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PRACTICAL ASPECTS OF MAINTAINABILITY

by

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Organised in co-operation with the Government of Japan and the Japan Management Association (JMA).

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Introduction.

"Maintainability is one of the parts of the Availability concept. One of the most used definitions is

> Maintainability.
> The combined qualitative and quantitative characteristics of equipment design and installation which enable the accomplishment of operational objectives with minimum consumption of maintenance resources, including manpower, personal skill, test equipment, tools and aids, technical documentation and spare parts, under operation environmental conditions in which unscheduled and scheduled maintenance will be performed.

The theoretical aspects om Maintainability are handled in a paper by dr. Jenney, the Availability concept in another paper by mr. Ullman.

This paper will mainly handle the Maintainability concept from the maintenance engineers' point of view. As the word Maintainability until quite recently was used by people engaged in design, development and evaluation of defence weapon systems only, the M concept might be unknown to many maintenance engineers in industry and other organisations dealing with commercial and civil problems. With more than 30 years of practical experience as maintenance engineer and maintenance manager within industry the author is quite convinced that the full understanding of the Maintainability concept and other related subjects will greatly improve the ability of the practical maintenance man to understand situations and conditions he has met and will meet in the future. He will also be competent to participate in the procurement of new equipment, with higher security of function (less failures) and higher maintainability (shorter time to repair), by utilising recorded experience data from existing equipment. The maintenance manager will be able to design better maintenance systems, including skilled manpower, suitable workshop and tools, technical documentation and a well controlled spare part supply, thereby meeting the demand set by the objectives for a good maintenance function:

> "At a specified production quantity and product quality minimize the cost for the production equipment and maintenance thereof"

MAINTAINABILITY VERSUS AVAILABILITY

The different expressions used may be a little confusing, specially as there are different words for the same concept as well as different concepts for the same word.

In this paper Maintainability is used to describe those qualitative properties of a system who influence on the amount and quality of maintenance activities needed to keep the system in or restore it to a specified operation condition and which maintenance is supplied by a standard maintenance organisation.

The relation of the Maintainability concept to other concepts used in this connection is

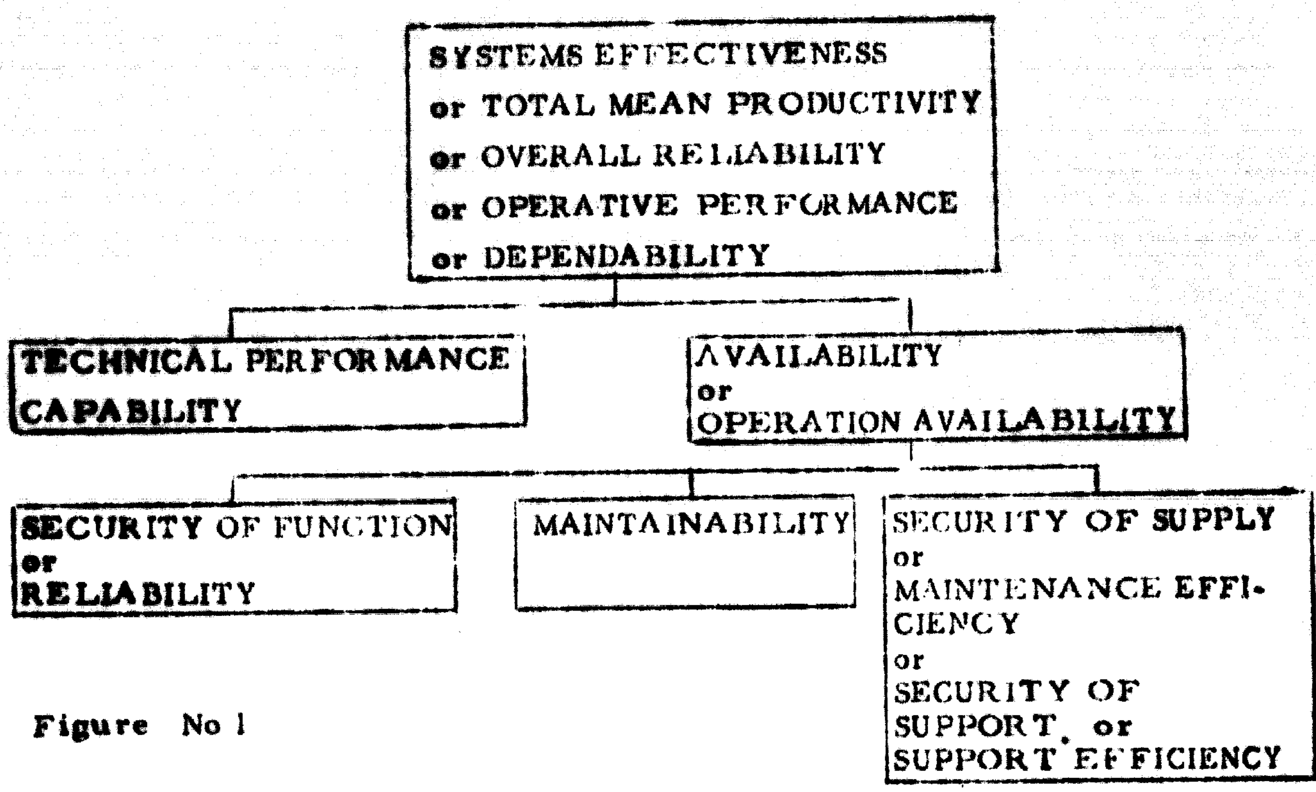


Figure No 1

In some papers Maintainability is used to describe both the above mentioned concept AND the properties of the maintenance organization included in the concept Security of Supply. The author would like to avoid such mixing of concepts as the Maintenance organization, represented by the concept Security of Supply or Security of Support, does not belong to the Properties of the technical system represented by the two other concepts. Of course, in reality the total function of the system will depend also on the Maintenance organization, which also is quite clear from the figure no 1.

DEFINITIONS USED IN THE PAPER

In the widely used U S Military Handbook 472 another definition of Maintainability is used:

- Maintainability is a qualitative property of a technical system, expressed as the probability that a piece of equipment will give the specified function within a specified time period after performance of specified and required maintenance activities according to established methods and with specified resources.

The definition of Reliability or Security of Function expresses the probability that a peice of equipment will function after a specified time period, while Maintainability expresses the probability that a failing piece of equipment will be restored to operative condiuon.

The measuring of these characteristics

Security of Function or Reliability	Mean Time Between Failures	MTBF
Maintainability	Mean Time To Repair	MTTR

Mean time for corrective maintenance (part of MTTR) $\overline{M}_{ct}$

Mean time for preventive maintenance (part of MTTR) $\overline{M}_{pt}$

MAINTENANCE ENGINEERS UNDERSTANDING OF THE MAINTAINABILITY CONCEPT

According to the definition mentioned the Maintainability concept handles those qualities of the equipment that determine the amount or quantity of maintenance work required to keep the equipment in operational condition and in accordance with specified requirements on service time (operation time). This required quantity of maintenance work depends on certain factors

- operation time per time period
- failure frequency
- required activities to prevent failures
- required activities to check equipment condition
- activities required to restore or repair the equipment
- activities required to modify the equipment in order to reduce the need of maintenance (improve the failure frequency and reduce the amount of maintenance activities as a total).

The quantity of maintenance has not yet got any name. It cannot be exactly measured. If cost is used the price of spare parts and manpower is included, and these can vary within wide limits, depending on country, skill, efficiency in the maintenance organization and efficiency of the manpower. Manhours cannot be used either, of the same reasons as for cost. The only practical method is to use a standard time manual. By using PTS (Predetermined Time Standards) the characteristics of the maintenance organization are eliminated. The maintenance quantity can then be established as "xxx MSH", a certain number of Maintenance Standard Hours. The real cost or number of manhours could then be derived from the simple calculation

$$\text{xxx MSH} \times \frac{100}{\%\ \text{MOE}} \times \text{cost/manhour} = \text{real cost}$$

MOE = Maintenance Organization Total Efficiency in relation to Maintenance Standard Hours.

In the future the manufacturers of industrial equipment might be able to supply information on both Security of Function and Maintainability for the equipment they manufacture and deliver.

To some extent this information is available to-day within certain branches such as electronic equipment and equipment manufactured in series, cars, lorries, tractors etc. The information is also available within certain complex areas such as space crafts and other types of equipment for military and semi-military operations.

To the "non-theoretical" maintenance engineer it might be a little confusing to hear the definitions on Maintainability. The most used definition relates the characteristics of the equipment to the characteristics of the organization for the supply of maintenance activities. This may be understood to mean that the Maintainability of a piece of equipment or a plant varies with the location of the equipment in operation, which as a matter of fact it does. As an example: In an industrialised country most tools can easily be bought in any hardware store while they may be non-existing in a developing country. If such tools are needed for the correct performance of maintenance activites the Maintainability of the equipment is better in an industrialised country than in a developing country.

The different qualitative properties determining the actual Maintainability and which are related to the qualitative properties of the maintenance organisation must be clearly specified. If this is not done and correct measures are not taken to bring the equipment and the maintenance organisation into accordance to each other the calculated or expected Availability will be impossible to arrive at.

An example: A complete hospital was delivered from Sweden to Tunisia about ten years ago. To start with it was operated by the Swedes as a university hospital. Then it was given over to the Tunisians. The bulbs were of the normal Swedish standard type with Edison socket, while the Tunisian standard is the Swan socket. When the supply of bulbs with Edison sockets was consumed there were nc such bulbs available in the country. The hospital could not be used to its full capacity until either the lamp sockets or holders had been changed or bulbs could be supplied from outside.

Another example: The designer of an electro-mechanical calculating machine suggested the use of screws with Phillips-heads because these would give some advantages over normal slotted head screws (dimension, tensile strength). The customer (a military organization) made a survey on available tools within the organization and found, that no such screwdrivers were on the procurement plan. The next step was to find out if these screwdrivers could be purchased in the local market where the calculators were planned to be used. There was no supply of the screwdrivers in that market. To increase the Maintainability of the calculator the normal slotted screw must be used.

Factors affecting Maintainability

According to the definition the factors affecting the Maintainability will be

- the design philosophy used
- the number and sizes of modules (groups of components, units)
- the accessability for testing the condition and the function of each module
- the accessability for maintenance activities, both testing, failure detecting and failure analysis, condition checking and condition monitoring as well as replacement and repair activities
- the presence of devices facilitating monitoring or intermittent checking of function and condition
- the qualitative content of technical documentation and the comprehensibility in the presentation of this information.

These factors are all related to the design of the equipment as such and to some extent to the environment in which it is to be used (space for maintenance activities around the machine).

These factors together give a certain level of Maintainability, which could be called Theoretical Maintainability. To describe it in a more popular way - the qualitative properties are related to an ideal and specified maintenance organization. However, in practical life this ideal maintenance organisation does not exist, with a few exceptions.

To get a better grasp of the real maintainability some more factors or characteristics have to be considered, namely:

- availability of testing instruments
- availability of tools and other aids for the performing of all types of maintenance activities
- availability of premises for maintenance activities also space around the machine in case it cannot be moved to the maintenance premises
- supply of spare parts and maintenance material
- competence of maintenance personnel and their skill
- operation and maintenance records, quality of information, accessability of recorded information.

The real maintainability is determined by the relation between the theoretical maintainability of the actual equipment and the ability of the existing or planned maintenance organization to meet all requests created by the operation of the equipment.

This understanding of the Maintainability concept also leads to some general conclusions:

A. No one of the people involved can be solely responsible for the characteristics determining the Maintainability in practical life.

B. The designer must specify the requirements on the maintenance organization to achieve a specified Operation availability.

C. The maintenance engineer (or manager) must analyse the maintenance organisation ability to meet the requirements specified by the designer as outlined in B.

D. The management must realize the fact that each piece of equipment has its own specific requirements on the maintenance organization and that these have to be filled to obtain the specified or requested production availability.

E. The management and the maintenance manager must realize that both the Security of Function and the Maintainability are "designed-in" qualities that may be improved during the lifetime of the equipment, also that these modifications and improvements to the greatest part are the respons- abilities of the user of the equipment and consequently to a smaller part are the responsabilities of the manufacturer.

F. All parties concerned must realize that any change in the maintenance organization, resulting in a decrease of the qualities which negatively will affect maintainability, in practice will result in a lower production availability, meaning more lost production time, less utilisation of the invested capital and a poor economy. In many cases in developing countries it also will lead to higher demand on foreign currency for purchase of spare parts or too early replacement of larger pieces of equipment.

MAINTAINABILITY AT THE DESIGN STAGE

Most of the characteristics affecting both the Security of Function (failure frequency) and Maintainability (required quantity of maintenance work) of a machine or plant are determined at the design stage. The designer has to select components and assemble them to a machine or "technical system" meeting the requirements of the customer, both those expressed by the customer and those not expressed but necessary.

Usually components with a high Security of Function (low failure frequency) are expensive. If the designer should use such components only the machine will be very expensive and in the competition it would be difficult to sell it. If cheaper and less reliable components are selected the machine would be low priced and easy to sell, but very soon the customer would find out and the machine would get a poor reputation, perhaps also cause claims from the customer, prolonged guarantee etc.

As long as the purchaser pays more attention to the initial price of a machine it will be difficult to get machires with both good production and good availability. If only purchasers could be pursuaded to consider the lite time cost the situation would change and the maintenance function would be given a fair chance to maintain a high availability at a low cost. At the same time production would find they do not have so many difficulties and irritating situations as now is the rule.

For the time being only a few customers know about all the characteristics and pay attention to them. The designer has to compromise between price on one side and security of function and maintainability on the other. Which type of a compromise he selects will largely depend on the customers demands. To some extent it will also depend on how well the customer is aware of the operation environment for the machine and how much he tells the designer and/or manufacturer.

In appendix 1 an attempt to a checklist for designers and purchasers will be found. It could probably be used for checking tenders, evaluation of competing machines etc, maybe also as a memorandum for plant engineers, maintenance engineers etc.

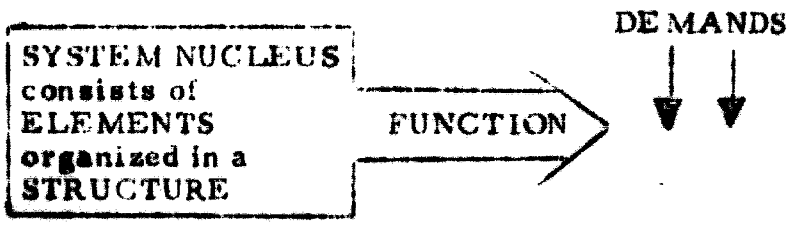
MODULARISATION

Modularisation may be regarded as a combined design and maintenance philosophy. It follows the main philosophy of the Systems Concept.

The definition of a System used here is the following:

MODEL OF A SYSTEM

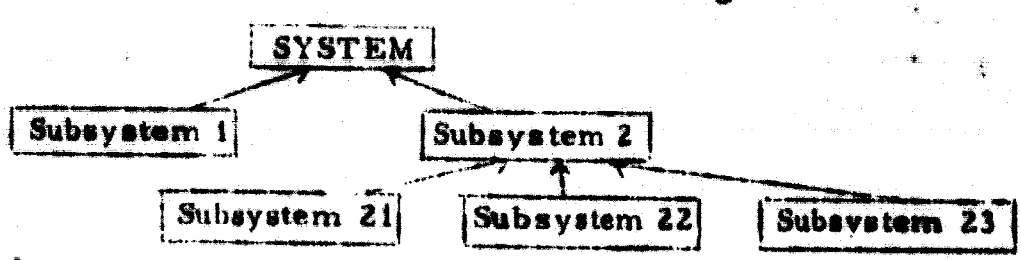
Fig No 2



- SYSTEM is a comprehensive name for a FUNCTION and a SYSTEM NUCLEUS.
- The Function has qualitative properties and always contributes positively to comply with a demand from the user of the system, or to meet and fulfil objectives.
- The Nucleus contains ELEMENTS, which are all needed to realize the Function. The Elements are organized in a STRUCTURE which characterizes how the Elements co-operate in room and time.

A System may be identified at different levels. At the highest level it is identified as ONE system. At lower levels it is identified as two or more SUBSYSTEMS, each one with a specified function, contributing positively to the function of the system at the next higher level.

Fig No 3



A technical system can be handled in the same way. If the smallest part is called "component" a certain number of components must be used to achieve a certain function. These components together may be called a "unit". If now a unit can be designed in such a way that it can be replaced as a unit it may be called a "module". Sometimes the expression "assembly" is used.

The optimal module is determined by a large number of parameters, according to Goldman and Slatterly, "Maintainability - A major Element of System Effectiveness", more than 40. However, in practice a fairly good result may be reached using a simplier method.

Assume that a number of machines are located the same distance from the place where maintenance is performed. The spare parts cost is "p" and the replacement intensity corresponds to the failure intensity "l". The cost for spareparts during 1 000 operative hours is p x l. The total cost P is then

$$P = \frac{c}{\Sigma l} \left[p_1 \cdot l_1 + p_2 \cdot l_2 + p_3 \cdot l_3 + \ldots \ldots p_n \cdot l_n \right]$$

which indicates that the modularisation should be made so that the product of "p" and "l" for each module has the same size.

Modularisation is used fairly much in standard products like cars, buses, lorries, electronic equipment etc. Some modules are equipped with indicating or monitoring devices, indicating failure, condition, function etc.

The benefit of modularisation is mainly shorter repair time, sometimes also lower cost because standardisation of the modules make it possible to manufacture these modules in larger series.

The adventages of modularisation is clearly indicated by some figures from the Scandinavian Airline System for different types of aircrafts.

The Douglas DC-7 is a long distance aircraft with four combustion engines. It is made according to the older design philosophy known as "safety first". After a number of flight hours the aircraft is taken to pieces, checked and inspected and again assembled. The interval and amount of manhours spent varies, as an example the total overhaul after 9 000 flighthours takes 20 000 manhours.

The Sudaviation SA-210 Caravelle has two jetengines. The design is partly made according to the older principle, partly the modularisation principle.

The modularisation principle is still more used in the well known Douglas DC-8, a four jet long distance craft. One more step towards a complete modularisation is taken in the DC-9, a two jet short and middle distance aircraft.

The modularisation in these cases means that instead of taking the aircraft apart in small pieces for inspection, checking, replacement of parts or repairs, the aircraft is checked while it is waiting in an airport. Some checks are made rather frequently, some at intervals around 5 000 flighthours. The stop time for checking is short. If a module is found deviating from the specifications it is quickly replaced by a new or overhauled module. The ground time for the aircraft is cut down compared to the old DC-7.

The table below gives the cost per passenger and km.

Type	Passenger	Speed	Maintenace cost/flighthour	Cost/seat/km
DC-7	120	500	260	.00433
SA-210	86	850	200	.00274
DC-8	225	900	260	.00128
DC-9	110	900	160	.00160

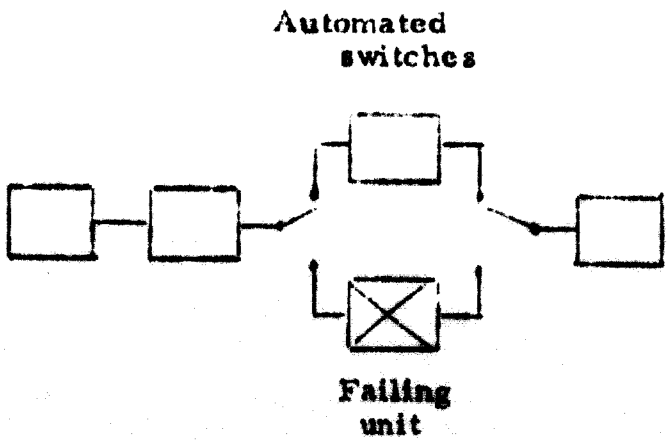
The Availability of the aircrafts also varies. The more maintenance they need the longer time they are on the ground. As the DC-9 has the lowest maintenance cost per flighthour it is in the air more than the other types.

One conclusion is that Modularisation is one way to shorter maintenance time and lower maintenance cost, meaning also a better Availability.

Another practical advantage of modularisation is that components with lower security of function (higher Failure Frequency) can be assembled in an exchangeable unit, with quick connectors, and two of that particular unit in parallel. There could also be an automated switch device and the total rate of Security of Function could be increased by adding a Redundancy factor to the system.

If one of the unit fails the other one automatically takes over the load. The failing one can be replaced with a new or repaired unit at convenience within the normal MTBF for the unit.

Fig No 4



Modulatisation also increases the possibilities to utilise condition monitoring. If a unit can be continously checked it can be replaced before it reaches the non-function level.

Obviously the level of modularization can be selected to give shorter or longer replacement time, thereby affecting the MTBF. An example:

An electric motor consists of the following parts, which could be called Spare Parts

Shaft
Bearings
Armature
Armature windings
Stator
Stator windings
Connection terminals
Shields with bearing cover plates
etc.

It is possible to make a module of the following parts:

Shaft, Bearings, Armature, Armature windings

and this module can be called an Armature Assembly and it can be kept as a Replacement Unit (or Replacement Module).

Obviously the electric motor can be considered to be a RU. (Replacement Unit).

Which one to select depends on

- Availability of technically skilled personnel
- Price of the different RU
- Maximum allowable stop time for replacement
- Interest on money invested in RU
- Number of machines the RU can be used for
- Delivery time for the different RU
- Probability of failure or Failure frequency.

The example is a standard product and in most cases the manufacturer can supply any of them without changing the design. If the machine or plant is a special one, excisting in one or only a few units or being an entirely new product to be manufactured for a certain customer (such as military aircrafts) the selection of the correct level of modularization is essential for the future performance of the machine, plant or equipment.

It would lead us too far to go deeper into details. What is mentioned here is done so to point out one more side of the problem which has to be taken up to discussions between the purchaser and the manufacturer or supplier.

MAINTAINABILITY CONSIDERATIONS AT THE FACTORY PLANNING STAGES AND INSTALLATION

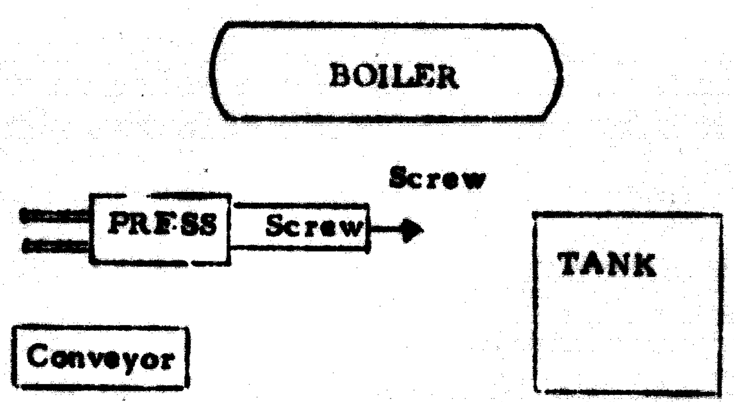
If the factory planning engineer is well informed about the qualities of the machines related to Security of Function and Maintainability he can consider the demand on space and facilities for the practical performance of the expected maintenance work. Unfortunately it happens far too often that a machine is placed in a space where it is necessary to dismount parts of it to be able to move it into the desired spot. When these parts have to be mounted again to complete the machine the space is too narrow for lifting aids, hooks, wires and hoists. It has happened many times that holes have to be taken up in cealings and floors and walls. After the machine is mounted these holes are closed permanently and when it later on becomes necessary to perform some maintenance work the space again is too narrow. Thus the maintainability of a machine can be greatly reduced.

Some of the questions mentioned in Appendix 1 can be used to check the factory planning.

When a plan for a factory or other installation is made it is essential that the maintenance engineer approves these plans before they are finally approved by the responsible person. It is always difficult to introduce changes in approved plans, besides these changes always are more expensive than changes made at an earlier stage. To move concrete bases and concrete walls cost much more than to draw some new lines on a piece of paper.

When a machine or plant is installed the future possibilities to maintain the machine can be greatly influenced. Usually a plant engineer has made an installation drawing, showing where exactly the machine or piece of equipment should be placed. In many cases he then had no possibility to check the necessary space for assembly and disassembly of the machine. It might happen it will be rather difficult to disassembly one specific machine after the surrounding equipment has been mounted. The example below is fetched from a modern brewery.

Fig No 5



The screw fot the press from time to time must be taken out for cleaning deposits and for checking the thrustbearing. As the press is mounted now it must be loosened from the foundation, turned a little and then there is a space enough to remove the screw. There are not only foundation bolts, also some pipelines have to be disassembled to facilitate the turning of the machine. The completely unnecessary turning operation could have been eliminated by mounting the press at an angle already at installation.

Of course, it is possible to turn the machine permanently, but until recently no one has thought about that. It is also quite expensive to do so now, as some machines have been added to the plant without considering the possibility to turn the press before they were mounted. These new machines must be moved some feet to allow turning the press permanently.

MAINTAINABILITY DEMONSTRATIONS

The quantification of Maintainability is quite difficult. For machines or plants manufactured in just a small number or one single specimen only the only way is simulation of operation conditions in combination with an analysis of the technical system in details. This method is of course quite expensive.

Another method can be used on machines, instruments and other pieces of equipment manufactured in series. It is called "Maintainability Demonstration" and is described in US MIL-STD-471, Maintainability Demonstrations, 1966.

There are so far only a few Maintainability Demonstrations made and available for study. One was performed about two years ago on an electro-mechanical calculation machine for special purposes.

The calculator consists of the following modules:

Key board	Puncher	Power unit
Reader I	Printer	Motor
Reader II		Transmission
Operation unit		Transmission unit
8 printed circuits.		Stand

The number of modules is 20. Of these the 8 printed circuits contain roughly 350 integrated circuits. The calculator and the power unit are of the electronic type, the remaining modules are mainly mechanical with a few electronic components.

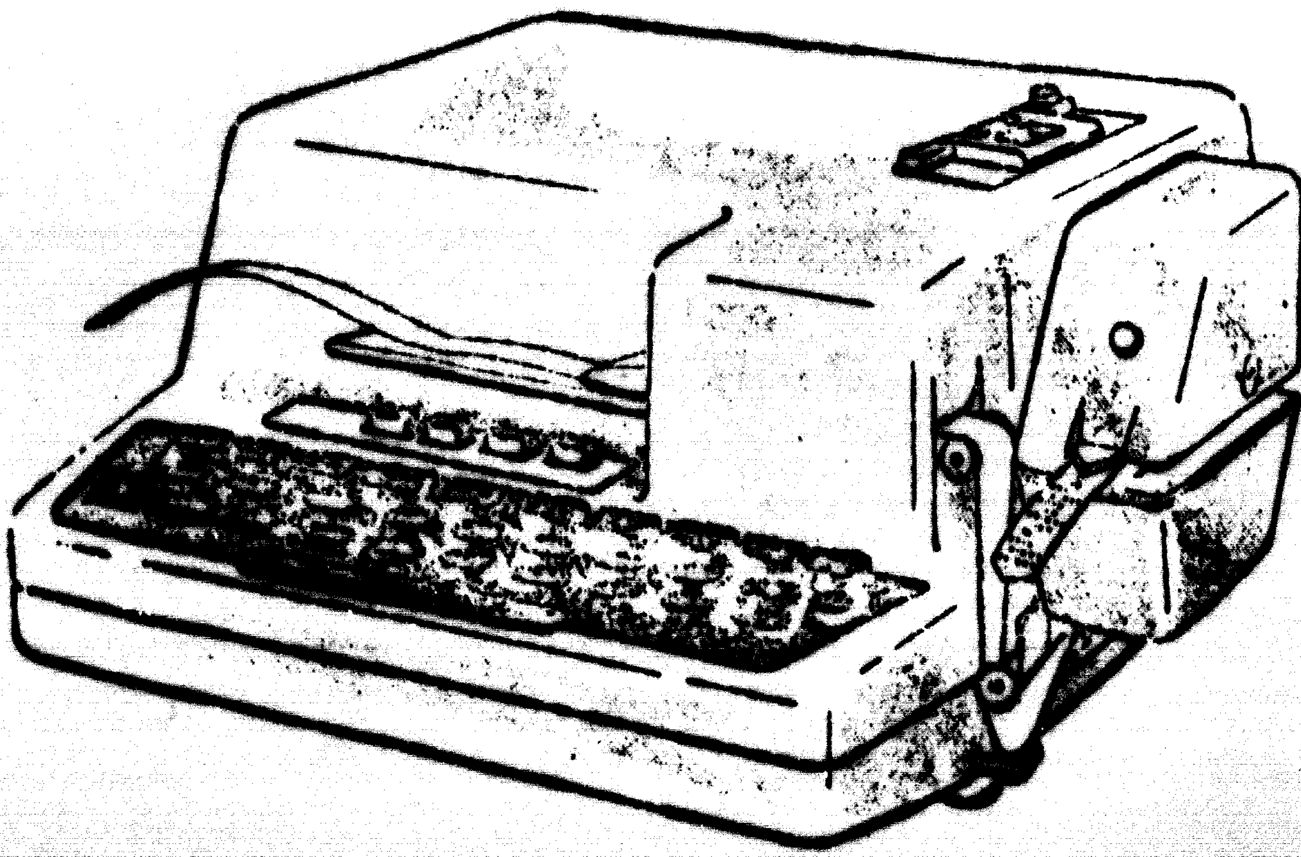


Figure No 6

The Maintenance philosophy used depends of course on the operation of the calculator. It is used in the army under rather rough conditions, from hot dry summer weather to very cold winter and also during the autumn rather high humidity.

For a Maintainability Demonstration the following conditions must be specified:

- Operation environment
- Mean down time
- Mean intervals for preventive maintenance
- Test methods
- Single and double failure rate
- Selection of personnel for demonstration
- Establish specification for Mean Time To Repair and Maximum Time To Repair.
- Selection of failure intensity and distribution of failures
- Technical Documentation for the calculator.
- Maintenance environment
- Mean life time for wear-out
- Supply of replacement units RU
- Qualifications of personnel

Of these figures and information some are of more general interest than other. The Mean Time To Repair, $\bar{M}_{ct}$, was derived from a large number of similar units and from other Maintainability Demonstrations. The Maximum Repair time $\bar{M}max_{ct}$ was found to be 90 minutes and the mean value $\bar{M}_{ct}$ was 30 minutes.

The Maintenance organization normally has three levels, of which the highest one is a central workshop with facilities to repair all modules in the calculator. On the other two levels the repair consists of replacement of modules.

The time for a complete repair consists of cueue time, failure localisation time and repair time. As the normative Maintainability will be found at the lowest level it was decided that the demonstration should be performed at this level, under field conditions. The mobile workshop exterior and interior are shown in figures 7 and 8.

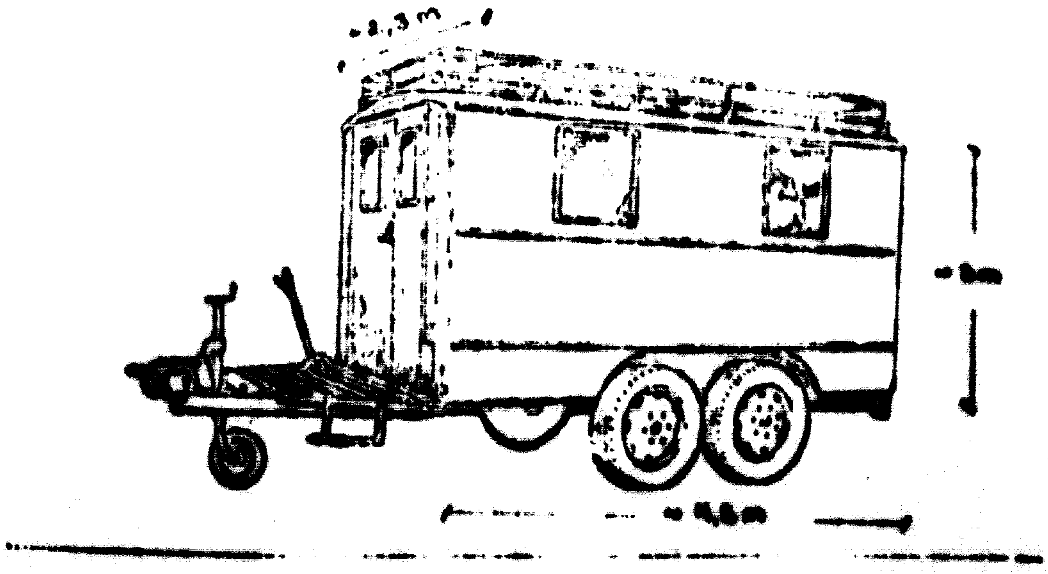


Fig. No 7

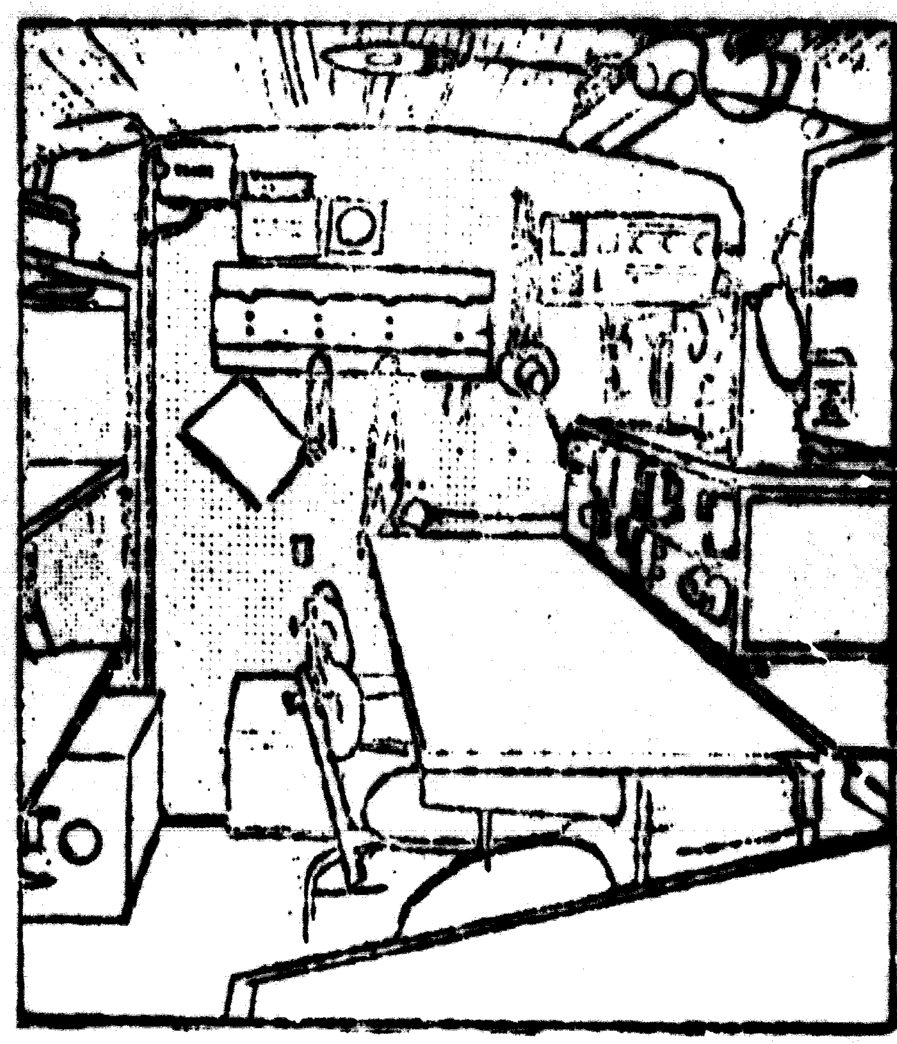


Fig. No. 8

The failure intensity was predicted according to the stressmethod for the electronic modules. For the mechanical components in the keyboard, readers and printers a test was made by the manufacturer and the failure intensity was calculated on that basis. In both cases the expected operation profile was considered. The result is shown in table 9 below.

Module	Failure int. no/10^6 hours		Contribution to total failure int. %	No of failures
	Electr	Mech		
Keyboard electr.	1.19		0,2	0
mech.		85	13,2	13
Reader I electr.	23,73		3,7	4
mech.		10	1,6	2
Reader II	31,85		5,0	5
Printer electr.	28,56		4,5	5
mech.		120	18,7	18
Puncher electr.	1,75		0,3	
mech.		50	7,8	8
Printed circuit 1	19,41		3,0	3
2	16,97		2,7	3
3	14,25		2,2	2
4	20,38		3,2	3
5	25,72		4,0	4
6	22,20		3,5	4
7-8	27,33		4,3	4
Power unit	44,95		7,0	7
Motor	20,89		3,3	3
Clutch		20	3,1	3
Operation unit electr.	21,5		3,3	3
mech.		5	0,8	1
Transmission		20	3,1	3
Stand	11,96		1,2	2
SUM	332,70	310	100	100
	643			

Table 9. Failure intensity

According to the testmethods used the number of failures during the demonstration should be set to 100.

After discussions with the designer a table showing how the failures should be simulated was drawn.

According to the specifications the number of double failures should be 10 %. As independent double failures are considered unlikely it was decided to make the double failures of the primary/secondary failure type.

In the programme some other conditions were established, such as

- which personnel should be used (not which one)
- how many
- test equipment available in the mobile workshop
- how the failures should be introduced and time checked
- how the personnel should report.

The result.

When the demonstration was performed TV cameras were installed to observe the proceedings in the mobile workshop. Each failure was repaired and the report finished before the next calculator was taken in. Two trained operators selected at random from a group of six were working about four hours for the first 26 failures.

The time for operator no 1	Total time 225 minutes Mean time/failure 17 minutes
for operator no 2	Total time 190 minutes Mean time/failure 15 minutes.

When these 26 failures had been taken care of, the established objective of the demonstration was fulfilled and no further tests were necessary. The Maintainability was found well within the specified values and the specified quality of the calculator and the maintenance organisation were both accepted.

This result has later on been discussed with organisations who themselves have performed similar demonstrations. The method is fairly expensive but gives a good information. However, it has so far not been used for products in the civil market but it would be rather interesting to try it on equipment like lorries, buses and cars.

MAINTAINABILITY DURING THE OPERATION PHASE

During the operation phase the Maintainability of the equipment will change, so does the Efficiency of the Maintenance Organisation. Both these will affect the availability of the equipment for production, the quality of the product and the total cost.

The following topics will be discussed:

1. The performance of specified maintenance operations
2. Fault finding and repairs
3. Checking and monitoring of equipment condition.
4. Recording of performed maintenance activities, down time and production figures.
5. Use of the recorded information to improve Maintainability.

1. To perform specified maintenance activities.

To retain the qualitative properties of the equipment it is essential to perform all specified maintenance activities correctly and at the correct time. These specified activities can be:

- Cleaning operations
- Lubrication
- Inspections and adjustments
- Replacement of mod les at predetermi ed time intervals
- Checking condition of the equipment.

These are well known to most maintenance people as Preventive Maintenance and the interested reader may find lots of information on this subject in different papers.

In this paper it will only be pointed out the importance of the Preventive maintenance and the hazards of neglecting it. If a small defect is allowed to develop to a failure it very often happens that a fatal breakdown will be the result. It would have cost a small sum and only a few minutes stop to replace the defect component before the fatal failure is a fact. When this fatal failure has occured it might very easily cost 10 or 50 times more to repair the equipment.

2. Fault-finding and repairs.

Many failures develop so quickly that no method exists to detect it before it is fatal. Some others cannot be checked or monitored, such as those caused from outsides sources, human failures, thunderstorms and similar.

Under certain conditions it might be too expensive to have a complete preventive maintenance. This happens sometimes when the utilisation of the equipment is low, which means there is time to allow a stop for a repair.

Even if a good preventive maintenance is applied certain systems are difficult to check, meaning that failures will come unexpectedly. In these cases it is important to find the failure as quickly as possible, define it and repair. This is valid for complex subsystems such as electric control systems, electronic systems, hydraulic control systems and pneumatic control systems. Power systems generally are simplier and easier to observe and it is also fairly easy to find failing components in the power systems.

For such important control systems the manufacturer should be requested to supply complete technical documentation to facilitate logical fault-finding and sometimes a function test programme should be used. These documents will be discussed later in the paper.

Even with the best technical documentation is of no value if the maintenance personnel is unable to use them. The maintenance craftsmen, both electricians and fitters, should be trained in using the method known from the teletechnical fields as "logical fault-finding" or "trouble shooting". The operation is performed to the greatest part on diagrams and drawings and even if the security laws allow only electricians to perform work in electrical plants the mechanically trained personnel can never be forbidden to think, which is the essential part of the logical fault-finding technique.

When the failing component is defined the repair in most cases means a replacement of the component with a new one. Only rarely the component itself is repaired. However, under certain conditions it might be necessary to do so, maybe no spare part is available.

The replacement of the defect component should be done correctly and if necessary the assembly should be checked carefully and the function verified before the machine is put in operation again. Again, the maintenance personnel must be well trained and feel the responsability. To use inspectors or let the foreman inspect the work is of course possible, however, it is not the very best solution as it undoubtly will delay the work.

"Fight the weak components".

There is a certain philosophy used in several industries when repairs are performed. It might be called "Fight the weak components". It aims directly to an improvement of the qualitative properties of the equipment affecting the maintainability. The application of this philosophy also involves training of the performing maintenance personnel.

Whenever a repair is necessary the performing man makes an analysis of the failure, answering some simple questions like:

- what component failed first?
- why did it fail?
- is the component too weak for the load and the stress?
- is there an outside cause of this failure?
- has some other component too low capacity or a defect?
- can the component be replaced by some other component which has enough capacity or other properties in order to prevent a repetition of the failure?
- can some form of preventive action prevent the failure from going to a break-down?

The skilled maintenance man in most cases is capable of doing such a simple analysis. If he is unable he is instructed to discuss the failure with his foreman or with an engineer. The main advantage is that the discussion is started while still the circumstances and memories are fresh. If the failure only is recorded in the Maintenance record a considerable time may elaps until the case comes up again. The recording never can be made so detailed that all circumstances are available at a later time. Besides, there might be repeated failures of the same component without anyone taking notice of it.

The very best result, a better maintainability and lower failure frequency, will be obtained if this philosophy is combined with careful analysis of recorded information.

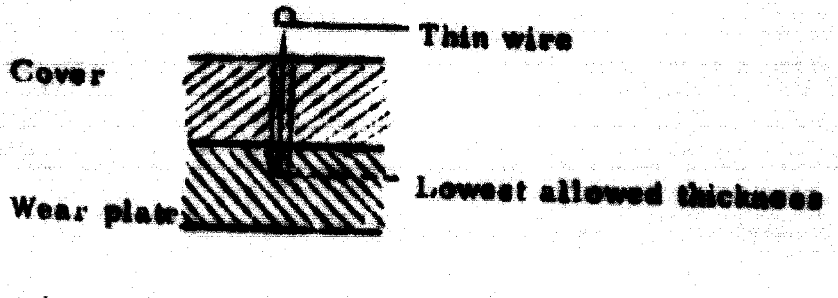
3. Checking and monitoring of condition.

During the last decade a considerable improvement has been achieved in maintenance generally. A number of old and new methods for checking or monitoring the condition of components of all kinds have been applied as an essential part of modern preventive maintenance.

An ingenious maintenance man is sometimes able to find means to replace visual inspections, often after dismounting or disassembly, with simple and quick, dependable and inexpensive objective measuring methods. An example:

In a cyclone the wear plates must be checked for wear regularly. To check, the man had to stop the air flow by shutting down the compressor, lock the starter, climb some 20 meters up on top of the cyclone, open a cover and inspect. As the wear plate was mounted close to the wall the measuring of the remaining thickness was quite difficult and unsure.

He drilled a small hole from the outside and 2 mm into the wear plate. 2 mm corresponds to the wear during one month of operation.



The checking is performed by means of a thin wire. If it is stopped in the hole the thickness still is enough for one month's operation. If the wire is not stopped the thickness is too low and the wear plate must be replaced within a month.

There are now numerous other methods for checking the condition of both electrical and mechanical components. A few of them are related here:

A. The SPM method for checking bearings. Utilizes the small mechanical transient (shock vawe) in the material, caused by the small damages in the bearing surface caused by continous operation under load or by foreign particles entering a bearing with the lubricant. Not to be mixed up with vibration analysis. Indicates wear and damages in ball and roller bearings with a very high safety level and very early during the development stage of any failure.

B. Ultrasonic leak detector. Utilizes the ultrasonic noise caused by a leak in a hydraulic or pneumatic component. Used during operation conditions. Reacts for a very tiny leak inside a valve or a cylinder on unbelievable long distance and without influence from other noise sources. A leak of .5mm could be indicated at a distance of 14 meters.

C. Infrared camera. Utilises the special film for infrared light. Indicates temperature differences of less than one degree C on surfaces. Can be used on a distance.

D. Temperature indicating paint, chalk or tape. Used everywhere on components where a change in condition gives a change in temperature, preferably an increase.

Of course, temperature recording instruments, pressure recording, flowmeters and suchlike can and should be used much more in plants. During the latest years a fairly large number of plants and individual machines have been designed for continous monitoring of parameters indicating condition or changes in condition. Within certain fields, such as military and commercial aircrafts, the test equipment is mounted in a separate unit, which at certain intervals is connected to the aircraft and a more or less complete condition test is performed. The result is recorded.

The same principle is used onboard ships. Sometimes a computer is used to connect the various transmitters to the instruments. A SPM instrument is used to check a large number of bearings and the result is recorded.

If the output signal is found to be higher than a preset limit value an alarm signal is released. In some cases the alarm also stops the machine if the alarm signal is not observed within a specified time.

The effect on the maintainability is obvious. The defects are detected before they have developed to a failure. The defect component or unit or module can be replaced before secondary failures have occured. The downtime will be short and the cost lower than if the failure leads to an unexpected stop, often called a break-down.

4. Recording of performed maintenance.

The recording of performed maintenance activities and the technical information in connection with repairs is justified only if the collected information is used for analysis of the equipment performance and as basis for improvements of the failure frequency, failure intensity and maintainability (in its widest sence).

To facilitate the utilisation of the collected information each input must be correct (as far as this is possible) and contain relevant information. According to the author's experience the following information is essential:

A. Identification of object. Machine number, preferably logical code. In most cases five digits are enough. The first indicates the main group, such as

1xxxx	=	heat treating equipment, kilns, furnaces etc
2xxxx	=	rolling mills
:		
9xxxx	=	conveyors, transport equipment

The second digit indicates the subgroup, such as

11xxx	=	blast furnaces
12xxx	=	open herth furnaces
13xxx	=	electric arc furnaces

The third digit is used to divide the equipment in still smaller groups, such as

131xx	=	experiment furnaces
132xx	=	furnaces up to 5 tons charge capacity

The two last digits are the individual number within each group.

B. Identification of components. In most cases a two-digit code can be used. As each work order always contains both Machine number and Component code the later can be special for certain groups of machines. The following page shows such a component code for a cement factory.

Under certain conditions a three-digit code may be necessary. However, it is not necessary to have a very detailed code. The code is used only for sorting out interesting work orders for a more detailed analysis. It is not necessary to be able to identify one of several hundred of ball and roller bearings directly in the record. It is easier to use the work order.

Component code for cement factory.

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
00	[illegible]	[illegible]	[illegible]	[illegible]	
01	[illegible]	[illegible]	[illegible]	[illegible]	Lifting arm, boom
02	[illegible]	[illegible]	[illegible]	[illegible]	Chassis, frame
03	[illegible]	[illegible]	[illegible]		Wagon-bridge, fork carrier
04	[illegible]	[illegible]	[illegible]	[illegible]	Lift pillar
05	[illegible]	[illegible]	[illegible]	Fuel tank	Fuel tank
06	[illegible]	[illegible]	[illegible]	Lifting wire	Lifting wire
07	[illegible]	[illegible]	Bearing housing	Lifting chain	Lifting chain
08				Block and hook	Block, fork
09	[illegible]	[illegible]	Observation windows	Operators house, windows	Operators house, windows, berth
10	[illegible]	[illegible]	Gear case	Gear case	Gear case
11	[illegible]	[illegible]	Shafts in gear case	Shafts in gear case	Shafts in gear case
12	[illegible]	[illegible]	Gears	Gears	Gears
13	[illegible]	[illegible]	Drive shaft	Drive shaft	Drive shaft
14	[illegible]	[illegible]	Carrying shaft	Carrying shaft	Carrying shaft
15	[illegible]	[illegible]	Ball & roller bearings	Ball & roller bearings	Ball & roller bearings
16	[illegible]	[illegible]	Seals, packings, gaskets	Seals, packings, gaskets	Seals, packings, gaskets
17	[illegible]	[illegible]	Brake linings	Brake linings	Brake linings
18	[illegible]	[illegible]	Plain bearings	Plain bearings (see 71)	Plane bearings (see 71)
19			[illegible]	Conveyor	Conveyor
20	[illegible]	[illegible]	Belt drive, wheels, pulleys	Belt drive, wheels, pulleys	Belt drive, wheels, pulleys
21	[illegible]	[illegible]	Chain drive, pulleys	Chain drive, pulleys	Chain drive, pulleys
22	[illegible]	[illegible]	Elastic couplings	Elastic couplings	Elastic couplings
23	[illegible]	[illegible]	Rigid couplings	Rigid couplings	Rigid couplings
24	[illegible]	[illegible]	Hydr.coupling, converter	Hydr.coupling, converter	Hydr.couping, converter
25	[illegible]	[illegible]	Mech.clutch	Mech.clutch	Mech.clutch
26				Steering gear	Steering gear
27				Wire drum, sheave	Wire drum, sheave
28	[illegible]	[illegible]	Carrying springs	Carrying wheels	Carrying wheels
29	[illegible]	[illegible]	Guide rollers	Steering wheels	Steering wheels
30	[illegible]	[illegible]	Mechanical controls	Mechanical controls	Mechanical controls
31	[illegible]	[illegible]	Servo-units	Servo-units	Servo-units
32					
33					
34					

Component code for cement factory.

Code	FURNACES, MILLS	[illegible]	[illegible]	[illegible]	TRUCKS, TRACTORS
35	Tension units	Tension units	Tension units	Tension units	Tension units
36					
37					
38					
39					
40	Electric motor, windings	Electric motor, windings	Electric motor, windings	Electric motor, windings	Electric motor, windings
41	Brushes, spil-rings	Brushes, slip-rings	Brushes, slip-rings	Brushes slip-rings	Brushes slip-rings
42	Limit switches	Limit switches	Limit switches	Limit switches	Limit switches
43	Push buttons, hand switches	Push buttons, hand switches	Push buttons,hand switches	Push buttons, hand switches	Push buttons hand switches
44	Controllers	Controllers	Controllers	Controllers	Controllers
45	Contactors, relays	Contactors, relays	Contactors, relays	Contactors, relays	Contactors, relays
46	Voltage regulators	Voltage regulators	Voltage regulators	Voltage regulators	Voltage regulators
47	Connections	Connections	Connections	Connections	Connections
48	Leads, cables	Leads, cables	Leads, cables	Leads, cables	Leads, cables
49	Fuses	Fuses	Fuses	Fuses	Fuses
50	Auxilliary transformer	Auxilliary transformer	Auxilliary transformer	Auxilliary transformer	Auxilliary transformer
51	Diode, rectifiers	Diode, rectifiers	Diode, rectifiers	Diodes, rectifiers	Diodes, rectifiers
52	Lamps, all kinds	Lamps, all kinds	Lamps, all kinds	Lamps, all kinds	Lamps, all kinds
53	Fixed resistors	Fixed resistors	Fixed resistors	Fixed resistors	Fixed resistors
54	Variable resistors	Variable resistors	Variable resistors	Variable resistors	Variable resistors
55	Inductor	Inductor	Inductor	Inductor	Inductor
56	Condensers	Condensers	Condensers	Condensers	Condensers
57	Electronic tubes	Electronic tubes	Electronic tubes	Electronic tubes	Electronic tubes
58	Electromagnetic speed control	Electromagnetic speed control		Generator	Generator
59	Solenoids	Solenoids	Solenoids	Solenoids	Solenoids
60	Hydraulic pumps	Hydraulic pumps	Hydraulic pumps	Hydraulic pumps	Hydraulic pumps
61	Hydraulic motors	Hydraulic motors	Hydraulic motors	Hydraulic motors	Hydraulic motors
62	Pressure gauges	Pressure gauges	Pressure gauges	Pressure gauges	Pressure gauges
63	Shut-off valves	Shut off valves	Shut off valves	Shut off valves	Shut off valves
64	Pressure control valves	Pressure control valves	Pressure control valves	Pressure control valves	Pressure control valves
65	Directional valves	Directional valves	Directional valves	Directional valves	Directional valves
66	Flow-control valves	Flow-control valves	Flow-control valves	Flow-control valves	Flow-control valves
67	Hydraulic cylinders	Hydraulic cylinders	Hydraulic cylinders	Hydraulic cylinders	Hydraulic cylinders
68	Filters, coolers	Filters, coolers	Filter, coolers	Filters, coolers	Filters, coolers
69	Tubes, hoses	Tubes, hoses	Tubes, hoses	Tubes, hoses	Tubes, hoses

Component code for cement factory

FURNACES, MILLS		[illegible]		[illegible]		CRANES		TRUCKS, TRACTORS
	70		70	Crank-case, motor block	70	Crank-case, motor block	70	Crank-case, motor block
	71		71	Crankshaft bearings	71	Crankshaft bearings	71	Crankshaft bearings
	72		72	Crankshaft	72	Crankshaft	72	Crankshaft
	73		73	Conn.rod, piston, rings	73	Conn.rod, piston, rings	73	Conn.rod, piston, rings
	74		74		74	Camshaft, gear	74	Camshaft, gear
	75		75	Valves, springs, rockers	75	Valves, springs, rockers	75	Valves, springs, rockers
Pneumatic cylinders	76	Pneumatic cylinders	76	Pneumatic cylinders	76	Pneumatic cylinders	76	Pneumatic cylinders
Directional valve, air	77	Directional valves, air	77	Directional valves, air	77	Directional valves, air	77	Directional valves, air
Flow and pressure controls	78	Flow and pressure controls	78	Flow and pressure controls	78	Flow and pressure controls	78	Flow and pressure controls
Air pipes, hoses	79	Air pipes, hoses	79	Air pipes, hoses	79	Air pipes, hoses	79	Air pipes, hoses
Water pump, housing	80	Water pump, housing	80	Water pump, housing	80	Water pump, housing	80	Water pump, housing
Impeller and shaft	81	Impeller and shaft	81	Impeller and shaft	81	Impeller and shaft	81	Impeller and shaft
Water valves	82	Water valves	82	Water valves	82	Water valves	82	Water valves
	83		83	Air cooler	83	Air cooler	83	Air cooler
Oil cooler	84	Oil cooler	84	Oil cooler	84	Oil cooler	84	Oil cooler
Air conditioner	85	Air conditioner	85	Air conditioner	85	Air conditioner	85	Air conditioner
Air filter	86	Air filter	86	Air filter	86	Air filter	86	Air filter
Fan housing	87	Fan housing	87	Fan housing	87	Fan housing	87	Fan housing
Fan wheel	88	Fan wheel	88	Fan wheel	88	Fan wheel	88	Fan wheel
Water pipes, hoses	89	Water pipes, hoses	89	Water pipes, hoses	89	Water pipes, hoses	89	Water pipes, hoses
Lubrication pump	90	Lubrication pump	90	Lubrication pump	90	Lubrication pump	90	Lubrication pump
Lubrication distributor	91	Lubrication distributor	91	Lubrication distributor	91	Lubrication distributor	91	Lubrication distributor
Lubrication fitting	92	Lubrication fitting	92	Lubrication fitting	92	Lubrication fitting	92	Lubrication fitting
Lubrication pipes, hoses	93	Lubrication pipes, hoses	93	Lubrication pipes, hoses	93	Lubrication pipes, hoses	93	Lubrication pipes, hoses
	94		94		94		94	
Trolley brush, trolley arm	95	Trolley brush	95	Trolley brush, arm	95	Trolley brush, arm	95	Trolley brush, arm
Bare conductor	96	Bare conductor	96	Bare conductor	96	Bare conductor	96	Bare conductor
	97		97		97		97	
	98		98		98		98	
	99		99		99		99	

C. Failure cause code.

Normally a two-digit code is enough. The code shown below has been used in different branches of industry with a good result.

1st group. Material, design, manufacturing.

11 = material failure, flaw, crack etc

12 = wrong handling of material (heat treating crack)

13 = failures in manufacturing (grinding cracks)

14 = incorrectly selection for the application

15 = fatigue cracks

2nd group. Installation

21 = incorrectly aligned

22 = damaged at installation

23 = bad connection

3rd group. Operation

31 = overloaded

32 = bad handling

33 = insufficent lubrication

34 = wrong lubricant

35 = lacking preventive maintenance

36 = bad repair

4th group. Environment

41 = corrosion from gases

42 = excessive heat

43 = water, high humidity

44 = outside causes, accidents, thunderstorm, flood

5th group. Normal failures

51 = normal weal

Please observe that there is no Miscellaneous cause. If such one is used, most of the observations will be recorded on that cause because people sometimes are lazy, sometimes they think they do not know the correct cause etc.

Of course, the code should be made according to the needs within the industry, however, it would be an advantage if more industries could use the same codes.

D. MAINTENANCE WORK TYPE CODE.

For many reasons it is necessary to split the total maintenance cost on a) the objective and b) the cost type.

This may be done by adding two digits to the normally used account number for maintenance. In the main accounting it might be unnecessary to split the maintenance cost, however, on the maintenance management and production management level this is of essential value.

Objective code.		Cost type code.	
-1	Abnormal reasons	-1	Labour cost
-2	Break-downs	-2	Overhead
-3	Preventive maintenance	-3	Spare parts
-4	Repairs following PM	-4	Outside labour
-5	Other repairs	-5	Purchased material
-6	Modifications to reduce need of maintenance		
-7	Modifications requested by production		

The reasons for splitting the repairs on -1, -2, -4 and -5 are

A. Abnormal causes cannot be prevented by adding PM.

B. Break-downs might be possible to avoid by changing or adding PM.

C. Repairs following PM indicate that some defects have been found when PM was performed. There should be some such repairs to show the effectivity of PM.

D. Repairs not following PM indicate that operators and other people in the production departments keep their eyes open. It might also indicate insufficient PM.

E. -1 and -2 jobs are connected with unplanned stops, while -4 and -5 are performed during planned stops. Unplanned stops are always disturbing production and may cause severe losses, while planned stop may cause planned losses.

The cost type code is mostly used to follow the amount of manpower and how well the spare part supply follows the demands.

Analysis should be made on these codes in combination with the stop type code.

E. STOP TYPE CODE.

It is of interest for both the production people and the maintenance people to follow the development of stops in the production departments. Sometimes in modern industries the stops are recorded immediately they occur. At that moment it might be impossible to establish the correct cause as far as the cause falls within the maintenance field . If a three digit code is used the same code can be used for both production and maintenance.

When a cause falls within the production department they establish the cause themselves. If the cause has something to do with maintenance the production people use one code introduction. On the maintenance job order the real cause is added after an analysis.

In this connection it should be mentioned the importance of recording production operation hours and, in some cases, the produced quantity and maybe also quality. The best way is to record these figures compared to the calender and the clock. It facilitates utilization of the record for many purposes, such as determining the MTBF, Mean Time Between Failures, which is the measurable quantification of Reliability, and also the MTTR, Mean Time To Repair, which indicates the Maintainability.

There is a few more information of interect, such as

- time for request
- time for job start
- time for job finish
- performing department
- performing personnel

5. Utilization of recorded information to improve maintainability.

If a manual recording system is used it might be rather difficult to find the indications of too low Maintainability. Even in a computerized system the indications might be rather unclear.

As Maintainability is measured in Repair or Activity time such figures should be available. If the codes described earlier in this paper are used it is possible to sort out the repairs and PM activities, find the labour time and calculate the maintenance cost. The waiting time and the stop time are useful for the analysis.

If the analysis covers a number of similar equipment, a number of buses, a number of airplanes, a list can be made giving the following figures:

- Average, max and min values for waiting time
- Average, max and min values for work time, MTTR, $Mmax_{ct}$ $Mmin_{ct}$
- MTTR for different subunits and components
- Total average maintenance cost including spare parts
- Total cost
- Total stop time

This list is analysed and most likely a maintenance engineer can read out where improvements could be made, such as

- replacement of components with failure frequency above average
- introducing more effective maintenance methods
- better maintenance organisation

If the maintenance object is a large plant or machine the same listing could be used. However, it should be remembered that in these cases the analysis should cover a longer time period to get more information to guide the decisions. If the analysis covers only a short time the listing is unnecessary. In such case the direct analysis of the record is sufficient.

The correct and complete recording of data from operation and maintenance is the best help for a maintenance engineer in his endevour to improve both Security of Function, Maintainability and Maintenance Efficiency.

THE TECHNICAL DOCUMENTATION

One of the key points in procurement and maintenance work is the technical documentation for the equipment. The importance of the documentation increases with increasing complexity of the equipment.

Technical documentation is expensive. For complex equipment it is not unusual that the complete documentation will cost 5 - 15 % of the investment including installation. This fact must be remembered when two or more offers are compared. The future value of the documentation is very often underrated at the decision stage.

The need for technical documentation of course varies with the type of equipment. For very complex units the need is greater than for simplier units. A large number of similar units, such as buses, can carry the cost of a more complete documentation than one single unit, such as a pump or generator set.

In many cases the manufacturer of a single unit, such as a rolling mill, is unable to provide complete documentation because the manufacturer has no real operation experience. In these cases the customer must realize his duty to collect, process and record information and convert the collected experience into usable technical documentation. If he neglects that, his equipment most likely will not give the estimated performance.

The complete list of technical documentation should contain:

- Description of the equipment, design, operation, capacity, measurements, weights, demand on supply such as electric power, water, air, gases etc. Space requirements for installation and maintenance, for operation and storing material for production.

- Complete assembly drawings, at least the essential parts.
- Diagrams and connection tables for electric, hydraulic, pneumatic and electronic systems included.
- Advices for dismounting and mounting, for fault-finding, eventually test programmes for function testing.
- Wear limits, adjustment measurements etc necessary for the correct checking of wear conditions and correct alignment and adjustment of the equipment.
- Spare parts catalogue, recommended spare part store list.
- Lubrication instructions.
- Maintenance plan including instructions for the performing of maintenance activities.
- A description of the normative maintenance organization used for the calculation of Availability, Systems Effectiveness, Reliability and Maintainability, Capacity and Capability.
- A list of special tools, instruments and other aids necessary for the performance of condition monitoring, condition checking, failure localisation and performance of preventive and corrective activities.

The British Navy has developed a special form of design methodology called DDS, Design Documentation System. The designer works side by side with skilled maintenance engineers. Step by step during the design work the maintenance engineer works in the documentation necessary for the performing of all maintenance activities.

For complex systems the same Navy has developed a diagnostic documentation system called FIMS, Functionally Identified Maintenance System. This system includes maintenance instructions, fault-finding advices including diagrams etc, test programmes for function etc.

The practical situation for any maintenance engineer would be greatly improved if these became more widely accepted and used.

Technical documentation language.

The designer and the advanced maintenance specialists very often use a language which is difficult for anyone else to understand. This fact should be recognised and measures taken to translate the scientific language into normally used workshop language.

If this is not done the maintenance personnel will meet great difficulties to understand the documentation correctly and utilise the valuable information contained.

Another problem is foreign languages. As the author comes from a country where one of the "smallest" languages in the world is used he is well aware of the difficulties to supply correct information to the operators and the maintenance personnel.

In the developing countries these difficulties are still greater because in many cases the personnel available in such countries do not have any industrial tradition at all. In the industrialised countries the children meet technical equipment already in the nursery in the form of mechanical toys, even advanced electronic equipment such as TV, radio, record players, tape recorders etc. When these youngster grow up and have finished their education they enter industry with a natural background and they are used to utilise technical aids. For them a complex machine may contain something new, but as they are accustomed to handle such things it does not give them too many problems.

In the international field much can be done to improve the situation. A common terminology would be appreciated. In this connection it would be helpful to all engineers all over the world if the English language could be used as basis for the terms used.

If the other languages could base their terms on the English, a better understanding would be possible between other languages, such as Russian translation to Swahili or whatever the need could be.

MAINTAINABILITY AND THE MAINTENANCE ORGANIZATION.

As already has been mentioned the qualitative properties of a system known as Maintainability are based on a normative maintenance organization.

If the calculated result of an equipment should be possible in practical operation the actual maintenance organization must be able to provide the minimum services indicated by this normative maintenance organisation.

This of course is no real problem if the equipment consists of a new plant, starting from scratch. When a new piece of equipment is added to an existing plant or organisation the problem is more complicated. The existing maintenance organisation already has some parts of the necessary capacity and the problem is now, how much more is needed to meet the demand from the new equipment.

Today it is rather unusual that a new piece of equipment is so similar to the already existing equipment that no actions are necessary to improve the maintenance organisation in some or other respect. The development within the technological field is very quick and the competition between the manufacturer of industrial equipment is so hard that they have to introduce newly developed units more often than before.

If the responsible poeple do not consider these facts when they order a new piece of equipment, the expected or calculated benefit will be impossible to reach. When decisions on purchase of equipment are made the maintenance organisation should be and must be one of the facts to be considered. It is senseless to concentrate the efforts on the equipment only. Even the best equipment in the world does not operate satisfactorily without the qualitatively and quantitatively correct amount of maintenance.

It must also be remembered that it takes time to increase the quantity and quality of maintenance resources. The analysis of the need in these respects must start already at the first step of an investment project, usually called the definition stage. When the decision to buy or start the investment is taken it is already too late.

The most important part of the maintenauce resources is the personnel, their qualifications and number (in that order, please). A well qualified maintenance man is always more efficient than a man with less skill. No incentive wage system in the world could change that fact.

To improve the qualitative properties of the maintenance organisation several different actions can be considered, such as:

- a rational maintenance job preparation and planning organisation
- a continous training and up-grading programme
- an incentive wage system.

Someone may ask how an incentive wage system can improve quality. The fact is that in order to introduce an incentive wage system all the rest must be introduced first. As managers are inclined to look at efficiency and cost first it is much easier to "sell" them on improving the general conditions in the maintenance department using the increased efficiency as a bait.

During the last years a large number of industries have been carefully analysed to find the relation between efficiency, earnings, wage system type and general atmosphere in both production and maintenance departments. The reports can be found in a booklet called "The Condemned Peicework", available also in a number of other European languages. The common meaning is that the straight incentive or piece rate wage system gives a lot of stress and other disadvantages. The system having the smallest disadvantages for the personnel and which still contains enough stimulation to work efficiently is "the Premium Wage System". In this system the earnings come from two or three different wage types.

The first part of the earnings comes from a fixed rate wage, usually between 50 and 90 % of the total earnings. The size is established based on Job Evaluation and an agreed difference between the highest and lowest levels.

The second part can be a bonus, or Premium Wage, calculated either on group efficiency compared to established standard time, or individual piece rate. The individual efficiency is seldom used in maintenance departments.

The third part can be an individual wage based on Merit Rating. In the merit rating such factors as presence at work, usability for several types of jobs, care for material and tools and number of employment years can be considered.

Sometimes a fourth type of wage is used, a production bonus, based on an agreed Standard production, defined both as quality and quantity.

The most used type consists of 75 % fixed rate, 5 % Merit rated wage, and 20 % group efficiency incentive. This type is used in many maintenance organisations today.

Too often the job preparation and planning organisation is neglected. If the job order is not prepared correctly the worker has to spend a lot of his valuable time to find out how the work should be performed, which tools and spare parts are needed, which technical documentation is needed and where can it be found. The result is that the worker spends a lot of his time on walking forth and back, collecting things he had forgotten or did not know he had to use. These conditions will result in an unwanted atmosphere of irritation, feeling neglected, low interest for the job, laziness etc.

It would lead too far to go into these details here, however, the problem is very serious, especially in developing countries.

The training and up-grading of the maintenance personnel at all levels is of great importance for the efficiency. In too many cases the maintenance manager and his engineers think they have to do all the technical and economical decisions themselves because their personnel is not competent to do it. With a good atmosphere and good training the worker is capable of making many of the small decisions himself. But can he be expected to make these decisions without knowing how a decision is made and the basis for decisions?

The training and up-grading should be considered as a continous problem. As a consequence the training programme also must be continous.

The equipment and the maintenance organisation must be brought up on equal level, both in quantity and quality, otherwise the total result will be unacceptable.

MAINTAINABILITY IN THE DEVELOPING COUNTRIES

The interest for the qualitative properties of an equipment known as Maintainability is steadily increasing in the industrialised countries. The reason may be the harder economical conditions in most of these countries, resulting in demands from management on high utilisation of the invested capital. As the time consumed for maintenance activities in most cases has to be planned together with the production planning, it is obvios that even other professionals than the maintenance specialists will find it necessary to reduce the "spoiled" time, meaning they ask for higher reliability and better maintainability.

In developing countries the problems have another nature. In many cases the problem is to find more manual work for an unemployed population. The economical problems have to be pushed into the background. If the efficiency of the maintenance department is a little low it does not mean so much. However, very soon the situation most likely will change. When a developing country starts to export its products to other countries they face the problem of quality control. One phase of the quality control problem depends on the machinery, the production equipment.

This means that the qualitative demands on the maintenance personnel most probably will be the first to tackle. The solution is organization and training.

The second problem facing an exporting industry is quantity on time, security in delivery plans. This problem calls for reliable machines, working when they are planned to work. Unplanned stops will cause a lot of trouble. Such stops have to be as short as possible, and the repair must be done with skilled people and to such a quality that the equipment retains its quality. Again, the solution is training to a certain part, organization to another part and better reliability and maintainability of the equipment will do the rest.

Even if the production economy, utilization of the invested money, is a second hand problem it will become the first rather soon. No country can afford to spend money without considering how it should be returned. Most of the developing countries have a shortage of foreign exchangable currency. Mortgages have to be paid, interest too. If the return of investment is too low the entire economy of a country will suffer, prolonging the development period for that country. The industry of the country has to work efficiently and economically. Existing industries have to be maintained to a certain level to prevent them from loosing money even if the initial investment already is returned or written off.

Loans are always expensive means to get investment capital. Very often these loans are in foreign currency. When a country considers an investment they must be sure they get the best possible equipment for the money. The best possible equipment is the one that has the highest utilisation level, meaning the equipment has a high reliability and good maintainability.

Spare parts are always serious problems for developing countries. One solution is to reserve a certain amount of currency for the future import of parts from the country of origin, another is the establishment of base industries, foundries, steelworks, mechanical manufacturing industries. If such base industries are working within the country they can take over the manufacturing of spare parts and substitute import by own manufacturing.

Local, national or even regional manufacturing of certain spare parts is one way of improving the maintainability of a plant. Reduced investment in spare parts, more foreign currency available for the purchase of new equipment, possibilities to manufacture own machines are some other benefits.

When the best possible equipment is wanted it is the customer who must specify what he wants. An investor must not rely on the supplier, even if he happens to be the most experienced company in the world within his field. A practical case may describe what can happen.

A manufacturer of a certain type of machinery is well known all over the world as the very best one. A company was offered his machine and a competitor's. A careful calculation of the life time cost was made.

	Manufacturer I	Competitor
Initial cost	147 780,-	178 300,-
Maintenance cost per annum	25 100,-	8 600,-
Expected life	12 years	12 years
Cost of ownership for 60 machines	27 540 000,-	11 320 000,-

In the absolute most normal case the purchaser would look at the initial cost only and choose the lowest bid. The competitor's bid is 2 millions higher than the well known manufacturer's.

The developing countries have to learn how to buy, a tricky technique which is not too well known in the industrialised countries. Then how could it be possible? In the industrialised countries too many of the decisionmakers have too many prejudicies, bound to traditions and prestige. In the developing countries at least there are not too many traditions of that type.

When a plant or piece of equipment is delivered to a developing country the maintenance man usually is informed when it arrives. This must be changed. The equipment delivered to the developing country most likely is designed for an industrialised country.

The maintainability is designed in on the wrong level, the normative maintenance organization which is the basis for the calculated maintainability does not exist in the developing country. Even such a small thing as a hydraulic puller for a gear or bearing is impossible to find. When it is needed it will take hours to remove the gear or bearing, compared to minutes if the puller is available. The puller should have been delivered together with the machine, of course, but no one asked if the puller was available and no one asked if some tools were needed.

Just to show how carefully a procurement project is handled to obtain the best plant at the lowest total life time cost the content of a part of the request used when inviting manufacturers tenders is shown on the next page.

If this procedure is followed the production manager and the maintenance manager will have the greatest possibilities to get a plant that really works and gives the best possible benefits to all concerned. And please remember, there is no easy way to success.

PURCHASE CONTRACT FOR . . . .

<u>The Maintenance Part.</u>

1. Operative plan
2. Maintainability
3. Maintenance general programme
4. Test philosophy
5. Quality and quantity of maintenance personnel
6. Training programmes
7. Existing resources
8. Information and progress meetings
9. Responsability for the system
10. Inspection before delivery
11. Guarantee
12. Repair services
13. Maintenance documentation
14. Time plans
15. Failure reports
16. Procurement recommendations, maintenance resources
17. Reliability analysis
18. Standardisation
19. Directions for maintenance
20. Modifications
21. Installation
22. Technical assistance
23. Safety directions.

APPENDIX I

MAINTAINABILITY CHECKLIST

1. SELECTION OF COMPONENTS

- Which Standards are acceptable?
- Which MTBF is requested?
- Which other components are likely to be damaged in case of a failure?
- Is the component available in the customers country?
- Can a failure be indicated? How? MTBF?
- Can the function be tested? How?
- Does the selected component comply with the specifications?

2. MODULARIZATION

- Which level of modularization is the most suitable?
- Which of our standard modules are acceptable?
- Which level of skill is necessary for replacement of the module?
- Is this module available in the customers country?
- Can the function be tested? How? MTBF?
- Are test connections standard? If not, can they be added?
- Can the module be repaired locally? Necessary skill level?

3. ASSEMBLY OF COMPONENTS

- How is the component assembled?
- Which tools and aids are needed? Are they available?
- Same for disassembly?
- Is written instruction needed?
- Threaded holes for ass. or disassembly?
- Space around the component for removal?
- Space for tools?
- Which other components have to be removed to facilitate replacement?
- Instructions for installation and testing?
- Limits for function or wear? Recommendations for replacement?
- Which will be the MTTR

4. MOUNTING OF MODULE

- How is the mounting of the module designed?
- Which tools and aids are needed? Are they available?
- Same for dismounting?
- Is written instruction needed?
- Lifting facilities? Available?
- Space enough for the removal of the module? For testing?
- Space for tools and lifting dev.?
- What must be removed to replace the module?
- Instructions for replacement?
- Limits for function? Recommended service time?
- Which is the MTTR?

4. GENERAL DESIGN TECHNICAL COMPLEXITY MTBF MTTR

- Does the complete equipment contain

Electronic components ? How many ?
Printed integrated circuits ? How many ?
Electric relais ? How many ?
Circuit breakers ? How many ?
Manual switches ? How many ?
Electric DC-motors ? How many ? Types ?
Electric AC-motors ? How many ? Types ?
Special motors ? How many ? Which types ?
Generators ? How many ? Which types ?
Cables ? What types ? Connection types ?
Limit switches ? How many ? What types ?
Pushbuttons ? Lamps ? Instruments ? Indicators ?

Hydraulic pumps ?
Hydraulic motors ?
Hydraulic cylinders ?
Directional valves ?
Pressure control valves ?
Flow control valves ?
Fluidistors ?
Filters ? Strainers ?
Hoses ?
Rotating connections ?
Dust filters ? Instruments ? Test valves ? Test connections ?
Pneumatic motors ?
Pneumatic directional valves ?
Flow control valves ?
Pressure control valves ?
Rotating connections ?
Hoses ?
Filters ? Noise dampers ? Test valves ? Test connections ?
Lubricators ? Oil circulation pumps ?
Oil tanks ? Level indicators ? Flow indicators ?

Maintainability checklist, continued.

5. NORMATIVE MAINTENANCE ORGANIZATION.

Which manning would be able to take care of all maintenance activities?

Give the figures in manhours per one thousand hour of operation.

Mech.Eng.	Electr. Eng.	Electronic Eng.	Hydraulic Eng.	Other Eng.
Mech. maint. techn.		Electr. maint. techn.		Electronic maint. techn.
Fitter I	Fitter II	Fitter III	Fitter IV	
Welder I	Welder II	Electr. I	Electr. II	Electr. III
Pipe fitter I	Plumber	Carpenter	Bricklayer	Other
Semiskilled mech.		Semiskilled electr.		Semiskilled other
Working in shifts?		Daytime?		Nightwatch?
Machine tools?		Welding units?		Other machines?
Test equipment? Please specify type and number.				
Transport equipment for personnel?				
Transport equipment for parts and modules?				
Recording procedure?				
Follow-up procedure?				
Expected MTBF?		Expected MTTR?		Expected Availability
Calculated value of spare parts?				
Is a spare part list supplied? [redacted]				

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