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

D01905

United Nations Industrial Development Organization

Distr.
LIMITED
ID/WG.62/45
16 October 1970
ORIGINAL: ENGLISH

Symposium on Maintenance and Repair in Developing Countries

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

PLANNING AND CONTROL IN MAINTENANCE OF GROUPS OF SIMILAR EQUIPMENT

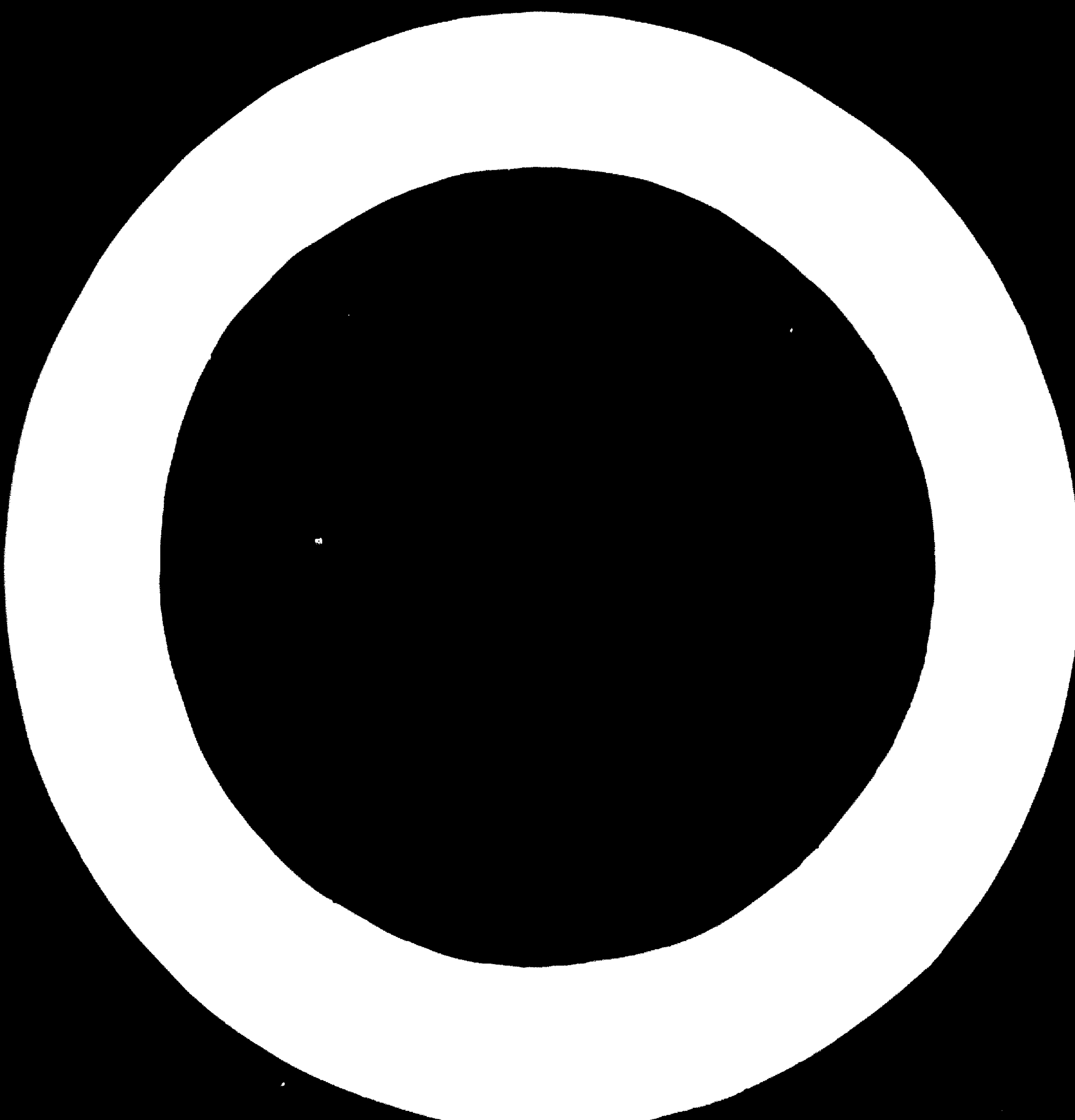
by

W. M. J. Geraerds
Netherlands

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

---

id.70-5780



C O N T E N T S

1. MAINTENANCE AND PRODUCTION.

1.1. Growth of the Maintenance task.

As long as mankind uses tools, experience shows that using tools brings along a decline in suitability through wear and tear and in some cases sudden breakdown. It was rather simple at first to replace or repair the tools; usually the user could manufacture the tools himself from raw material found in the open country and time was not money yet. As technology lead to the development of complexer tools specialisation began. Maintenance became more expensive, the operator lacked the skill to accomplish the maintenance task and the high investments in tools did not allow long intervals out of operation due to maintenance. To-day's installations and machineries require an efficient execution of maintenance so as to minimise production costs. In order to organize maintenance, the maintenance function has to focus on production.

1.2. Relation of production to maintenance.

Production presents itself to Maintenance in the requirement of repair of the means of production when they have broken down. Maintenance serves production in returning the failed equipment into the operational state, thus supplying potential production capacity. This relation of production to maintenance can be visualised in a diagram, as shown in figure 1.

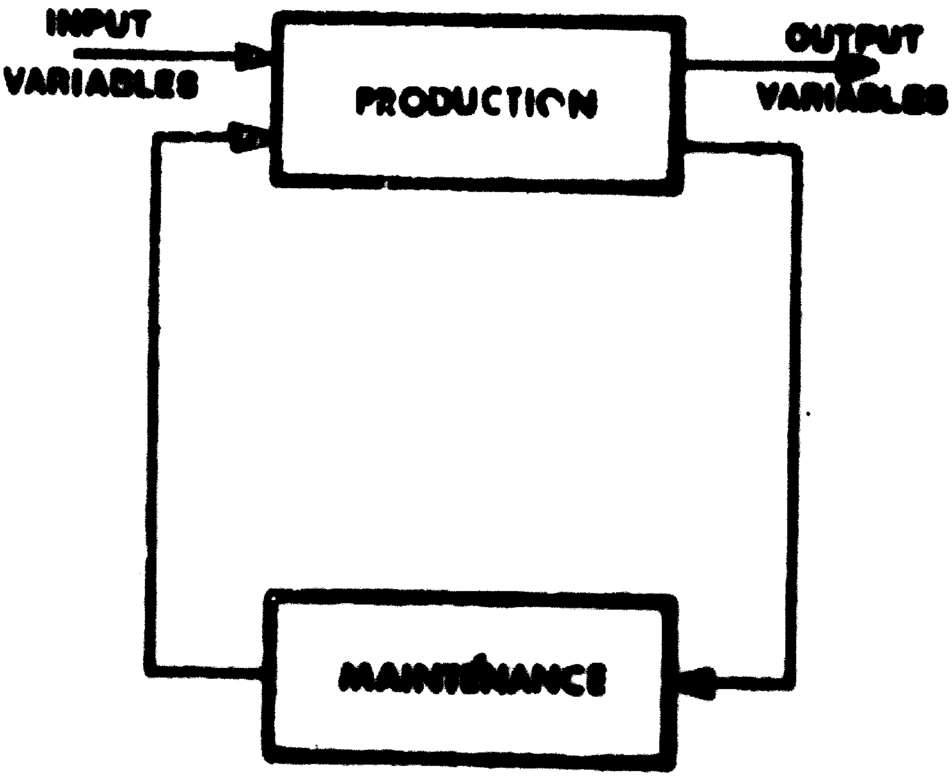


Fig. 1 RELATION BETWEEN PRODUCTION FUNCTION AND MAINTENANCE FUNCTION.

2. MAINTENANCE PLANNING AND CONTROL.

2.1. Maintenance as a closed system.

In the simplified flow diagram in fig. 2 the maintenance process is caracterised by the change in states that units to be maintained undergo, starting from the state of operational use returning to this state. To fulfil the task set by production it is necessary to control this flow of the units through the maintenance phases. By situating production in this flowdiagram as shown, the interrelated behaviour of maintenance and production can be detailed further.

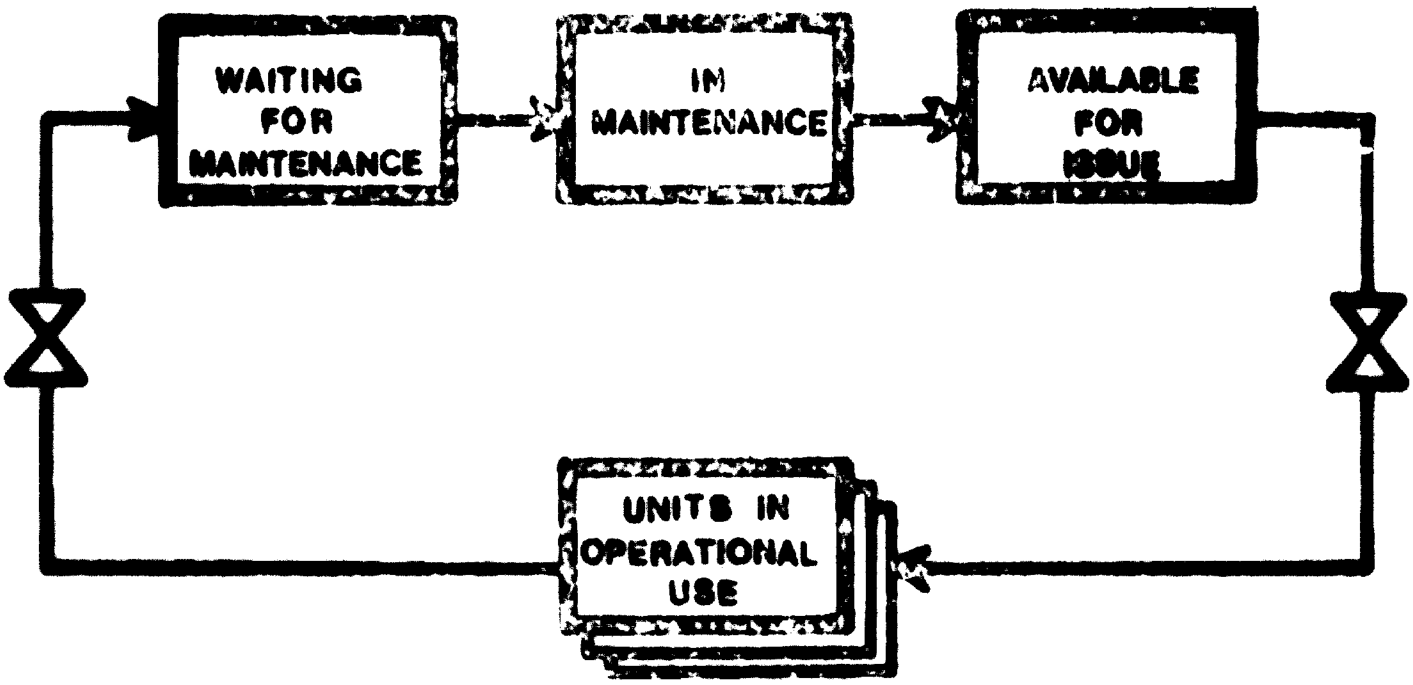


Fig. 2 MAINTENANCE AS A CLOSED SYSTEM

2.2. Controling Maintenance

Maintenance control did not develop as a matter of course. In the initial phase of a new production process all attention and effort was directed to set production going, because it is of vital importance to obtain the products. The increasing number of failures and down times exceeded acceptable limits. Neglecting long term effects, decisions were aimed purely at direct results, showing maintenance control acting like a fire brigade. Making up the seeming shortage of capacity by an increase of maintenance personal did not solve the problem. It then was understood that maintenance should be organized.

2.3. Analogies of maintenance and production.

The far-reaching similarity of maintenance activities and manufacturing activities, together with the vast amoun. of knowledge and experience of production control, demand a comparison of the production control system with the maintenance control system. This comparison is visualized in the analogous diagrams in figure 3. Analysis

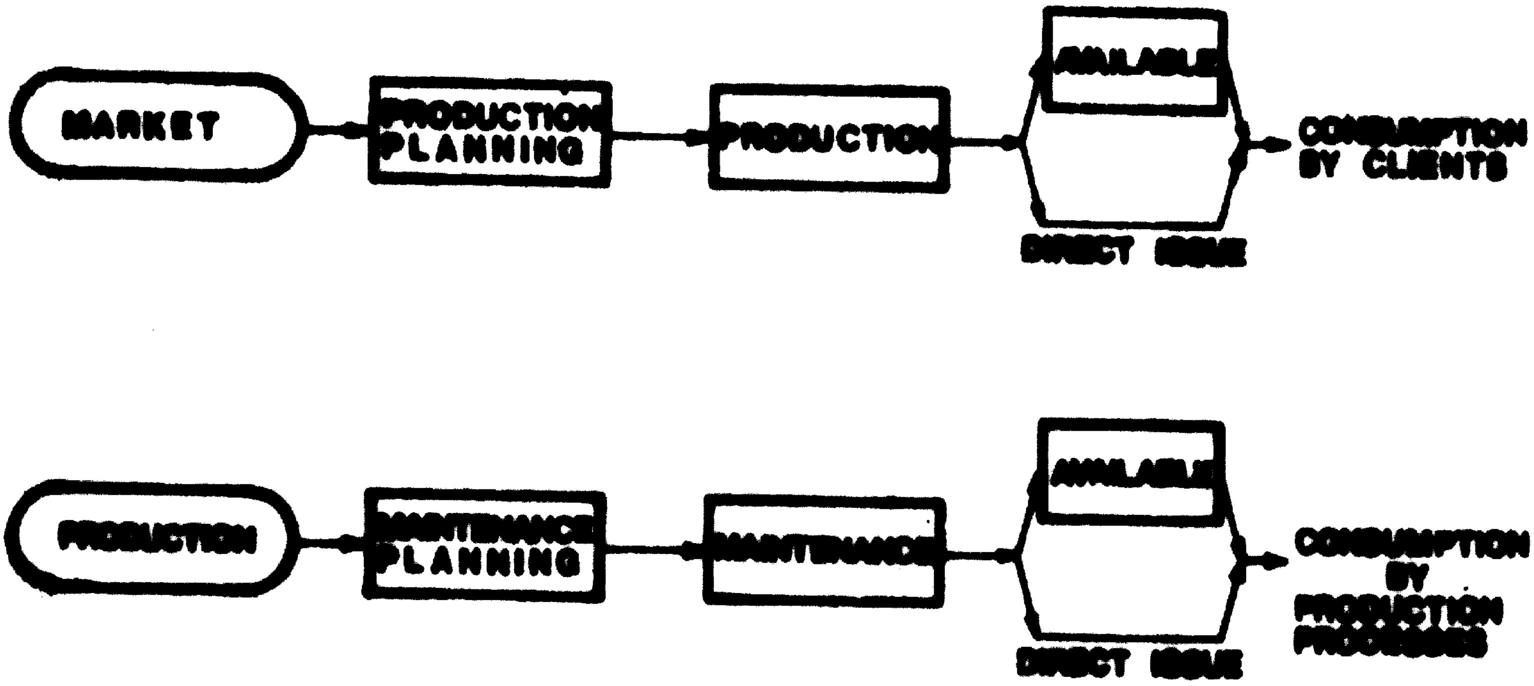


fig. 3 ANALOGOUS FLOW DIAGRAMS OF PRODUCTION AND MAINTENANCE

leads to the following major conclusions: [1]

- Long term planning, mid term planning, scheduling and process-planning as they have been developped for production control systems, can be applied in maintenance control systems.
- Study of the behaviour of the market cannot be compared with the study of the behaviour of objects to be maintained. The knowledge in this field is is still in the early stages of development.

- Relatively simpler than in production is the problem of tuning in maintenance requirements by production and the maintenance capability of the organization as all objects to be maintained -the future clients- are known beforehand and as production and maintenance can be controled within the same organization.

2.4. Maintenance Planning and Control.

2.4.1. Maintenance Planning is necessary in order to be able to decide whether the available maintenance capacity has to be adjusted or reserved and whether inventory control measures regarding maintenance parts are required. The accuracy of the forecasts that can be reached however is often insufficient because of the stochastic failure behaviour of the objects to be maintained. More regularity can be achieved by using a preventive maintenance policy, which will be treated in this paper for the case of a group of similar objects.

2.4.2. Maintenance Control.

The execution of maintenance control requires that throughput time standards are set, in order to be able to decide on the necessity of corrections of the maintenance process in execution. These standards however will have to vary from case to case, as the different individual objects do not arrive for maintenance in the same technological state. Therefore, if possible, a buffer will have to be available serving as a compensator for the varying throughput times and for the varying demand. The use of this buffer -the turnaround- will be treated later in this paper.

3. PREVENTIVE MAINTENANCE.

3.1. Definitions.

The literature shows a variety of definitions of maintenance, which is not unusual in all that concerns managerial aspects. In order to prevent ambiguity it is necessary to define maintenance as it is understood in this paper.

MAINTENANCE is the total of activities serving the purpose of retaining the production means in or restoring them to the state that is considered necessary for the fulfilment of their production function.

CORRECTIVE MAINTENANCE or REPAIR is the maintenance that has to be executed in order to restore production means from the failed state tot the operable state.

PREVENTIVE MAINTENANCE is the maintenance of production means in the non-failed state with the objective to prevent or reduce failures.

3.2 Reasons for preventive maintenance.

If a "wait and see" policy is used maintenance is executed only after the event of failure. In many a case this cannot be accepted. As far as that goes the following aspects can be distinguished:

- safety
- availability
- plannability.

3.2.1. Safety.

Quite some of today's equipment involves high energy, speeds, forces, radiation, and such-like. The design being complex and requiring operation within narrow limits, a relatively small deviation from normal operation may lead to serious accidents, endangering operators, users and others. In order to reduce this risk preventive inspections and preventive replacements are executed. It is rather difficult and often impossible to determine the trade-offs of costs and results. As in addition to that the preventive maintenance has to achieve an almost certain result, practive in this field is usually based on experience and tradition. Often realisation has to be enforced by law. Safety however is not the leading aspect in determining a preventive policy.

3.2.2. Availability. [2]

Availability is the ratio of the sum of the up times and the sum of the up- plus down times of a system, measured over a period of time. The down time share is determined by two factors: the number of failures in the period and the average time required for maintenance.

Connected to the number of failures are the quantifiable properties failure rate and reliability. Today's knowledge in this area is operations research centered, which implements that rather detailed quantitive data are needed in order to arrive at conclusions suitable for practical application in determining maintenance policies. On the other side however it highlights the necessity of a decision to be made by production concerning what is expected in this respect. The failure rate in particular is a property that is useful in the determination of a preventive policy, as the standard set can be compared with information of the actual results that can be collected relatively easy.

Connected to the average time required for maintenance is the quantifiable property maintainability. This property, like relia-

bility, is a probability concept known in operations research. A reduction of the maintenance time includes an increase of time available for production. It is assumed that a good preventive policy reduces the sum of the maintenance times for corrective plus preventive maintenance.
It is to be noticed that research in some cases showed that an unsatisfactory availability was not improved by increasing the preventive maintenance effort. [1,3].

3.2.3. Plannability.

How far better maintenance control can be achieved is primarily dependent on the quality of the maintenance forecasting process and of the regularity of the demand for maintenance. Both can be improved by introducing preventive maintenance. The preventive maintenance policy chosen implies the determination of the periodicity, thus enabling the forecasting of times at which preventive maintenance will be due. As the content of the maintenance activities to be executed will be more or less similar each time, the maintenance capacity needed each time can be forecasted too.

Regularity of the demand for maintenance will not turn up as a result of merely introducing preventive maintenance. Corrective maintenance - though expected to decrease - will still be needed at irregular times. If the preventive maintenance is spread out equally in time, the total demand for maintenance capacity will still be fluctuating strongly, as figure 4 shows. These fluctuations can be reduced by influencing the short term demand for preventive maintenance.

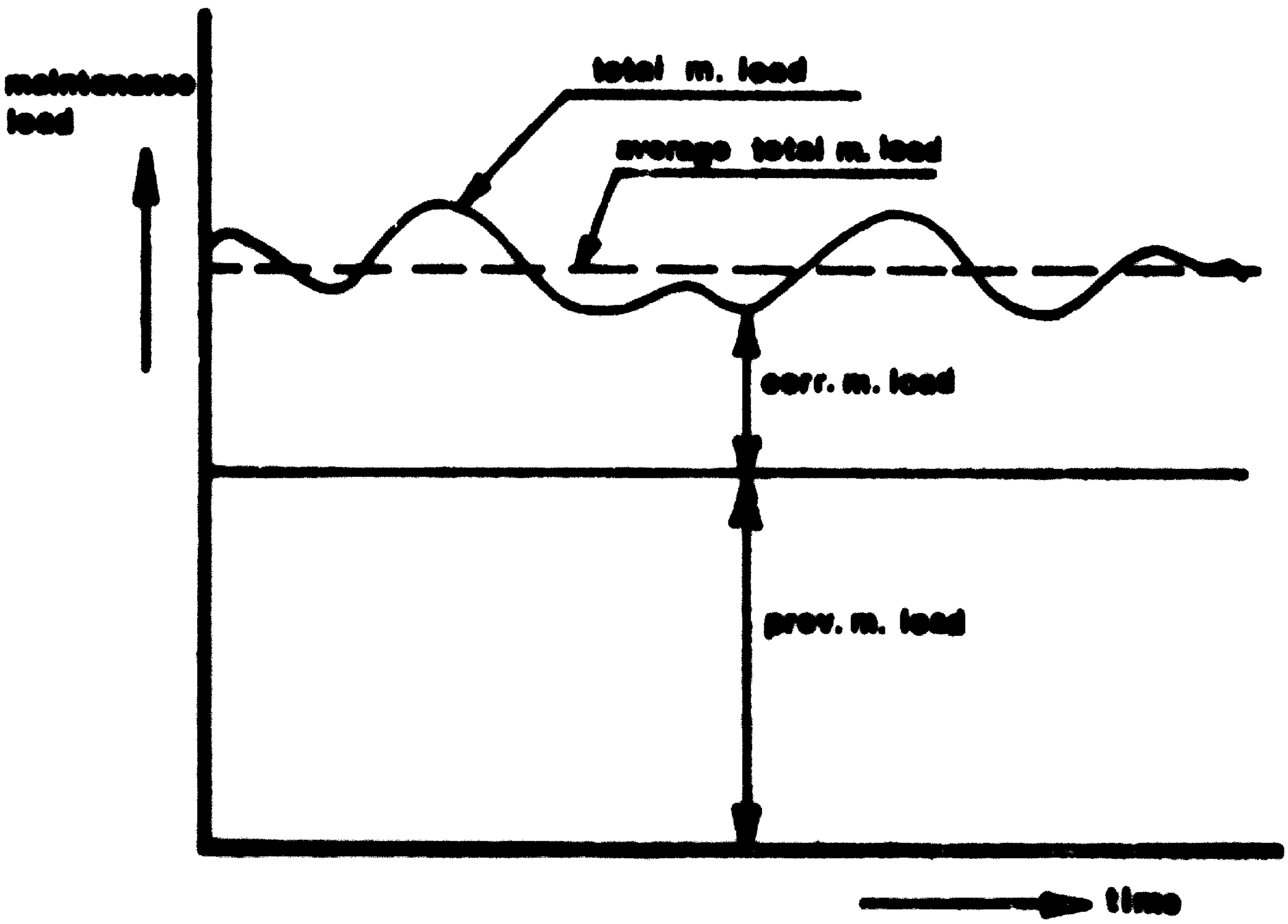


fig. 4 **TOTAL MAINTENANCE LOAD**

(planning constant prev. maintenance load)

As figure 5 illustrates maintenance demand originates from two sources: the unforeseen event of failure leading to a direct demand for corrective maintenance and the preventive policy leading to an indirect demand for maintenance. Indirect demand means that there is an amount of time play allowed as to the point of time at which maintenance must start at the latest. This opens up the possibility of fitting in preventive maintenance in the total schedule. The result - for the ideal case - is illustrated in figure 6. It is evident that the scheduling

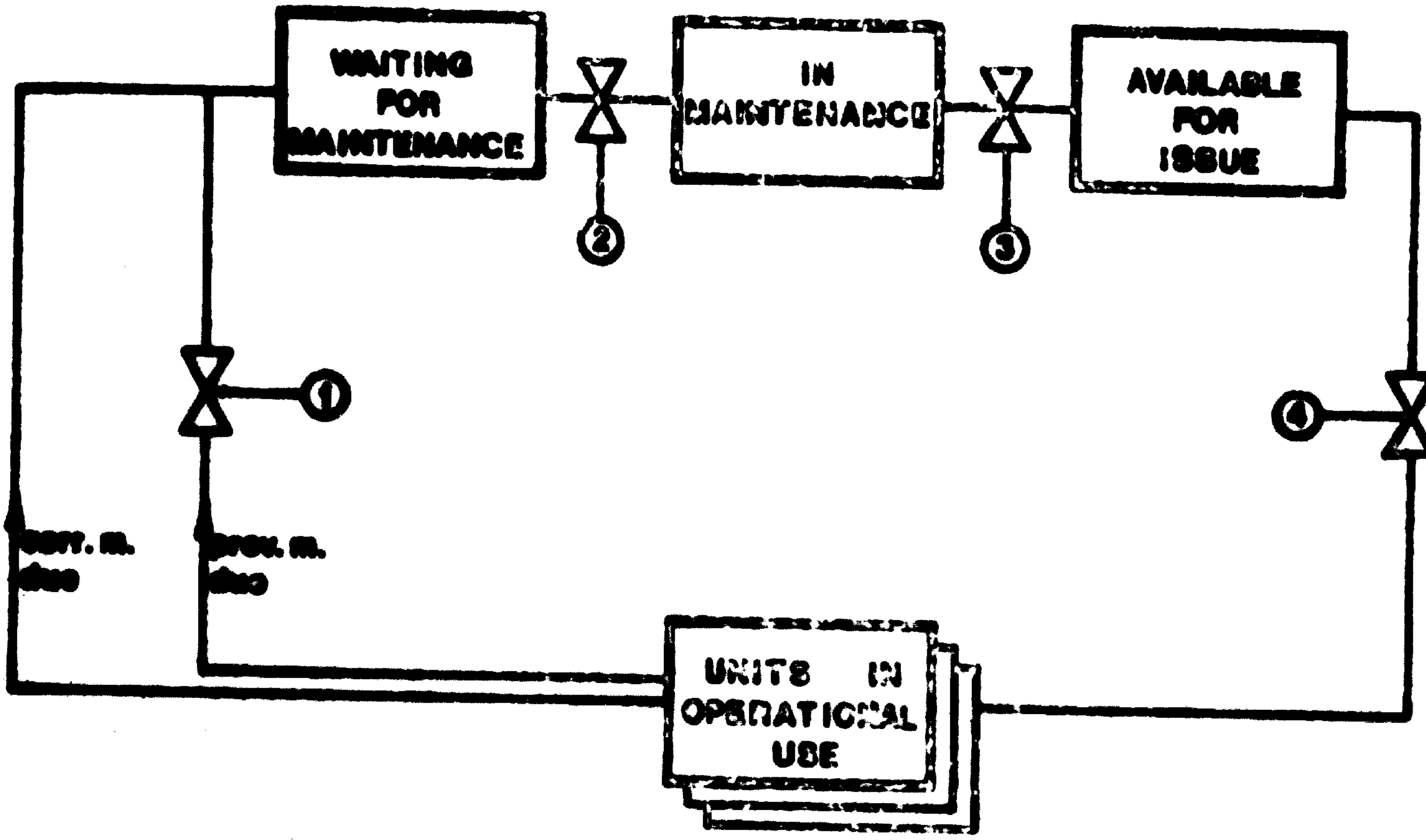


Fig. 6 FLOW CONTROL IN THE MAINTENANCE LOOP

of preventive maintenance should make maximum use of the possibility to plan preventive maintenance in the time periods that production does not need the objects requiring maintenance. As stated, the choice of a preventive maintenance policy implies the determination of the periodicity. Distinction has to be made between two cases, dependent on the relation between the operation intensity and the sensitivity for failure as a result of the operation intensity. The operation intensity is measured in some unit of consumption typical for the system concerned, e.g. mileage per unit of time for motor vehicles, flying hours per unit of time for aircraft, hours of operation per unit time for compressors, etc. If a means of production

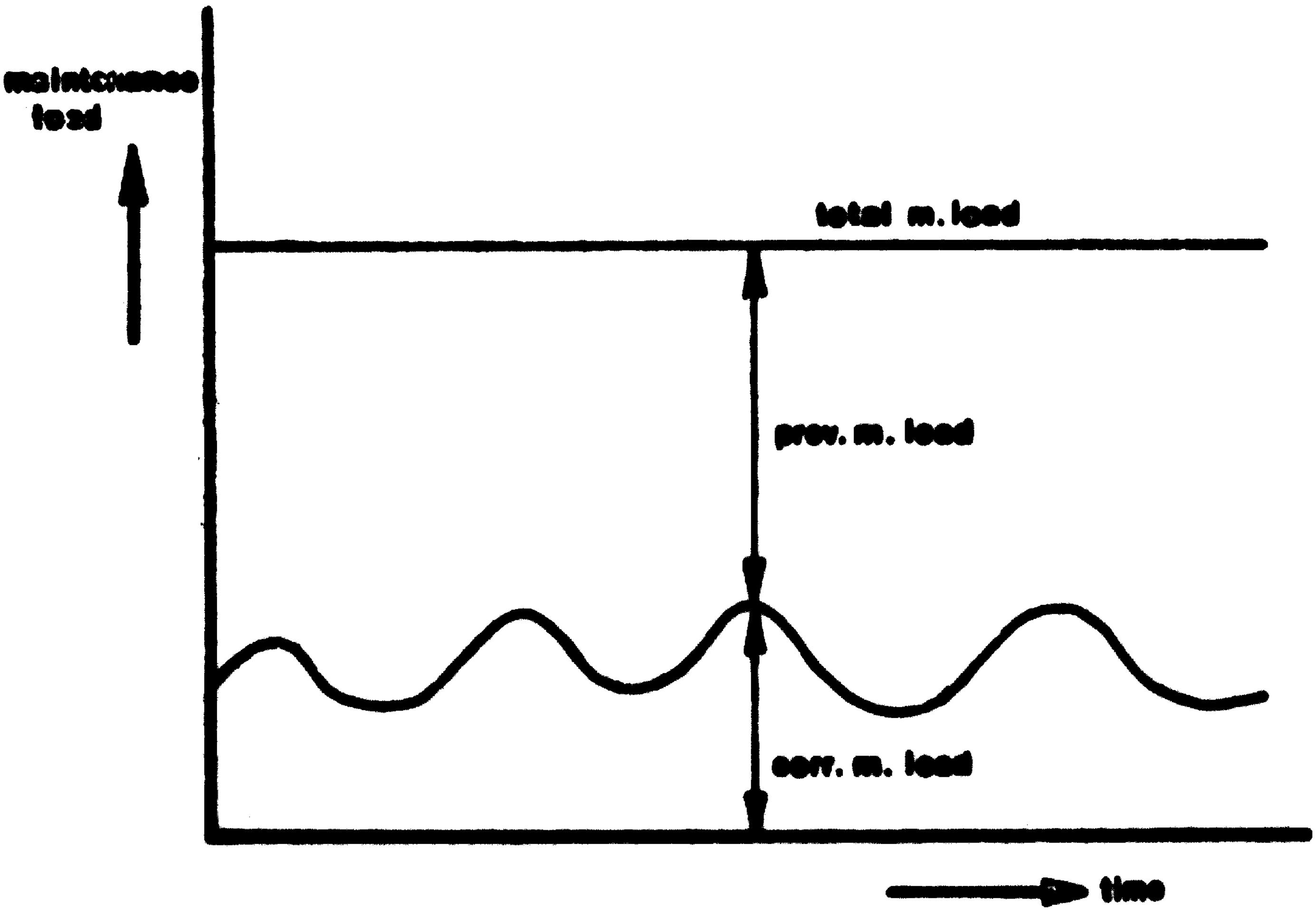


fig. 6 **TOTAL MAINTENANCE LOAD**

(planning capacity adjusted prev. m. load)

- further called "system" in this paper - has a high operation intensity the resulting failure behaviour will be connected to it. Most systems show a characteristic property, meaning that the system will fail when the characteristic property has reached a certain value, the fatal limit. By measuring the value of the characteristic property periodically - preventive policy - it is possible to forecast failure, that enables anticipation on the failure by execution of preventive maintenance before the fatal limit has been reached, even if there is an non neglectable variation in the fatal limits of systems of the same make and type. Figure 7 illustrates endurance curves one can come across [1] ; curve C cannot be regarded as characteristic since it is not sensitive enough to be suitable for forecasting the time of failure of the individual systems. Curve A is typical for e.g. the wear of tyres of motorvehicles; curve B is typical for e.g. the oil consumption or for the oil pressure of combustion engines. If a system has a low operation intensity

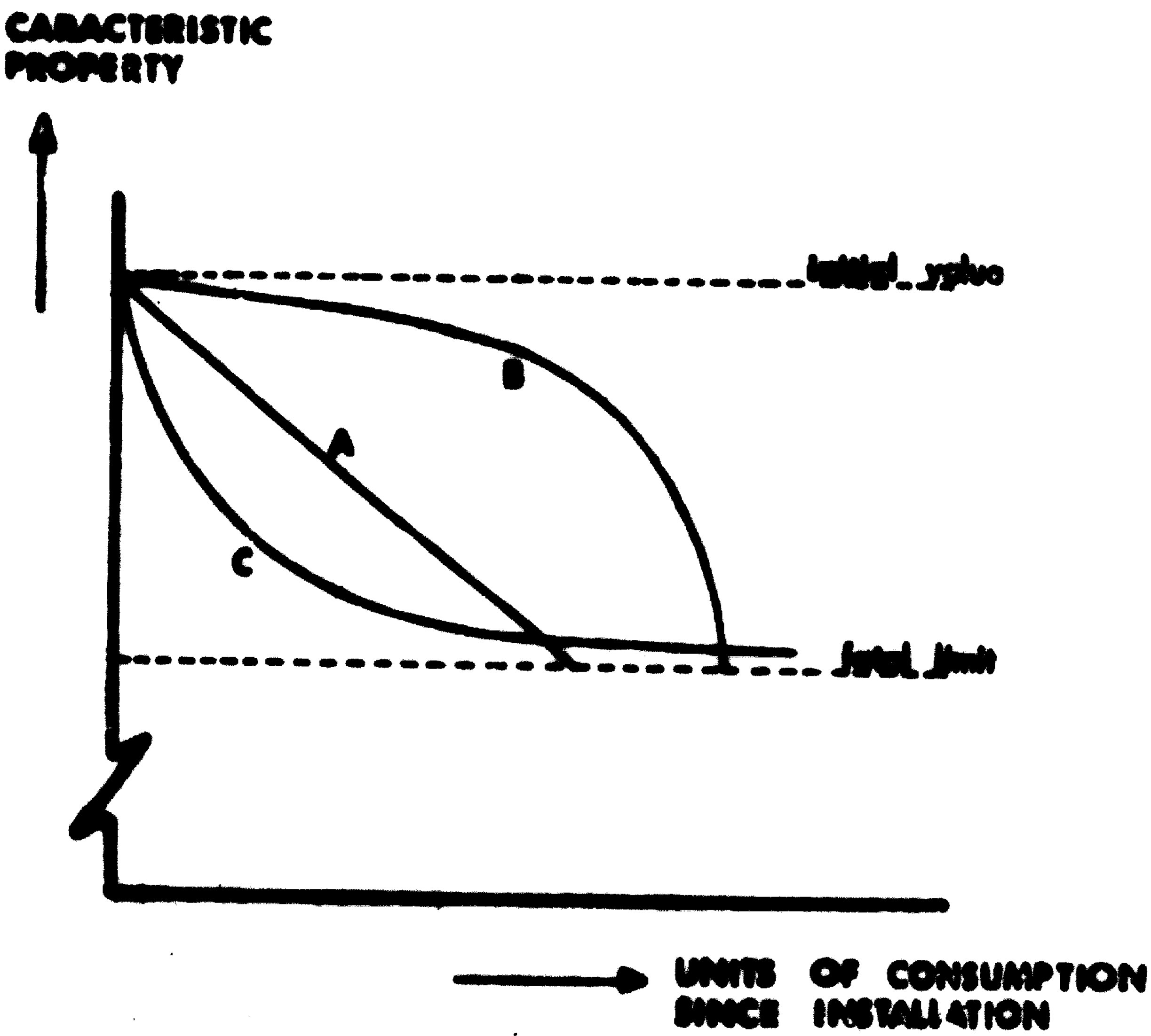


Fig. 7 ENDURANCE CURVES

the resulting failure behaviour will not be connected to it. The symptom observed is wear and tear, corrosion and such-like. Typical in this case is the fading away of properties which are not directly connected to the proper operation of the system, but nevertheless cannot be neglected because failure can be expected before the event of passing the fatal limit of a characteristic property. In this case a preventive policy requires the more or less arbitrary choice of the interval for preventive maintenance. In aviation maintenance policies of this type are known as "IRAN" (Inspect and Repair As Necessary) or as "TARAN" (Test and Repair As Necessary). Forecasting is possible in this case because the intervals are known. [4]

The foregoing shows that a preventive maintenance increases the plannability of maintenance because the arrival of systems due for maintenance can be forecasted, together with some play as for the definite decision of the moment maintenance has to begin.

4. GROUP MAINTENANCE.

4.1. Introduction.

Studying alternative maintenance policies and the methodology of selection of a policy in a concrete situation leads to distinguishing between the following types of objects by the using organization [1] :

- large, singular systems (such as the energy supply system in a factory, a radar installation, a paper manufacturing machine, etc.)
- groups of identical, rather simple and cheap objects (such as bulbs)
- groups of identical rather complex and expensive objects (such as motorvehicles, aeroplanes, lathes, etc.).

The group treated in this paper is the category mentioned latest, the group of identical, rather complex and expensive objects.

4.2. Availability and turnaround.

Availability - in correspondence with the generally accepted concept - is a property of a system. That implies that we have to think of one singular specimen though the availability behaviour may have been derived from the behaviour of a group of identical systems by statistical analysis. But even in that case the conclusions representative for the group will be formulated in a form that enables application in cases concerning one individual specimen. In accordance with this concept para 3.2.2. stated that improvement of the availability of a system has to be found by seeking for ways that lead to reduction of either the failure rate, or of the time needed for maintenance. If the result is unsatisfactory from the point of vieuw of production the outlook seems to be rather pessimistic.
This however, does not hold true, in the case that a group of similar objects in one organization is concerned. The ultimate objective of maintenance is to serve production as far as the requirements of production go. These requirements concern first of all uninterrupted operation during production periods. In the second place production expects restoration of the production capability within short time in the case of breakdown, and in the end, as a matter of course, all this should be accomplished under optimal cost conditions.

In the case of a group of similar objects the requirement of production can be expressed in the number available instead of in terms of availability of one specimen. In addition to this number needed for operation there will be a number which is somewhere in the maintenance process. It is necessary, then, to have at one's disposal an additional number, which is called the turnaround.

It is evident that as far as the reliability and the maintainability cannot be improved, a better availability of a group can also be achieved by an increase of the total number.

4.3. Forecasting demand.

An essential information needed for the planning of maintenance is the expected number arriving for maintenance. We can compute that number as an average from the operation intensity, the prevention maintenance period in units of consumption and the number required by production. We will do that in two steps.

Step one converts the figures in terms of units of consumption into figures of units of time, for one specimen of the group, according to the formula:

$$PMPT = \frac{PMPC}{OI} \quad (1)$$

in which

OI = Operation Intensity

PMPC = Preventive Maintenance Period in units of Consumption

PMPT = Prevention Maintenance Period in units of Time

Example:

OI = 600 hrs per year

PMPC = 1800 hrs per overhaul

then

$$PMPT = \frac{1800}{600} = 3 \text{ years between overhauls.}$$

Step two concerns the computation of the expected numbers of arrivals, according to the formula:

$$NAPM = \frac{NRP}{PMPT} \quad (2)$$

in which

NRP = Number Required by Production

NAPM = Number of Arrivals for Prevention Maintenance

Example (continued) :

PMPT = 3 years between overhauls
NRP = 21 piece
then

$$NAPM = \frac{21}{3} = 7 \text{ overhauls per year.}$$

As this number contains preventive maintenance only, there will be a chance of incidental additional demand for corrective maintenance calling for the same maintenance capacity. This additional demand must be estimated on the basis of experience and judgement. Because the maintenance organization concerned usually handles a diversity of types, incidental underestimation of the capacity needed for one type will compensate incidental overestimation for other types.

4.4. Computation of the turnaround.

As was explained in para 4.2. the maintenance process requires a turnaround. Leaving out fluctuations in operation intensity, in maintenance throughput times and such-like, we can distinguish two causes for the arrivals for maintenance, namely the preventive policy and the failures requiring corrective maintenance of the same level. Therefore the turnaround is computed in two steps.

Step one regards the turnaround due to preventive maintenance only. It is computed according to the formula:

$$TPM = NAPM \times MTT \quad (3)$$

in which

MTT = Maintenance Throughput Time

TPM = Turnaround for Preventive Maintenance.

Example (continued) :

NAPM = 7 overhauls per year
MTT = 2 months = 1/6 year
then
TPM = 7 x 1/6 = 1 1/6 piece.

This number, 1 1/6 piece, is not very practical for several reasons. All figures used in the computations are averages and do not allow for fluctuations leading to higher requirements. Neither does the preventive turnaround contain any demand for corrective maintenance due to incidents such as unexpected breakdown. Finally it is not possible to procure 1 1/6 system, the number has to be a discreet number. This leads us to

step two: the determination of the TT, the Total Turnaround. From a theoritical point of vieuw it is possible to compute the TT by statistical analysis with methods derived from operations research. In general this is not very well possible because of the load of information that has to be processed, due to the sophisticated level of the mathematical models concerned. Apart from that, the decision to be made is an unique decision, which requires thoughtful consideration by management. The considerations that will have to lead to the final decision: "how many pieces will be procured as total turnaround in addition to the number required by production?" will take into account the following aspects:

- The mission effect of the system concerned; mission effect explicitly states the penalty for the organization of having less in operation [4,5]

- seasonal trends in the use, as for periods in the year that allow for more pieces in maintenance, than the Total Turnaround, because less pieces are required by production than the normally required number
- price of one piece
- re-procurement possibility, especially in the case of the impossibility to buy an additional piece in the future if the estimates made now might appear too optimistic later.

The final determination of the total turnaround, then, is made by a decision process that goes along these lines, assisted by the quantitative data supplied by the computations mentioned before.

4.5. Determination of the input variables.

The computation in formulas (1), (2) and (3) were based upon the input variables:

- OI, Operation Intensity
- PMPC, Preventive Maintenance Period in units of Consumption
- NRP, Number Required by Production
- MTT, Maintenance Throughput Time.

OI. If the system concerned is new, the Operation Intensity has to be estimated on the basis of experience with comparable systems or from the production plans. It should be noticed that the operation intensity is the average for the group, found by considering the number required by production, so leaving out the number meant to serve as turnaround.

PMPC. The Preventive Maintenance Period in units of Consumption has to be determined on the basis of advice of the manufacturer, combined with own experience and expectations, in particular in regard of the way of operation and of the influence of the environment typical for the organisation concerned.

NRP. The Number Required by Production is to be determined in the way appropriate for the system concerned; this - of course - is not a maintenance task.

MTT. The Maintenance Throughput Time has to be estimated as an average on the basis of experience with comparable systems. Due to the rounding off of the Turnaround for Preventive Maintenance to the Total Turnaround the initial Maintenance Throughput Time has received more play. It is of importance to compute this play and announce it as such, in order to prevent the gradual increasing of the intended throughput times to a level where the additional play is not available any more as the buffer for the fluctuations. The computation of the play goes as follows (compare with formula (3)):

$$TT = NAPM\ (MTT + PMTT)$$

in which

TT = Total Turnaround

NAPM = Number of Arrivals for Preventive Maintenance

MTT = Maintenance Throughput Time

PMTT = Play in addition to the Maintenance Throughput Time

To find PMTT we rewrite the formula as follows:

$$PMTT = \frac{TT}{NAPM} - MTT \qquad (4)$$

Example (continued):

TT = 2 piece (assumed that the considerations meant in para 4.4, step two, lead to the decision to raise the Turnaround for Preventive Maintenance, TPM, from 1 1/6 to a Total Turnaround, TT, of 2 pieces)

NAPM = 7 overhauls per year

MTT = 1/6 year

then

$$PMTT = \frac{2}{7} - \frac{1}{6} = \frac{5}{42} \text{ year, which}$$

comes to, roughly, 1½ month. The significance of this figure is to be judged by comparing it with the value of the MTT, being 1/6 year or 2 months. This shows the great impact on throughput time play as a result of a small difference in the turnaround.

It is evident that an organization introducing a computational approach such as the method described in this paper cannot work along the lines indicated. In that case the computations will serve as a check on the possibility of maintaining a system without affecting the number required by production.
In some cases that may lead to the decision to require a maximum throughput time for certain systems, in order to achieve that goal.

4.6. IRAN or TARAN.

The foregoing paragraphs of this chapter were based on the assumtion that the Operation Intensity lead to a preventive policy having the nature of an overhaul, due to wear as a result of operating the system concerned. In the case that an IRAN or TARAN policy is used formula (1) does not apply. Instead of computing the Preventive Maintenance Period in units of Time its value is determined directly on the basis of practical considerations. The other computations can then be applied in the same way.

5. INTRODUCTION PHASE.

5.1. Arrival Pattern. In the foregoing paragraph it was supposed - though not stated - that a group was in use and, hence, showed a pattern of arrival that was more or less equally spread. This however is not so in the initial phase of the introduction of a group of systems of a new make and type. If we assume that we procure a group, all at one time and put the group into operation simultanously, we will have to face very serious fluctuations in the arrivals for maintenance after a while. The symptom is illustrated in figure 8. It learns that we will find an enormous increase in arrivals for maintenance after some time, having a peak value after a time period, equal to the Preventive Maintenance Period in Units of Time (PMPT). We see the repetition of this peak again and again after the same intervals, though the height of the peak decreases gradually because the pieces will not be due for maintenance all at the same time.

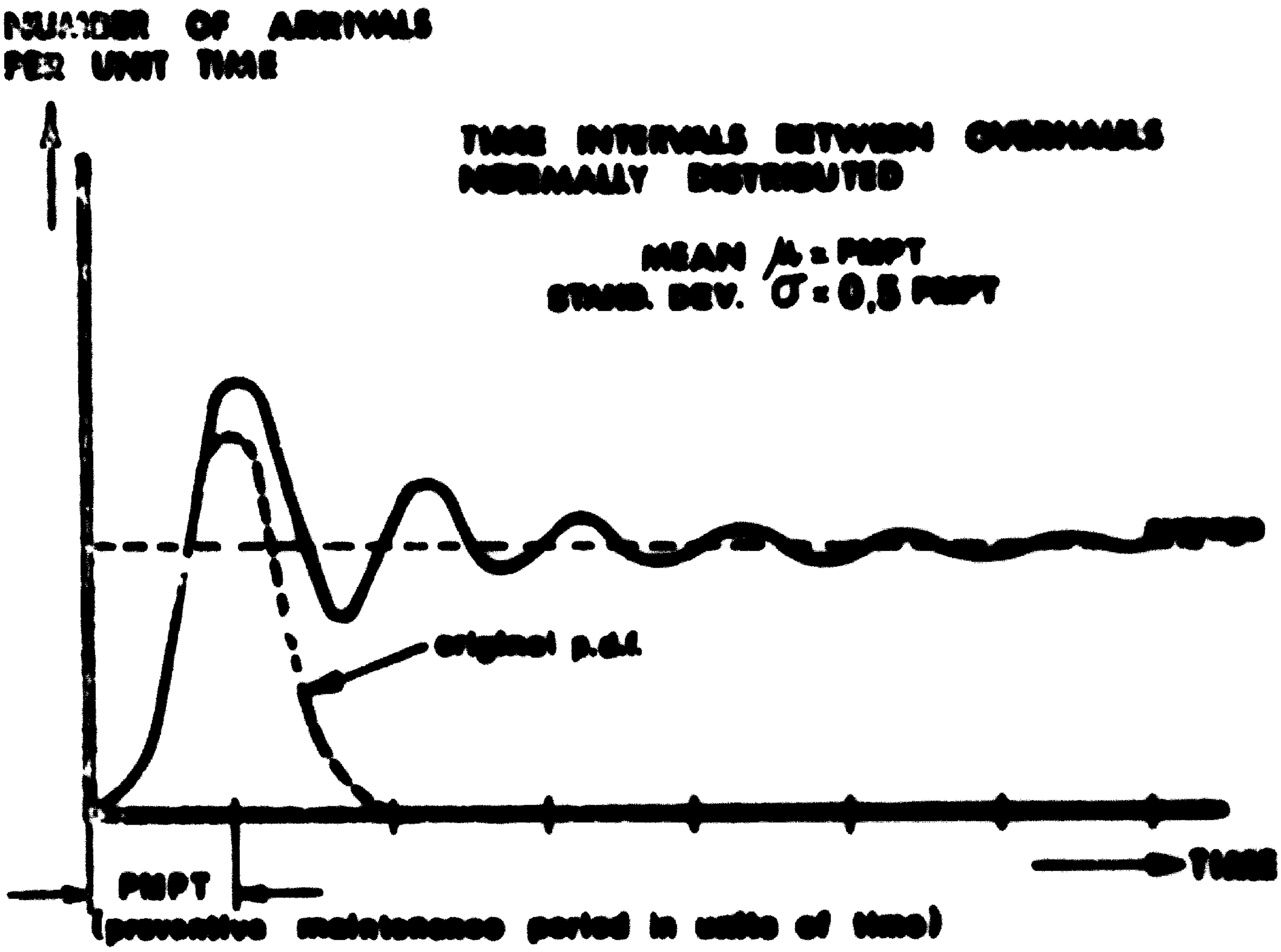


fig. 8 ARRIVAL PATTERN FOR OVERHAUL.

5.2. **Smoothing the arrivals.**

If we do not use a preventive policy the same accumulation of arrivals will appear. It is evident that it is necessary to anticipate on the first peak. This is possible by taking in

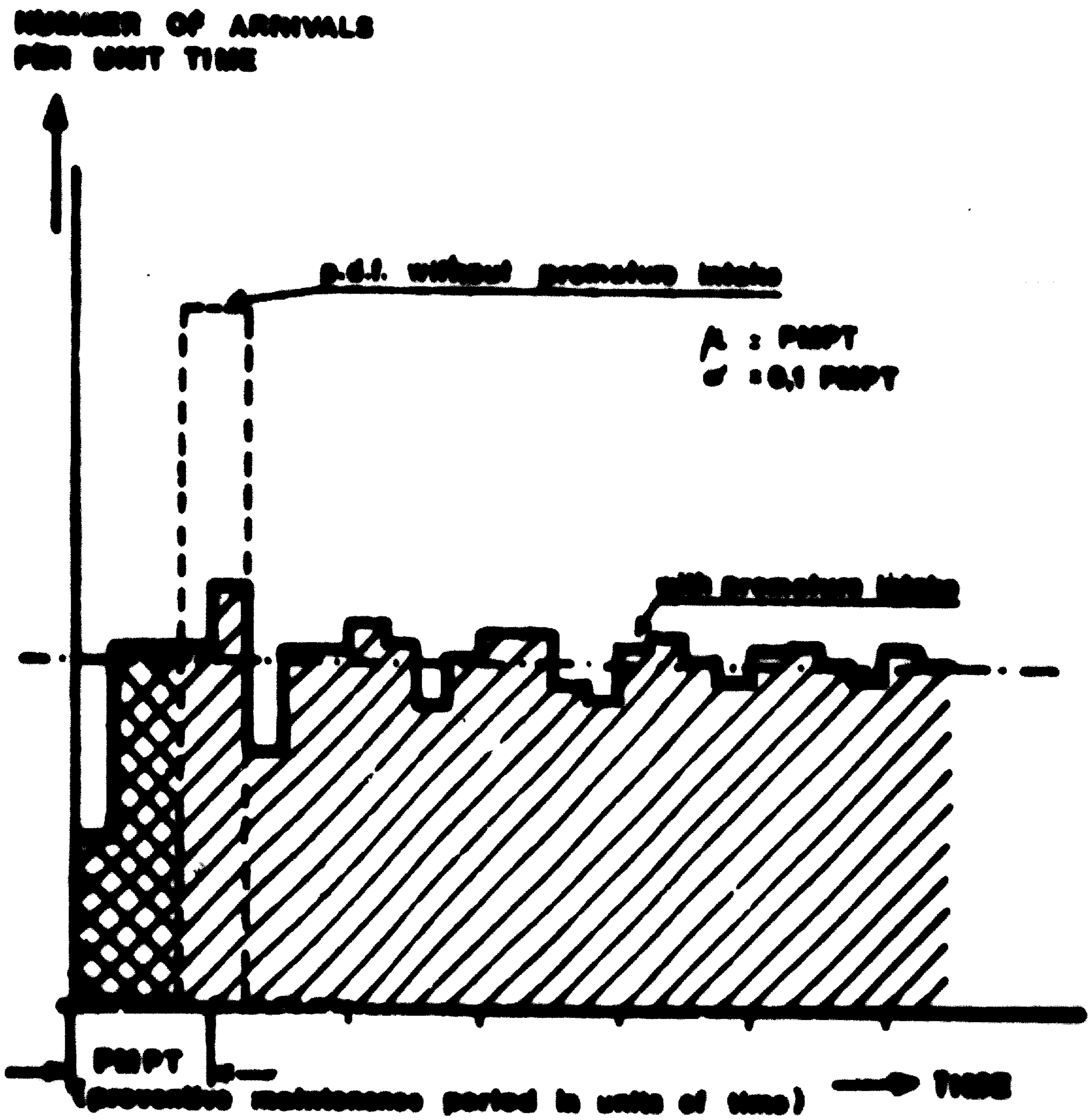
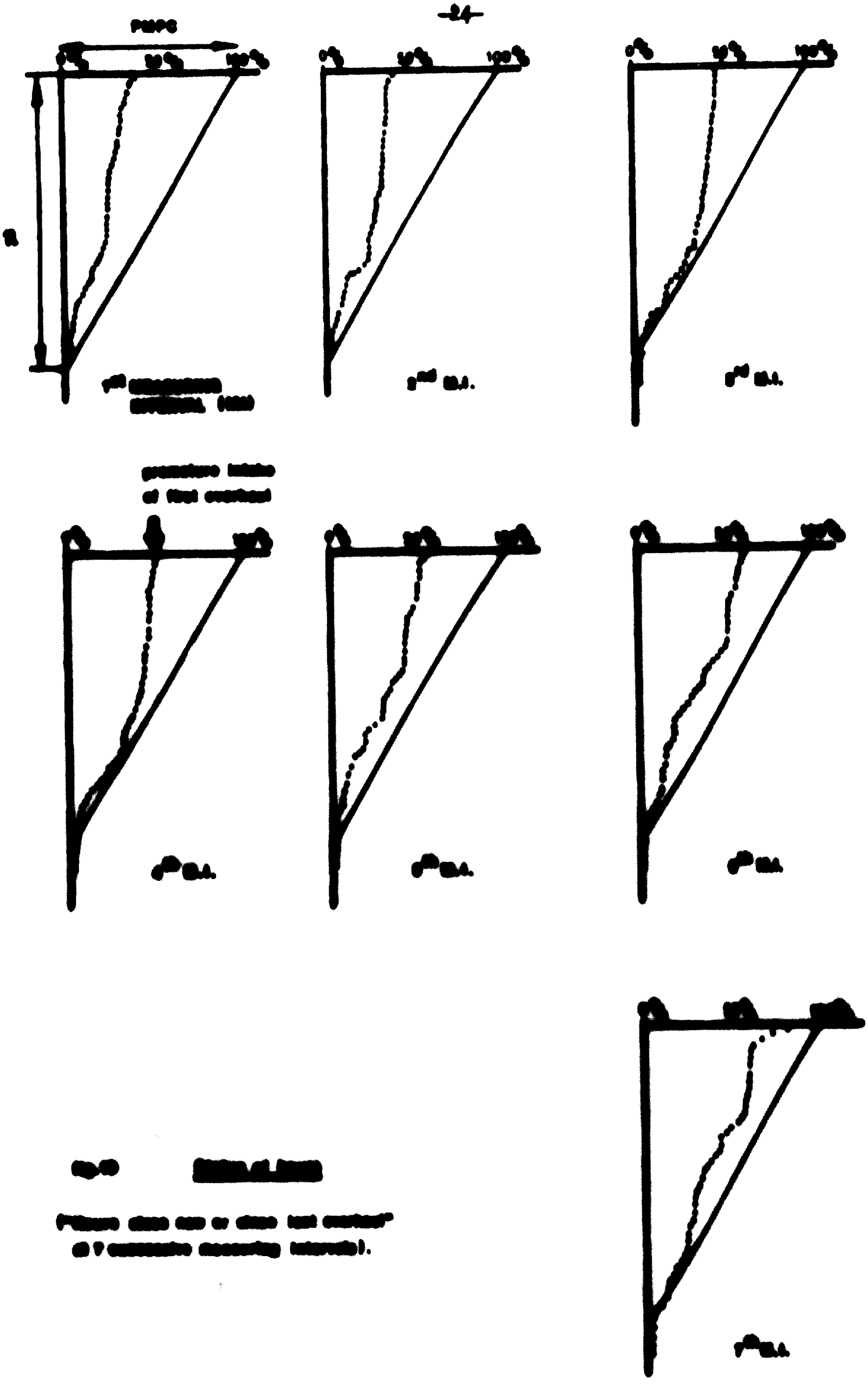


Fig. 9 [illegible]


0%
50%
100%
2nd M.I.
3rd M.I.
4th M.I.
5th M.I.
6th M.I.
7th M.I.

[illegible]

[illegible]

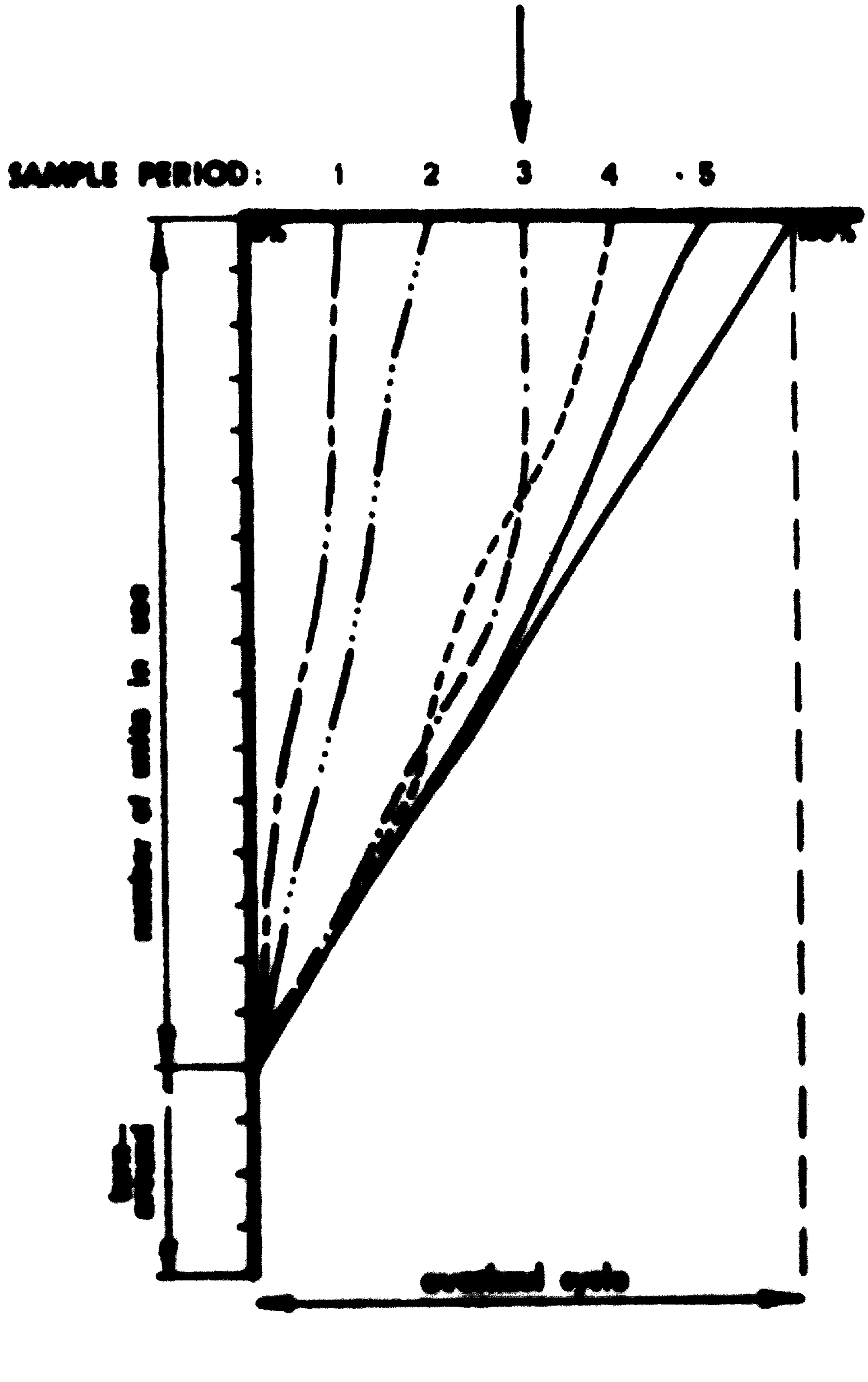


Fig. 11 5 SUCCESSIVE NDO-STATUS SAMPLES WITH PREMATURE OVERHAUL START AFTER SAMPLE AT ULTIMATE OF PERIOD 3 (REAL CASE)

MEGU

CONTROLE CYCLUS...

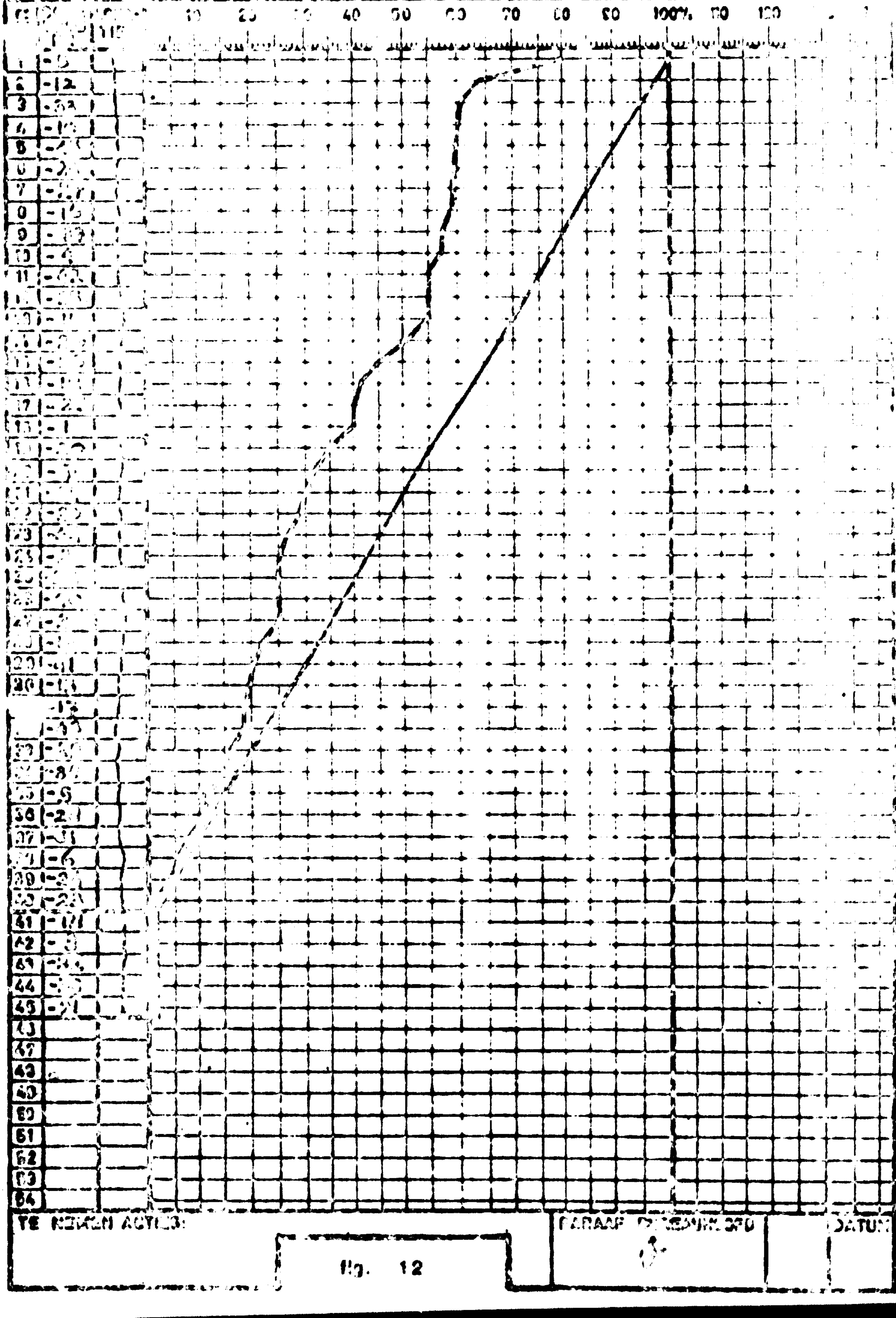
CATEGORIE

ONDERHOUD CONCEPTIE REV.

RAPPORT...

KWARTAAL				1/2 JAAR		
1	2	3	4	1	2	1985

THEOR. REV CYCLUS 4000 DRU | PRAKT REV CYCLUS 4000 DRU 100% | 100%



TE NEMEN ACTIES:

PARAAF

DATUM

fig. 12

the first pieces for preventive maintenance at an earlier time than prescribed by the Preventive Maintenance Period. The result of such a premature intake is illustrated in figure 9. As to production it means that the number of pieces out of operation for maintenance will not exceed the number reckoned with as turnaround.

Though these considerations indicate what should be done, they don't show how this process can be controled. Collection of the actual data in order to compute the probability functions underlying figures 8 and 9 is rather complicated, if possible at all. There is, however, a rather simple controling aid in the form of a graph. If we measure the consumption since new or since overhauled at fixed intervals, and make up a graph by plotting the status of each piece ranking them in sequence of the consumption figures. We will find graphs such as illustrated in figure 10. The staggerline is the ideal case of regular arrivals. As far as the plotted line does not incline towards the staggerline, natural distribution of consumption over the pieces is insufficient. The decision to start premature overhauls is made by means of this graphic picture. Figure 11 shows the results of superposition of the periodic measurements in one picture. The form used for this purpose in a real application is shown in figure 12.

6. <u>CONTROLING MAINTENANCE EXECUTION</u>.

6.1. <u>Intake</u> [4,6]

After the passing of the first intake period described in para 5.2 the stable phase begins. The objective in this phase is: guarantee to production that the number production requires will be available. The objective of maintenance control, then, is to see to it that the number of pieces waiting for maintenance or being in maintenance will not exceed the Total Turnaround. This will have to be achieved by anticipating on short term fluctuations by feed forward control. Here again the status graph is used. If we find a status as presented in figure 13 we can fairly well assume that the arrivals in the near future

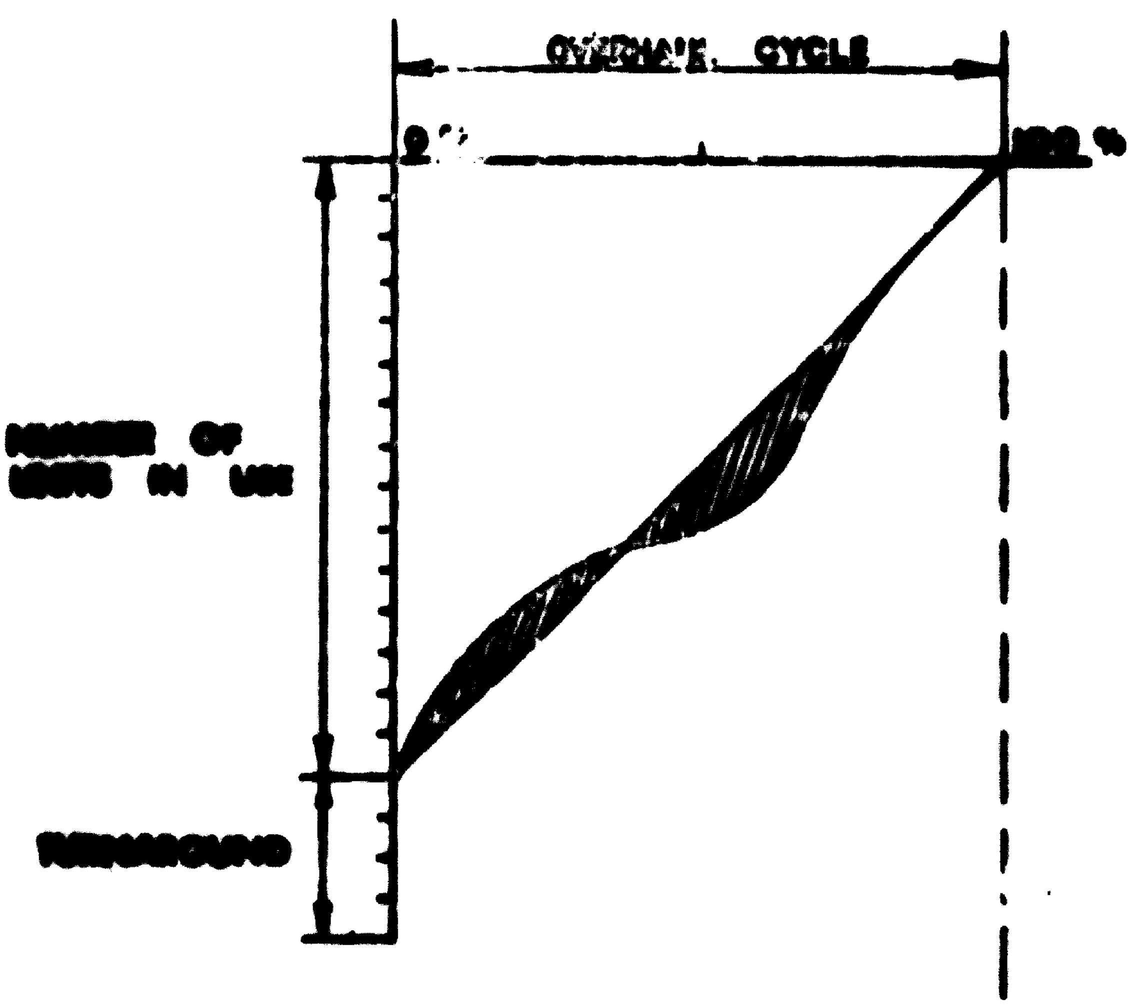


Fig. 13 EXAMPLE OF NBO-STATUS.

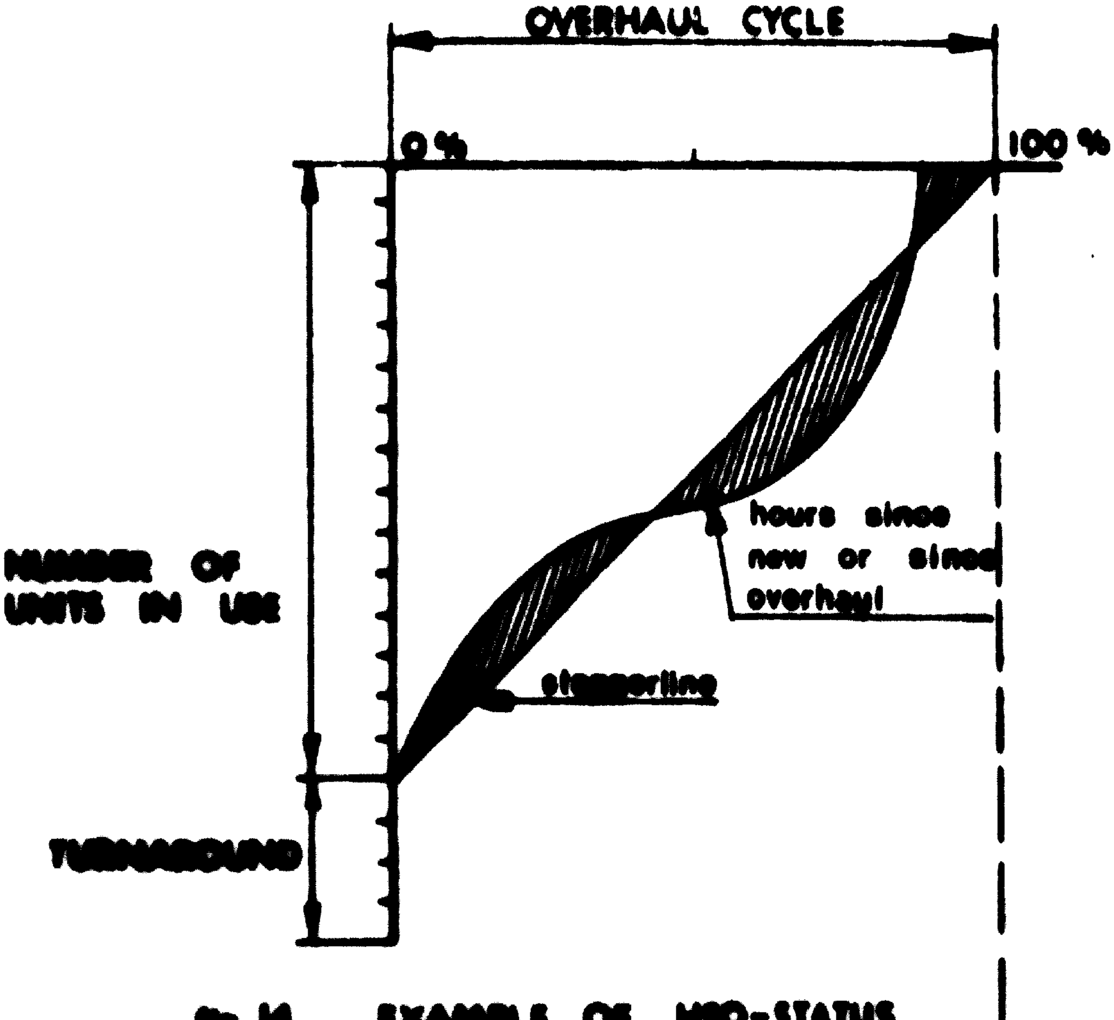


Fig. 14 EXAMPLE OF HSO-STATUS.

will be regular. If however the status found shows a picture as visualised in figure 14, it is fairly certain that the number of arrivals will be lower than normal in the near future, but will be higher than normal shortly afterwards. This can be prevented by taken in pieces with the highest hourstatus earlier than normal. Instead it also may be possible to influence the individual Operation Intensity by employing the stragglers for more intensive operation jobs in the next future.

6.2. Priority.

The Maintenance Organization needs two fundamental priority rules. The first concerns the intake in the maintenance process (valves no. 1 and no. 2 in figure 5), the second concerns the priority of the diversity of types being in the maintenance process, determining the time of becoming available (valve no. 3 in figure 5). Apart from secondary factors to be reckoned with the priority should in both cases be based first of all on the ultimate objective, serving production. This can be found relatively easy in using the state of the turnaround. Types having no piece available for issue will have priority over types having pieces available for issue; types having exceeded the total turnaround will have priority over others.

6.3. Corrections by feedback.

The first experience usable for correction for the assumed and predicted values can be found in the premature overhauls. As the turnaround is available at the time of overhaul anyhow, taking in the first can be done with the additional objective to study the characteristic properties of the system. That will enable to confirm or to correct the Preventive Maintenance Period in units of Consumption. Besides the bill of Material can be made up in order to pre-order material for the overhauls to come and a more accurate forecast of the maintenance capacity can be determined.

During the normal operational life of a system the values assumed or predicted initially, will have to be adjusted. As a matter of fact that will have to be done immediately after any serious change in e.g.

Operation Intensity or in the Number Required by Production. This however is not sufficient because there are gradual changes that will be noticed too late. In order to prevent that, a periodic check on the essential values has to be executed. In the case where this system is applied - The Royal Netherlands Air Force - there are two checks. One is based on the Operation Intensity, the other is based on the experience of the organization executing the maintenance.

The Operation Intensity is measured periodically. If the Operation Intensity differs more than 10% of last value, the operation Intensity and all computations concerned are changed according to the new value. As a matter of fact the "new" Operation Intensity is not merely used as such. The value expected in the future is smoothed by means of a relatively simple smoothing formula known as "single exponential smoothing" [7] . The measuring is based on the reporting of the hours accumulated since new or since the last overhaul, of all systems in the group. As the same figure is known from the foregoing period, it is very simple to compute the hours operated during the period since the foregoing reporting. The reporting period is determined by the rule of the thumb that the measuring period should be somewhere between one tenth and one sixth of the total period concerned, in this case the Preventive Maintenance Period in units of Time. For practical purposes the reporting period is rounded off to quarters of a year, half years or years.

As quite some systems may show a seasonal trend, the Operation Intensity should be computed as a moving average over the past period of 12 months. The planning based on it can be regarded as rolling planning.

The organisation executing the maintenance gains experience by maintaining the systems. This may lead to an increase or decrease in the Preventive Maintenance Period in units of Consumption. Also the Maintenance Throughput Time may have to be changed. In order to obtain the advice of the organization executing the maintenance a meeting should be held periodically. In the case where this system is applied this meeting is held once a year for each make and type.

7. **CONCLUSIONS.**

1. Systems in operation in groups generally require a preventive maintenance policy in order to be able to plan maintenance.

2. The arrivals for Maintenance can be forecasted on the basis of the Operation Intensity, or on the basis of age if the Operation Intensity is low.

3. If the Number Needed for Operation is not to be affected by Maintenance an additional number, the turnaround, will have to be procured.

4. If a new group is put to operation more or less simultaneously the first overhauls will have to be executed prematurely in order to prevent the number in Maintenance exceeding the turnaround.

5. Forecasting arrivals on short term can be done by means of a graphical representation of the hours-status.

6. In order to adjust assumed and computed values the primary variables should me measured periodically and experiences should be discussed periodically.

LIST OF ILLUSTRATIONS

LITERATURE

1. GERAERDS, W.M.J., "Towards a Theory of Maintenance". Paper presented at the NATO-Conference on Problems in the Organisation and Introduction of Large Logistic Support Systems, Luxembourg 19-22 May 1970, 58 pp.

2. GOLDMAN, A.S. and SLATTERY, T.B., "Maintainability: a Major element of system effectiveness". John Wiley & Sons, New York, 1964, 282 pp.

3. HUSSEY, P.A. and THOMAS, S.G., "Are scheduled component overhauls necessary". SAE-National Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, Oct. 5-9, 1964. 8 pp.

4. GERAERDS, W.M.J. "LTP-beheersingssysteem voor motorisch aangedreven gronduitrusting bij de Koninklijke Luchtmacht".
Literatuuroverzicht TDCK, 11, 1967, nr. OR 97, pp. 175-196 en 11, 1967, nr. OR 99, pp. 247-270.

5. KARR, H.W. "A method of estimating spare-part essentiality". Rand paper P-1064. 17 April 1957.

6. KAUFMANN, A. "Methodes et modèles de la recherche operationelle", Tome 1, Dunod, Paris, 1962. 534 pp.

7. BROWN, R.G., "Smoothing, forecasting and prediction of discrete time series". Prentice-Hall, Inc., Englewood Cliffs, N.Y. 1963. 468 pp.

7. 10. 71