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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

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TRAINING OF MANPOWER IN MAINTENANCE FROM THE STANDPOINTS OF EQUIPMENT DESIGN, MANUFACTURE AND OPERATION*

Prepared by the
UNIDO Secretariat

based on the work of

Prof. Dr. Jovan Todorović**

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** Professor, Motor Vehicle Department, University of Belgrade, Yugoslavia.

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A. INTRODUCTION

Rapid economic growth is a prerequisite for the availability of consumer and capital goods. Both types of goods may either be imported or manufactured locally. In both cases, the availability of infrastructure and energy is of great importance. Also, machinery, equipment, transport and other vehicles as well as information and other kinds of logistic support materials are necessary inputs.

Generally speaking, developing countries satisfy their needs for capital goods, technology, communication and systems support by imports from developed countries. At the intial stage of development, this is probably the only possibility. Appropriate support from developed countries is required at this stage. However, developing countries should make greater efforts to develop their own technologies, manufacturing base and know-how in order to ensure sustained development and render their economies independent as far as possible and capable of satisfying most of their needs in terms of consumer and durable goods. They will thus ensure that development is in line with their particular needs and take maximum advantage of natural endowments, available raw materials, energy resources and climatic and other conditions.

In order to fully utilize imported plant, machinery and technology, developing countries do not only need foreign exchange. Likewise important is the availability of raw materials, energy, transportation facilities, communications, after-sales services and distribution of products in the local market. This requires specific knowledge in different fields, and it is therefore of great importance to enhance the intellectual potential, knowledge and know-how of local personnel.

Knowledge is a prerequisite of development. While education and training schemes will initially concentrate on the proper utilization of imported machinery and technology, further programmes should aim at enabling trainees/students adapt and develop new technologies, machinery and equipment on their own, taking due account of local conditions, new scientific achievements and developments in the field of electronics. Thus, apart from 'applied knowledge', 'creative knowledge' is required and should be fostered at an early stage of development.

The problems related to maintenance of industrial plant and machinery should be given special attention. They involve technical and technological processes of great complexity. The availability of maintenance services contributes greatly towards the optimum exploitation of improved plant and machinery. In view of the scarcity of foreign exchange in developing countries this issue merits particular consideration in order to extend the life-cycle of imported equipment, and increase the technical availability of such equipment.

In order to strengthen maintenance services in developing countries, knowledge at all levels needs to be increased. Therefore, training should be extended not only to operators and maintenance staff, but also to management involved in decision-making in regard to maintenance planning, organization and execution, setting up work-shops, purchase of spare parts, etc. Training in the field of maintenance will ensure better utilization of available plant and equipment and thus a higher return on investment.

The purpose of this paper is to highlight specific issues related to training from the points of view of the designer, manufacturer and user of machines and other capital goods. Accordingly, the necessity of promoting 'creative knowledge' in training courses will be emphasized as it is of utmost importance for the development of a country's indigenous know-how and technology. An attempt will be made to also deal with complementary issues such as supply of spare parts and acquisition of capital goods. In short, the paper will discuss maintenance-related issues to be considered in designing, producing, importing and utilizing new equipment.

B. LIFE CYCLE AND COST EFFECTIVENESS

Every technical system has a determined and comparatively limited life. The total life cycle is calculated by adding the time required for designing and producing the equipment, and for the utilization of such equipment during its serviceable life. Life cycle is a complex term, comprising three different groups of activities as shown in figure 1 below,i.e. development, production and operation of plant. These are mutually interrelated in many ways.

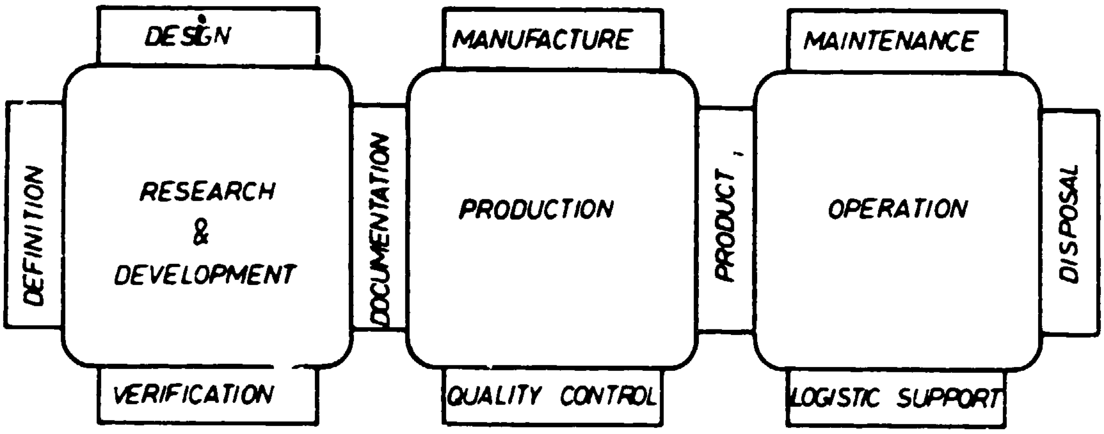

Fig. 1

The implementation of each activity or part thereof requires 'efforts'and financial investment in capital assets.Thus, one can establish the total costs of the life cycle equivalent to the total amount of the funds invested in both activities. Figure 2 gives a breakdown of the costs of the life cycle. While the table is self explanatory, it should be pointed out that it comprises the most important elements only. In individual cases, the cost structure mav be quite different.

Evaluation of the feasibility of a particular investment needs to take account of the different functions the technical system is capable of providing, i.e. 'system effectiveness'. This term indicates to which degree the system satisfies the requirements in accordance with planned or desired targets. System effectiveness depends primarily on reliability -

the capability of the system to operate without failure and on availability, that is the actual technical availability of equipment in relation to its full productive capacity.

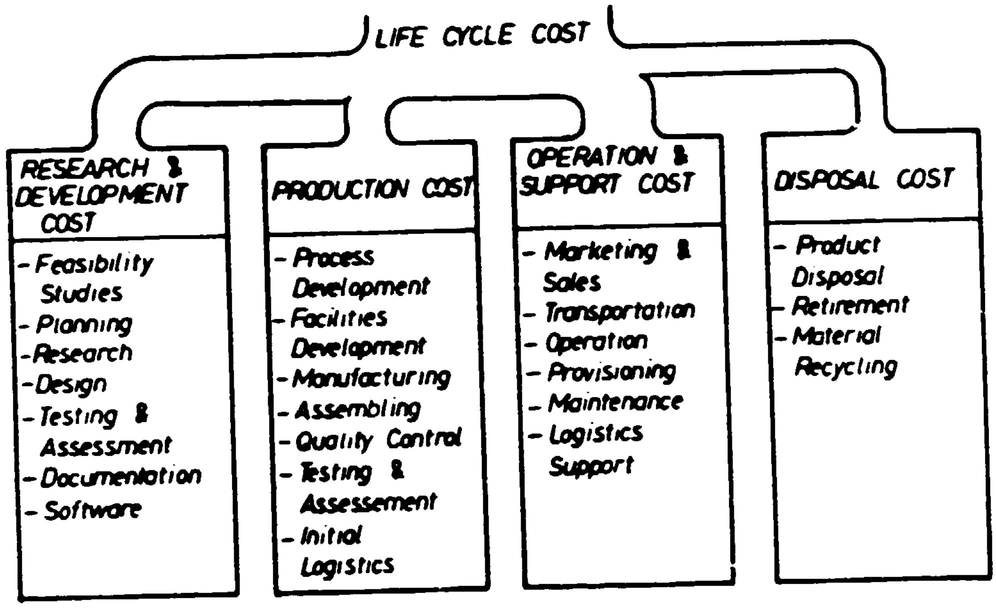

Fig. 2

Effectiveness of the funds invested (effectiveness of the cost of the life cycle) depends on the effectiveness of the technical system (capital goods, machinery, plant) per unit of asset invested in all stages of the life cycle. This is illustrated by figure 3 below.

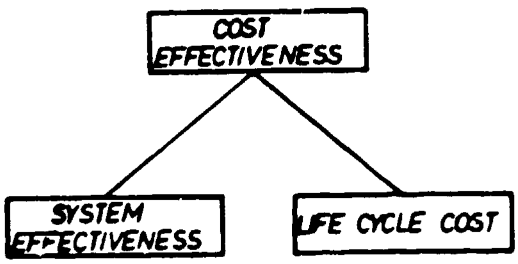

Fig. 3

In order to ensure the highest possible effectiveness of the funds invested /1, a number of requirements has to be met. First of all, the technical system itself should have favourable properties of reliability and suitability for maintenance from the design point of view. In addition to these essentially internal factors, important external factors such as material supplies, servicing, maintenance, spare parts provision, etc. have to be taken care of as well. This involves servicing and maintenance facilities, warehouses, operation and maintenance personnel, their qualifications and knowledge, availability of technical and other documentation, etc. All these elements are covered by the term Integral Logistic Support and are studied within a separate scientific discipline - Logistics. A schematic presentation of the contents and targets involved in logistics is shown in Figure 4. It is beyond any doubt that the activities and procedures covered by the Integral Logistic Support also impose certain investment in determined 'efforts'. These costs are part of the total life cycle costs, as explained earlier.

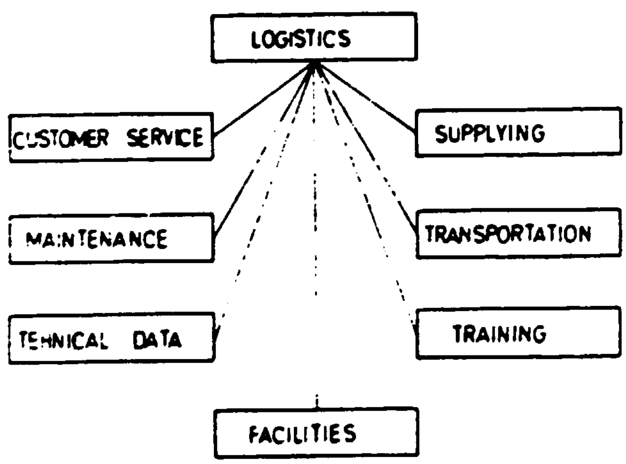

Fig. 4

The share of the cost of logistics in the total investment is illustrated schematically in Figure 5 below. This figure shows the purchase price of the equipment as the peak of an iceberg, with the cost of items related to logistics being invisible at the time of purchase of the

/1 Blanchard, B., Design and Management of Life Cycle Cost, M/A Press, Portland, 1978 equipment. The purchase price covers the cost of the manufacturer of equipment with regard to its development and production, and a profit margin. The remaining costs of the life cycle are borne by the purchaser (with the exception of warranty claims). These costs are usually higher than the purchase price. As can be seen from Figure 5, the larger part of these costs is related to maintenance. Thus, maintenance costs considerably affect the cost of the total life cycle of machinery and equipment and frequently acccunt for the largest share in the total cost of logistics. /2

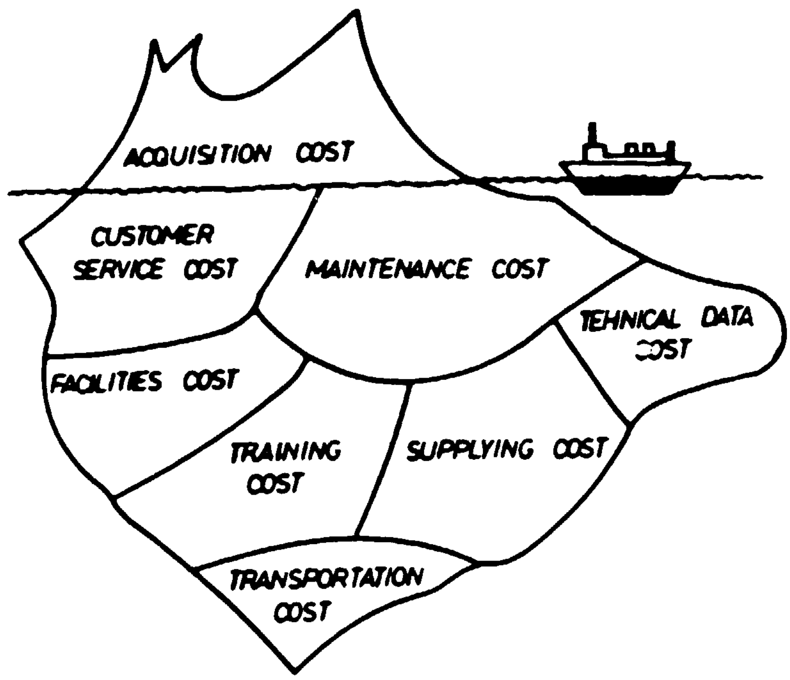

Fig. 5

The proportion of the cost of individual components of the life cycle of technical systems is of great importance. It applies more or less to all types of technical systems and to their operation. Literature on this topic is abundant. It is stated, e.g. that the cost of maintenance of trawler tractors over a period of eight years exceeds the purchase price by 4 to 5 times /3, while the cost of maintenance of light trucks over a period of five years and with mileage of 200,000 km exceeds the purchase

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/2 Todorović, J., Cost effectiveness optimization - An important system target, Int. J. Prod. Res., 1982, No.3

/3 Kuznjekov, E.S., Problems in automobile reliability and maintainability control (in Russian), Vissaja Skola, Moscow, 1977 price by 3.5 times. Similar data are available on machine tools, agricultural machinery, and also for computers and electronic systems /4 and /5. It may be expected that in developing countries the costs of logistics will be higher than in industrialized countries.

C. THE MAINTENANCE PROCESS

The term maintenance covers all activities related to the prevention or removal of failures. As a technical system is assumed to be fully operational and 'as new' after maintenance activities have been completed, the maintenance process may also be referred to as the process of renewal /6.

The process of maintaining technical systems depends on two variable factors, i.e. the length of operation of the system before maintenance is called for depending on the reliability characteristics of the system, and the time required to perform maintenance activities to render the system fully operational again. It should be mentioned at this juncture that any technical system may have to be kept in 'storage'. Agricultural machinery, which has seasonal use, is a case in point. This has to be taken into account, as machinery and equipment which are not being used over a prolonged period of time will require maintenance and overhaul before they can be used again.

The basic status of a system could best be analyzed by using 'the status time picture', which is shown in general terms in Figure 6. It is shown in relation to the total (calender) time, which means that all time intervals have been included: time in operation or 'up-time' (t_u), time in failure or 'down-time' (t_d) and storage time (t_s). The example has been drawn up so as to cover all other important elements affecting 'the status time picture' of the system, beginning from its manufacture and start-up (zero point).

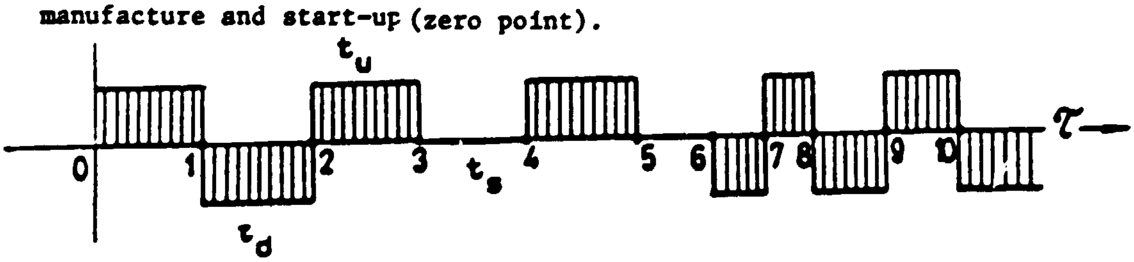


Fig. 6

/4 Ankenbrandt, F.L., Electronic Maintainability, Chapman-Hill, New York, 1960

/5 Kuznjekov, E.S., Maintenance and reliability of motor vehicles (in Russian), Transport, Moscow, 1977

/6 Cox, D.R., Renewal Theory, John Willex and Sons, New York, 1962

It is assumed that immediately after leaving the manufacturing plant there is need for the system to be operated, and that the system is operating in the period 0 - 1, being in proper condition and performing adequately. At the point of time 1, however, a failure occurs and the system changes its status. Since the system is repairable, the failure is removed by maintenance during period 1 - 2, and the system is restored to operating condition. At point 3, the need for operation ceases and it is anticipated that the system will not be operated through a prolonged period of time. The system is put in 'storage' after having been specially prepared for this. One must make sure that the system is fully operational when stored. The actual condition of the system during the period 3 - 4 is, however, not known without special tests being performed. In the example given it is assumed that such checks are not performed so that the 'time status picture' for the period 3 - 4 does not provide information on the status of the system. At point 4, a need arises again for the system to be operated. It is taken out of 'storage' and should operate satisfactorily. The system is needed to operate until point 5 in time, when it is put in 'storage' again. However, when it is required to operate at point 6 in time, it does not function. During period 5 - 6, when the system was in 'storage', a failure occurred and the system therefore does not work. It is in 'down-time' until maintenance activities have been completed, i.e. point 7 in time. During the period 7 - 8, the system functions satisfactorily, but at point 8 the need arises to carry out preventive maintenance. Accordingly, the system is again in 'down-time' condition. After preventive maintenance has been carried out, the system operates again, until at point 10 in time another failure results in a break-down, etc.

All time intervals shown in Figure 6 are essentially incidental or random values. The length of the period of time up to the occurrence of the failure is incidental and so are the factors determing the duration of the maintenance process. Also, many random factors affect the period of time in 'storage'. Accordingly, all stages in the utilization of a technical system are dependent on random factors. This applies to maintenance and its implementation as well.

It is important to emphasize that the various time intervals described above are structured in a complicated way. This also applies to 'up-times' and 'down-times'. 'Up-time' excludes all 'down-times' and break-downs caused by power failures, climatic conditions, absence of operators, lack of work to be carried out, time required for washing and lubrication and for feeding with energy fuels, etc. 'Down-time' also includes the time spent waiting because maintenance facilities are occupied, transportation poses a problem, labour is not available, and most importantly, spare parts are in short supply. Detailed analysis is required to determine how to achieve minimum 'down-time' of the system. In many cases, and especially in developing countries, the time spent waiting for spare parts is a factor which considerably affects the overall 'time status picture', i.e. the duration of 'down-time' and the utilization of the total available time.

The process of maintenance can be evaluated in many ways. A simple but good indicator is the so-called availability expressed by the ratio between the actual time in operation and the total time the system was designed to be available for productive use. It is obvious that availability will be higher at shorter 'down-times'. As reduction in failure shut-downs is achieved through a better maintenance system with adequate logistic support (primarily with respect to the supply of spare parts), it may be concluded that availability can be increased by an improved maintenance system. This obviously increases the total effectiveness and reduces the costs of the achieved effectiveness.

The duration of 'down-time' under failure depends to a large extent on the machine to be maintained. One therefore refers to properties built into the technical system relating to maintenance. This is usually evaluated by means of the so-called 'maintainability' which includes the length of time required to accomplish a maintenance process. The higher the maintainability, the higher the probability that maintenance procedures will take less time. This means that a technical system has to be specially adapted to maintenance. In addition to satisfying the performance requirements, providing a production output at determined quality, and along with the capability of operation over longer periods of time without failures, modern machines and other capital goods have to be designed so as to ensure they are maintainable, i.e. easy to maintain and requiring fewer maintenance activities than older designs. Indeed, in certain aspects one can 'design-out' maintenance by developing components which do not require maintenance at all during a life cycle.

D THE MAINTENANCE SYSTEM

The concept of a maintenance system lies in its quality to improve the effectiveness of the system. There are two essential conceptual possibilities: preventive and corrective maintenance (PM and CM in Figure 7). In the first case, maintenance procedures are carried out before failures occur and they are undertaken in order to prevent or delay failures. The corrective maintenance concept, on the other hand, is designed to apply maintenance after a failure has occurred. In this case, the task is to restore the system from 'failed' to operative status. Both concepts can be used in conjunction, and then we speak of combined maintenance (OM). Combined maintenance can be carried out in several ways, but usually it is undertaken in such a way that parts of the technical system are maintained preventively, while the remaining parts are maintained after a failure has occurred.

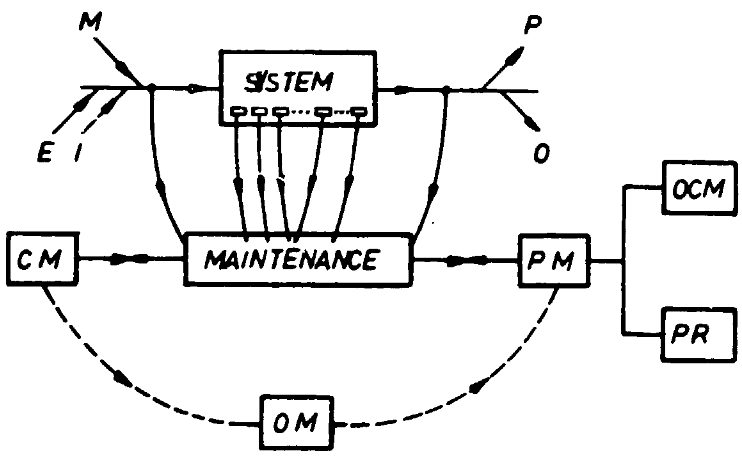


Fig. 7

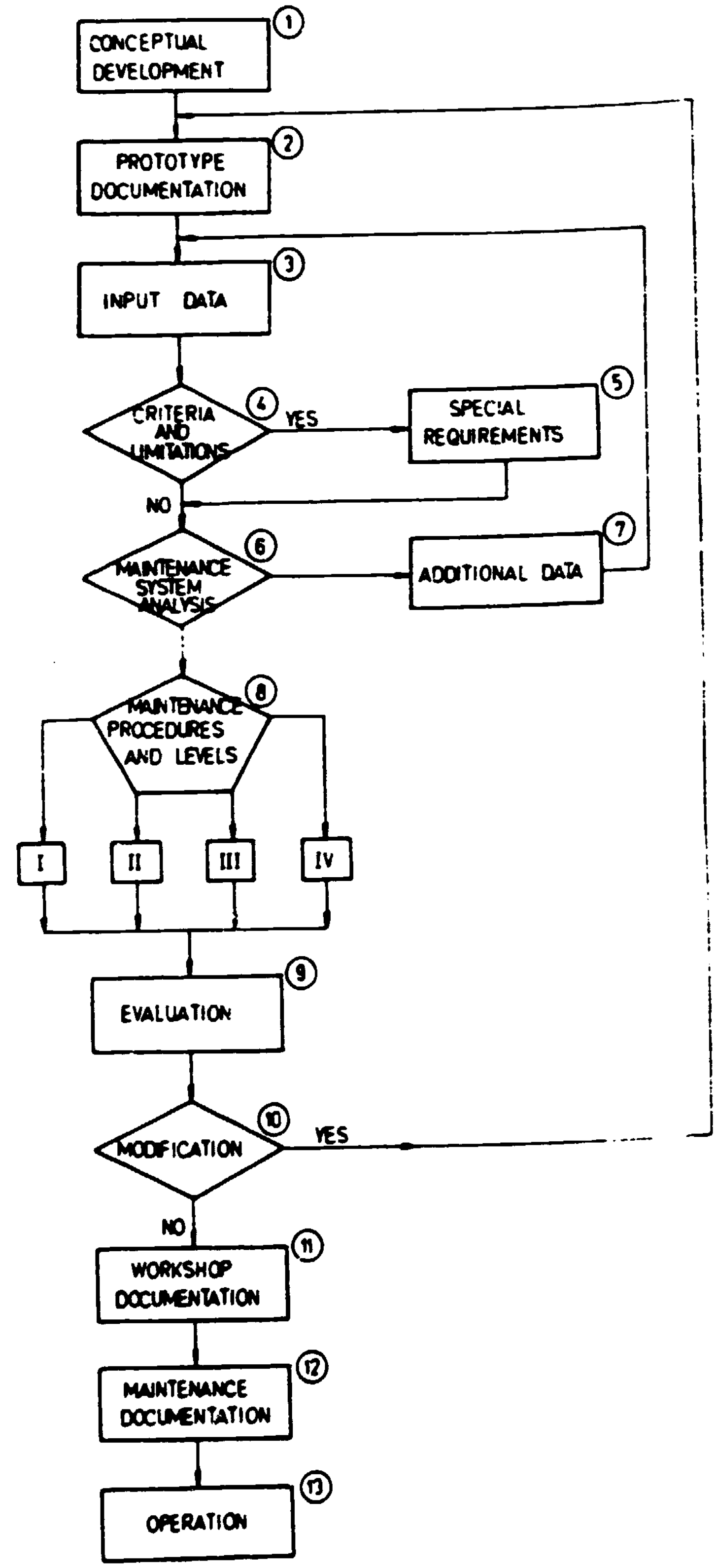
Preventive maintenance which is obviously much better than corrective maintenance (prevention is better than cure), can be carried out in several ways. It may comprise 'on condition maintenance' (OCM) and 'preventive replacement' (PR), which was popular up to some time ago. The 'on condition maintenance' is preferable from the financial point of view and also contributes to an increased level of availability.

In addition to these conceptual elements, there are two other elements of importance for the quality of a maintenance system, i.e. organization and technology for individual maintenance processes. However, these are questions that have to be solved separately i each individual case, depending on the type of equipment and other circumstances. These parts of a maintenance system cannot therefore be analyzed in detail. It may be necessary to only indicate that a successful maintenance system presupposes an adequate information system to provide the required information on the operation of the machines to be maintained, and on all factors affecting the maintenance process (failures, operating conditions under which the machine has been used before the failure has occurred, operating load, climatic conditions, quality of operators and their knowledge, spare parts supply, etc). These are specific problems which have to be taken into consideration in order to get a clear picture of the knowledge required for maintenance purposes.

E. MAINTAINABILITY IN THE DESIGN OF TECHNICAL SYSTEMS

In designing technical systems, due attention is to be paid to their operating performance and easy maintainability. In case of failure it should be possible to quickly repair the system. In this context, the environment in which the machine is used as well as its specific functions are to be taken into account. When designing machines or other capital goods for use in developing countries, this issue becomes particularly important and there may be special requirements to be met. While one cannot give specific instructions regarding the design in the diverse world of equipment, there are, however, certain general principles to be borne in mind. Figure 8 below gives an overview of the various issues involved. It shows in particular that an analysis of maintenance problems has to be undertaken from the outset, at the stage of developing the basic concept of the system (item 1). On this basis, maintenance requirements are to be included in the product design and in prototype documentation (item 2). A detailed analysis of the maintenance system includes an estimate of technical availability of the various elements of the system and an estimate of the costs and duration of maintenance (item 3). Next, the criteria and possible limitations have to be defined (item 4). In certain cases, priority should be given to specific criteria, such as technical availability required, safety, etc. (item 5). Based on the prototype documentation and available information on criteria or limitations, an analysis of the anticipated maintenance is to be undertaken (item 6). The first part of this analysis evaluates the available information regarding the conceptual solution of the maintenance system. If the analysis shows that information available is insufficient, additional data is to be sought and further tests or experiments may become necessary (item 7). If the analysis shows that the maintenance concept in sufficiently defined, procedures are established for each individual maintenance activity and the levels are defined at which these activities are to be carried out (item 8). Also, estimates have to be made regarding the duration of each individual maintenance activity (active maintenance time). The qualifications of the workers as well as the tools and other auxiliary means have to be determined. Furthermore, the costs of maintenance activities have to be indicated.

After completion of the maintenance system concept, a general evaluation is to be undertaken (item 9). In case this evaluation indicates that results have not been achieved and maintainability is below the required level, modifications for improvement will have to be made (item 10). If the general evaluation is satisfactory, the final workshop documentaion as well as the maintenance documentation will be prepared (items 11 and 12). After comprehensive tests have been completed, the system may be produced for commercial exploitation and put into operation (item 13).



1 CONCEPTUAL DEVELOPMENT
2 PROTOTYPE DOCUMENTATION
3 INPUT DATA
4 CRITERIA AND LIMITATIONS
YES
5 SPECIAL REQUIREMENTS
NO
6 MAINTENANCE SYSTEM ANALYSIS
7 ADDITIONAL DATA
8 MAINTENANCE PROCEDURES AND LEVELS
I
II
III
IV
9 EVALUATION
10 MODIFICATION
YES
NO
11 WORKSHOP DOCUMENTATION
12 MAINTENANCE DOCUMENTATION
13 OPERATION

Fig. 8

F. BASIC APPROACH TO TRAINING FOR MAINTENANCE

As is apparent from the above, maintenance is a very complex issue. The Theory of Maintenance - also referred to as the Renewal Theory /6 - has therefore been developed to study the different theoretical and practical implications of maintenance. The Theory of Maintenance is part of the Theory of Effectiveness which is a general scientific discipline concerned with the problems of operation and maintenance of technical systems to achieve planned targets. Being a relatively young branch of science formulated over the last few decades, the Theory of Maintenance is still being developed. New approaches, contributions and methods are being incorporated in order to adapt maintenance systems to the environment in which the technical system in question operates. This is especially important for developing countries with their different social, economic, technical and natural environments.

All personnel at the plant level involved in maintenance-related issues therefore needs to undergo special training. Managers and supervisors of manufacturing plants, managers of maintenance divisions, engineers and technicians involved in development, design or purchasing, but also staff from ministries, state agencies, government or private organizations or banks involved in decision-making with regard to the acquisition of all kinds of capital goods should be adequately trained. This training should first be undertaken at the formal educational level and later-on during the course of their employment, i.e. in the form of in-service training.

Personnel involved in the design of maintenance systems, workshops and equipment and in planning maintenance requirements including spare parts procurement are in particular need of training. They should be capable of applying the theories referred to above and of finding their own solutions to maintenance problems arising out of special circumstances, such as unfavourable local environment, manpower problems, shortage of foreign exchange,etc.

Training for trainers is another important aspect as trainers will be responsible for passing on knowledge, be it at the university, technical training institutions or workshop level. Otherwise the dissemination and up-grading of knowledge will not keep in step with the requirements of industry.

A wide range of personnel at different levels is engaged in maintenance-related activities and requires varying degrees of prior educational or vocational training. Therefore, training programmes must be comprehensive, diversified and adapted to the individual needs of the trainees. Separate training programmes should be developed for the various groups of personnel to broaden their knowledge and skills and, most importantly, stimulate creative knowledge. Unfortunately, this aspect is often overlooked in developing countries.

G MAINTENANCE TRAINING AND ACTIVITIES FROM THE POINT OF VIEW OF EQUIPMENT USERS

Maintenance training from the user's point of view is a very important aspect which should be included in all maintenance training programmes, especially in developing countries. It should be included in education programmes as an umbrella for existing training schedules. The main objective is again to further creative knowledge to enable trainees to develop maintenance systems commensurate with the particular conditions in their countries, including the level of industrial and technical development, climatic conditions, capacities and capabilities to undertake proper maintenance of equipment, etc. UNIDO has already done considerable work in this respect /7.

Therefore, training programmes must be based on the theories mentioned above and be sufficiently comprehensive to cover the various phases that a good maintenance system should comprise. Training programmes for personnel engaged in development, design and manufacture of machines and other capital goods, purchasing of such equipment from local or foreign sources and design of maintenance systems should include the following issues:

- Theoretical considerations (Theory of Effectiveness, Theory of Reliability) as the theoretical framework to facilitate better understanding of the operations of technical systems and the occurrence of failures;

/7 See: UNIDO Report on the First Consultation on the Training of Industrial Manpower, Stuttgart 1982, ID/296
UNIDO's Training Activities in the Area of Industrial Maintenance, ID/WG.469/3 (SPEC.)
UNIDO Report on the Regional Expert Group Meeting on Human Resources Development in Industrial Maintenance in Africa Preparatory to the Second Consultation on the Training of Industrial Manpower,UNIDO/PC/146
UNIDO Aide-Mémoire for the Second Consultation on the Training of Industrial Manpower, Paris 1987, V.87-84272, 3658T

- Objectives of maintenance in economic terms, including life cycle costs as well as possibilities for cost control;
- Maintenance management including maintenance strategies based upon the properties of the equipment in question;
- Maintainability, i.e. the suitability of technical systems for maintenance, including methods for adapting machinery to maintenance requirements under different conditions and environments;
- Maintenance system including preventive and corrective maintenance, and system structure (organization). This should provide an input to maintenance-related engineering and design work;
- Knowledge of information systems and data processing to provide data for maintenance design and programming (data on failures, down-time, maintenance undertaken, cost/benefit analysis);
- Integral logistic support to provide the knowledge required for managing inventories;
- Elements of optimization methods for the selection of the best solution of maintenance alternatives to meet set criteria within existing limitations.

H CONCLUSION

This paper discusses only generally some questions indicating the need of introducing a system of training for maintenance from the standpoints of equipment designers, manufacturers and users. The idea is to emphasize the need of organizing the training system on higher levels which in some developing countries has not yet been achieved, but which represents a basis for the development of domestic technologies, in developing new technical systems adapted for maintenance. In order to achieve an increased rate of development, developing countries have to ensure their own knowledge based on the achievements of science and technology elsewhere and in particular in the developed world. This applies fully to training for maintenance or to the education of those working on the development of new machines and equipment and systems for their maintenance.

The practical implementation of the concepts explained above requires detailed elaboration for each particular case, depending on actual conditions, achieved level of development, existing education system, types of machines and capital goods to be maintained, operating conditions, environment, etc. A certain degree of co-operation for a larger number of countries at a similar level of development, or for a larger number of relatively different types of technical systems is not excluded. In this framework there is room for serious consideration to be given to possibilities for international co-operation with a view to organizing specialized training courses, schools and other forms of training activities in individual countries, regions, industrial sectors, in a similar way to that applied in training personnel employed to maintain machinery and equipment. Experience which UNIDO has had so far in this area provides the basis for success in such a widened scope of manpower training in developing countries.