously is not a question only of maintenance cost. This also falls on management to decide as a matter of policy on which to base the calculations.

How about the technical development in the field of our processing machinery? Will there shortly come in the market better, more reliable equipment with higher productivity, better precision, lower failure rate, better maintainability, and lower price for which it would be wise to wait?

How about the failure rate? What frequency of failures must we expect notwithstanding a thoroghly planned preventive maintenance? And for each considered alternative? What resources must be spent on preventive respectively on corrective maintenance? For present equipment there will probably exist an experience on which to base the judgement but for prospective new equipment we have less experience and have to ask the manufacturer for his opinion and more or less rely on that. What will the running-in time be for new equipment? Is the maintenance planned by the manufacturer so, that the "teething troubles" will be overcome in short time? When will we thus attain the planned productivity?

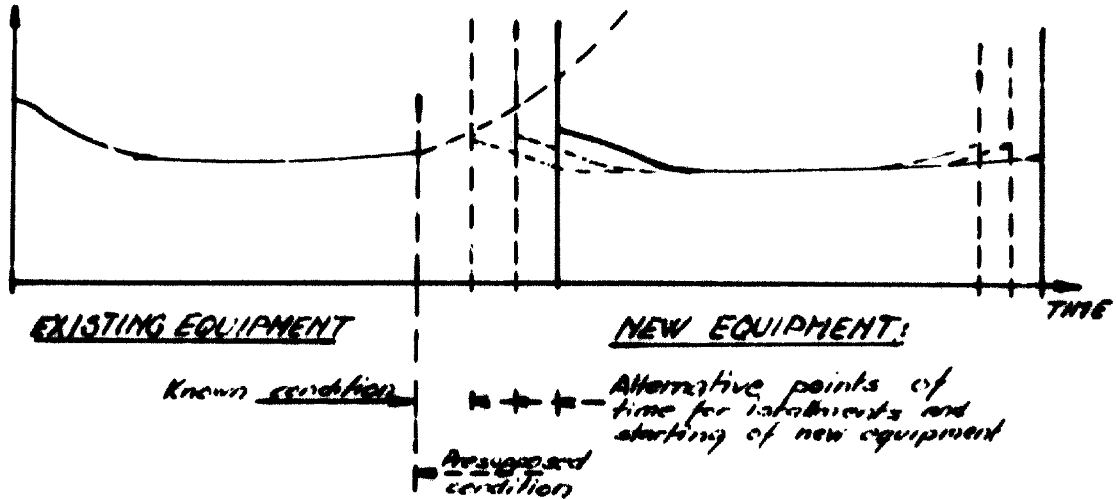
If failures during operation occur, causing production stop, what will be the cost for shut down at different periods of time? Obviously we do not get paid for products not delivered. If however the product is demanded intermittently and therefore produced to stock, the deliveries are not always upset by a failure. How important is an undisturbed production and what will a disturbed production cost in money at different intervals? If an undisturbed production is inescapable what will necessary spare capacity cost? What will a maintenance organization cost, in the different alternatives, which can deal with all possible failures within short time?

Generally, these various points of uncertainty show that the matter of maintenance or renewal has to take into account all considerations due in an investment calculation, where a clever judgement about the future is necessesary. In other words maintenance is not just a question for the maintenance department but for the management as well.

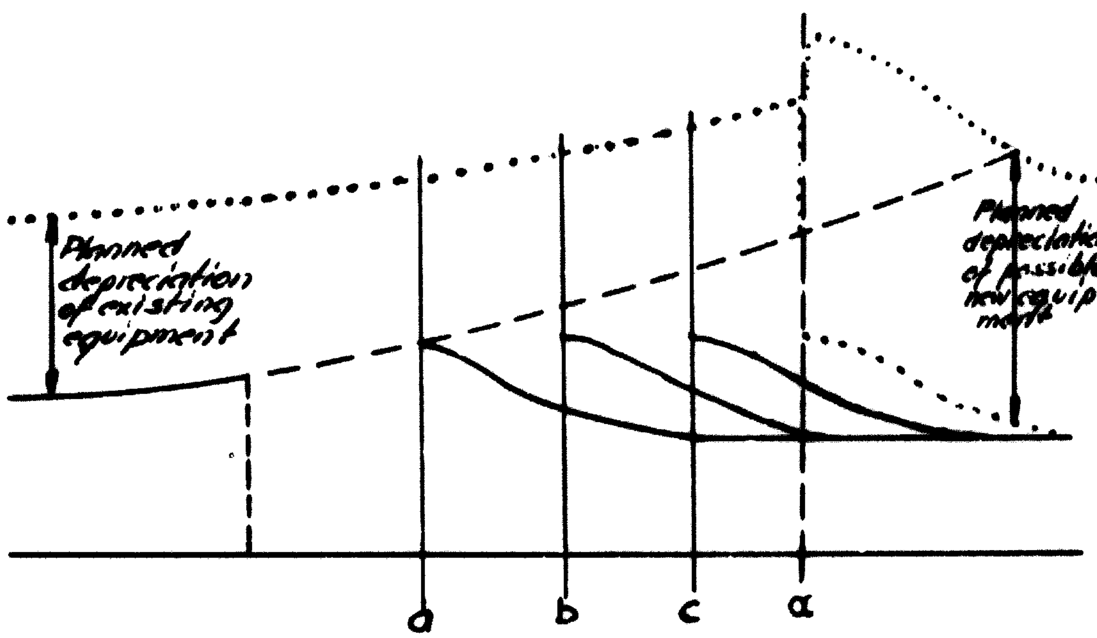
In the following sections of this paper some of the aspects given hitherto under section A will be examined a bit further.

B. Maintenance and repair costs of existing and new equipment

Let us look at the "bath-tub curve" as demonstrated above. We also draw the corresponding curve for tentative new equipment installed to replace the first one. If we have reliable statistics for the existing one and can judge about the future for the new one based on reliable figures from tentative contractors, we would be able to make a diagram good enough to use for decisions. It might look like this:



Let the curves represent not only the rate of failure but total operating costs including maintenance costs but excluding investment costs. The maintenance cost should also include cost for shut down operation when unexpected failures have occured (or can be presupposed to occur) which prevent operation while being repaired. If we cut out the interesting part of the diagram and add the curve for depreciation costs for invested capital (which costs should be planned to be heavier in the beginning of the useful life) we get this diagram



From the bare operation cost point of view we should renew the equipment in question as soon as possible, say at point a), that is obvious. If we take capital cost into account and merely add this cost in the same unit we might get a diagram according to the dotted lines, which means to say, that the machine has not earned its own investment until point d) If we renew at points b) or c) we must pay the remaining depreciation by income from the new machinery or by selling the old or in some other way .

These simple diagrams might serve the purpose to show the importance of considering all costs as well as of having as good and reliable information as possible about operation and maintenance costs, about future productivity demand, about how maintenance might be split upon preventive and corrective maintenance, what might be the frequency of necessary shut down for repair and what might be the cost for interrupted production in case of such shut down.

The first and primary care is to have statistics on existing equipment showing all actual, important facts to make it possible to forecast with reasonable security what will be the maintenance frequency and cost for this equipment.

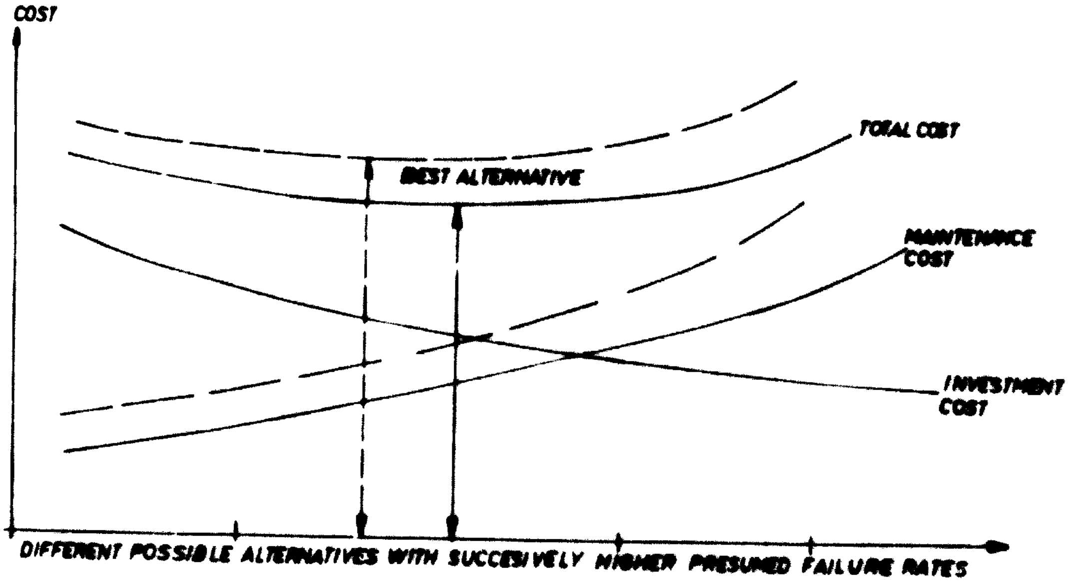
Secondly, the possible new equipment should at tendering stage be sufficiently known to facilitate the corresponding forcast, and of course to plan in before hand the necessary maintenance resources and training.

The cost for shutting down operation unexpectedly is of great importance in case there is a considerable risk for such shut downs and we have to reckon with a great deal of corrective maintenance. We can conclude that from our operation statistics. If so our organization for maintenance must have a high degree of readiness for quick corrective actions, which is more expensive than working strictly to a plan of preventive maintenance. To decide what the shut down cost is in different operation environments is important and must fall upon management. To stop operation in a moment when any produced item is immediately consumed by the customer must apparently cost more than if we produce to stock and delivery is not interrupted. Of course keeping a stock will cost, but might be necessary just for this purpose. If so, this cost is a maintenance or operation cost to be taken into the account and like the rest charged to the produced items. An other solution to avoid delivery interruption in case of failure is to have double equipment, one in operation and one stand by ready to shut in. This cost is also heavy but is in some application necessary, when interrupted delivery just cannot be accepted. When comparing the cost for existing and new (or renovated and modernized) equipment, this calculated risk of failure is of utmost importance. Cost for shut downs and possible costs for remedies against interrupted delivery must be judged with care and taken into account.

C. Investment costs vs. operation costs from maintenance point of view Cost trends

To avoid failures or diminish the risk for failures, equipment could be built with a high degree of security of function, such as with best material and high accuracy and after thorough and careful prototype testing. This costs much under the heading of investment and reduces the maintenance cost. The maintenance cost can also be reduced by raising investment costs if the designer gives the equipment a high degree of maintainability which means mainly two equipment qualities. The one is the possibility to take quick corrective actions in case of failure by seeing to it that defects can be quickly localized by indication routines and measuring points, by easy opening up for inspection and by easiness to change all parts exposed to stress and wear. The other is to include indication devices, where possible for indication of successive wear of exposed parts, so that preventive actions can be planned and performed in due course in production slack period.

If different alternatives of equipment design are considered it might be possible to represent the variations of the cost for investment vs. cost for maintenance in a diagram like the following (costs are broken down to each produced unit or can be discounted to present moment)



The diagram is principally valid but can naturally not be generally applied to industrial equipment in this simple way. It shows however, that it is possible to find some design, where total cost is lowest. A lower failure rate would be to expensive on the investment side. A higher would be to expensive on the maintenance side. The presupposed shut down costs could be or could not be included in the maintenance cost when calculation is done. In certain applications where failure is prohibitive the best solution might be to have a moderate failure rate at a comparativly low investment cost and to have a stand by reserve unit to fall in in case of failure. A single unit with very high security of function i. e. extremely low failure rate would cause a prohibitively high investment cost.

A main point in this section is to discuss the trends in changes of costs or how to find a good solution which is good still after years of service. Two main points in the industrial price trend are the raising wages and the resulting higher mechanization of production. When using successivly less manpower to produce a certain amount of equipment it is obvious that it will be comparatively cheaper to produce and more expensive to maintain, as maintenance is a handwork. A machine, which is built in series on a production line with efficient methods, efficient tools and a high degree of mechanisation, still takes a certain number of manhours to pick apart and to reassemble not to speak of the time to measure and inspect all the parts to decide whether they must be exchanged for new ones. If we look at that diagram again we might judge, that after a few years the maintenance curve would be like the dotted one which would result in a new total cost curve and a new point for minimum cost more in favour for higher investment and lower maintenance. As the equipment is meant to live for a number of years one must consider the mean maintenance cost during the life of the equipment. Again therefore these maintenance calculations require good judgement about for how long time the equipment must serve and how the manpower costs will develop during that time.

This tendency of successivly less maintenance is accelerating in the developed industry areas of today and stronger as industrialation is pronounced. The actual situation in an area and swiftness of the trend of changing towards quicker scrapping and renewal may be considered as an indication of the degree of industrial development. If one can judge about this trend and compare this with the trend in manpower cost one has a good ground for judging the future best combination of investment and operation costs.

There are of course reservations to be done here. As touched on before, the investment/maintenance cost combination is not always the only criteria. There might in some cases be special operational reasons for limiting the failure rate more than would be dictated by cost considerations. Consequences of failure might be prohibited for reasons, which cannot be valued in a cost calculation. Further, even the more expensive, more secure-of-function equipment needs maintenance. This maintenance though less frequent and more planned, less corrective and more preventive, needs skill and accuracy and might well be more expensive per manhour, which must be taken into account and prepared for.

D. Useful life of machinery
Market requirements.
Effectiveness-cost-relation aspects.

Referring back to sections A and B, these were presupposing that the useful life of the machinery ends, when it is worn to such an extend, that further maintenance would be uneconomical and that no other circumstances would influence the point of time where renewal would be due. In many cases however, the problem is more complicated as the flow of income from the production of the machinery, intended to pay for investment and operation costs, is not as steady as presumed. The production is sold on a market with the usual conditions. Suppose, that the trend of the market is such, that the price drops for some reason, perhaps a competing product better and cheaper as a result of the technological development. Or suppose that the demand at same price drops to a lower rate for similar reasons. Or suppose [illegible] that the demand raises as we might deal with a modern product which is coming into extended use.

What happens then to our calculation? In the first case the income drops. The production could be the same as the demand for the product does not drop. The cost for the production, investment as well as operation costs, are constant. Our income does not pay enough any more and further operation would be at a loss. If this new situation prevails, our useful life is up. A new machinery with lower costs, cheaper maintenance, less shut down, generally cheaper in operation per product unit and this perhaps by a higher more mechanized production would be the solution, if we want to stay in the market.

The second case is similar. We want to stay in the market notwithstanding the fact that the demand drops. To do that we must lower our costs per unit. Our lifetime for the existing machinery is up and a new machinery lifetime must begin. The market can however, change the other way. Suppose that we have a machinery, perhaps a bit uneconomical but it pays for its costs, while it is used a certain number of hours per week. We are considering renewal for reasons of investment and operation costs. Suppose that the demand raises. We can meet the demand by running two shifts. The operation costs per unit might be raised a bit but the investment capital is utilized better and we could operate the machinery in a new economical situation that lenghtens the useful life until we have still higher operation costs because of maintenance demands.

In this case we might be tempted to invest in a new better machinery in order to utilize the new situation and serve our clients by a higher production, but that is another story. Our old machinery did no doubt get a bit longer life.

Conditions in that part of the surrounding market, where we ourselves act as buyers, namely, where we aquire material, will of course affect our calculations in a significant way. Prices can vary to or against our favour and the supply of material can diminish or stop entirely. For maintenance the supply of spare parts thus is a specially important point. Supplyers of equipment keep spare parts in stock for a limited time after stopping the production of certain equipment models. After that spare parts, on special order, will be very expensive if at all possible to aquire. Supplyers of equipment can vanish from the market entirely and nobody takes up their production. Supplyers sometimes have an unpleasant habit of changing their models, to improve them, without saying a word, which can mean different spare parts, which then suddenly do not fit into our equipment when we want them to. All these things about spare parts have to be thoroughly investigated when we consider the interesting alternatives, as described in section A. In other words, speaking of lifetime, when will the useful life of our equipment end just because the spare part will raise in price to a prohibitive level or because they cannot be aquired at all !

Still another situation for us as buyers can arise. If for instance a machine appears on the market, which can do the same job at a lower total price per produced unit than can be done with our existing machine, then it would be profitable for us to change, provided our still not depreciated capital costs can be taken care of within our calculation. In that situation we would consider the useful life as ended. We might even be able to sell the old machine and let the income help the remaining depreciation.

Our conclusions of this discussion is that our machinery is a part of a system, a link in a production-distribution chain, where more circumstances than just maintenance conditions and maintenance costs decide the length of the useful life. These circumstances can be represented by a model of our machinery which could be called the effectiveness-cost-relation. The effectiveness of our equipment is represented by the services it can, and does, accomplish and the price that is paid for these services, whereas the resources to be spent for the purpose are represented by the costs, specified above in section A. "Normal profit calculation" These services and spent resources must be in balance and even give the necessary surplus to pay for general overheads and the profit by which investment capital can be raised. When such balance no more can be supported, the machinery is not "alive" and if this situation turns out to be stable the useful lifetime is up.

The conditions which dictate prices and costs can differ from what was once presumed and so the once planned life time can unexpectedly be shortened. If then the invested capital is not depreciated or in other words not fully utilized that will mean a loss. Therefore it is always advisable to depreciate at a higher rate in the beginning of the existence of the machinery, when it is possible to survey the conditions with more security and later on, when unexpected changes might occur, be sure to minimize the possible loss if conditions should turn out to be such that the machinery must be taken out of operation.

It is further advisable sincerely to consider an overcapacity in the beginning, if calculations show , that the then somewhat higher costs, because of the limited utilisation of the equipment, can be accepted even with the relatively higher depreciation in the beginning. Should then the market turn out to be able to consume a bigger production, such one is prepared for and possible to accept. This means in other words, that a lower profit is accepted in favour of a possibility to accept variations in the market requirements.

This discussion is principally valid also for a piece of machinery which is part of a complex installation, where the market prices are valid only for the products of the latter. The raising maintenance costs for the piece of machinery in question is affecting the total production cost and the market price and market demand will limit the costs that can be accepted. Each piece of equipment has not only a cost but also a price for its services, which, though only calculated as part of the market price, has to be in balance with the costs.

E. Facilities for maintenance

From what is said above it can be concluded, that the maintenance cost as part of the operation costs must be known or presupposed with a certain security or confidence, if we want our calculation to show itself as reliable. So we must be able to predict not only the maintenance demand, planned preventive or unplanned corrective, as well as the failure rate. When and how often will corrective maintenance be necessary? What disturbances of operation and of product delivery do we have to take into account? We must as well know how the necessary maintenance actions best should be performed and how much they will cost. This in turn makes it necessary for us to know how we should build up and arrange the necessary maintenance resources to make these as fit as possible for the job. This is to say that the maintenance department should be able to cope with any maintenance requirements that arise and still be continuously occupied with essential jobs, or in other words capable to do its part of the job to keep operation costs within the limits and still be as cheap as possible.

There have been found examples where maintainers sat alongside with steel-milling machines in steel works day and night, in three shifts, doing nothing but wait for failures to occur, to be able to set about the corrective job immediately. It would be much better not only for pure economical reasons to do a preventive job on these mills once in a while to ensure that they work satisfactorily in between preventive maintenance occasions.

This is not an example with general validity. In many cases it is better to have spare stand by equipment, if operation must be uninterrupted and to do corrective maintenance jobs when necessary. Examples of this is modern electronic equipment, where preventive jobs do not meet with the requirement to really be preventive, as many of the components often break down on irregular intervals, which cannot be predicted. Preventive jobs, that require opening up of equipment, can also insert new defects. Of course such preventive jobs as regular testing and measurement of operating standard without opening up, are done.

So the relative importance between preventive and corrective maintenance is individual for each kind of equipment and depending on such things as the requirements for uninterrupted service.

Whatever the case, it is important to know as far as possible, which maintenance jobs, preventive and corrective, must be reckoned with. This knowledge is the base on which the maintenance resources must be built. This knowledge must be aquired in all possible ways by pressing the contractor, by collecting information from other sources where possible, and specially by maintaining an own reporting and information collecting system for following up experiences of one s own equipment. Contractors are often eager in these days to collect information about their delivered equipment in operation.

So all actual jobs should be listed as far as it is possible to know anything about them. Each job should be specified as much in detail as possible giving:

- frequency, fixed or predicted
- whether initiated by calendar or operation time or by indication
- whether preventive or corrective
- efficient working time for the job
- manhours and thus number of men as an average
- necessary tools, transport equipment, other workshop facilities etc.
- estimated requirement of spare parts and other material
- appropriate instructions and drawings
- necessary capability or training standard of the maintainer responsible for the job
- which part of the organization (operators, inspection squads, maintenance workshop specialists etc) is most suitable to do the job.

The summing up of these facilities,manhours , instructions etc makes up the necessary maintenance facilities of the factory in question. Of course it is not possible to cover all jobs by this listing. A number of small jobs, one different from the others will always arise so an addition of workshop capacity to make up for this balance will be necessary. Further it must be kept in mind that the frequency of the different jobs as given mostly in operation hours will vary when speaking in calendar terms, weeks, months etc, with the production rate or the utilisation of the machinery in operation hours per month. Thus the capacity of the maintenance department varies with the actual production rate, in so far as a certain number of operation hours will generate a certain amount of maintenance necessary to bring the equipment back into top trim.

However, this list of specified jobs, each specification being a rough instruction, with, when necessary for more intricate jobs, reference to a special instruction book, is the nucleus of what can be termed as the Maintenance System.

This maintenance system can be looked upon as a maintenance planning and control device with the aim of keeping the material of whole technical system at specified operation availability and at a controlled - and lowest possible - cost.

Such a system - in its general lines and build-up - is generally applicable to maintenance of any complicated technical system, and is of course already used in many applications, however, under various labels and vocabularies.

The main parts of such an administrative planning and control system would be as follows:

Planning, survey
Ordering
Maintenance Instruction
Planning, detail
Performance
Follow up, survey (macro)
Correction of survey planning
Follow up, detail (micro)
Correction of detail planning
Correction of Maintenance Instructions

These headlines do not say much as they are. Take however first a look at the diagram.

The main planning function comes directly under the management. This planning is done in rather broad lines, budgeting, say a year ahead, but also a somewhat less fixed planning for say 3 years ahead and a long range prespective planning for say 6 or 7 years ahead. This planning is reconsidered each year and "rolling" forward a year each time.

The input data are mainly the requirements, predicted for the time to come, based on planned production, machinery condition and the resources such as money, labour, space, buildings etc., put at the maintenance departments disposal by management. Requirements for maintenance and resources must correspond, hence the two-way communication.

Plans must be put into activity by an ordering function at right instant, not too late (for detailplanning) and not too early (creating too much possibilities for disturbing reordering).

Ordering from Survey planning is followed by a Detailplanning function comprising all sorts of necessary work shop planning and work preparation.

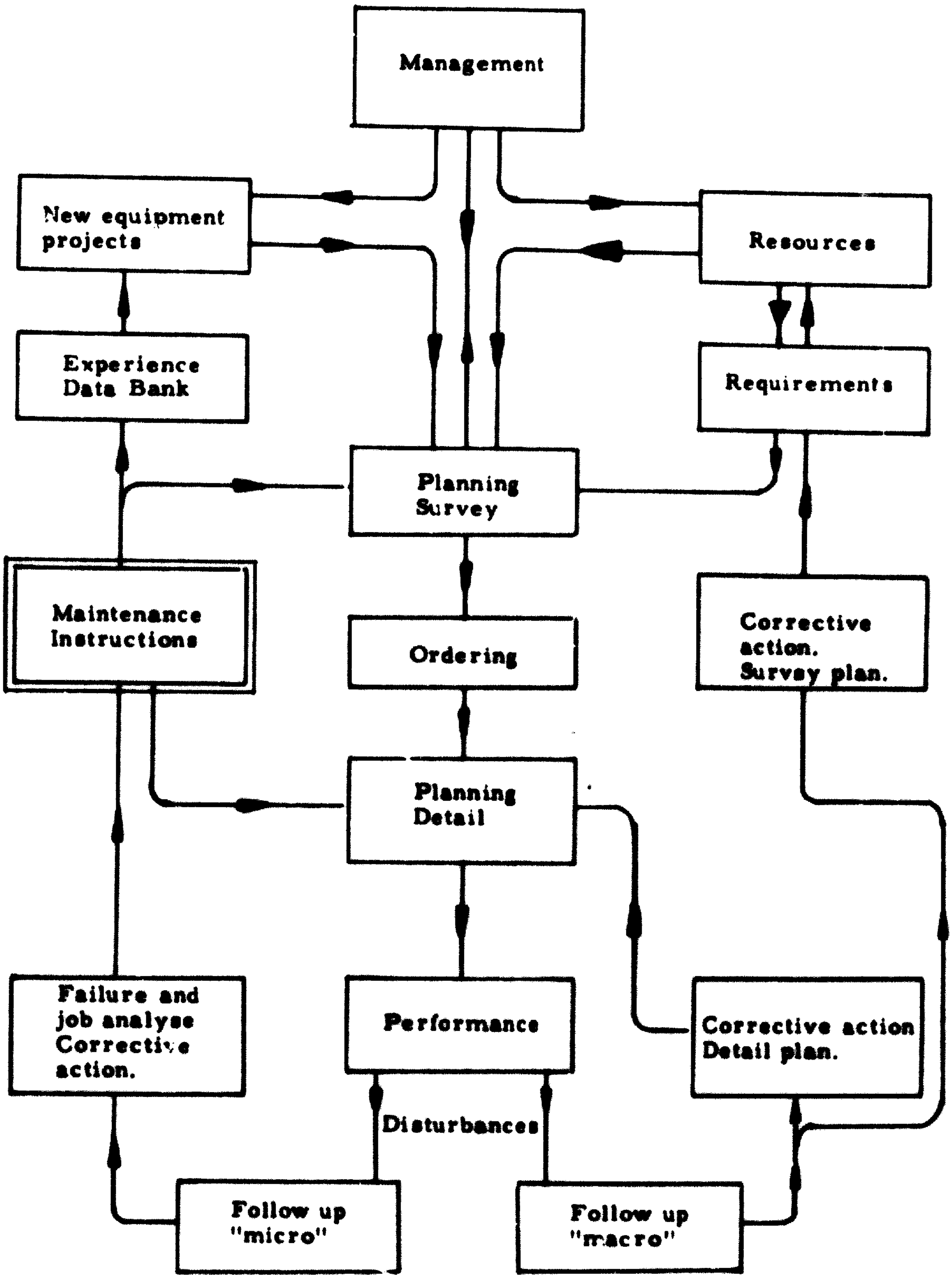
This is followed in due course by the Maintenance Performance, the actual trouble shooting-dungaree-spanner-oil can phase of the job.

In the diagram has been omitted - for simplicity reasons - the pointing out of various administrative connections with the different production activities .

Input information signals to the planning functions can be executed by routines such as consumed service time which makes preventive maintenance due, or service capability data, which reveal that gradual failures are to be expected.

If now all input information and all planning was correct everything would be just fine. Nothing in this world however, turns out as good as expected.

So is the case with maintenance. All sorts of disturbances occur. For instance the demand for maintenance will turn out to be different. The failures will occur when production for a demanding sales department is at its peak and when the machinery just must not stop, the lack for skilled people will suddenly become apparent when we did not expect, to mention just a few examples.



<u>Maintenance System</u>

(Administrative maintenance planning and control system)

The "Macro follow up routine" should be able to catch and report such things and turn them into corrective action at the different planning levels. If the disturbances are such as to require substancial alterations of the volume of maintenance and therefore make alteration of resources supply necessary, it must be taken care of by the survey planning function, which might require new resources at disposal by management decision.

In our diagram we also had a space called Maintenance Instructions. These are actually the nucleus of the system and therefore specially marked by a double frame.

These instructions describe the different jobs to be done on each item (and subitem, exchange item etc.) and also state for each job the different details as given above.

All these information data are required for planning such things as

- required resources, economical, technical and others
- downtime for machinery
- most efficient use of the maintenance organisation
- development of maintenance organisation to meet future demands etc.

Above was mentioned the "macro" disturbances. It can however, also be experienced how the maintenance instructions turn out to need modification. The "Micro follow up routine" should be able to catch all such occurances as when the bitter reallity differs from written instructions. The source of this information are the failures with the corrective maintenance actions as well as the prescribed or as necessary judged, preventive jobs. These should be efficiently reported and analysed and if this analysis points out that a modification could be of value a corrective action in the form of new editions of instruction means new input information to the planning functions.

This analysis of failures and jobs also adds to the experience of machinery service and design and reveals possibilities of improving security of function and maintainability of the machinery as well as of improving the maintenance organization to give a more efficient maintenance supply.

This experience can be used for modernizing the existing production equipment (which for the sake of simplicity has not been indicated in the diagram) but also for formulating the reliability and maintenance requirements and predictions when specifying new equipment.

Two main points in using this Maintenance System are to be specially underlined in this connection.

One is the possibility to maintain an actual knowledge of maintenance requirements of the different machinery pieces. We have earlier underlined the necessity of knowing as much as possible of our maintenance requirements. By means of the reporting which is a part of the System we always get new actual information to correct the one we already have and to fill in the gap, where our knowledge was not sufficient.

The other is, which is already touched upon, the possiblity to maintain an actual plan over the necessary maintenance resources , their capacity now and in the future. This means a practically working plan over the building- up for new production equipment and - if lacking - for the present production equipment of

- maintenance requirement knowledge for completing the instructions
- personnel capacity , training recruitment and
- material capacity, i.e. workshops, tools, spare parts, transport equipment, other workshop utilities etc.

The maintenance requirement knowledge might well call for workstudies in traditional meaning to be carried through either at home or at the contractor of new equipment. The personnel and material capacity might often, when we are uncertain of the exact amount and when this is expected to vary to a great extent especially in the way of difficult-to-aquire specialists, with advantage be bought from other companies, maintenance contractors.

F. Type of machinery, equipment and branch

The reader of this paper now undoubtly will ask for more detailed information for actual, generally valid maintenance costs, lifetimes, failure rates and appropriate maintenance resourcee for different types of machinery, equipment and branches. Such information used with care could, would be natural to think, be a good guideline for the maintenance and production engineers when tackling these problems.

Such information could however be very misleading, and will not be given. Above is shown what a great number of interferring conditions, typical for each certain factory , that affect the profitableness in a determining way. This will specially be valid for developing countries, where individual conditions for each country are known only by executives in and experts of this country, or can be found by special studies. Further more each enterprice has its routines of normal profit calculation and as we here deal with profit problems, which are not different, principally, than other such problems, the best way is for the production and maintenance engineers to find out all the different factors, which affect their profit, predict their possible trends of change in the near and distant future, sit down with the accountant experts and see which alternatives can be satisfying.

Then design their Maintenance Systems and make their maintenance plans for the time to come and plans for an appropriate and efficient maintenance department. This requires a thorough look into the future for many different affecting factors.
As the saying goes: " It is difficult to predict, specially about the future!" It has however to be done. And doing so one must judge the rate of uncertainty valid for the different factors and how a misjudgement could affect the result. And further by the reporting system find out how these factors really come true.

G. Financial and tax aspects

Financing of big modernization schemes or of renewal of machinery involves tax aspects of which nothing generally can be said. The tax laws vary not only from country to country but also from time to time. The governments want to control the industry in such a way that it will be beneficial for employment or generally for development and to direct employment-creating investments to areas or branches where this is thought to give desired results. Investments can therefore cause tax allowances in some areas (or countries) as well as extra taxes in others. These will have to be considered as plus or minus in the investment calculations.,according to normally used methods.

The economy of investement will be strongly affected by the source of the money. If the enterprise has its own money set aside for investments a decided annuity of interest and depreciation has to be calculated. If the money is borrowed this annuity is fixed by the conditions of the loan. Any possible subsidies, governmental or others, dictate their own conditions. The different scientific models designed for maintenance/renewal problems touched upon in section III are sometimes designed to take these financial interest and tax aspects into account.

All these questions are however normal in connection with investment calculations, which do not fall within the frame of this paper.

III Discussion about methodologies for supporting decision on maintenance or renewal and their application

From what is said above under section II A it should be obvious that the proper method to support a decision on maintenance or renewal is a regular investment calculation, where different alternatives are compared in reference to profitability and where the cost of a suitably arranged maintenance is playing its proper part. As investment calculations are beside the aim of this paper, it is not the proper place to discribe or evaluate different such methods.

As many of the important factors, that influence the result considerably, have to be based on judgement or even qualified guesswork, the soundness and probability of these are more important than whether a more or less sophisticated method is used.

Here will however be presented in short one method, worked out by the Machinery and Allied Products Institute, USA. The method was presented for practical use in 1951 and is adopted by several industries in the USA and Europe. Among the published works on the method are the following:

G. Terborgh: Dynamic Equipment Police. (Giving the teoretical background)

MAPI Replacement Manual, (Background in short)

Company Procedural Manual on Equipment Analyses, (Practical instructions, forms etc.)

Business Investment Policy, (Certain revision of earlier recommendations, where the influence of taxes are taken into consideration.)

The MAPI Principles

MAPI holds the position, that the most important problem of an investment calculation for machinery and other equipment is a question of time:

"When must an equipment be replaced by a new one?"
"What does it cost to use the old one another year?"

If one waits too long, the operation costs of the old one will be too high, if one changes too soon, the capital is not utilised correctly. Both cases represent too high costs.

To answer the question whether it is profitable to change an existing equipment for a new one, the MAPI-method compares the costs for the existing and the new equipment if either is used for next year ahead.

As is touched on earlier, the economical lifetime of an equipment depends among others on which competitors this equipment has and will have. With the successive technical development it is necessary to reckon with the fact, that an equipment used today, sooner or later will be replaced by a new one, as well as that an equipment obtained today, sometime must be replaced. In a calculation method, intended to answer the question when this replacement must occur, these new equipments and the costs for them must be taken into consideration.

As it is difficult to predict correctly necessary data for all in the future available machinery, the MAPI method simplifies the calculation by replacing those with presumptions, on which a calculation model is based.

The first presumption is that:

> All equipments, available on the future market have same optimal cost as the most economical, that can be aquired today. The optimal cost is here the minimum combined cost of average capital cost and operation cost, which includes an average "inferiority of operation costs"

Note 1.

"Inferiority of operation costs"
Suppose that we every year could have the best machine on the market and that this one can do the actual job at constant operational costs. Our existing machine will then be successively more inferior to this "every year best machine" because of wear and age. This "inferiority of operation costs" is given as a sum of money by which the difference of operation costs is increasing each year.

The second presumption is that:

> The equipment, which can be obtained today will with time be successively more worn by operation and older. Consequently it will be more and more inferior to equipments available in the future. Regarding the course of this inferiority of operation costs it is possible to do alternative presumptions. The MAPI method has three alternatives, namely:

I. The inferiority is linear to time

II. The inferiority is stronger towards later parts of the useful life.

III. The inferiority is stronger during the first part of the useful life.

The third presumption is that:

> For an equipment, already aquired and in use the sum of inferiority of operation costs (compared to a new equipment) and capital costs will be lowest during "next year". In other words, the operation costs will increase more than the capital costs decrease if the operation time is extended passed next year. The total yearly costs will increase year by year.

With these principles we have simplified the problem. As all future equipments are assumed to have the same optional cost we can limit the investment calculation to a comparison of next year's costs for existing equipment and the best that can be obtained today.

Next year's costs

For existing equipment next year's costs consist partly of operation costs, caused by the utilisation and partly of a capital cost, caused by the diminishing value during next year and the interest on the capital invested in the equipment.

For new equipment, which can be obtained today, next year's costs must be calculated differently. We can devide this cost in the following parts:

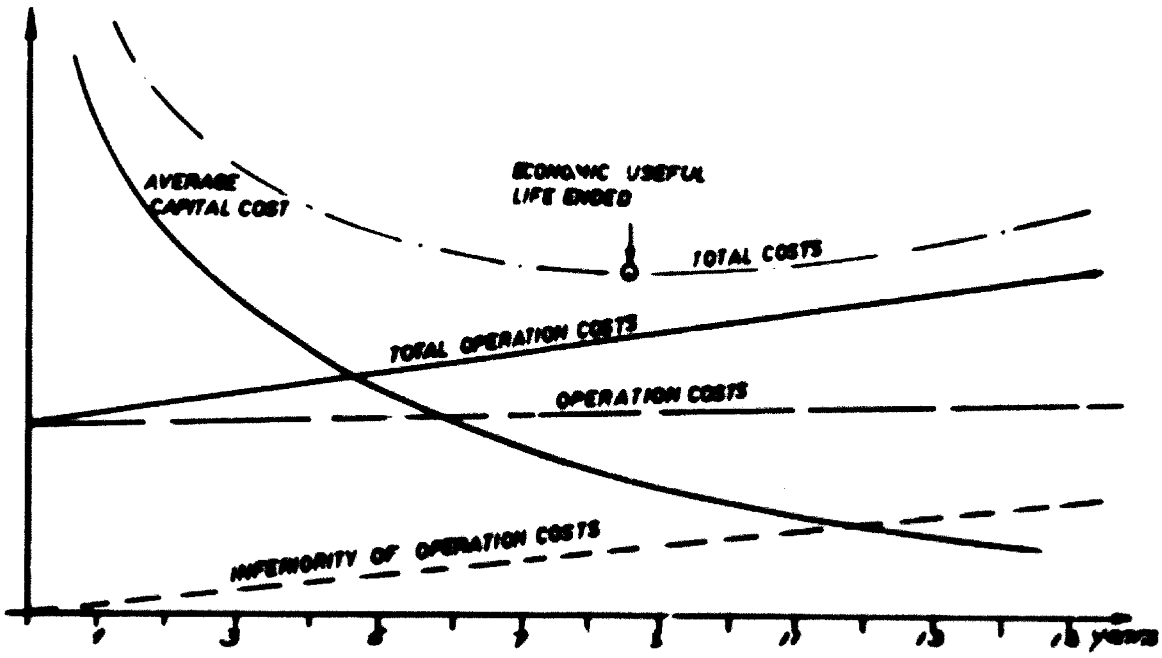
1. Operation costs
2. Capital costs
3. Inferiority of operation costs.

Operation costs are, as for existing equipment, those current costs caused by next year's utilisation. Capital costs depend on the presupposed best useful life. 2). Obviously we must first find this.

If we for the presumed new equipment have calculated the average capital cost per year for a successively extended useful life (lower per year as life is longer) and the operation costs and to this have added the inferiority of operation costs and represented these in a diagram by curves, we will find that the total added yearly cost will have a minimum. The point of time for this minimum will show the economical useful life.

Note 2.

When considering new equipment one assumes, that it is totaly depreciated at the end of the useful life. Earlier it is assumed that when considering replacement of existing equipment, this might not be totaly depreciated. This will be taken care of by this method.



It is now possible to compare the total yearly cost for "next year". If this is done for a number of successive "next years" it will be possible to find out, which year the total costs of a new equipment will be less than those of the existing equipment (at least according to this simplified method) and when consequently this one should be replaced.

The mathematical development and a thereupon based nomogram, available for simplifying the use of the method, will not be shown here.

Scientific work

It is natural, that problems concerning maintenance or renewal have attracted interest from scientists of economy in cases, where the equipment turn over is a heavy item among the costs of an enterprise.

An example of such work found in the science literature (1), concerns a company operating 140 electrical fork lift trucks. Two problems are posed

a. What is the optimum working life of an average truck in the fleet and to what extent is this life affected by discounted cash flow (DCF) considerations?

b. Should the optimal replacement policy for the average truck be imposed for every truck in the fleet, or should a separate policy be formulated for those trucks the maintenance cost of which differ much from the average?

The effect of capital allowances for tax purposes is included. The author designs and compares two mathematical models, the first of which is associated with the total average costs per year, the other with the present value of all future costs and comes to the following conclusions:

1. The study has well demonstrated the importance of considering capital allowances for tax purposes.

2. The two investigated models have yielded comparatively flat objective functions near their optimum points, which suggests that it would be more meaningful and practical to specify an optimum range of equipment life in a replacement policy, rather than a single value of the economic life.

3. The two models give somewhat different results. Model 2 is more appropriate theoretically, if technical obsolescence could be taken into account. Model 1, which suggests replacing the equipment more frequently than Model 2, has the advantage of providing an opportunity of assessing technical innovation and new design of equipment at shorter time intervals.

Apparantly this work discusses possible models for supporting decisions of maintenance or renewal and is using an example of strictly limited structure. Furthermore the statistically acquired information of how maintenance costs of these trucks vary with time does not seem to be very reliable. It might have been worth while by using all maintenance costs instead of as in this case the costs for just 10 trucks out of some 140, to find out a more realistic function of maintenance cost against operation time.

A later example of scientific work is concerned with simultaneous determination of optimal repair policy and service life (2). The author says, that the problem of determining optimal service life of a machine has been discussed during a long time in the literature under the assumption that repair costs are given. Empirical findings and theoretical discussions suggest however, that repair costs and service life are related and should be determined simultaneously.

The cash flow associated with a machine is treated in the paper as a continuous process. The flow is affected by the two decision variables repair and service life. The aim of the decision maker is assumed to be the maximation of the present value of the cash flow.

The author claims that among various methods suggested in recent development of control theory one of the most promising is Pontryagin's Maximum Principle. Built on this Principle the work suggests a mathematical model by which it would be possible to find the optimal form of "repair policy" i. e. money successively spent on preventive and corrective maintenance as well as "service life" or operation time.

A later work (3) is suggesting a modification of the model of reference (2) using also the Pontryagin's Maximum Principle, where the aim is to obtain the maximal value of owning the equipment i. e. the maximum discounted income plus discounted selling value by choosing the amount of preventive maintenance and the sale date. This model is no doubt a valuable development of the model of reference (2) To be useful for the practical engineer however, that presumption must be valid, that maintenance costs, the influence of maintenance on productivity, and as well on sale value and productivity deterioration if not maintained preventively, must be known with certain security and expressed in exact figures suitable for calculation.

The same or corresponding restriction is of course valid for all theoretical models. This scientific work is most welcome and promising. Before such work can yield practical solutions of more general interest for production and maintenance engineers and investment decision makers there must be more information available based on effective information collection and data processing systems to make sure that the input data in the models are appropriate Furthermore these data, strongly influenced by local environments, will not be generally valid without restrictions for branches or types of equipment. Consequently each enterprise must have its own information collecting work done continuously. Finally when such information is available the models must be tested under different conditions and environments in different branches and on different types of equipment.

By such work it might in due time be possible to shorten the way for the decision maker to the goal of making sound maintenance/renewal decisions. In the mean-time the traditional investment calculations will be the main help. However, developed and detailed these might be done there is no shortcut of the way to find correct cost and income information and to sound judgement about the trends of the future. There will be no withcraft in future mathematical models by which correct information collection and data processing and the oldfashioned sound judgement and common business sence can be by-passed. The only thing we can hope to do is to give the decision maker a better support.

References

1. A study in Equipment Replacement
S. Eilon, J.R. King, D.E. Hutchinson
Imperial College of Science and Technology
Operational Research Quarterly
Vol. 17 No. 1 March 1966
Pergamon Press, Oxford, London, New York, Paris
for Operational Research Society, London.

2. Simultaneous Determination of Optimal Repair Policy and Service Life.
B. Näslund
University of Stockholm
Reprint, Dept. of Business Administration
Box 23015, Stockholm 23

3. Optimal Maintenance Policy and Sale Date of a Machine
G. L Thomson
Carnegie-Mellow University
Management Science
Vol. 14 No. 9 May 1968

Note: Further references to be found in these papers

3. 4. 74