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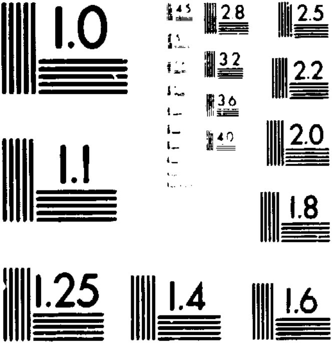

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SYSTEM OF PREVENTIVE MAINTENANCE OF CAPITAL GOODS

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SECTORAL WORKING PAPERS

During the course of the work on major sectoral studies carried out by UNIDO's Division for Industrial Studies, several working papers are produced by the Secretariat and by outside experts. Selected papers that are believed to be of interest to a wider audience are presented as the Sectoral Working Papers. These papers are more exploratory and tentative than the sectoral studies. They are therefore subject to revision and modifications before incorporation into the sectoral studies.

This paper was prepared by the Research Institute of Technology and Economy in Mechanical Engineering, Prague, Czechoslovakia, UNIDO consultants. The views expressed do not necessarily reflect the views of the UNIDO secretariat.

Preface

This study has been prepared as a part of the programme element "Study on the Capital Goods Industry" of UNIDO's Division for Industrial Studies, Sectoral Studies Branch.

The study has been made by the Research Institute of Technology and Economy in Mechanical Engineering, Prague, Czechoslovakia.

It is presented in the hope that it might stimulate a discussion of various models for preventive maintenance systems. Experiences from different approaches to the maintenance problem will later be included in a second world-wide study on the capital goods industry.

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INTRODUCTION

The economic problems of recent years, and in particular the shortage of capital, have led to a slowdown in the process of renewal of production equipment through new investment. However, new attitudes towards equipment life spans and innovations have begun to emerge, particularly in industrial activities where demand for materials has been increasing.

From the technical point of view, a growing proportion of the new generation of machines is characterized by higher levels of mechanization and automation. The average age and performance requirements of machines in use is also increasing. These factors have led to a need for improved quality and operational efficiency of maintenance. An analysis of current trends in the engineering industry has shown the following:

(a) A change-over from one-shift to multi-shift exploitation of machine tools and metalforming machines is reflected within two years by an approximately 30 per cent increase in maintenance demand;

(b) An extension of the working age of machine tools from 5 to 10 years will be reflected in an increase of as much as 40 per cent in maintenance demand;

(c) In an average engineering plant shut-downs of machines for routine maintenance account, on average, for 4 to 7 per cent of the time of performance of conventional machines. However, if such maintenance is neglected, machine capacity declines substantially, amounting to as much as 20-25 per cent of available production time.

These data are important enough to justify the increasing interest in the adoption of efficient and comprehensive measures aimed at providing adequate maintenance services.

In developing countries the above-mentioned general factors are accompanied by other specific influences, such as low standards of machine attendance, lack of qualified maintenance personnel, demanding climatic conditions, the location of establishments in remote areas and the lack of knowledge of modern methods of work.

An additional factor is the need for plants located in remote areas to achieve a high degree of self-sufficiency in maintenance, since there are only limited possibilities of prompt servicing by manufacturers or other establishments.

Providing adequate maintenance services depends on the working methods used in each enterprise. The main problem is the maintenance of capital goods. Maintenance as a part of enterprise activities is developed from the technical, economical, organizational and personal point of view. All the needed parameters of maintenance are, from the formal point of view, summarized below. The study defines the basic principles of work, the required organizational liaisons, the planning and control system, the technical arrangements etc.

The modern system of differentiated preventive maintenance described in this study is based on the following principles:

(a) Maintenance priorities are established according to the importance of the machines in the production process;

(b) Preventive care is practised so as to limit the occurrence of breakdowns;

(c) The maintenance programme is based on the calendar year, with a breakdown schedule for shorter intervals of time;

(d) As an economy measure, administrative work is kept down to an indispensable minimum, primarily through the restriction of the amount of data and documents;

(e) Maintenance is incorporated into the organization of the establishment by defining of its relation to plant management, production and investment.

The system is worked out in a simple alternative version for manual control, with the possibility of gradual conversion to computerized engineering techniques. It is applicable to practically all areas of industrial activity.

Chapter 1 of this study provides an introduction to the main problems and laws of maintenance in industrial plant. Chapter 2 describes the basic categories and modern principles of the maintenance system. Chapter 3 describes how to develop a maitenance model with the coupling of other activities of the plant. Chapter 4 deals with the maintenance planning process. Chapter 5 describes the maintenance information system. Chapter 6 reviews maintenance workshop techniques. Each chapter includes examples of maintenance systems under different conditions covering a wide spectrum of applications.

1. OBJECTIVES OF THE GUIDELINES FOR PREVENTIVE MAINTENANCE

Production machinery and equipment always need a certain amount of maintenance. Maintenance costs involve the volume of wages paid to maintenance personnel, the cost of materials and spare parts, servicing and overheads.

The costs of maintenance depend on a number of factors, the most important of which are as follows: the technical nature of the equipment; the number, value, age and technical standards of the installations; the organization of production (one or more shifts); the quality and equipment of the service; and maintenance personnel.

The results of the work performed by maintenance personnel can be evaluated by using various yardsticks, such as maintenance costs as related to the volume of the equipment and the value of production. However, from the point of view of the identification of the quality and efficiency of machine maintenance, it is most appropriate to adopt the maintenance down times as a basis of reference. The down times are the periods needed for carrying out both preventive and emergency maintenance operations. An optimal relation between the costs of maintenance and the down times can be fairly accurately determined for each individual establishment.

The objective of this paper is to describe proven maintenance working methods that would make it possible to optimize the relation existing between maintenance costs and the down times due to maintenance operations. The attainment of a minimum of down times at a minimum of maintenance cost within a relatively short interval of time may be of only a temporary nature. If maintenance costs are estimated below a technically indispensable minimum, after a delay of one or two years there will occur a rapid increase in maintenance down times resulting in production losses. A graphic representation of this potential situation in a conventional engineering plant is shown in figure 1.

Figure 1. Relationship between maintenance costs and machine down times

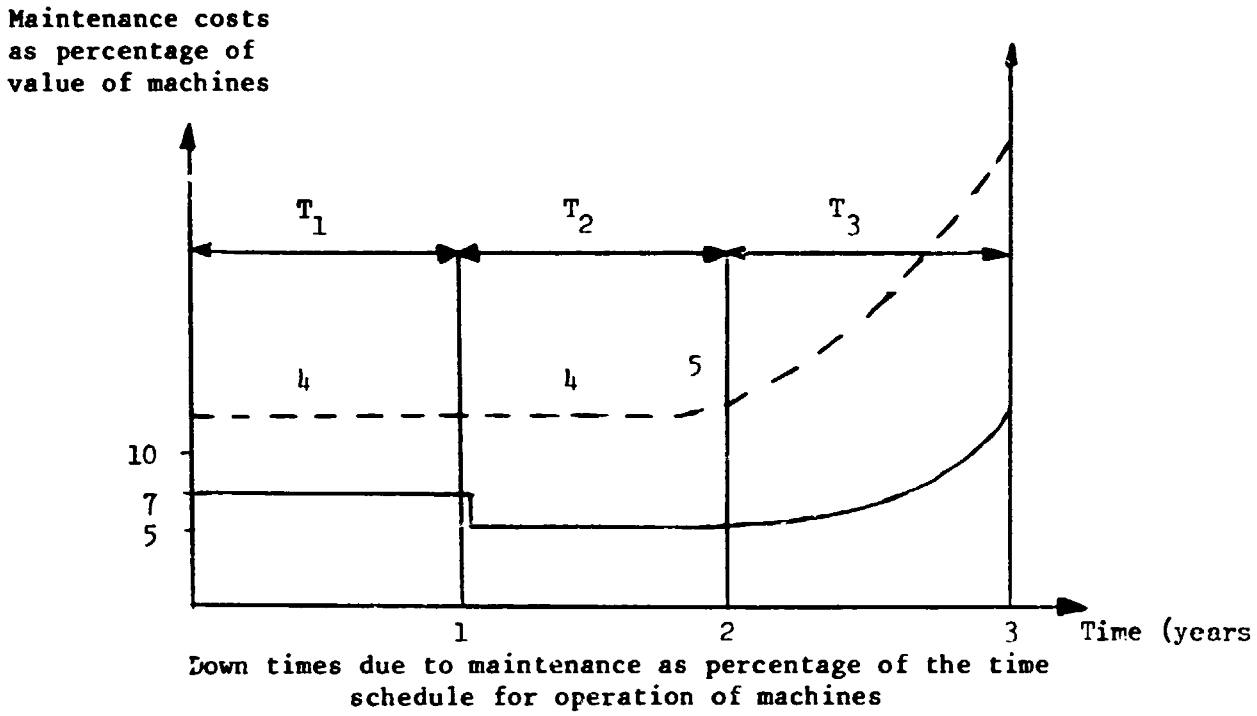


Figure 1 shows a situation where after a period of so-called constant intensity of maintenance (T_1) there followed a technically incorrect reduction of maintenance costs. During the period of what is called relative stillness (T_2), there initially does not occur anything worthy of attention, until in the course of the second half of this time interval the maintenance down times begin to grow as a result of a gradually increasing incidence of failures and breakdowns. The full impact of an erroneous decision to reduce the maintenance costs will then be experienced during the following period (T_3) of increasing intensity of maintenance, that is frequently characterized by a big increase of maintenance down times and costs. The setbacks caused by losses of time otherwise available for machine operation and the resulting deficiencies in the final production volume are, as a rule, substantially higher than the increase in maintenance costs.

This paper is designed to limit the above-mentioned production losses. It should be regarded as providing guidelines for operation, which must be adapted to local conditions.

2. METHODS OF PERFORMANCE OF MAINTENANCE

2.1 Principal terms used

Maintenance is a complex of all activities realized in order to ensure a serviceable state of machines and equipment during the whole time of their use in production. It consists of two principal categories:

(a) Preventive maintenance, which at pre-established intervals involves an inspection of the technical state of the machines, with correction and elimination of minor damages in order to extend the time of their trouble-free operation;

(b) Repairs, which serve to eliminate major damages and to restore the equipment to a state in which it is capable of operation.

Both these categories may be further subdivided.

Differentiated preventive maintenance is a complex system of maintenance which takes into account the varying importance of individual machines and items of equipment for the main process of production.

Investment-based renewal consists in replacement of useless or worn-out machinery by new ones.

The time of operation is the period during which a machine is used to carry out operations. This concept is usually adopted as a calendar term or in hours, with the pauses in operation included.

The overall technical working life span of a machine is the sum total of all times of operation from commissioning of a specific machine until the time when it has been definitely removed from operation.

A down time is a period during which a machine is inoperative. A down time motivate by maintenance, the so-called technical down time, is the time during which a machine is inoperative while maintenance work is carried out on it.

A maintenance worker is a worker who performs any one of the manual operations that form a part of maintenance attention.

An employee of the maintenance department is any member of the personnel engaged in this kind of work, irrespective of whether the work carried out is a manual, technical, auxiliary or engineering operation.

Maintenance costs are the total volume of financial means expended in the performance of maintenance work within a specific interval of time. For use in record keeping and planning they are subdivided into individual categories. These, as a rule, contain items of wages and salaries, prices of materials and spare parts, servicing maintenance by external suppliers and overhead items.

Labour input is the number of working hours spent by maintenance personnel in maintenance work.

A norm is an item of information that quantifies any specific kind of activity in the maintenance programme in such aspects as its labour input, urgency etc. It usually serves for planning the respective activities or for evaluation of the results of work.

2.2 Basic categories of maintenance

This section gives brief characteristics of the different categories. The details of work are dealt with in the following chapters.

2.2.1 Preventive maintenance

Inspection is a checking operation, which serves to verify the technical state of a machine and the amount of wear of its components. The necessary adjustment is carried out and minor deteriorations that might reduce the planned time of trouble-free operation are eliminated. In the event of the next operation being a repair, the objectives and extent of the inspection are formulated in more exact terms. Inspection is strictly scheduled for a specific period, with the time interval between successive inspections stipulated by norms in accordance with the importance and technical characteristics of the machine.

Diagnosis is an identifying operation forming part of the maintenance service and designed to check the basic characteristics of a machine and its component parts, such as the geometric precision, the intensity of vibrations, bearing temperatures, stress levels, the promptness of system reactions and the intervals of time between failures. Technical diagnosis uses specialized measuring and diagnostic instruments for obtaining the necessary items of information. Administrative diagnosis obtains specific data by means of an analysis of normally accessible recorded information, periodicity of failures and breakdowns, down times etc.

In general terms, diagnosis serves to determine the condition of machine parts, to detect the existence and causes of wear and breakdowns, to predict future behaviour of a machine etc.

Lubrication is part of preventive maintenance designed to reduce friction in mechanical systems through the application of appropriate lubricants to functional organs of machines such as bearings and guideways. As most of the lubricants are inflammable substances and some of them are even injurious to health, this kind of service is usually entrusted to a specialized section of the maintenance department.

Protection from corrosion forms an important constituent of the maintenance service where specific kinds of production equipment are dealt with. This activity is aimed at restriction of wear by corrosion that may be due to the effects of the environment technology.

2.2.2 Repairs

In-process repairs are based on the following: information obtained through inspection and revealing that the amount of wear of a machine has advanced to a point where it is no longer possible to eliminate it by minor maintenance work; and requests submitted by any other department in connection with the condition of a machine.

There exist two categories of repairs motivated by breakdowns, based on the extent of maintenance work required for making the machine operational again: defects requiring a labour input of less than eight hours, which are recorded for a specific period such as a week or a month; breakdowns requiring labour input of more than eight hours, which are recorded separately.

Major overhauls are the most extensive maintenance operations in terms of labour input and the expenses involved. The machines envisaged for such a repair are for the most part removed from operation for several weeks or longer. Frequently a machine is removed from its original site and transferred to a special workshop. As part of a major overhaul, reconstruction or modernization is usually also carried out. The value and performance rate of a machine after a major overhaul amounts to 80-90 per cent of the parameters of a new machine.

Where complicated machines are dealt with, a major overhaul can be carried out in successive steps, from one structural component to the next. As major overhauls are very demanding in respect of labour and material input, they should be included in a plan only after an analysis and comparison of their costs with those involved in acquisition of a new machine

2.3 Servicing constituents of maintenance

For satisfactory results, maintenance requires a number of activities of engineering, administrative, technical and production features, including the following:

(a) Technical and economic management of maintenance departments provided for by the competent engineering personnel. This involves in particular record-keeping, planning, technical preparation of repairs, supervision of the work in progress etc.;

(b) Control of the maintenance process on the basis of both the planned and the breakdown-motivated interventions by the maintenance department;

(c) Manufacture of spare parts is arranged in a specialized production workshop that forms part of the maintenance centre. Where necessary, it also has facilities that are necessary for renovation of worn-out parts;

(d) The supply service of the maintenance department provides, apart from acquisition of materials, spare parts, documentation etc., contacts with the servicing departments of the manufacturers of the machines in use, as well as with all co-operating centres within the plant and with outside organizations;

(e) Storage of spare parts, materials, lubricants, workshop aids and tools.

2.4 Methodical maintenance principles

2.4.1 Differentiation

The differentiation of machines is based on the fact that every machine has a particular rank of importance for the enterprise in which it is employed. This importance arises as a function of several factors, the most significant of which are as follows:

(a) Technological importance of the machine, above all as far as its technological capability of being replaced, its operational precision and other parameters are concerned;

(b) Production features, in the first place its productivity, possibilities of multi-machine attendance etc.;

(c) Technical characteristics of the machine, such as the rate of automation, complexity, number of assembly groups, sensitivity and resistance to environmental conditions;

(d) Price and anticipated useful life of the machine, the expected duration of its serviceability;

(e) Required service availability, operational safety and other factors.

For practical reasons the machines are divided into several so-called importance groups, each of them containing a limited number of machines. The division is effected by a competent worker of the maintenance sector. Table 1 serves as an aid for the expert assessment.

Table 1. Classification of machinery

Importance group of machines: Number	Importance group of machines: Evaluation	Percentage of total number of machines	Auxiliary criteria of the selection
1	Very important	15	Technological impossibility of being replaced High operational precision (0.001 mm - 0.005 mm) Higher automation rate Higher complexity (8 or more assembly groups) Long-term utilization of the machine Machines working in lines or continuous-duty machines Machines influencing operational safety High-price machines New machines or those with anticipated utilization of more than five years
2	Normal Conventional	55	Medium complexity (4 to 8 assembly groups) Average utilization (up to one shift) Mechanized machines and those of lower automation rate Machines that are exchangeable or replaceable Machines existing in larger quantities (more than three)
3	Auxiliary	30	Technically simple machines (up to 3 assembly groups) Machines utilized from time to time only Machines employed in auxiliary service

Incorporation of a machine into the importance group exerts a considerable influence on the extent and structure of maintenance activities. Table 2 illustrates the relationship between the importance group of machine tools and forming machines in a conventional engineering enterprise, the machines of which work practically in a single-shift regime of eight hours a day.

Table 2. Machine importance group and maintenance time losses

Importance group Number	Evaluation	Limit of time losses caused by maintenance (percentage)
1	Very important	3
2	Conventional	6
3	Auxiliary	Limitless

2.4.2 Preventive measures

Most of the machines utilized in the industry are subject to deterioration and wear. If maintenance activities are well organized, most of the complete failures can be forestalled by adopting preventive measures. Inspection and diagnosis are the primary aspects of correct maintenance.

When deciding the extent of preventive maintenance economic aspects also have to be considered. Preventive maintenance measures should be directed first of all to the machines belonging to the first and second group of importance. Even within these groups a certain share of defects has to be considered, although this percentage should not surpass a specified limit.

An example of varying percentages of preventive maintenance is shown in table 3.

Table 3. Variations in maintenance activities

Importance group		Maintenance share (percentage)	
Number	Evaluation	Preventive maintenance	Repairs of defects
1	Very important	80	20
2	Conventional	50	50
3	Auxiliary	20	80

2.4.3 Planning

Planning activities represent the third significant factor of modern maintenance, assuring the control of maintenance processes by using a plan or a system of plans. The most important plans are described below:

(a) Plans of an economic character are of primary significance and form a part of the overall renovation of the enterprise;

(b) Plans of maintenance costs involve external and internal maintenance. The relation between internal and external maintenance is the index of self-sufficiency of the enterprise. The internal maintenance plan is a function of labour and material costs and overhead expenses.

(c) Plans of a technical character meet the specific economic plans by operations carried out according to the needs of the machines, which could be preventive maintenance, routine repairs or thorough overhauls.

In case of need the plans are further subdivided and completed to cover other matters such as spare parts production.

The scope of the planning work must be maintained at the optimum level. A higher rate of automation and better utilization of the machines call for improved maintenance planning.

2.5 General algorithm of the maintenance process

Maintenance activities are composed of a number of partial actions. An overview of the process is shown in figure 2.

Management of the enterprise creates the basic conditions for maintenance of machines:

(a) During the phase of defining global parameters by detailing the financial means intended for the purchase of new machines and discarding unserviceable machines, and by determining the volume of final production, the range of exploitation etc.;

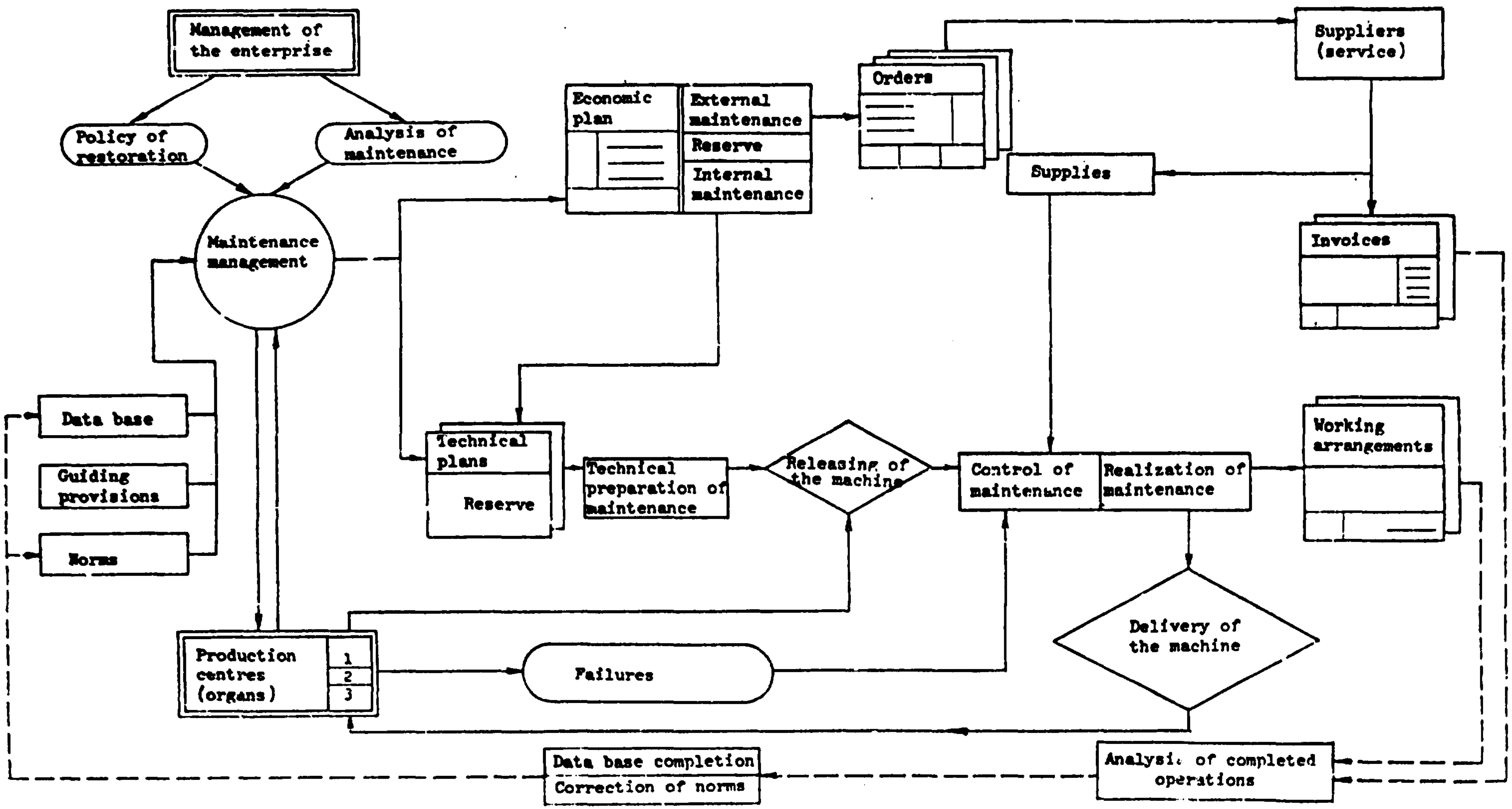
(b) During the phase of generation of conditions necessary for maintenance purposes, by establishing a responsible, competent body, determining its size and budget, approval of maintenance provisions etc.

Management of the maintenance sector lies within the competence of the authorities responsible for establishing the data and normative bases which allow high-quality planning, control and realization of preventive maintenance and repairs.

The economic plan determines the necessary financial outlays for maintenance with the aid of special budgetary models. The amount allotted for purchases of the external maintenance services forms the basis for covering orders placed with specialized suppliers. The financial volume designed for internal maintenance limits the span of operations carried out by the maintenance workers of the enterprise.

The technical plan specifies the individual items of preventive maintenance, routine service and overhauls. When setting up concrete plans, due regard is given to the normative base demands and to the claims raised by production centres. On all aspects of the maintenance plans budgetary reserves are kept, destined for covering unplanned requirements.

Figure 2. Stages in the maintenance process



At the appropriate time intervals the planned measures are passed to the maintenance technical preparation section and after the necessary administrative action released for implementation.

The maintenance management also ensures the timely release of the machine from the production process and its return to the production centres after the preventive maintenance measures or necessary repairs, if any, have been completed.

3. ORGANIZATION OF THE MAINTENANCE SECTOR

A specialized maintenance sector, hereafter referred to as the sector, is responsible for maintenance activities. The sector is a part of the enterprise organizational structure and ensures the operational readiness of the production equipment. As a rule, this sector is under the supervision of the technical management of the enterprise or, in large-size plants, the general manager.

In addition to preventive maintenance and repairs, the sector also carries out activities that are indispensable for the correct operation of the enterprise and cannot be ensured by production units or external suppliers, such as technical development work, small investments etc. However, the scope of such activities has to be limited. The machine shop of the maintenance sector is sometimes established in the form of a common workshop engaged in the production of spare parts, tools, various jigs etc. This common base is used to special advantage in smaller enterprises where only a small number of highly qualified workers is available.

Maintenance sector activities are linked with those of several other internal and external organs, such as the external service workshops.

The following description and suggested solutions are based on a specific organizational model of the maintenance function or sector. Other models are possible. The selected - centralized - model is described below.

3.1 Organizational model

A centralized model of the maintenance sector has proved to be most suitable for standard industrial routine. The centralized model has the following characteristics:

(a) It has responsibility for performance of preventive maintenance and repairs of all equipment employed in the enterprise;

(b) Its director is subordinated to the technical or general manager;

(c) It is responsible for the distribution of the financial means allotted for maintenance purposes.

The centralized maintenance sector concentrates all maintenance activities necessary for the smooth working of the enterprise. Such operations are performed either by internal workers or with the aid of external firms. In addition, centralization of responsibility allows direct monitoring of the sector by the competent authorities.

A component part of the centralized sector is a machinery and assembling shop engaged in manufacture of spare parts and execution of repairs of the machines.

3.2 Organizational structure

The internal organizational structure of the maintenance sector depends on the functions to be accomplished. A complete set of such functions forms a standard organizational pattern. By adaptation to specific local conditions an individual organizational pattern is produced.

Standard pattern

The standard pattern of functions is represented in figure 3 and the standard pattern of individual professions in figure 4.

3.2.1 Standard pattern of functions

The standard pattern is an operational aid facilitating the solving of organizational problems involved in maintenance. It restricts the possibility of a function being omitted when defining the scope of the tasks of the sector. The individual functional positions of the standard pattern are defined by the set of operations outlined below.

Management of the maintenance sector. This is the top organ of the sector subordinated directly to the manager or deputy manager. The management is responsible for the correct transfer of specific tasks into the internal structure of the sector for execution and checking.

Figure 3. Standard pattern of maintenance functions

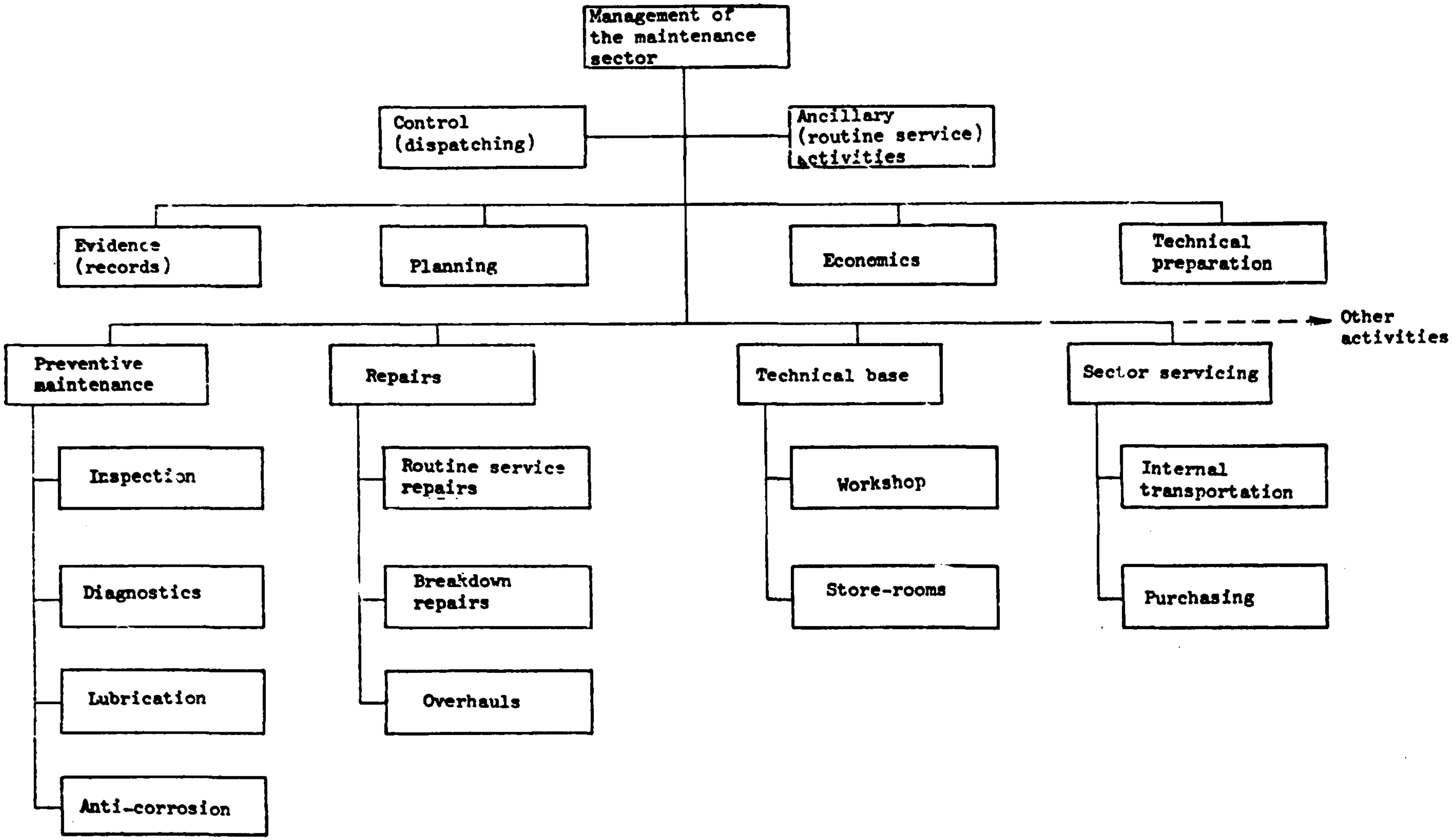
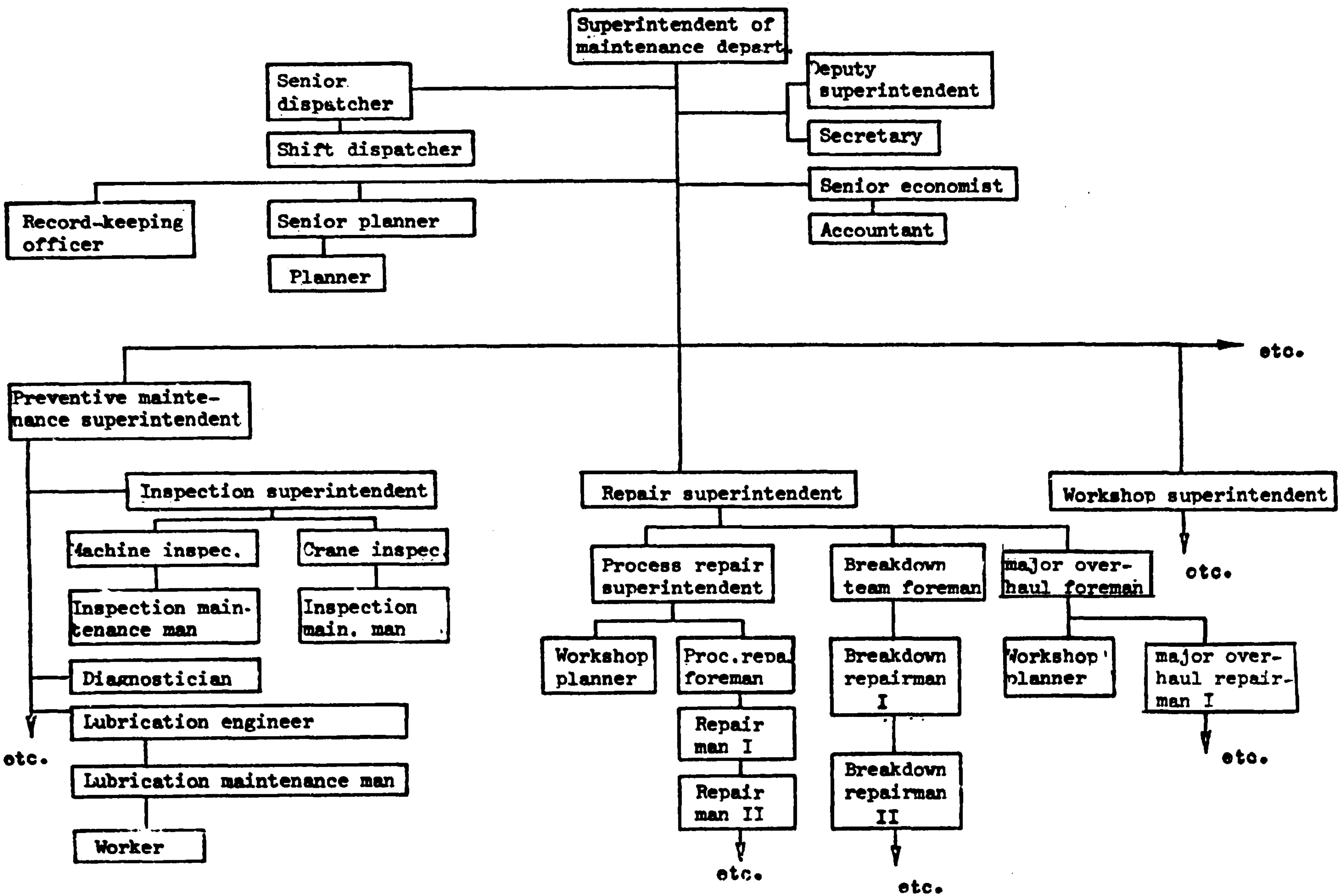


Figure 4. Standard pattern of maintenance professions



It is responsible for complete and undistorted transmission of information about the sector activity to the superior bodies. It ensures contact with other units of the enterprise. It incorporates the basic guiding provisions of the enterprise into the activity of the sector itself. It is responsible for observance of generally valid internal regulations of the enterprise. It ensures the development of the sector as a complete unit. It controls personnel policy of the sector. It co-operates in formulation and execution of the enterprise renovation programme. It makes decisions as to the exploitation of the sector capacities and distributes the financial resources allotted for maintenance purposes. It proposes and justifies to the enterprise management the basic sector activities.

Auxiliary activities. These represent an ancillary operational component of the sector management.

Control (dispatching). This is an operative function relating to the whole sector. It intervenes in case some deviations arise in the sector programme and if unexpected claims are imposed on its activities. It is provided with the communication links with other maintenance sector organs and, if required, can be connected with the general dispatching unit of the enterprise. It is authorized to inform the sector management about the situation prevailing in the controlled field of operation. It works out weekly reports for the sector management relating to the most significant repairs.

Evidence. This is a basic function, the purposes of which are listed below:

(a) To provide information about all equipment of the enterprise;

(b) To provide the equipment with identification markings;

(c) To process the inventory;

(d) To ensure completeness of technical documentation covering equipment;

(e) To issue necessary planning information;

(f) To summarize the results of the sector operation and process the respective documentation;

(g) To keep files - for a specified time - of all documents pertaining to the sector;

(h) To keep records relating to the personnel employed in the sector and to the sector agenda;

(i) To co-operate with the whole enterprise system.

Planning. The planning department is a central unit responsible for the implementation of all plans, except for some economic and operative plans of internal units of the sector. In addition, its primary duty is to work out technical plans and to prepare: drafts of the preventive maintenance plans and the plan covering current routine and overhauls; and the plan of total spare parts requirements.

Its other functions are:

(a) If there are no lower-ranking planning organs, to work out operational plans in co-operation with the inspection department;

(b) To analyze the demands which the other units of the enterprise impose on the sector activities and to incorporate them into appropriate plans;

(c) To carry out fundamental co-ordination of the needs of the maintenance sector and the production centres as to the operational readiness and serviceability of machines;

(d) To supply accompanying documentation to individual operations of the sector;

(e) To co-operate with the control unit if problems of deviation from the planned course of activities have to be solved;

(f) To carry out a comparison between planned operations of the sector and those actually accomplished;

(g) To co-operate with other organs of the sector;

(h) To review the basis for drafting technical plans.

Economics. The economic section is the central organ for controlling the allotted financial resources of the sector. Its tasks are:

(a) To co-operate with those units of the enterprise responsible for production and renovation activities;

(b) To analyze global budgets and plans of expenditures for maintenance purposes;

(c) To propose structuring of financial resources for maintenance into the internal enterprise framework;

(d) To check allotted funds;

(e) To analyze proposals for sanctions in case of failure caused by wrongful acts or incompetent handling;

(f) To work out economic valuation procedures;

(g) To review the structure of economic planning;

(h) To propose to the sector management the methods of composing economic indices of the sector.

Technical preparation department. In the field of construction the tasks of this department are:

(a) To schedule technical reports of damages incurred and to ascertain the causes of damages to machines;

(b) To determine the technical form of reparation;

(c) To determine the useful life of individual parts;

(d) To select and determine worn components that have to be repaired;

(e) To analyze proposals for reconstruction and modernization;

(f) To work out specifications of parts subject to repeated repairs.

Within the framework of technological preparation, procedures, descriptions of preventive measures and repairs, its tasks are:

(a) To work out the technology of production and renovation of spare parts;

(b) To calculate the incurred expenses;

(c) To take part in decisions made as far as the stock of parts to be stored is concerned;

(d) To raise claims for completion of the production stock in the own workshop;

(e) To check the observance of technological discipline in the execution of repairs;

(f) To introduce progressive technologies.

In the field of documentation, it is responsible for filing and maintaining important documents.

Preventive maintenance. This body co-operates with other units of the sector, especially with the planning group. Within the inspection section it takes over and sorts out the plans of individual operations and has the following tasks:

(a) To check periodically the technical condition of the machines;

(b) To transmit in case of need information necessary for detailing and updating the plan of normal service routine repairs;

(c) To co-operate in determining the causes of troubles and failures;

(d) To co-operate in setting the planning norms.

In the field of diagnosis it makes the necessary measurements and has the responsibility:

(a) To evaluate the ascertained data;

(b) To predict anticipated useful lives of individual equipment units for the rectification of plans;

(c) To check and maintain the correct technical condition of the employed instruments;

(d) To compile, in co-operation with the inspection section, the reports about the condition of critical operational sites.

As far as lubrication and anti-corrosion protection is concerned, it is responsible for:

(a) Organizing and controlling lubrication and anti-corrosion protective measures;

(b) Raising claims for allotment of adequate quantities and sorts of lubricants, protective materials, working aids and tools;

(c) Checking the condition of lubricants;

(d) Plotting graphic schedules of various operations;

(e) Checking lubricating procedures carried out by the operational personnel;

(f) Adopting modern methods of labour, such as contactless measurement of protective coatings;

(g) Co-operating with the inspection group when analyzing the development and causes of trouble and failures brought about by incorrect lubrication.

Repairs. The repair section is the main executive organ of the sector and is charged with the major part of maintenance activities. In the field of routine repairs and overhauls, the tasks of the repair section are:

(a) To take over time schedules of repairs from the planning group and to accept work documentation from the technical preparation section;

(b) To organize and control the course of works;

(c) To co-operate with the diagnostics section when ascertaining the necessary technical parameters of the machines and their parts;

(d) To transfer the repaired machines to the production centres;

(e) To take part in the completion of the technical documentation for individual machines.

With regard to failure repairs, it has to do the following:

(a) Take over failure reports from the production centres;

(b) Make decision about the method of repair;

(c) Remedy the incurred defects and breakdowns;

(d) Co-operate in determining their causes and formulating relevant protective measures.

Technical base. This comprises the workshops, store rooms etc. The functions of the workshops are:

(a) To ensure production and restoration of spare parts intended for preventive maintenance and repairs;

(b) To secure production of component parts for other types of manufacture, such as tools, aids, jigs etc.;

(c) To carry out disassembling and assembling procedures involved by repair activities, including all auxiliary acts such as cleaning, paint-coating etc.;

(d) To accomplish inter-operational inspection and output of machines and their parts.

In the field of storage, the aims are:

(a) To arrange storing of machines and their parts;

(b) To provide the necessary quantities and assortments of spare parts, materials, lubricants etc.;

(c) To keep in-process storages for storing in-process products;

(d) To follow the movement of stored-up articles, to maintain minimum reserve stock and to co-operate in liquidation of useless, unserviceable parts.

Servicing of the sector. The sector is serviced by ancillary and service-routine activities necessitated for its correction function. The internal transport service performs the transfer of machines, parts and materials within the enterprise, in co-operation with the purchase section it provides for the delivery from external suppliers. The purchase section secures the necessary parts, materials and other articles and means required for operation of the sector.

Other activities, such as the organization of the maintenance sector, usually include a number of other operations, such as maintenance of structural objects, electrical installation etc.

3.2.2 Standard diagram of crafts and professions

The standard diagram of functions, as indicated in the preceding chapter, forms a sort of universal modular system from which it is possible to set up any desired kind of diagram corresponding to the local conditions of each individual establishment. Usually, however, an application is worked out through derivation of a more detailed arrangement, a so-called diagram of crafts and professions. Figure 4 provides a partial illustration of the most important professions.

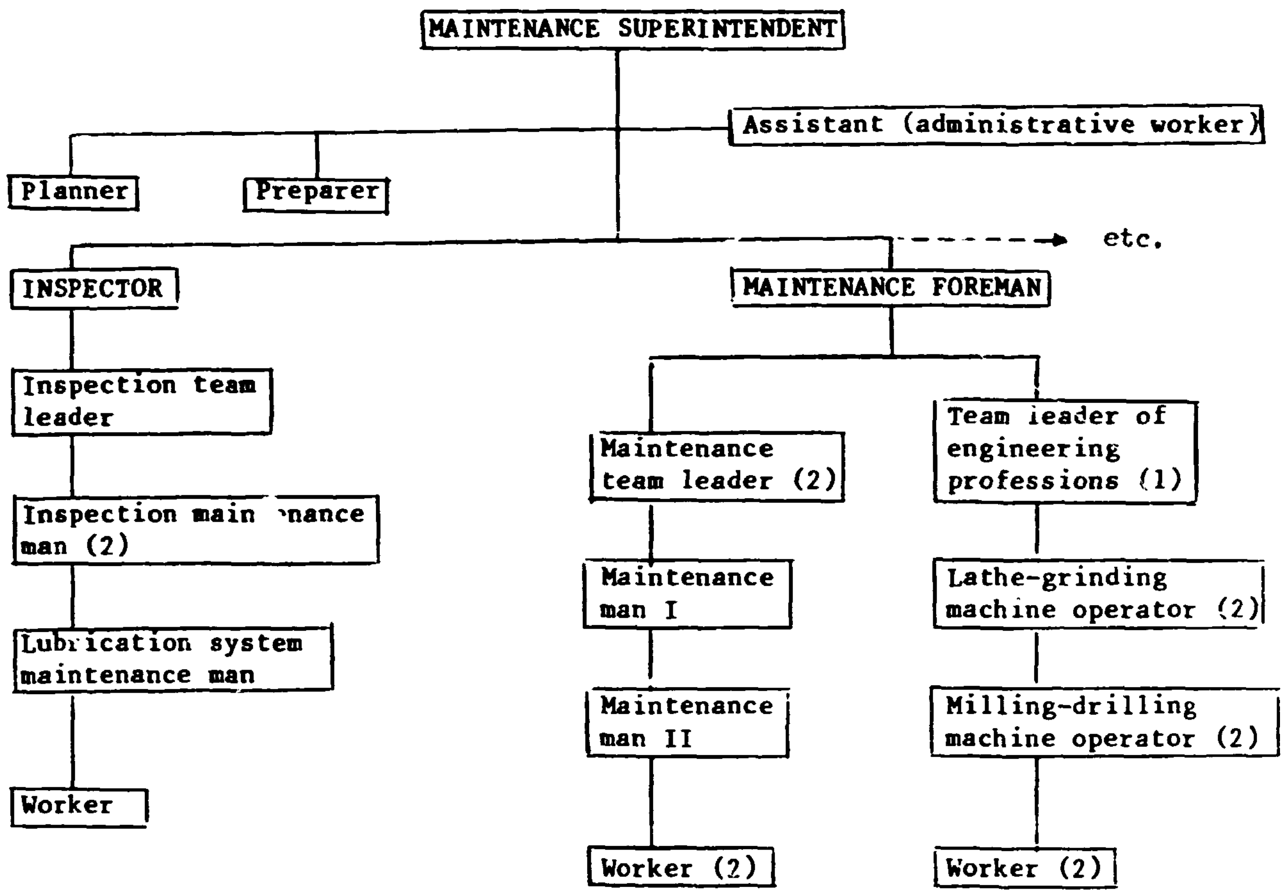
In the arrangement outlined, the diagram of a maintenance department would correspond to a relatively large plant, in the engineering sector one that employs a total of more than two thousand workers.

For smaller establishments, this standard diagram has to be reduced to what is termed an application arrangement.

3.2.3 Organization diagram of crafts and professions

To illustrate the organization a diagram of the maintenance department in an engineering plant employing 500 workers is shown in figure 5. The procedure essentially involves: safeguarding all functions assigned to the department; and the cumulation of functions based on the volume of labour necessary for their safeguarding, the professional affinity of individual functions and the number of workers in the maintenance department.

Figure 5. Maintenance department organization



The diagram focuses upon maintenance of machines and equipment. Examples of the cumulation of functions are as follows:

(a) The maintenance superintendent, apart from his normal functions, also ensures the operation of the dispatcher control system;

(b) An administrative worker performs secretarial work together with orientational activities;

(c) The planner performs the duties of planning and economics;

(d) The preparer discharges the duties of technical preparation, some of the attendance duties and those associated with the operational stores;

(e) The inspector, apart from inspection duties, also supervises the lubrication system and the anti-corrosive measures;

(f) The maintenance foreman takes charge of repair activities and supervises and controls the executive workers with the aid of the team leaders.

3.3 Liaisons of the maintenance department

Liaisons of the maintenance department are understood to mean its relations with other constituents of the organization, both within and outside the plant. These liaisons consist mostly in a flow of information such as orders and data, and seldom in a flow of material items, such as spare parts and production materials.

The most important liaisons exist between the maintenance department and the constituents of the plant decribed below:

(a) The plant manager controls the operation of the maintenance department, appoints its superintendent and formulates its regulations. The maintenance department is responsible to the plant management for efficient performance of maintenance service and for keeping the production machinery and equipment in a serviceable state.

(b) The staff department co-operates with the maintenance department in providing the required number of workers. It makes arrangements for improvement of professional knowledge and skill of the maintenance department workers through various forms of instruction and training.

(c) The maintenance department specifies a workable level of technical down times for capacity plans. The capacity planning department then considers the data while drawing up plans of utilization of available capacities.

(d) The maintenance department hands over to the production planning department a project of preventive maintenance and a plan of routine repairs and major overhauls with a specified time schedule of the operations envisaged by the plan. The production planning department then checks the maintenance plan draft or project against the requirements of the production plan. The respective comments are then discussed with the maintenance department. After justified comments have been duly considered, the maintenance department issues an operational plan.

(e) The department responsible for operational control of production co-operates with the maintenance department primarily in dealing with breakdowns and down times.

(f) The plant economics department determines the plant production costs and the basic economic indices of the maintenance department.

(g) The cost accounting department co-operates with the maintenance department in processing the routine accounting agendas, working out the data programmes, checking documentation, etc. Large maintenance departments can generally perform such tasks using their own staff.

3.3.1 Production departments

The production department influences the work of the maintenance department by causing machine wear. The production department workers must follow maintenance department instructions in minor daily duties of machine care and servicing.

The maintenance department calls attention to careless or faulty handling of machines, suggests improvements and applies sanctions. The production department also requests emergency repairs or interventions not directly associated with repairs.

3.3.2 Power engineering

The power engineering sector, unless in direct association with the maintenance department, provides the required assortment and amounts of energy of all sorts. The maintenance department ensures the serviceability of power engineering equipment and installations.

3.3.3 Investment and technical development department

The maintenance department co-operates with the investment and technical development department in the selection of equipment and handles its initial operations. It makes out specifications of obsolete machines for the technical development department and performs production activities not directly associated with repairs.

For more exact project formulation, the investment and technical development department avails itself of information provided by the maintenance department.

3.3.4 Department of material and technical supplies

The department of material and technical supplies provides all materials, spare parts, documentation etc. for the maintenance department.

Of a relatively autonomous nature are the so-called

3.3.5 External liaisons

Relatively autonomous liaisons are maintained by the maintenance department in larger plants where it is equipped with its own staff and facilities for provision of material and technical services. The relations involved primarily concern servicing stations, machine manufacturers etc., and may relate to information or material supplies.

4. PLANNING AND CONTROL OF MAINTENANCE

This part of the study of preventive maintenance is based on the following considerations:

(a) A plan is a basic instrument of control;

(b) Maintenance is the object of attention of a specialized system of planning methods;

(c) There exists a specific system of plans that makes it possible to plan individual categories of maintenance.

4.1 Planning of maintenance

4.1.1 Time structure of plans

The basic interval of time used for maintenance planning is one year. In a subsequent stage an annual plan of maintenance is broken down into shorter intervals of time, usually months, only exceptionally into weeks or days. In highly developed planning systems the time structure of plans involves monthly, weekly, daily and hourly itemization of assignments.

An annual plan is worked out from two points of view, the economic and the technical. Monthly and shorter plans are primarily technical.

4.1.2 Formal structure of plans

The primary maintenance plans originate in the three formal categories described below.

(a) Draft maintenance plans. These are formulated on the basis of generally applicable or plant-based norms and serve as a basis for discussion. The draft annual economic maintenance plan stipulates the volume of maintenance costs for the year dealt with in the plan. It is discussed with the economic department of the plant and ensures a balanced character of the process of renewal of machines, investments and maintenance.

The draft annual technical maintenance plan works out an itemized plan of maintenance of individual machines. It is discussed with the production centres and ensures individual attention to each machine according to its relative importance.

As both projects are worked out in different ways, they make possible the early detection and correction of any faulty planning.

(b) Maintenance plans. These are formulated after consideration of the draft plans and of comments or requests by the appropriate departments.

The annual economic maintenance plan may be broken down into monthly items taking into account major overhauls, all-factory leaves, technological shut-downs because of major repairs etc.

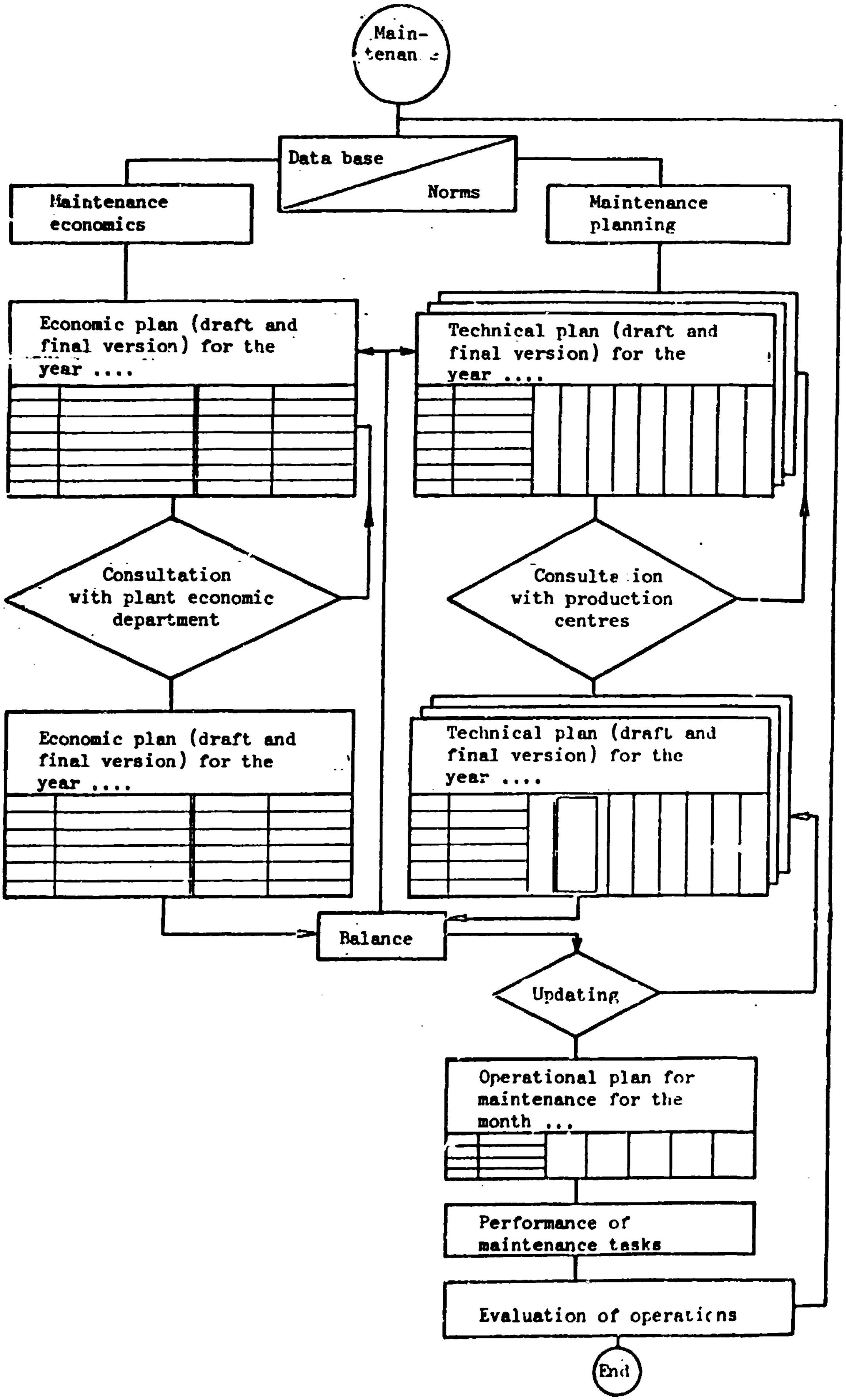
The annual technical maintenance plan is always broken down into monthly intervals to reflect loads imposed on machine capacity and to ensure balanced utilization of the maintenance personnel.

(c) Operational maintenance plans. These originate through updating monthly technical maintenance plans. Updating on the basis of the concrete situation existing immediately before the beginning of the planned period is carried out by the inspection department in co-operation with the production centres.

Updating is designed to eliminate inaccuracies in the structure of the plan.

The interrelations of formal patterns of maintenance plans are reflected in figure 6.

Figure 6. The interrelationship of maintenance plans



4.1.3 Economic maintenance plan

Determination of the total of economic demand for machine maintenance, expressed as machine maintenance costs NU_S, is based on variations of demand for maintenance as determined by the varying age, technical structure and utilization of the machinery. This process may be illustrated by the following means.

At the start of the planning period a specific number of machines are installed and utilized. This number can also be characterized by means of machine prices. The group of machines is formed by what is called the starting or initial machines ($S_{(V)}$).

By the end of the planning period, the starting base will have experienced certain changes. First of all, new machines ($S_{(n)}$) will usually have been installed.

Apart from this, some machines, called liquidated machines ($S_{(L)}$), will have been put out of commission for various reasons.

At the end of the planning period, the target machines ($S_{(S)}$), that is, those which remained in operation from the beginning of the one-year planning period, and the new machines ($S_{(n)}$) installed during that period were in operation, as reflected in the following equation:

$$S_{(C)} = S_{(S)} + S_{(n)} = S_{(V)} + S_{(n)} - S_{(L)}$$

Apart from the above changes motivated by the acquisition and liquidation of some of the machines, changes may be anticipated in the level of utilization in production and, thereby in the rate of deterioration in their technical condition.

From the above considerations it is clear that a special application of the principle of differentiation is involved. The variability of maintenance is not defined on the basis of production importance in a technical sense, but in relation to other parameters.

For such data it is possible in a relatively simple way to determine the value of the corresponding maintenance costs from the preceding planned year, or average data for a longer period of time.

From these values it is then possible to work out a draft economic maintenance plan for a specific planning period. One advantage of this procedure is that data are used which are available to the economic department of the plant or to its other sectors.

Under conventionally existing conditions, particularly where changes of the starting machines are slow, it may be assumed that the target maintenance costs ($NU_{(C)}$) vary in dependence on:

(a) The technical state of the starting machines ($S_{(V)}$) characterized by the relative maintenance costs of the starting machines indicated as an average over the past three periods ($NU_{(V)}$);

(b) The increase in maintenance costs of old machines ($S_{(S)}$), expressed by means of a coefficient $k_{(S)}$. This coefficient indicates an average increase in maintenance costs corresponding to the age of the machines as reflected in table 4 below. For other categories the value $k_{(S)}$ will have to be obtained by interpolation.

Table 4. Values of coefficient $k_{(S)}$

Average age of machines	Increase in age of machines (years)	Values of $k_{(S)}$
5	1	1.025
10	1	1.047
15	1	1.085

(c) The increase in maintenance demand due to the increasing technical complexity of new machines acquired during the planning period will be expressed with the aid of a coefficient $k_{(n)}$. The coefficient indicates an increase in maintenance costs after mechanization and automation have been increased by one degree as reflected in table 5. For the degree of automation see chapter 4.1.4.

Table 5. Values of coefficient $k_{(n)}$

Average degree of automation	Increase in degree of automation (years)	Value of $k_{(n)}$
1	1	1.032
2	1	1.056
3	1	1.079

(d) The increasing intensity of machine utilization during the planning period and its impact on maintenance is quantified by means of changes in average shift turnover. The concrete impact of shift turnover changes is expressed by an index of exploitation (I_E), reflected in table 6.

Table 6. Value of index I_E

Average shift turnover	I_E
1.00	1.00
1.25	1.05
1.50	1.11
1.75	1.15
2.00	1.19

The total costs of maintenance (NU_C) are then calculated according to the following formula:

$$NU_{(C)} = \frac{NU_{(V)} \cdot I_E \, (S_{(S)} \cdot k_{(S)} + S_{(n)} \cdot k_{(n)})}{100 \cdot I_{PU}}$$

$NU_{(V)}$ = Costs of maintenance in percentages of the price of acquisition of the machines in the course of the past three periods (relative costs).

I_E = Index of exploitation of the machines.

$S_{(S)}$ = Price (in local currency) of acquisition of old machines.

$S_{(n)}$ = Price (in local currency) of acquisition of new machines.

$k_{(S)}$ = Coefficient of increase of maintenance costs, depending on the age of the machines.

$k_{(n)}$ = Coefficient of technical complexity of the new machines.

I_{PU} = Index of increase of the productivity of maintenance since the last period.

The above form of calculation respresents a basic simple alternative. More complex alternatives operate, for instance, with a more detailed subdivision $S_{(V)}$ and $S_{(n)}$ into categories of importance, establishing more detailed age groups of machines.

The basic alternative arrangement can be used for construction of an economic maintenance plan for a period exceeding one year, in which case it frequently yields even more exact results.

4.1.4 Technical maintenance plans

Individual maintenance plans for specific machines are prepared in response to the following needs:

(a) To determine the volume of labour input into maintenance for calculation of the numbers of workers required;

(b) To spread the performances in time so as to make optimum use of the available maintenance personnel;

(c) To inform the production centres so as to make them conversant with the dates and extent of technical shut-downs and thus able to adapt their production plans accordingly;

(d) To provide a reserve for unforeseen breakdowns.

The plans are drawn up with the aid of norms based mainly on statistically or otherwise determined data on maintenance requirements. In this category of maintenance plans the most important are: a plan of inspection and in-process repairs; and a plan of lubrication and corrosion-inhibiting operations.

(a) Plan of inspections and in-process repairs

This plan is of key importance because it covers most operations and maintenance work - approximately 50 per cent. The plan is based on the fact that each machine requires in the course of a year a certain volume of maintenance work.

The principal index of maintenance volume is the so-called degree of labour input in a machine (S_p). This is determined from the so-called basic degree of labour input (S_{p-Z}) stipulated by means of design and process characteristics and more exactly by a maintenance characteristic.

Design and process characteristics. Design and process characteristics objectively evaluate the existing properties of each machine, in particular its complexity, technical standard, weight and degree of perfection. Complexity is evaluated by means of the number of structural and design characteristics.[1/] Examples are given in figure 7. Technical standard is evaluated by means of four degrees of mechanization and automation. Their

1/ A more elaborated system for complexity analysis has been presented by UNIDO in First global study on the capital goods industry: Strategies for development, ID/WG.342/3.

definition is given in table 8. Weight is evaluated in tons. The degree of precision is defined by means of the attainable working accuracy of the machine (see table 9).

To absolute values of the characteristics are assigned values in points the sum total of which serve as a yardstick for determination of the basic degree of labour input (S_{p-z}). A complex review is afforded by table 11.

Maintenance characteristic. Since a machine evaluated as outlined above may operate under varying conditions, it is necessary to correct the basic degree of labour input by means of a maintenance characteristic (see table 7). This is determined on the basis of self-sufficiency of maintenance, that is, by the extent to which maintenance can be provided from the own resources of the establishment.

Table 7. Maintenance characteristic

Self-sufficiency of maintenance (percentage)	Coefficient of correction
40- 50	1.30
51- 70	1.15
71- 80	1.00
81-100	0.85

Note: For determination of the characteristic of complexity of a machine by the number of subassemblies it is possible to make use of the following model examples. The machines are evaluated in what is called their basic outfit. Other potential special outfit of individual machines, such as:

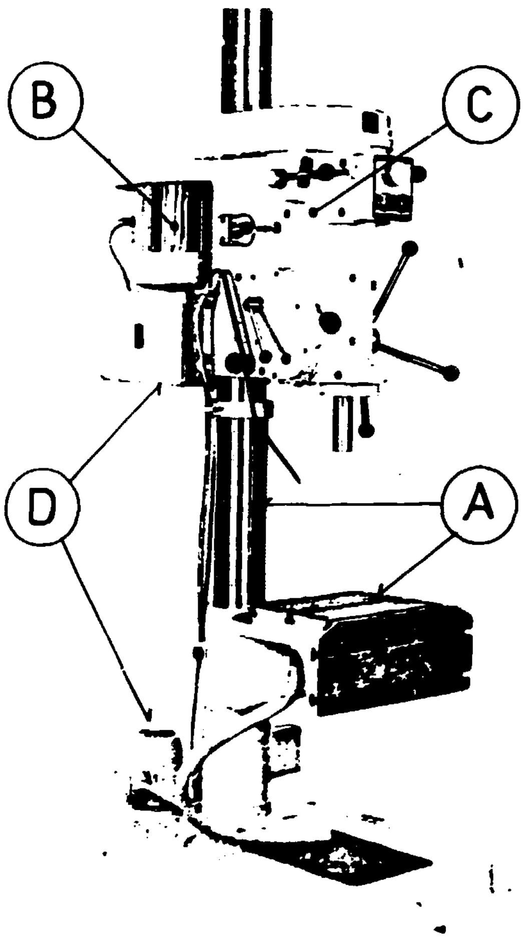
- accessory copying attachments
- turret heads
- positioning, clamping indexing fixtures and jigs etc.
- storage magazines, feeders, ejectors etc.
- shaping, milling, grinding units
- centralized cooling or lubrication systems etc.

should be evaluated additionally in their sum total as self-contained subassemblies.

Figure 7. Examples of definition of complexity of machines

(a) Single-spindle round-column drilling machine	Number of subassemblies

Maximum ∅ = 32 mm; depth = 200 mm; Morse 4; 2.2 kW;
weight = 650 kg

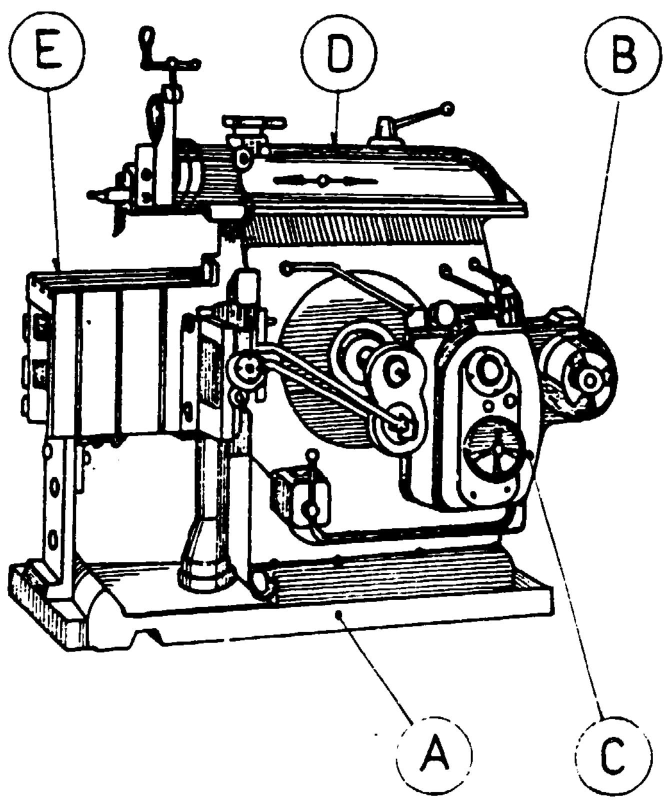


A - Upright with bracket	1
B - Electric motor and electrical installation	1
C - Tool head	1
<u>Basic outfit</u>	3
D - Cooling system	1
<u>Total complexity</u>	4

Figure 7. Examples of definition of complexity of machines (cont'd)

(b) Shaping machine	Number of subassemblies

Stroke = 280 mm; maximum dimensions of work-piece = 300 mm x 250 mm x 200 mm; 1.5 kW; weight = 500 kg

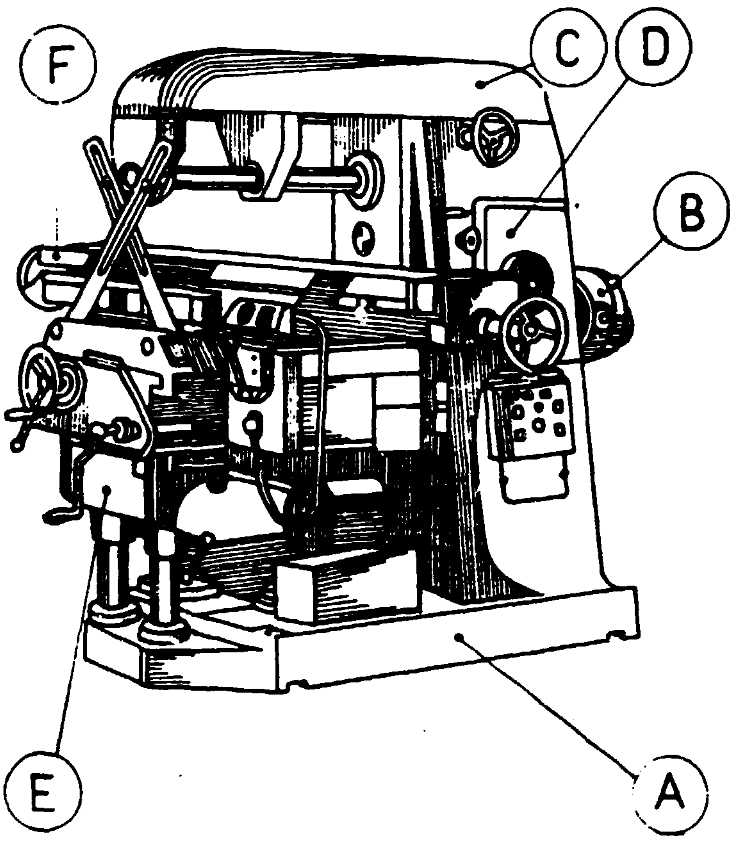


A - Frame	1
B - Electric motor with electi ical instalation	1
C - Transmissions - rocker arm	1
D - Tool arm	1
E - Slide-mounted clamping table	1
Total complexity	5

Figure 7. Examples of definition of complexity of machines (cont'd)

(c) Universal knee-type milling machine	Number of subassemblies

Clamping surface of table = 350 mm x 1,600 mm; working dimensions = 300 mm x 1,250 mm x 400 mm; Morse 5; 15 kW; weight = 3,800 kg

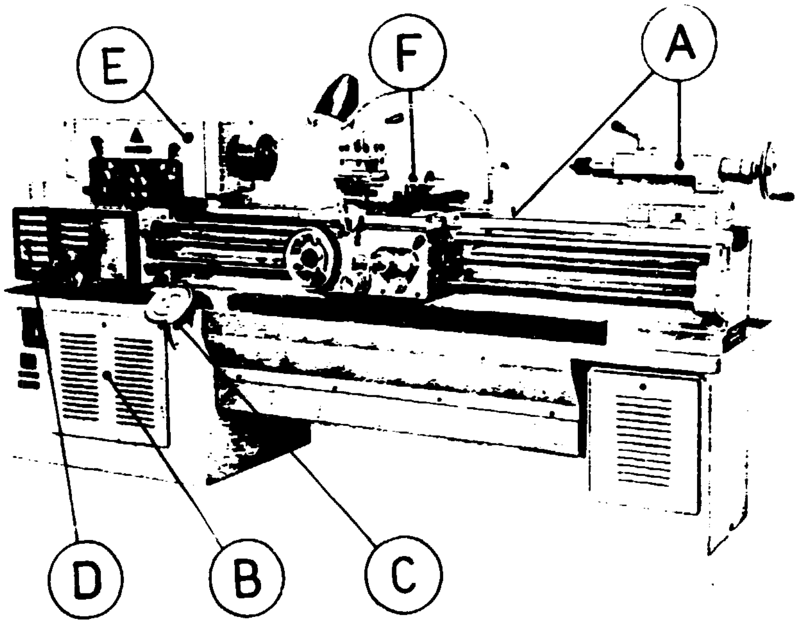


A - Upright	1
B - Electric motor with electrical installation	1
C - Milling heads V x H	2
D - Transmission and distribution gear box	1
E - Knee-type work table	1
F - Slides	1
Basic outfit	7
G - Dividing head	1
H - Rotary table	1
CH - Cooling system	1
I - Shaping head	1
Total complexity	11

Figure 7. Examples of definition of complexity of machines (cont'd)

(d) Universal centre lathe	Number of subassemblies

Swing 380 mm/215 mm; length of turning = 1,250 mm;
Morse 4; 6 kW; weight = 1,850 kg

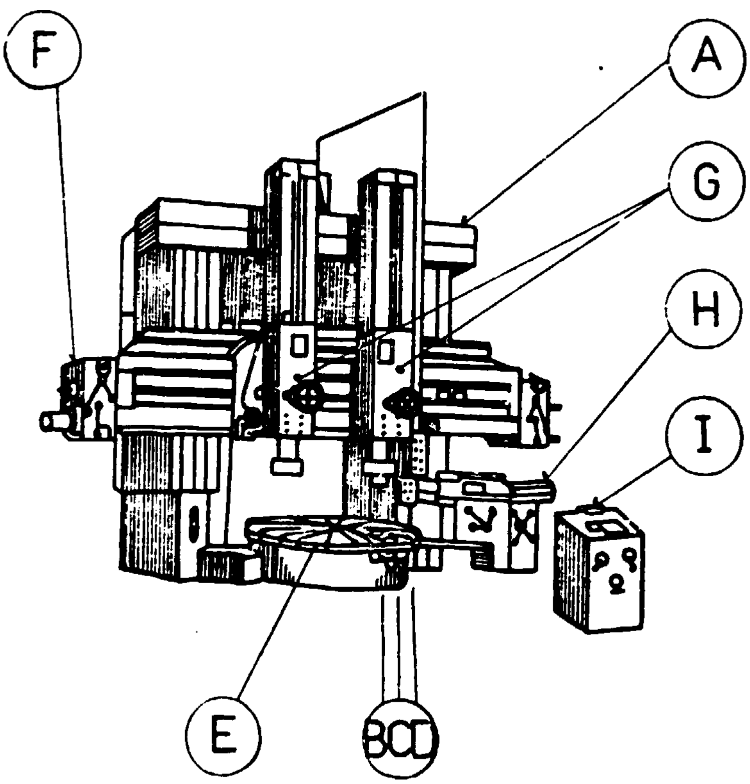


A - Bed with tailstock	1
B - Electric motor with electrical installation	1
C - Gearbox	1
D - Feed and threading gear box	1
E - Headstock	1
F - Slides	1
Basic outfit	6
G - Cooling system	1
H - IKS copying attachment	1
Total complexity	8

Figure 7. Examples of definition of complexity of machines (cont'd)

(e) Double-column boring and turning mill	Number of subassemblies

Maximum ϕ = 4,000 mm; clearance under slides = 2,550 mm;
80-180 kW; weight = 100,000 kg



A - Double-column frame	
B - Ward-Leonard set	1
C - Electric motor and electrical installation	1
D - Gear box	1
E - Revolving table-tool head	1
F - Traversable cross rail	1
G - Vertical slides	2
H - Side head	1
<u>Basic outfit</u>	9
CH - cooling system	1
I - Control panel	1
J - Shaping	1
K - Grinding	1
<u>Total complexity</u>	13

The coefficient of correction which in a complex arrangement expresses the influence of self-sufficiency of maintenance on labour input, or more precisely on the input of expenditures. Labour input in this case increases or reduces the number of points determined by means of the design and process characteristics approximately within the scope of one degree of labour input.

Table 8. Machine mechanization and automation

Degree of technical standard	Machine characteristics
1	<u>Machines controlled manually</u> All drives, clamping, removal of material, measurement etc. are carried out by the machine operator. Example: hand- and foot-operated bending machines, level shears bending rolls etc.
2	<u>Mechanized machines</u> At least one of the machine functions is mechanized (usually the electric motor, the hydraulic system etc.). Example: simple machine tools, metalforming machines, pumps etc.
3	<u>Semi-automated machines</u> More than one function is electrically, hydraulically or pneumatically controlled; at least one function is automated (displacement of stock, some of the working operations etc.). Example: turret lathes, copying machines, mechanical looms.
4	<u>Automated machines</u> Most of the functions are automated by means of control mechanisms (cams, pins, punched cards etc.) or by means of partial systems (numerical control). Example: numerical control machines, pneumatic and hydraulic textile machines etc.

Table 9. Machine precision

Level of precision	Machine characteristics
3 Very precise	The machines operate in tolerances of the order of 0.001 mm to 0.005 mm. Readout of values is largely electronic or optical. Examples: measuring machines, jig-boring machines etc.
2 Precise	The machines operate in tolerances of the order of 0.01 mm to 0.05 mm. Readout is usually arranged on metallic scales. Examples: machine tools, metal-forming machines etc.
1 Less precise	The machine operates in tolerances of the order of 0.1 mm. Examples: woodworking machines, hand-operated machines, hoisting equipment, pumps, mixers etc.

The degree of labour input (S_p) is determined according to the procedure outlines in table 10.

For construction of a technical plan of maintenance a six-step planning system defined for three categories of machine importance is used.

For determination of a maintenance regime, maintenance planning tables are used. The tables are set up according to specific criteria for the different categories of machine importance. In the tables only basic labour input is calculated, that is, the labour that goes into inspections and in-process repairs, with the times required for diagnostics, lubrication and protection from corrosion included in both categories.

The total labour input into maintenance is determined from the basic labour input and from the reserve envisaged for emergency repairs. The reserve is not added to individual degrees of labour input, but always to the whole category of importance.

The general construction of the technical plan of inspection and in-process repairs is reflected in figure 8.

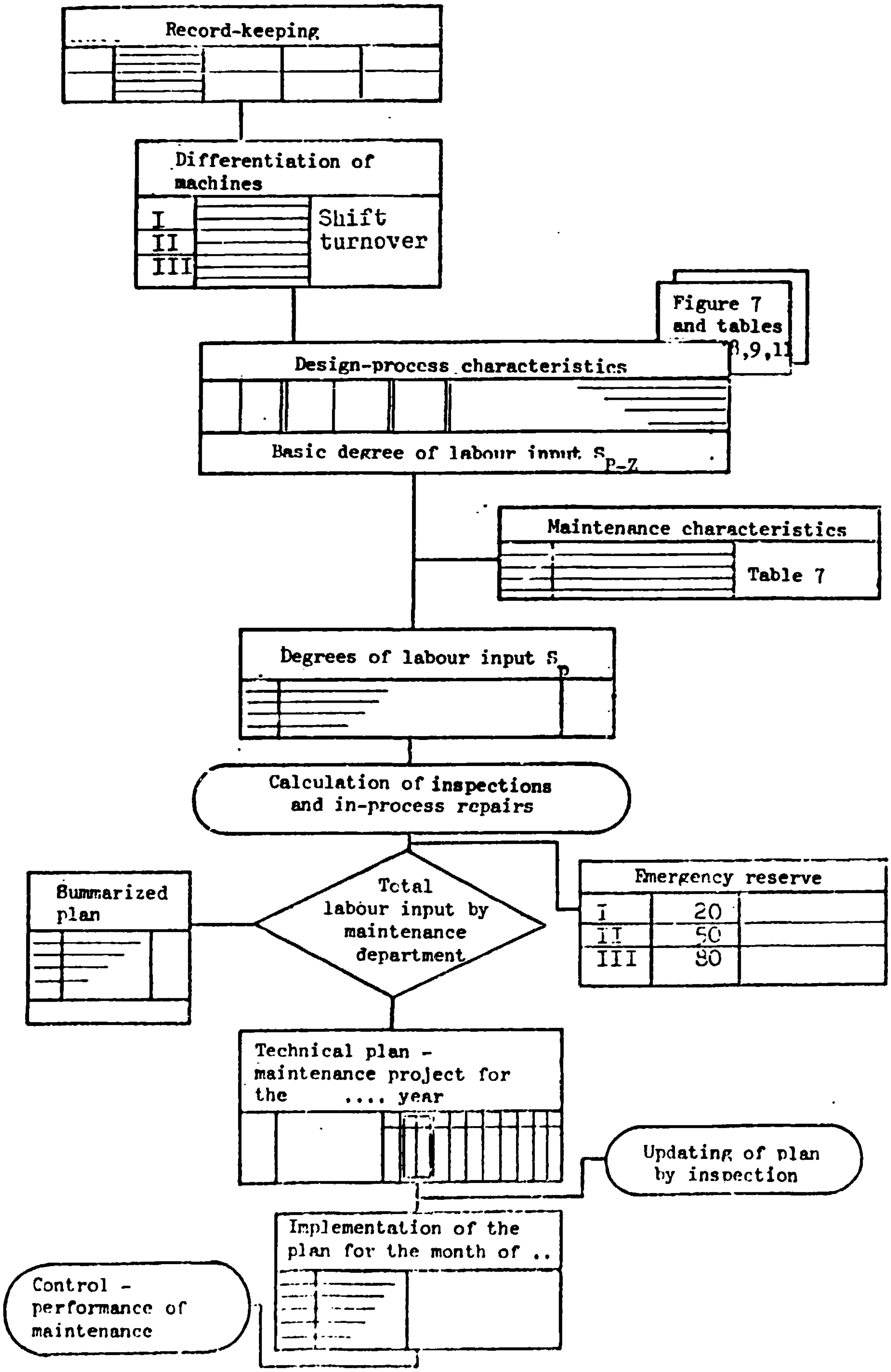
Table 10. Machine design, process and maintenance characteristics

Number of operation	Description of operation	Data source	Labour input
1	Selection of machine	Machine records	
2	Determination of design-process characteristics		
	Complexity Breakdown into subassemblies	Figure 7	
	Technical standard Classification in degrees of mechanization and automation	Table 5	
	Weight Ascertainment of necessary information	Technical documentation	
	Precision Classification precision groups	Table 6	
3	Assignment of values in points Sum total of points	Figure 7	Basic degree of labour input (S_{p-z})
4	Determination of maintenance characteristic	Table 4	
5	Correction of total value of points from operation 3		
6	Assignment of a degree of labour input S_p		Degree of labour input S_p

Table 11. Machine design and operational characteristics

Criteria evaluation								Total evaluation	
Complexity		Degree of mechanization and automation		Weight and size		Degree of precision			
Number of sub-assemblies	Points	Technical level	Points	Tons maximum	Points	Required precision	Points	Total points	Basic degree of labour input
1	1	1	6	1	1	Tenths of a		8- 60	1
2	4			1.5	8	millimetre	5		
3	9	2	24	2	11			61-120	2
4	16			2.5	13	Hundredths			
5	25	3	72	3	15	of a milli-		121-180	3
6	36			3.5	17	metre	50		
7	49	4	144	4	18			181-240	4
8	64			5	21	Thousandths			
9	81			6	23	of a milli-		241-300	5
10	100			7	25	metre	100		
11	121			8	27			301 and	
12	144			9	29			above	6
13	169			10	31				
14	196			11	33				
15	225			12	34				
				13	36				
				14	37				
				15	38				
				20	45				
				30	55				
				40	63				
				50	71				
				60	78				
				70	84				
				80	90				
				90	95				
				100	100				

Figure 8. Development of maintenance plans



A summarized plan is a document that contains simplified definitions of individual items of the annual technical plan.

Updating of the plans is carried out by the machine inspector for the draft annual plan three months before the beginning of the planning period, and for the monthly plans 10 days before the beginning of the month involved.

From the above procedure of work it is evident that inspection occur in the maintenance process in two phases: as supervisory acts of maintenance; and as an updating function between the plan of inspection and in-process repairs and the operational plan. Both phases depend on one another, since inspection has not only a maintenance function, but also an updating function.

The objective of the first phase is to ascertain the technical state of the machine under review and to make arrangements for its operation. The objective of the second phase is to predict the development of the technical state until the next inspection or in-process repair. If the development anticipated by the norm data takes place, the subsequent planned operations do not change. Otherwise, particularly where in-process repairs are required, an appropriate official takes charge of the necessary modifications and revisions of the plan, determines the extent, the target date and the character of the next maintenance operation, and then hands the revised data over to the department of repair planning, followed up by the maintenance control department.

(b) Machine lubrication plan

Lubrication implies the provision of the required amount and assortment of lubricants to be introduced between surfaces of friction of the machines. This forms part of preventive maintenance and is an extremely effective intervention, since at a relatively low cost of about 5 per cent of total maintenance costs, it has a notable influence on the capability of operation, working life span and accuracy of the machines. For practical applications, lubrication is subdivided into in-process lubrication for conservation and functional lubrication.

In-process lubrication for conservation is usually carried out by the machine operators, for instance as part of preparation of the machine for a working shift in the morning and of its grooming and the end of a working shift. These auxiliary lubricating operations are usually prescribed on an instruction plate attached to the machine and containing basic instructions for the machine operator (see example below). It is advisable to mark all machines with these instruction plates, or at least those belonging to the top categories of importance. In practice, it is found useful to mark with blue colour those points of the machine which are to be lubricated by the operator. The operation and performance of the lubrication system for in-process conservation are not scheduled in the plan, but are subject to check-ups conducted by the technician in charge of lubrication or by the machine inspector.

Instructions to machine operator

Before starting to work:

Make sure the machine is clean;
Fill oil to spots of lubrication marked with blue colour;
Check control levers for correct operation;
Switch on the machine.

When work is finished:

Switch off the machine;
Clean the machine;
Apply corrosion inhibitor to machine parts marked for the purpose;
Notify the foreman about any abnormalities in machine operation (noise, vibrations, inaccuracies).

Functional lubrication is a specialized maintenance activity carried out by the maintenance personnel. Its principal objective is to provide the corresponding amounts and quality of lubricants in machine lubrication systems, as in the periodical lubrication of specific points of machines. The points of lubrication envisaged for functional lubrication by specialized workers should be conveniently marked with red colour to prevent confusion.

It is advisable to plan the operations of functional lubrication, particularly for machines in the top two categories of importance. The corresponding plan shall be worked out by the technician in charge of lubrication. An advantage of this plan is its standard arrangement, because, as a rule, only the performance times are changed. The basic data for planning functional lubrication are presented in table 12.

Table 12. Lubrication planning

Machine or part	Replenishment of charge (hours of operation)	Replacement of charge (hours or years of operation)
Ring bearing	90	1,200
Antifriction bearings		
Lubricated with oil	90	1,200
Lubricated with grease	-	4,800
Gearboxes and hydraulic systems		
Charges of up to 50 kg of lubricant	90	2,400
Charges in excess of 50 kg of lubricant	180	4,800
Centralized oil handling system	180	8,600 and more
Turbines	-	20,000 and more
Transformers	-	5-10 years
Switches	-	3-5 years

Under adverse operating conditions, such as dust, humidity and high temperatures, the times are shortened by as much as a half.

The formal arrangement of lubrication plans may vary considerably. As a general rule, the plan should specify the machine and the type of lubrication operation, the number of the production centre, the time of performance, the type and quantity of the lubricants and any special instructions. For important machines instructions for lubrication are usually attached to the lubrication plan, with a sketch of the machine showing lubrication points and details of the kinds and amounts of lubricants, periodicity of lubrication etc.

Within the scope of the lubricating activities is usually included the care of the hydraulic circuits and sets of the hydraulic media. Similar arrangements are also envisaged for protection from corrosion.

One specific kind of lubrication plan is the so-called working schedule of lubrication rounds. It is mostly worked out for categories of first importance, but its use is frequently extended to the second category. A working route schedule may also contain technological instructions for lubrication and, where necessary, is supplemented with the required documentation. Its objective is to make possible the precise shut-down of a machine and the optimization of time intervals between individual operations. Thus it also serves to control lubricating operations.

4.2 Control of maintenance

4.2.1 System characteristics

In respect of the control of maintenance, we shall be interested only in the component of the control system that is linked with technical planning, that is, not with what is called economic value control, which can be covered by means of the corresponding item in the economic plan, but with operational control.

The objectives of operational control are as follows: in preventive maintenance and in-process repairs, to safeguard their implementation within the scheduled target dates, including their synchronization with the needs of the production centres; with regard to emergencies and failures, minimization of the production shut-downs involved.

In a more specific sense, the control of maintenance safeguards the implementation of an individual maintenance operation, whereas in broader terms it safeguards a complex of maintenance operations, including their liaisons with other activities. In the first instance, there prevails what is called a dispatching control that intervenes particularly where deviations from the plan are to be dealt with. Its function is thus largely a passive one, as it waits for the occurrence of an undesirable situation which it helps to resolve. In the second instance, the control steps in as an active continuation of the planning function and keeps systematic record of each moment in the progress of maintenance work. It includes breakdowns in its agenda in the same way as the dispatching system of approach.

The system approaches to maintenance control cannot be used in practice without a certain technical outfit. This is not only a question of signalling and communication links arranged in the same way as in the dispatching control centres, but also of equipment that makes it possible to display the course of the process of maintenance at any given moment. The highest-category systems use computers. For conventional maintenance requirements, the system of a control centre arranged on mechanical lines is usually sufficient. This simple system is reflected in figure 9 and consists of the following elements:

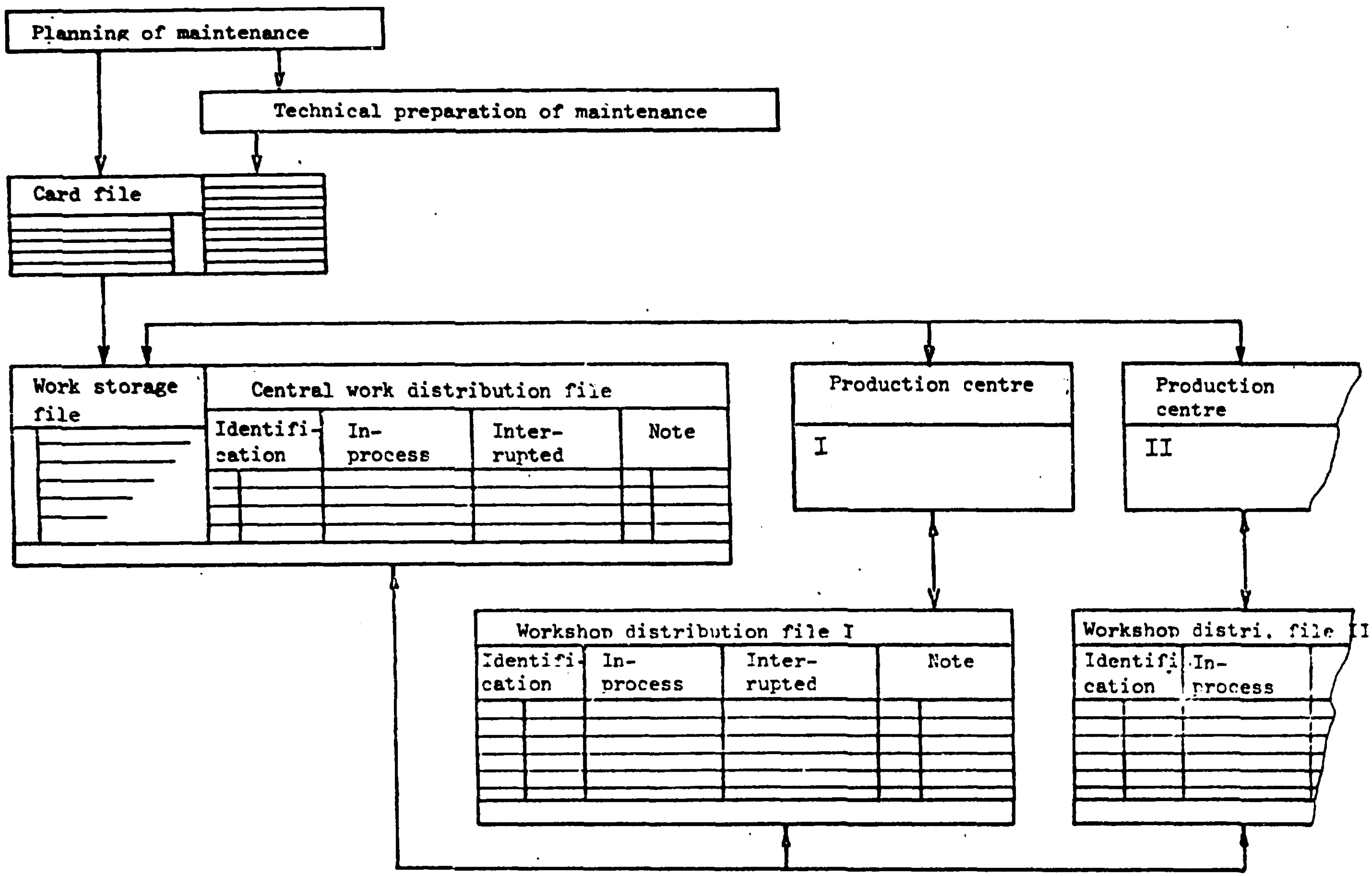
1. Technical elements of the control centre (hardware)

   Card file of work documents;
   Planning board consisting of a storage magazine and a central distributor;
   Peripheral distributors of work at group work stations. These are usually designed for individual workshops, but they may have more general applications;
   Connecting links and signalling (telephone lines, signal lights, acoustic signals etc.);
   Memory elements (files etc.).

2. Work documents of the system (software)

   Operational plans;
   Report cards of failures and breakdowns;
   Inspection regulations or instruction cards for repairs;
   Technological documentation of repairs;
   Repair job cards;
   Other documents as required.

Figure 9. Organization of maintenance control centre



4.2.2 Description of activities involved

The process of maintenance begins with the provision of the plans of maintenance, the accompanying documentation and a failure report card. The documents for the different operations performed are deposited in transparent envelopes. White envelopes are provided for preventive maintenance and in-process repairs and red ones for failures or breakdowns. The colour pattern may be a wider one for GO, LUBRICATION etc.

The documents associated with the maintenance plan are placed in a card file. The failure report cards go straight into the work storage file.

The documents of planned operations to be performed are shifted into the work storage file in chronological order as scheduled by the plan, but in an arrangement under which the respective maintenance worker or team of maintenance workers has one operation in progress and another one ready in the work storage file. Only exceptionally are more operations prepared for execution.

The decision about removal of an operation from the work storage file or about the correction of a failure lies with the workshop foreman or the maintenance team leader, jointly with the official in charge of the control centre.

In the central distributor the state of work in progress is indicated by the location of the envelope with accompanying documentation. The originals together with the work materials are filed in the workshop distribution indexes or transferred to the place where the maintenance operation is to take place.

After completion of the work the foreman checks the data, returns the envelope to the central distribution index, and, if necessary, make the appropriate changes on the distributors.

The worker in charge of control takes over the documentation of a completed operation, complements it with the filed materials, removes the operation from distribution and passes it on for accounting. At the same time, he hands over the next operation for execution.

Thus the control centre keeps a permanent and complex record of the movements of the workers and of the capability of operation of the equipment.

4.3 Major overhauls of machines

Major machine overhauls are the most extensive operations performed by maintenance workers. During such overhauls important interventions are made in the technical structure of repaired machines.

4.3.1 Decision on major overhauls

The large number of major overhauls, as in the case of machine tools where up to 80 per cent of all components are at some time replaced, calls for considerable technical and economic expertise. A major overhaul involves a decision as to whether a machine is still worth a repair or whether it should be scrapped and replaced by a new one.

Decisions about major overhauls are always made on the basis of an assessment of a number of facts, particularly the following: the extent of the envisaged major overhaul; the anticipated costs of the overhaul; the time during which the machine will be inoperative; and the availability of a replacement machine in the event of the original machine being scrapped.

It is also possible to use a system of evaluation as indicated in table 13. The table shows that from category 5 onwards a major overhaul should be contemplated when there is approximately 50 per cent of wear. The decision as to whether to carry out the major overhaul also depends on the strategy adopted, or on one of two basic strategies.

Table 13. Evaluation of the technical state of a machine

Category	Physical wear (percentage)	Extent of physical wear of machine	Characteristic
1	0-10	New	Up to 1 year after putting into operation.
2	11-20	In perfect order	As good as new, in perfect order or up to one year after major overhaul.
3	21-30	In good order	Operates without defects; shortcomings can be corrected by in-process repair.
4	31-40	In order	Operates with acceptable performance and accuracy within tolerable limits; shortcomings can be corrected by in-process repair.
5	41-50	Worn	Operates with impaired performance, impaired accuracy and with failures which in part exceed the normal limits; shortcomings can be corrected by a major overhaul (within 2 years).
6	51-60	Considerably worn	Operates with considerably impaired performance and accuracy and with failures exceeding the normal limits; shortcomings can be corrected by a major overhaul (within 1 year).
7	61-70	Much worn	Operates with much impaired performance, inaccurately and with high incidence of failures; requires a major overhaul without delay.
8	71-80	Heavily worn	Operates with very low performance, very inaccurately, with very high incidence of failures; after a replacement has been found, machine will be scrapped.
9	81-90	Very heavily worn, partially damaged	Is nearly incapable of operation and should be scrapped without delay.
10	91-100	Completely worn out	Is completely incapable of operation and, consequently, scheduled for scrapping.

(a) Conventional major overhauls

These are the most widely used. They consist essentially in a comprehensive dismantling of the machine, the replacement or repair of most of its component parts and reassembly of the machine.

An advantage of this strategy is the physical renewal of most of the components, and thus a substantial improvement of the technical condition of the machine. Drawbacks are the high expenditure involved in such an overhaul and the usually long time during which the machine is idle. This sometimes makes it necessary temporarily to replace the corresponding production capacity.

(b) Progressive major overhauls

These are also sometimes referred to as spread overhauls. This strategy consists essentially in the progressive repair of individual subassemblies, such as the headstock and gearbox. Under this arrangement there are intervals between the successive stages of major overhauls when the machine can be used in production. The strategy reduces the difficulties caused by long shut-downs of a machine when a conventional strategy is used. Being carried out at the machine site, it also represents a less demanding job for the repair shops. The use of this alternative, however, depends to a certain extent on the design arrangement of the machines concerned.

The strategy of progressive major overhauls comes near to a system without major overhauls, with the machine maintained in a state capable of operation only through preventive maintenance and in-process and emergency repairs.

The two basic strategies of major overhauls can be modified by various means, the most important of which are described below:

(a) Arrangement of repairs by replacement. This method involves the immediate replacement of a worn-out machine at the working site by a repaired one. A major overhaul is carried out later. This arrangement of repairs is conditioned by the replacement facilities, that is, by the existence of at least one surplus machine used as a replacement. This replacement procedure is used to advantage when a number of machines of the same or similar type are installed, as in the textile industry.

(b) Major overhaul with modernization. This is a highly desirable method of repair. It consists in an arrangement whereby a machine is not repaired to its original technical level, but is supplemented with items of equipment that serve to improve its original properties, such as mechanical feeding-in or clamping of parts to be machined and accessory control systems.

Major overhauls involve a number of successive stages and operations, arranged in series, others in parallel. It is therefore important to pay attention not only to the technology of the repairs, but also to their planning and control.

4.3.2 Planning and control of repairs

In respect of control, the principal stages and operations that must be synchronized both in time and in their subject matters within the scope of a major overhaul are the following:

(a) Preparatory stage

- Justification of the major overhaul entered into the minute book;
- Incorporation in the plan after consultation with the production centres;
- Arrangements made for supplies from external providers;
- Preparation of technical documentation and provision of materials.

(b) Stage of realization

- Cleaning and disconnection of the machine and its transfer to the site envisaged for repair;
- Rough dismantling into structural subassemblies;

- Progressive dismantling into individual parts;
- Complete cleaning of parts;
- Technical inspection of parts, analysis of their wear and classification into those that can be reused without reconditioning, those that can be mended, and those that cannot be mended;
- Specification of the way in which repairs will be carried out;
- Provision of spare parts from the store, by acquisition from external providers or by manufacture in the plant workshops, to replace those which have been scrapped;
- Reassembly of structural subassemblies;
- Reassembly of the machine as a whole;
- Surface finishes;
- Running-in of the machine.

(c) Handing-over stage

- Complex verification of machine parameters in the presence of its future user, measurement of accuracy, performance etc.;
- Handing-over of the machine to its user;
- Conclusion of technical and economic aspects of the repair liquidation of costs, filing of documents etc.

The details of preparation and subdivision of major overhauls differ according to a number of intervening factors, particularly according to whether an individual repair or a series of repairs is involved.

5. MAINTENANCE INFORMATION SYSTEM

A maintenance information system includes the following elements: a complex of data and verbal information items; a set of bearers of this information (documents, magnetic tapes, discs etc.); and procedures for the movement or transformation of the data.

The objective of an information system is to make possible efficient planning, control, performance and evaluation of maintenance. The information system must ensure not only the movement of information within the maintenance department, but also interconnections with other activities inside the plant and outside it.

A complex maintenance information system may be subdivided into a number of basic components:

(a) Information on the plant. This makes it possible to learn about the structure of the production programme and other characteristics of the plant related to maintenance;

(b) Information of a record-keeping nature. This summarizes the main technical, economic and legal characteristics of the machines;

(c) Information on machine performance. This specifies important data on changes in the age and technical pattern of the machines and in their utilization in production;

(d) Special information. This includes specialized information required to characterize such matters as: incidence of machine failure; costs involved in maintenance; and classification of machines into specific categories of importance, technical level etc.

Detailed analysis of a maintenance information system exceeds the scope of this study. Attention will therefore be focussed on selected maintenance subsystems that have a relatively general applicability.

5.1 Information for preparation of maintenance plans

As most of the required information items have been specified in earlier chapters, this section will be mainly concerned with the formal arrangement of data on the documents during their practical use in industrial establishments.

5.1.1 Economic plan

A working arrangement of the required information items is shown in table 14, which is a blank form of an economic maintenance plan. The plan form can also be used as a statement on the fulfilment of the plan, thus making it possible to establish a direct comparison between the planned and the attained values.

5.1.2 Technical plan

The information required for drawing up technical maintenance plans is very extensive. It has already been defined in connection with the methods of planning of inspections and in-process repairs, including the required circulation of information. An example of the required set of information is given in the annex.

5.2 Special information

Selected examples of special maintenance information are presented in table 14.

5.2.1 Information submitted by maintenance superintendent

(a) Summarized maintenance information. Summarized information provides a statement for a specific period of time. It makes possible an analysis of the situation in the maintenance department as part of the plant. The necessary data are contained in table 15 and serve primarily for the transmission of information to other sectors of the plant and as a basis for discussion about the maintenance service. The vacant items at the end of the table are reserved for any other data that may be required.

Table 14. Economic maintenance planning data

Project - Plan - Statement*		Year:	Organizational unit		
	Item	**Designation**	**Plan**	**Current situation**	**Notes**
1.	Price of acquisition of installed machines by 1 January	PC			
2.	Machine additions by 31 December	$S_{(n)}$			
3.	Machines removed by 31 December	$S_{(U)}$			
4.	Costs of machine maintenance as an average of 3 years	$NU_{(V)}$			
5.	Determined: Coefficient of ageing	$k_{(s)}$			
6.	Determined: Coefficient of technical complexity	$k_{(n)}$			
7.	Determined: Index of productiveness of maintenance	I_{PU}			
8.	Planned index of exploitation of machines	$I_{(E)}$			
9.	Planned costs of maintenance of machines, including:	$NU_{(C)}$			
10.	Internal	NU_I			
11.	External	NU_{EX}			
12.	Reserve	NU_R			

* Delete whichever is not applicable

Approved by:

Worked out by: Date: Date:

Table 15. Summarized maintenance information

Summarized information by maintenance department — Organizational unit:

Plan – Statement*

Item	Description	Designation	Period
1	Total acquisition costs of basic assets, including:	PC	
2	Machines	PC	
3	Addition of machines by ...	$S_{(n)}$	
4	Machines removed by ...	$S_{(U)}$	
5	Total production of plant	V	
6	Total number of plant employees	P_P	
7	Total costs of maintenance, including:	NU	
8	Maintenance of machines	NU_S	
9	Emergency repairs	NU_P	
10	External costs	NU_{EX}	
11	Number of maintenance department employees, including:	P_U	
12	Engineers and technicians	P_{IT}	
13	Floor area of maintenance workshops	m^2	
14	Total production of maintenance department	PU	

* Delete whichever is not applicable — Approved by:

Worked out by: — Date: — Date:

(b) Reports on key repairs. Reports on key repairs are envisaged as operational information presented at the weekly conference of the plant management. An example is given in table 16.

5.2.2 Information on reliability of machines

Machines of the first category of importance exert substantial influence on the plant production capacity. Since their importance generally remains unchanged for longer intervals of time, it is necessary to follow information on their parameters of reliability. The knowledge thus obtained makes possible an optimization of the maintenance system and, thereby, maintenance of the operational capability of the equipment. The information required in order to characterize the reliability of machines of the first category of importance is reflected in table 17. This document serves for manual checking of the required information where limited numbers of machines are dealt with. Larger groups require different computation procedures.

The upper part of the document records individual operations performed by the maintenance department, while the required maintenance characteristics are computed in the lower part.

The calculations, although not theoretically perfect, are useful because of their practical significance.

The data are computed for a specific period of time (a month or a year). For longer periods of time it is necessary to establish a time sequence that permits both an analysis of past developments and prediction of future behaviour (see table 18).

5.2.3 Information on spare parts

Spare parts are very important for maintenance. Their availability, quantity and assortment frequently act as limiting factors in the maintenance process. The provision of spare parts is usually conceived as a relatively autonomous subsystem of maintenance primarily involving planning, record-keeping, storage, purchase, renewal and use of spare parts.

Table 16. Example of report on key repairs

Key repairs		Week:		Organizational unit:
Item	Department number	Machine number	Causes (Code number)	Description
1	621	Capillary furnace 01-836-21	2	Larger extent, replacement of heating elements
2	385	RC 63 turret lathe 04-251-13	3	Spare part of spindle not made in time. The original part, wrongly hardened, manufactured for the second time
3	243	BPH 20 grinding machine 03-581-16	1	Modernization of electrical switchboard
4	243	BUA 20 grinding machine 03-593-02	1	Modernization of electrical switchboard.
5	218	Workshop truck 02-561-24	3	Non-observance of target date for delivery of spare parts by outside supplier

Notes: Production of item 2 endangered

For item 2 temporary replacement provided

Key to code of causes:

1. Scheduled time of repair exceeded
2. Scheduled costs exceeded
3. No arrangements made for repair

Worked out by: Date:

Table 17. Machine reliability analysis

	Machine:						Department:		Category of importance:		
Number of case	Nature of case	Time (from -to)	Shut-down	Identification data				Repair data		Worked		Cost (1)
				Site	Spare part number	Cause	Way of liquidation	Labour input	NU (cost	Since last repair	Since beginning of year	
01												
02												
03												
04												
05												
06												
07												
08												
09	Minor repairs											
Total			(2)					(3)	(4)		(5)	

Mean time between repairs	$T_{mean} = \frac{\text{item 5}}{\text{number of case}}$	Specific costs of maintenance	$N\ \% = \frac{\text{item 4}}{\text{item 1}} \cdot 100$
Intensity of repairs	$L = \frac{1}{T_{mean}}$	Times of inactivity of repair teams	$K\ \% = \frac{\text{item 2}}{\text{item 5}} \cdot 100$
Mean time of repairs	$F_{mean} = \frac{\text{item 3}}{\text{number of case}}$	Costs of 1 hour of operation	$Kn = \frac{\text{item 4}}{\text{item 5}}$
	Worked out by:		Date:

Table 18. Analysis of operational properties of machines

Item			Period (years, months, weeks)				Index	Notes
1.	Technical capacity							
2.	Shutdowns for planned repairs							
3.	Shutdowns for failures							
4.	Total of shutdowns for repairs							
5.	Number of repairs							
6.	Proportion of breakdowns (based on hours)							
7.	Total proportion of shut-down times for repairs (based on technical capacity)							
8.	Proportion of inspection repairs							
9.	Real capacity							
10.	Total repair costs							
11.	T mean[a]							
12.	L . 100[a]							
13.	F mean[a]							
	Worked out by:						Date:	

a/ see table 17.

Such an extensive complex of operations imposes extraordinary demands on the information system. The basic element of a specialized spare-parts information system is the spare-parts registration card, which as a rule includes: the number of parts, name, supplier, affiliation to a machine (or its general applicability), dimensions, weight, price, designation of basic material, number of workshop drawing, number of route sheet, minimum amount (reserve) kept in storage, identification of place of storage and number of item on store records, storage life span of part in hours and other data where necessary.

Other documents indispensable for the provision of spare parts are: catalogues and lists of spare parts, plans of spare part manufacture, report cards of spare part damage etc.

The information background required for the provision of spare parts is one of the most complicated aspects of the maintenance information system as a whole.

6. MAINTENANCE WORKSHOPS

Prompt and rational maintenance depends to a considerable extent on the technical equipment available to the maintenance personnel. This does not mean only items such as tools, working aids and small instruments used by each repairman. An important constituent of the technical outfit of maintenance personnel is a specialized work station or maintenance workshop. There are two basic categories of such workshops.

6.1 Operational maintenance work station

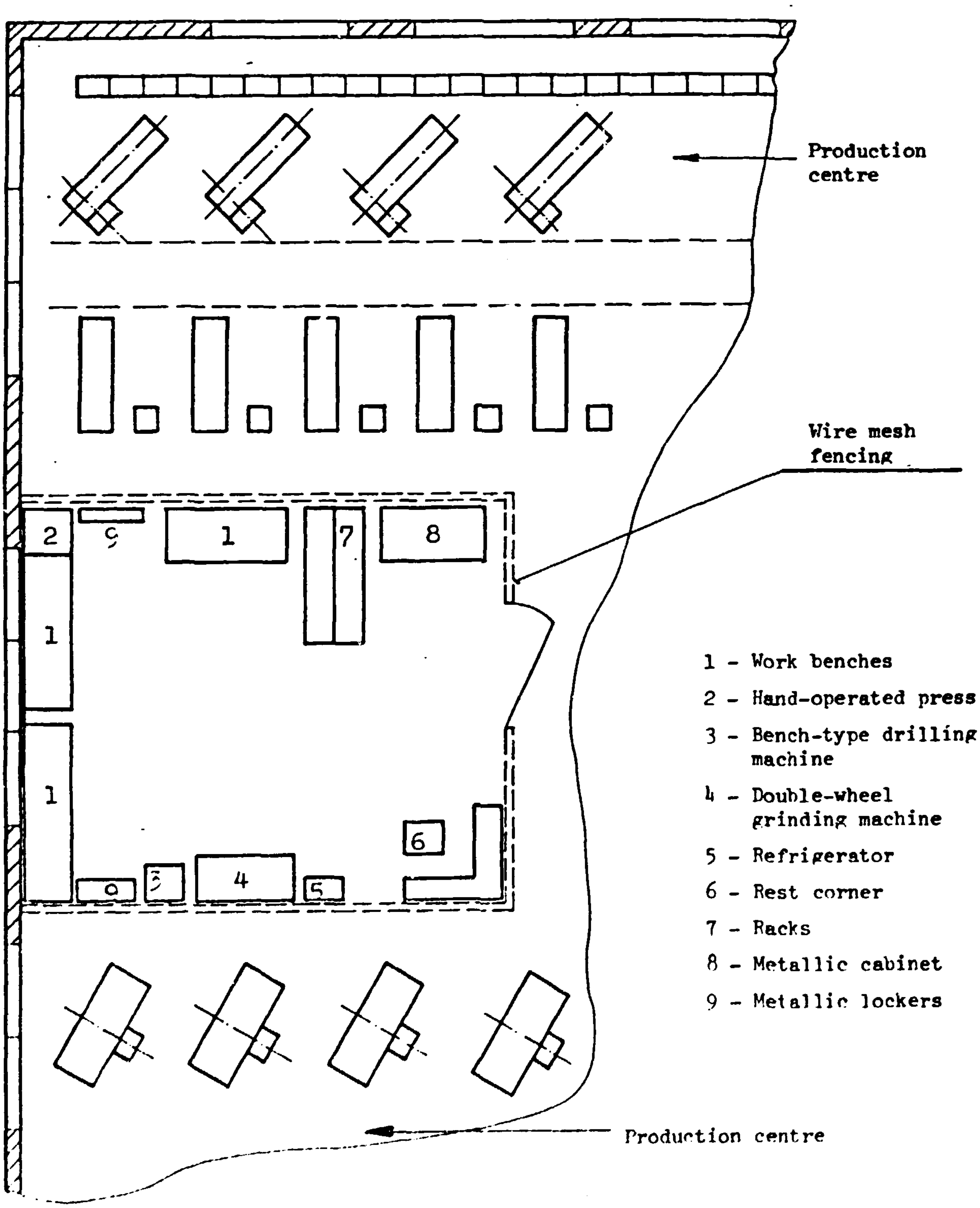
The operational maintenance work station is a basic unit of maintenance facilities. It is essentially an auxiliary work station that caters to a specific part of the plant. It is usually arranged in such a way that: the distance to the most remote machines that is taken care of does not exceed 25 to 30 metres; and the sphere of machines attended to form an integrated organizational unit (centre), a self-contained technological complex of machines (such as a group of milling machines), and a physically delimited part of the plant (a production hall etc.).

A repairman's operational work station serves primarily as a base for storing tools and aids of personal use, for dismantling, repairs and testing of separate machine subassemblies, and for storage of minor spare parts. This work station is also equipped with individual auxiliary machines, work branches, storage areas and a rest corner. In larger operational work stations (10-15 workers), it is convenient to extend the work station outfit by adding other technical equipment and facilities, particularly a surface grinding machine, a simple lathe and a welding set. The floor area of such a work station should amount to approximately 8 m^2 per worker of the maintenance department. An example of an operational maintenance work station envisaged for three workers on one shift per day is shown in figure 10.

6.2 Repair workshop

Practically every plant must be equipped with both an operational maintenance work station and a central repair workshop. In the workshops a considerable part of preventive maintenance is also carried out.

Figure 10. Maintenance work station



The workshops form an organizational unit with the necessary technical and administrative staff (see figure 11) and manufacturing and assembly sections.

The manufacturing section is engaged in manufacture and renovation of some of the spare parts, usually simple ones and those of limited size and weight. The workers in this part of the workshop are specialized only for work performed on machines. These are for the most part specialists trained in several crafts, such as lathe-grinding and the operation of milling and drilling machines.

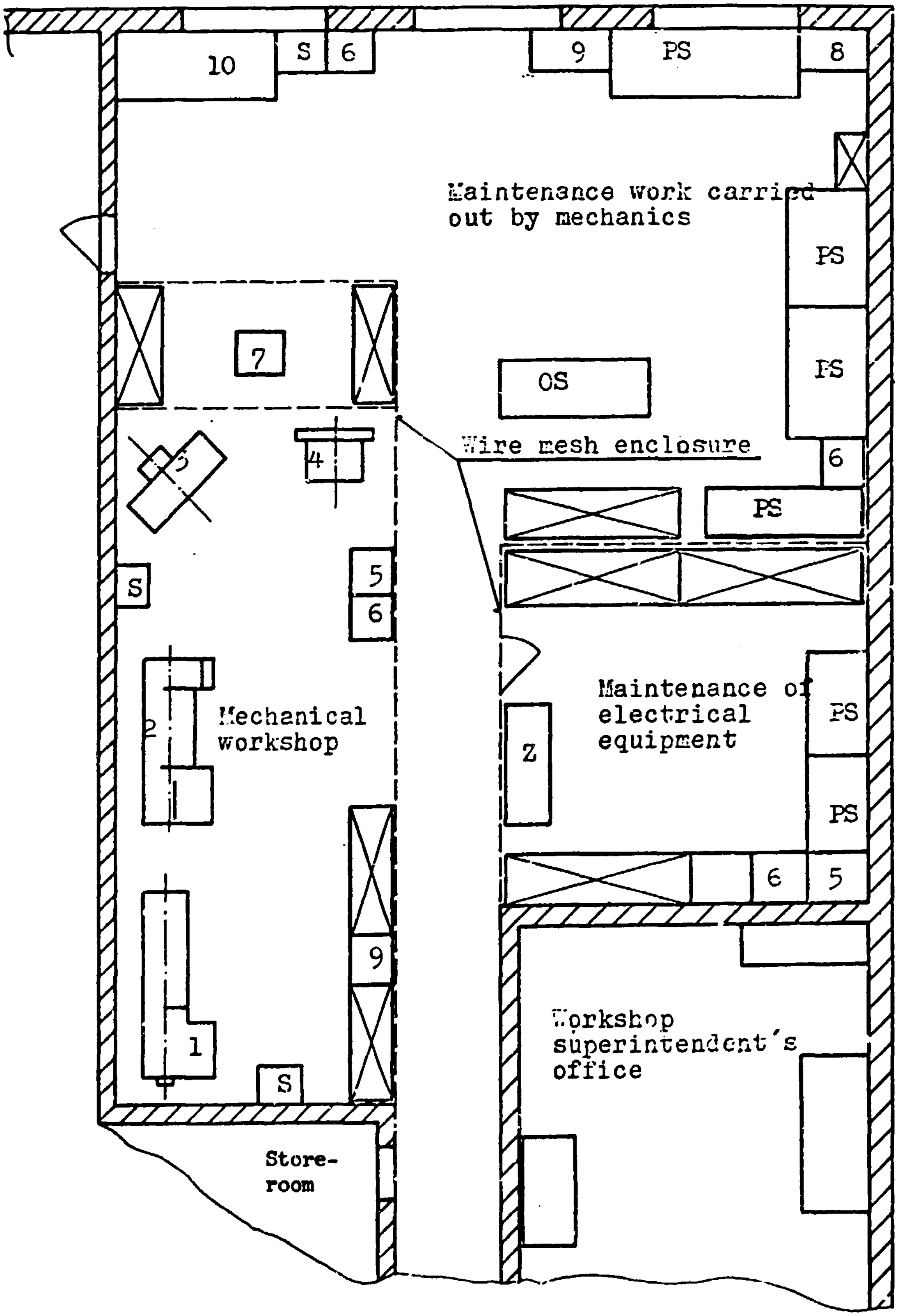
The assembly and dismantling of machine subassemblies are carried out in the assembly section. The workers engaged in this section usually travel between a work station in the workshop and the machines that are being repaired in production certres.

In many establishments these workshops form the largest technical maintenance units and may contain a number of specialized facilities, such as a tinsmiths' workshop and a workshop for construction crafts. One of the conventional alternative arrangements for this kind of workshop is shown in figure 13.

Such workshops usually engage part of their capacities in jobs not directly associated with maintenance, for instance, small-scale manufacture of special machines.

In workshops of a similar type, extensive and technically demanding repairs, particularly major overhauls, cannot usually be carried out. An impediment in this respect is not only the limited capacity of the workshop, but also technological limitations due to the impossibility of making arrangements for complex maintenance technologies. In exceptional situations, major repairs can be arranged through co-operation within the plant or with outside suppliers of more sophisticated spare parts.

Figure 11. Maintenance workshop organization



Note:

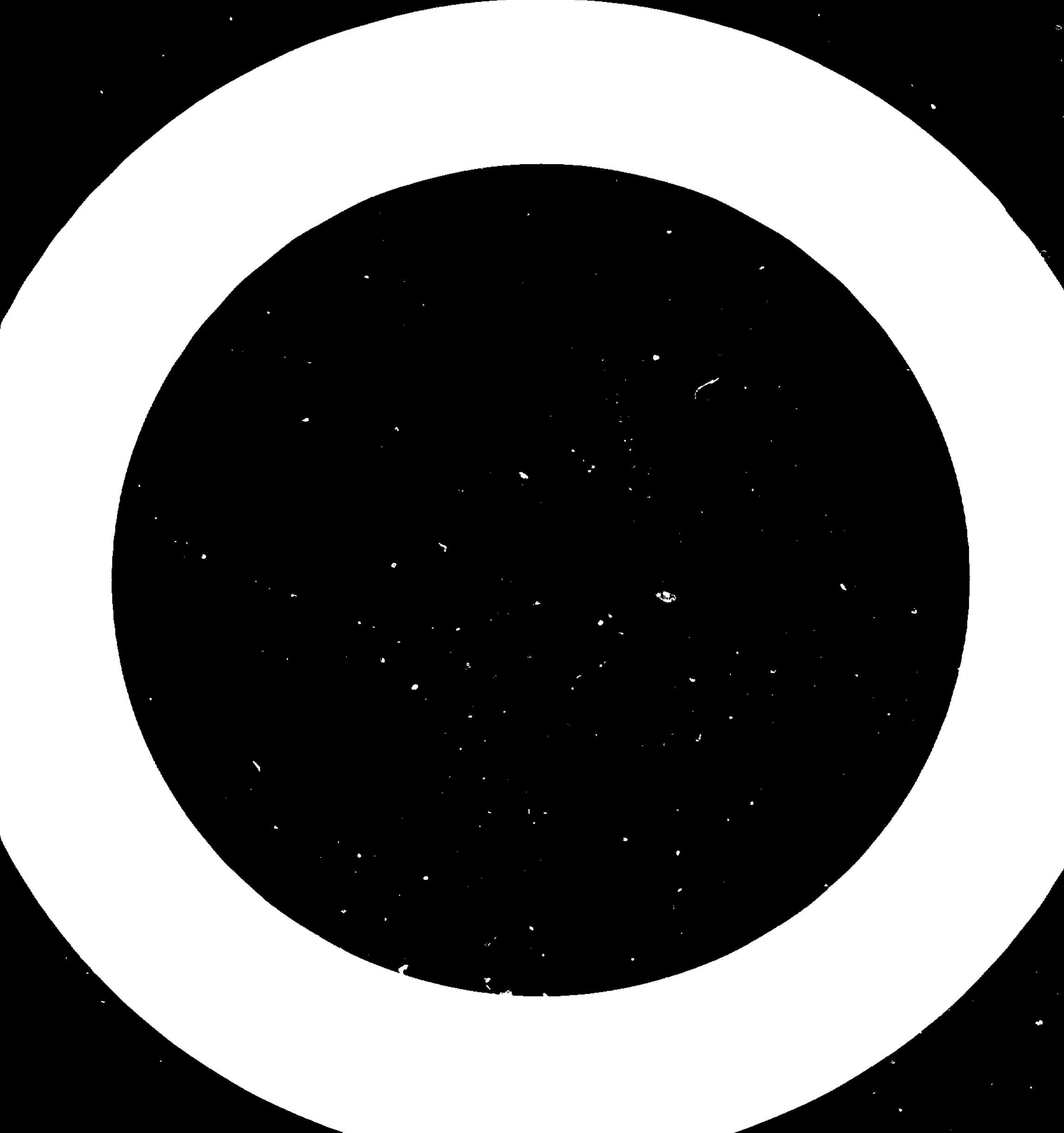
1 - Universal lathe
2 - Universal grinding machine
3 - Universal milling machine
4 - Radial drilling machine
5 - Hydraulic bench press
6 - Double-wheel grinder
7 - Marking-off table
8 - Bench-type drilling machine
9 - Oil cleaner
10 - Washing machine for parts

S - Lockers for working aids

PS - Work branches
CS - Table
Racks

Z - Lock-up cabinets

Larger establishments, or those with a high degree of self-sufficiency, must usually carry out a larger number of extensive maintenance operations, including major overhauls. In such cases the number of workers and the technical capabilities of the repair shops must be increased. Special workshops are built for major overhauls. These workshops are frequently all-purpose units which also produce equipment. In their largest forms they are relatively autonomous establishments and may be established on a purely commercial basis. A workshop of this kind is described in the annex.



Annex

EXAMPLES OF THE SYSTEM OF DIFFERENTIATED PREVENTIVE MAINTENANCE

Examples of the practical application of the general instructions for organization, planning and control of preventive maintenance and repairs are given in this chapter. These examples are based on the practice of industrial establishments in Czechoslovakia, and cover the widest possible scope of problems associated with preventive maintenance.

The first example is concerned with the methodology involved in the preparation of a plan of inspection and in-process repairs in a conventional engineering establishment where part of the production equipment is automated. The second example illustrates a repair shop of a larger establishment capable of performing more extensive repairs and major overhauls of machines. It thus complements the size range of repair shops dealt with in chapter 6. The third example outlines maintenance arrangements in a textile factory, and the fourth shows maintenance organization in basic food processing industry.

Plan of in-process repairs in engineering production

The workshop of an engineering establishment engaged in the manufacture of agricultural machines and light-duty tractors has been selected as an example. This involves engineering production carried out in short and medium production runs to meet average demand. Medium-sized production lots are manufacured on machines with a higher degree of automation, such as turret lathes and automatic lathes. These belong largely to the first category of importance.

The establishment has mechanical equipment of varying complexity and demand for labour input by maintenance personnel. The main machines are utilized for production in two shifts per day; machines engaged in ancillary production are run in one shift per day. The machines are divided according to their respective categories of importance in the production programme and arranged in work tables on the basis of the generally applicable documents described in chapter 4. The tables cover the following aspects of preventive maintenance for the various items of equipment used (see tables 19-23).

- Annual labour input for in-process maintenance;
- Number of operations performed by maintenance personnel;
- Kinds of operations performed by maintenance personnel;
- Time demands;
- Capacity calculation;
- Pattern of crafts involved;
- Total capacities of workers.

The data are used for the annual preparation of a plan of inspections and in-process repairs (see table 23).

Specialized workshop for major overhauls

A specialized workshop capable of carrying out major overhauls, referred to as repair shop hereinafter, is a more extensive and complex facility than the workshop dealt with in chapter 6. Moreover, it operates under a different system; contrary to the in-process repair workshop, it is practically independent of the system of the production centres.

The following example of a relatively small repair shop serves as a basic model for the establishment of repair shops of practically any size. The example is an abridged form of a project study.

Production programme of repair shop

The production programme of the repair shop involves a number of items which contribute in different ways to total production:

	Percentage
Major overhaul of machines	65
Manufacture and renewal of spare parts	20
Other production	15
	100

Table 19. Machine design and process characteristics

Machine	Complexity		Mechanization		Weight		Accuracy		General evaluation	
	Subassembly	Points	Degree	Points	Tons	Points	Category	Points	Points	Degree of labour input
AN 35 five-spindle automatic lathe	8	64	3	72	3	15	3	100	239	4
VZB 6 unit-built machine	9	81	3	72	4	18	3	100	271	5
ANK 135 automatic lathe	7	49	3	72	3.5	17	3	100	238	4
A40 automatic lathe	6	36	3	72	3	15	2	50	173	3
AB 80 automatic lathe	7	49	3	72	3	15	3	100	236	4
AN40 six-spindle automatic lathe	10	100	3	72	3.5	17	2	50	239	4
DAMFF6x160 semi-automatic lathe	11	121	3	72	5	21	2	50	264	5
VR 6 radial drilling machine	7	49	2	24	2	11	2m	50	134	3
FA3AV universal milling machine	6	36	2	24	2	11	2	50	121	3
FVS MZ vertical milling machine	7	49	2	24	2.5	13	3	100	186	4
V20/2 drilling machine	5	25	1	6	1.5	8	2	50	89	2
ZM16 threading machine	4	16	1	6	1	1	1	5	28	1
FYE 25 hydraulic press	4	16	1	6	2	11	1	5	38	1
VS 32 drilling machine	4	16	1	6	1	1	1	5	28	1
VR 4A radial drilling machine	5	25	2	72	1.5	8	1	5	110	2
VR 2 radial drilling machine	5	25	1	6	1.5	8	1	5	24	1
F6320 hydraulic press	7	49	1	6	7	25	1	5	85	2
SV 18RA centre lathe	5	25	1	6	2	11	2	50	92	2
S 32 centre lathe	6	36	1	6	2	11	2	50	103	2
1 K 341 lathe	8	64	2	24	3	15	2	50	153	3
VS 32 A drilling machine	5	25	1	6	1.5	8	1	5	44	1

Table 20. Machine characteristics

Importance category	Maintenance self-sufficiency (percentage)	Correction coefficient
I	60	1.15
II	75	1.00
III	80	1.00

Table 21. Machine maintenance

Name	Type	Degree of labour input	Labour input (Nh)	Maintenance operations: Number of (inspections) x (hours)	Maintenance operations: Number of in-process (repairs) x (hours)
Machines of importance category I (utilization in two shifts per day)					
Five-spindle automatic lathe	AN 35	4	500	6 x 20 = 120	2 x 190 = 380
Unit-built machine	VZB 6	5	600	6 x 25 = 150	2 x 225 = 450
Automatic lathe	ANK135	4	500	6 x 20 = 120	2 x 190 = 380
Automatic lathe	A 40	3	400	6 x 15 = 90	2 x 155 = 310
Automatic lathe	AB 80	4	500	6 x 20 = 120	2 x 190 = 380
Unit-built machine	VZB 6	5	600	6 x 25 = 150	2 x 225 = 450
Six-spindle automatic lathe	AN 40	4	500	6 x 20 = 120	2 x 190 = 380
Semi-automatic lathe	DAMF6x160	5	600	6 x 25 = 150	2 x 225 = 450
Radial drilling machine	VR 6	3	400	6 x 15 = 90	2 x 155 = 310
Universal milling machine	FA 3 AV	3	400	6 x 15 = 90	2 x 155 = 310
Vertical milling machine	FV 5 MZ	4	500	6 x 20 = 120	2 x 190 = 380

Table 21. Machine maintenance (cont'd)

Name	Type	Degree of labour input	Labour input (Nh)	Maintenance operations: Number of (inspections) x (hours)	Maintenance operations: Number of in-process (repairs) x (hours)
Machine of importance category II (utilization in two shifts per day)					
Drilling machine	V20/2	2	225	4 x 10 = 40	1 x 185 = 185
Threading machine	ZM 16	1	100	4 x 5 = 2C	1 x 80 = 80
Drilling machine	V20/4	3	300	4 x 15 = 60	1 x 240 = 240
Hydraulic press	PYE 25	1	100	4 x 5 = 20	1 x 80 = 80
Drilling machine	VS 32	1	100	4 x 5 = 20	1 x 80 = 80
Drilling machine	VS 32	1	100	4 x 5 = 20	1 x 80 = 80
Drilling machine	VS 32	1	100	4 x 5 = 20	1 x 80 = 80
Radial drilling machine	VR 2	1	100	4 x 5 = 20	1 x 80 = 80
Radial drilling machine	VR 4A	2	225	4 x 10 = 40	1 x 185 = 185
Hydraulic press	P 6320	2	225	4 x 10 = 40	1 x 185 = 185
Centre lathe	SV 18RA	2	225	4 x 10 = 40	1 x 185 = 185
Lathe	RN 36	2	225	4 x 10 = 40	1 x 185 = 185
Machines of importance category III (utilization in one shift per day)					
Centre lathe	S 32	2	40	4 x 10 = 40	
Lathe	1 K 341	3	60	4 x 15 = 60	
Drilling machine	VS 32	1	20	4 x 5 = 20	
Drilling machine	VS 32 A	1	20	4 x 5 = 20	

Table 22. Determination of maintenance labour input

Degree of labour input	Number of machines	Maintenance operations in production man-hours	
		Inspection	In-process repairs
Importance category I			
3	3	270	930
4	5	600	1,900
5	3	450	1,350
	Total	1,320	4,180
Correction based on maintenance characteristic x 1.15		1,518	4,807
Importance category II			
1	6	120	480
2	5	200	925
3	1	60	240
	Total	380	1,645
Correction based on maintenance characteristic x 1.00		380	1,645
Importance category III			
1	2	40	
2	1	40	
3	1	60	
	Total	140	
Correction based on maintenance characteristic x 1.00		140	

Table 22. Determination of maintenance labour input (cont'd)

Maintenance labour input in preventive operations

	Production man-hours
Inspections	2,038
In-process repairs	5,965
Total	8,003

Maintenance labour input - elimination of failures (follow-up maintenance)

	Production man-hours
Importance category I 20 per cent of 6,325 Pmh	1,265
Importance category II 50 per cent of 2,025 Pmh	1,013
Importance category III 80 per cent of 140 Pmh	112
Total	2,390

Total labour input by maintenance personnel

	Production man-hours
Preventive maintenance	8,003
Follow-up maintenance	2,390
Total	10,393

Determination of maintenance personnel capacities

Total planned maintenance	10,393 production man-hours
Annual working time scheduled	1,870 hours

$$\text{Number of workers} = \frac{10{,}393}{1{,}870} = 5.55 = 6 \text{ workers}$$

Workers for inspection of machines	1
Workers for in-process repairs and correction of failures	5
Total of maintenance workers	6

Skilled workers	6
4 mechanics	
2 electrotechnicians	
Technicians	1
Labourers	1
Total	8

Table 23. Plan of inspections and in-process repairs

	Name of machine	Type	Importance category	Planning period (month, week)											
				1	2	3	4	5	6	7	8	9	10	11	12
1	Five-spindle automatic lathe	AN 35	I	I		I	PO	I		I		I	PO	I	
2	Automatic lathe	ANK 135	I	I	PO	I		I		I	PO	I		I	
3	Automatic lathe	A 40	I		I	PO	I		I		I	PO	I		I
4	Unit-built machine	VZB 6	I	PO	I		I		I	PO	I		I		I
5	Universal milling machine	VR 6	I	I		I		I	PO	I		I		I	PO
6	Drilling machine	V20/4	II			I		PO	I			I			I
7	Centre lathe	SV18RA	II		I		PO	I			I			I	
8	Lathe	RN 36	II	I			I		PO	I			I		
9	Drilling machine	VS 32	III		I			I			I			I	
10	Lathe	1K341	III	I			I			I			I		

Note: I - Inspection
PO - In-process repair

The principal part of the production programme, major overhauls, represents approximately 30 repairs of the average type of machine tools in category 4 of labour input. The spare parts are also intended to meet the demand of the other maintenance departments. Other production consists of a complex of various kinds of operations, such as production contracts for other establishments etc.

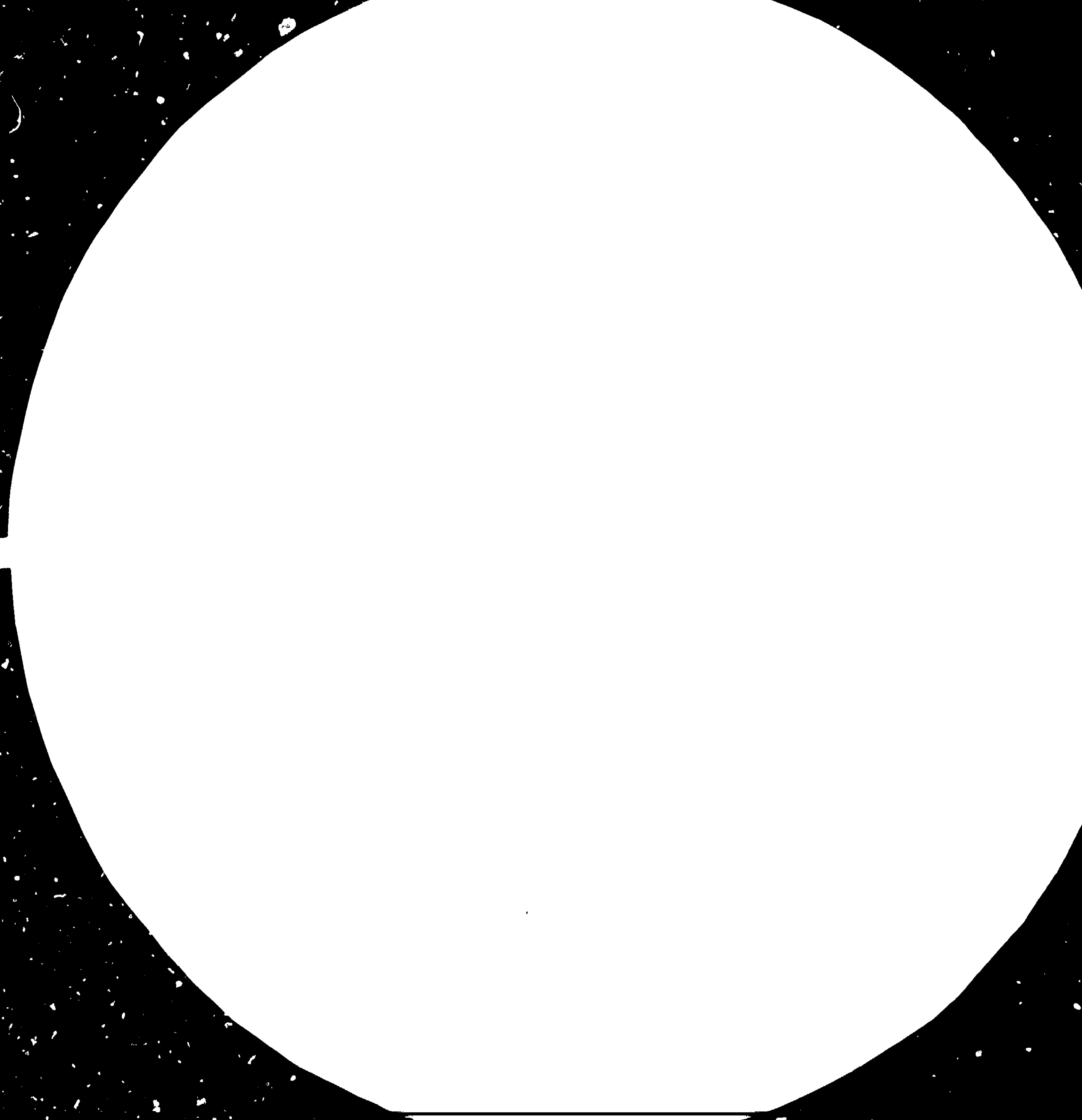
Manpower and capacities

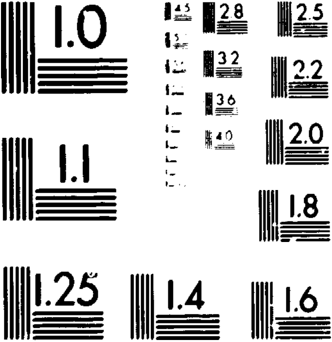
Working time scheduled for one worker in one shift	1,965 hours per year
Working time scheduled for one production machine in two shifts	3,920 hours per year
Average shift occupancy	1.35
Total number of employees	27
Engineers and technicians	4
Administrative personnel	1
Labourers	2
Production workers	20
Engineering crafts	7
Electrical crafts	3
Manual crafts	10 mechanics
Repair shop capacity	
Labour input by production workers	38,880 hours per year
Including:	
Engineering crafts	13,335 hours per year
Electrical crafts	5,895 hours per year

For the engineering crafts it is assumed that three workers are qualified for two professions, for example: lathe and grinding machine operator (2); and milling and drilling machine operator (1).

Number and pattern of machines

The repair shop has eight production machines.





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

Centre lathes	2
Radial drilling machine	1
Milling machines	2
Planing machine	1
Horizontal boring machine	1
Universal grinding machine	1

It also has three auxiliary machines (equipment washing machine, surface grinding machine and hydraulic saw) and a group of minor machines and items of equipment, such as double-wheel grinding machines, bench-type drilling machines, welding machines, a forge, a hardening furnace and an assembly press.

The size and nature of the repair shop are not suitable for certain operations, such as the manufacture of gears and of certain extremely large, high-precision or complex parts (spindles etc.). The total production self-sufficiency is set at 65 per cent, the remaining 35 per cent being obtained from external suppliers through the acquisition of spare parts and co-operation contracts.

Demand for workshop floor areas

The demands of the repair shop for floor areas are as follows:

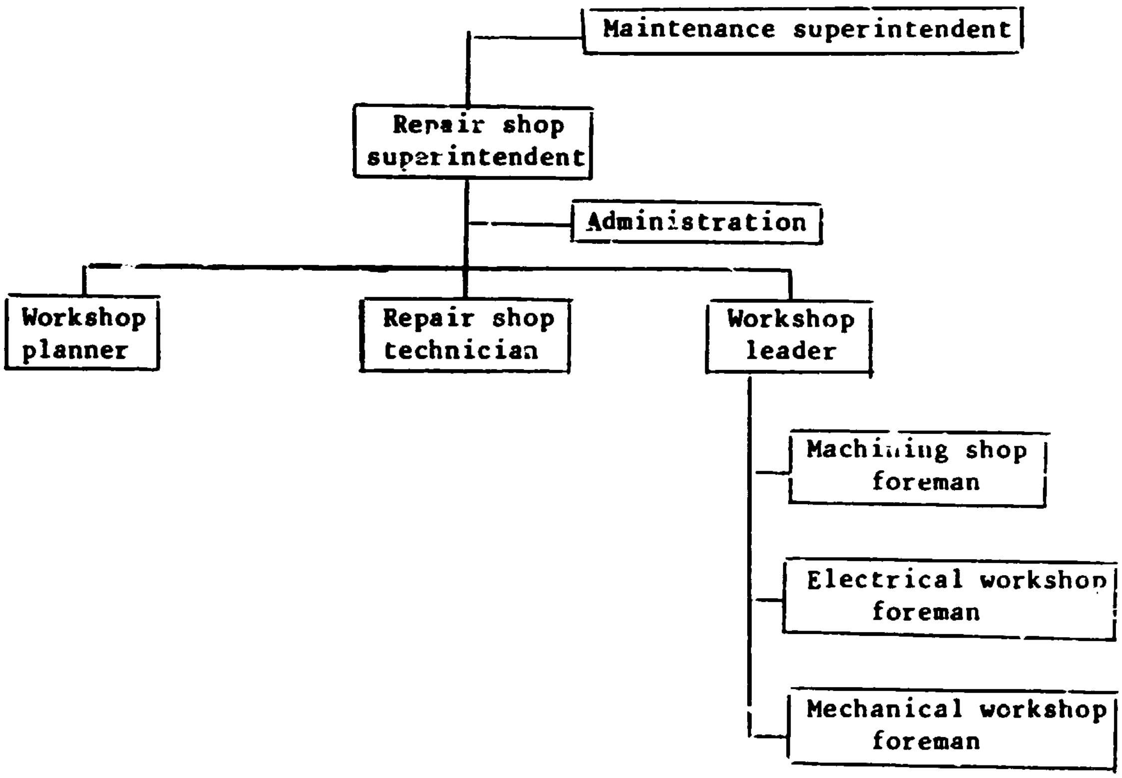
	Area (m^2)
Preparation of materials	20
Washing, degreasing	20
Machining shop	120
Electrical workshop	30
Assembly	100
Inspection	20
Tooling	25
Welding, forging shop	30
Intermediate stores	60
Other premises	35
Total production areas	460
Administrative and control areas	35
Total areas	495

The areas set aside for the social amenities of the employees are incorporated in the establishment as a whole.

Organizational affiliation of repair shop

The repair shop as a rule forms part of the maintenance department. Only exceptionally large repair shops can have the status of a self-contained, autonomous centre or establishment. The organizational structure of the repair shop is reflected in figure 12.

Figure 12. Repair shop organization



The organization is based on: co-operation within the maintenance department, primarily in the planning and technical preparation of repairs and the maintenance of the workshop equipment; and on the cumulation of functions where, in particular:

(a) The workshop planner not only discharges the duties of workshop planning, but also checks the work performed and takes over operational functions in stores;

The system of planning and control is usually equipped with at least the minimum technical control facilities.

The layout of the repair shop areas is shown in figure 13, together with representation of the main technological flow. It is better to locate the working areas of a technical and administrative nature on the floor above the workshop premises, or in a building annexed to the main hall of the repair shop. Such arrangements contribute to the efficient utilization of the process areas.

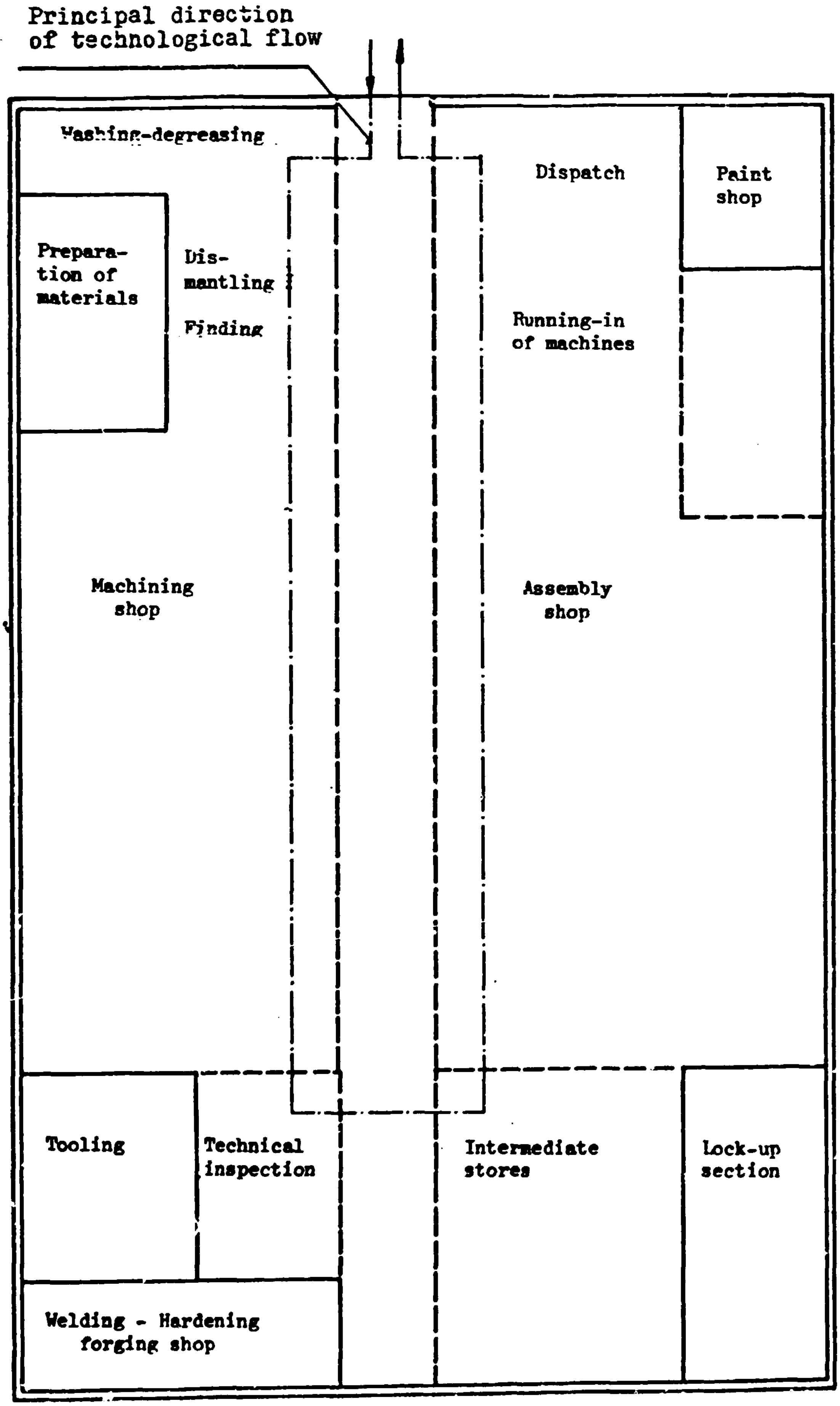
Repair shops of higher capacity are characterized by an increase in self-sufficiency from the technological point of view and from that of the weight parameters of the parts handled. They may also encompass the so-called peripheral crafts, such as carpenters' and tinsmiths' workshops and construction crews. In modern establishments it is also usually necessary to arrange for repairs of the instruments and elements of automation.

Maintenance in textile industry workshops

The textile industry is one of the industrial sectors frequently encountered in developing countries. Maintenance in textile industry establishments depends on the main technological processes employed and the production machines associated with it. One of the aspects involved is the existence of large groups of machines operating for the most part simultaneously, and the fact that the functions of machine setters and of maintenance workers are closely interlinked.

To illustrate the methods of differentiated preventive maintenance, the example of an integrated cotton mill engaged in the complex processing of cotton in the following production sectors has been selected: spinning mill (spun yarns); doubling shop (doubled yarns); weaving shop (cloths); thread spinning shop; finishing room (dyeing and finishing procedures); cords (for tyres); and ready-made products (bed linen).

Figure 13. Repair shop layout



Preparation of maintenance plan

Table 24 contains the basic data required for the preparation of a technical maintenance plan.

The production equipment is listed according to the sequence of passage of material in the production process.

Table 25 makes possible the direct construction of the plan, including its economic balance and calculation of the required capacities.

Balance of capacities	Hours per year
Total labour input by maintenance	29,846
Including:	
15 per cent external servicing	4,476
Internal labour input	25,370
Capacity of a maintenance worker	1,950

Number of maintenance workers: 13
Including 2 workers for dealing with emergencies

Table 24. Basic data for technical maintenance plan

	Name of machine	Technical parameters	Utilization (shifts)	Degree of labour input
1	Cotton cleaning machine	1 m width	1.76	4
2	Cording machine	1 m width	1.88	3
3	Drafting machine	7-8 heads	1.69	2
4	Flyer frame	120 spindles	1.72	3
5	Sliver-type doubler	20-24 slivers	1.69	2
6	Special doubler	5-6 jogs	1.69	2
7	One-sided combing machine	6-8 heads	1.88	3
8	Spinning machine	450 spindles	1.88	3
9	Doubler	90 spindles	1.59	2
10	Twining machine	350 spindles	1.59	3
11	Spooling machine	120 spindles	1.40	2
12	Swifting machine	40 spindles	1.53	1

Table 25. Elements of the maintenance plan

	Name of machine	Degree of labour input	Category of importance	Basic labour input (hours/year)	Coefficient of failures	Converted labour input (hours/year)	Number of machines in plant	Total labour input by maintenance (hours/year)	Structure of maintenance
1	Cotton cleaning machine	4	I	450	1.05	472	2	944	6xI; 2xPO
2	Carding machine	3	II	250	1.15	287	44	12 628	4xI; 1xPO
3	Drafting machine	2	III	50	1.30	65	10	650	4xI
4	Flyer frame	3	II	250	1.15	287	7	2 009	4xI; 1xPO
5	Sliver-type doubler	2	II	150	1.15	172	2	344	4xI; 1xPO
6	Special doubler	2	I	180	1.05	190	2	380	6xI; 2xPO
7	One-sided combing machine	3	I	250	1.05	262	7	1 834	6xI; 2xPO
8	Spinning machine	3	II	250	1.15	287	33	9 471	4xI; 1xPO
9	Doubler	2	III	40	1.30	52	8	416	4xI
10	Twining machine	3	III	60	1.30	78	12	936	4xI
11	Spooling machine	2	III	40	1.30	52	3	156	4xI
12	Swifting machine	1	III	20	1.30	26	3	78	4xI
	Preventive maintenance -							29 846	
	Including reserve for errors -							3 816	

Note: I - Inspection
PO - In-process repair

The specific conditions of maintenance of the textile sector make possible a more exact division of maintenance capacity:

Inspection category (including machine setting): 4 workers
Category of in-process repairs: 7 workers

Maintenance in food processing industry

Compared with other industrial sectors, the food processing industry shows certain specific problems. The principal ones arise as a result of strict hygiene requirements, others from the use of materials that are hard to machine (mainly stainless steels) and from the entirely different professional orientation of the operating personnel. Serious problems are also caused by the different arrangement of the time schedule of utilization of machines: uninterrupted operation during various intervals of time, with work stages lasting for several months.

A section of a medium-sized slaughtering line that forms part of an integrated meat-processing establishment has been selected as an example. This plant has a two-stage maintenance system concentrated in a centralized maintenance department.

The central shops are engaged in production and renewal of specific parts and in repairs of fixed assets. They are also equipped with a mobile servicing team which, when necessary, assists the detached maintenance services in the different sectors of the integrated plant.

The detached maintenance departments represent the second stage of maintenance of a more operational character. They are stationed in the different production sectors of the plant. They provide mainly:

(a) Preventive maintenance in its whole extent, that is, inspection, diagnostics, lubrication and protection from corrosion;

(b) Repairs of equipment failures which can be handled by the department personnel;

(c) Co-operation with the central maintenance service or with the external service for dealing with large repairs.

The integrated plant as a whole comprises the following production sectors:

- Light-duty slaughtering line (rabbits);
- Medium-duty slaughtering lines I (pigs), II (sheep) and III (calves);
- Heavy-duty slaughtering line (cattle);
- Production of processed meat (pork and beef);
- Production of canned meat;
- Ancillary and catering departments and facilities (receiving ramp, waiting pens, stall facilities, maintenance etc.).

The example focuses on the medium-duty slaughtering line I (slaughtering of pigs).

Specification of technical equipment of the line

The line is designed to handle 800 pigs per shift. The sequence of operations is reflected in table 26.

As a result of the high operational demands on the line, its dependence on work rendered by centralized maintenance and external servicing was reduced and its self-sufficiency increased to 85 per cent.

Specification of capacities

Internal capacities = 0.85 . 8,326 = 7,077 hours per year

Capacity of a maintenance worker = 1,950 hours per year

$$\text{Number of workers} = \frac{7,077}{1,950} = 3.62 = 4 \text{ workers}$$

This total includes: 1 electrical equipment maintenance worker

2 maintenance workers-mechanics

1 maintenance worker in charge of lubrication and ancillary equipment.

Table 26. Sequence of operations on a slaughtering line

	Name of equipment	Degree of labour input	Category of importance	Basic labour input	Coefficient of failures	Converted labour input
1	Waiting boxes	2	III	40	1.30	52
2	Weighing machine	2	I	250	1.02	235
3	Driving alley, showers	2	I	230	1.02	235
4	Inclinable lethaling trap	3	II	250	1.10	275
5	Elevator and conveyer	3	I	330	1.02	335
6	Bleeding-out channel	2	I	230	1.02	235
7	Gravity chute	2	II	175	1.10	192
8	Rolling-on table	2	II	175	1.10	192
9	Scalding tub with stretcher	5	I	530	1.02	540
10	Drive with conversion unit	3	I	330	1.02	335
11	Dehairer	4	I	430	1.02	437
12	Short roller table	2	II	175	1.10	192
13	Dehairer II	4	II	300	1.10	330
14	Long roller table	3	II	250	1.10	275
15	Butt remover	2	II	175	1.10	192
16	Elevator	3	II	250	1.10	275
17	Spreading conveyor	3	II	250	1.10	275
18	Cup conveyor	4	I	430	1.02	437
19	Chutes	3	II	250	1.10	275
20	Driving units	4	I	430	1.02	437
21	Auxiliary installations, mechanisms, pumps	5	III	100	1.30	130
22	Electrical installation	4	I	430	1.02	437
23	Installation of (cold) water	5	I	530	1.02	540
24	Installation of (hot) water	4	I	430	1.02	438
25	Gas distribution system	2	I	235	1.02	240
26	Quick-refrigerating plants (-18)	2	I	235	1.02	240
27	Refrigerating plants (-5)	3	II	250	1.10	275
28	Disposal of wastes, sumps etc.	3	II	250	1.10	275
				7,920		8,326

The principal maintenance operations are carried out during the second shift. The first shift is designed to correct failures in operation. Major repairs are carried out on rest days and during all-plant holidays.

Maintenance of an automatic line

Maintenance of automatic production lines represents a relatively self-contained problem to maintenance personnel. This is so primarily because of:

(a) The structural and design peculiarities of automatic lines, including the complexity of design and construction and the interdependence among the different components of the lines;

(b) The way in which automatic lines are utilized in production, including the utilization of the available time and the frequent uninterrupted operation.

In general, emphasis is placed on keeping idle time to an absolute minimum. This means those idle times which are caused by both preventive and corrective maintenance. This requirement is met by:

(a) Rational design of the lines, through unit-building, homogenization of the working life spans of individual components of the line, emergency reserves available for critical points etc.;

(b) Organization of maintenance, such as transfer of the principal maintenance operations so as to schedule their performance for times outside the regular working shifts, application of technical diagnostics, utilization of secondary maintenance based on workshop repairs of substituted modular components of the line, purpose-oriented over-dimensioning of the maintenance system in its capacity, its technical aspects etc.

Types of automatic lines

Present-day industrial practice uses two basic structural and technical arrangements of automatic lines.

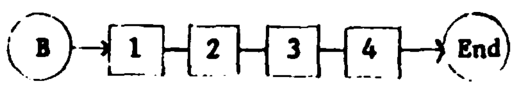
Flexible lines. The establishment of flexible lines is based on numerical control machines and their interconnection into what is called integrated production sectors and similar production complexes.

The flexible lines are for the most part composed of interchangeable work stations which can be interchanged in the event of a repair. The only non-interchangeable member of the system is the integrating element, a rack-type store resorted to between operations and equipped with a reach truck. It is essential in flexible lines. In the event of a more time-consuming failure, the flow of material is safeguarded by substituted transport facilities.

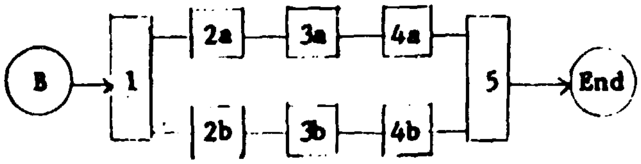
In view of the relatively great interchangeability of individual components of flexible lines, these as a rule impose less exacting demands on the organization of maintenance than the other alternative of automatic lines.

Hard lines. Hard lines are for the most part arranged as specific-purpose production units with a great variety of uses. They can be found in the engineering, food-processing and textile industries, in the production of building materials etc. From the ample range of specific applications there also results their highly heterogeneous structural and design arrangement:

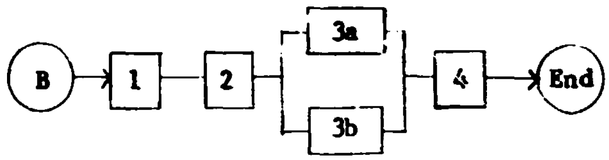
1. Series-type lines where the different work stations are arranged in tandem



2. Parallel lines, with the different work stations arranged abreast of one another



3. Combined lines, formed by a combination of the preceding basic types



Substantial influence on maintenance is exerted also by other structural elements used in hard automation lines, such as:

(a) Whether their operation is a synchronous (in a cadence) or an asynchronous one;

(b) Whether they have storage magazines used between operations and making it possible to bridge over certain down times by means of supplies arranged for in anticipation;

(c) Whether there exists the provision of advanced reserves for critical points with the possibility of by-passing the point of failure (with temporary impairment of the production capacity), or what is termed the provision of full and equivalent reserves of equivalent capacity etc.

From the maintenance point of view, the most demanding ones are the synchronized lines arranged in series and without reserves. In this instance a failure of any one of the members practically makes the whole line inoperative. In other words, the time reserve required to carry out a repair is equivalent, at a maximum, to the operational time of the line per piece, on condition that the repair can be carried out with the line as a whole in operation.

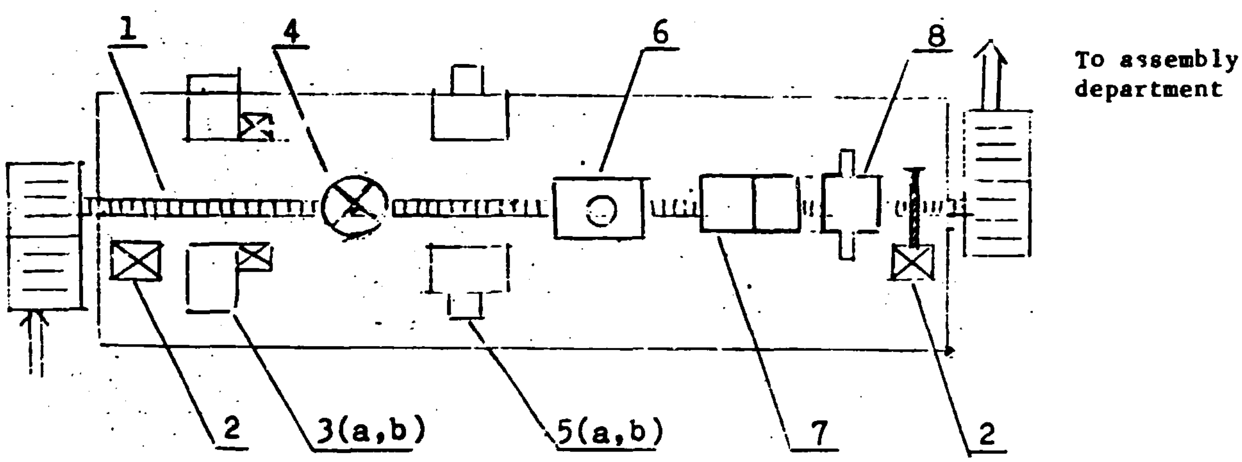
Upon this eventuality, which is the least desirable one, but nevertheless of frequent occurrence, is also focused the following example of the arrangement of a maintenance system.

Example of automatic line maintenance system

The line is a specific-purpose automatic line arranged for machining gearboxes (the dimension of which are 250 mm x 200 mm x 350 mm) operating in a cadence without storage magazines between operations, with a practical annual capacity of 14,800 gearboxes (approximately 4 pieces per hour).

The line consists of five machining stations, one auxiliary work station (washing - degreasing), one measuring station, two manipulators and one system of conveyance between operations. Transport of workpieces is arranged on technological pallets which are deposited on large-capacity transporting pallets for transport between the production preparation department, the line and the assembly department. Figure 14 contains a diagrammatic representation of the line.

Figure 14. Layout of machining line



0. Transporting pallets
1. Conveyor between operations
2. Manipulators
3. Milling units
4. Rotary table
5. Drilling units
6. Vertical machining unit
7. Washing machine and air blasting tunnel
8. Checking machine

Working mode of the line

The line operates in two shifts. For attendance, one operator is appointed in each shift (transporting pallets, supervision of operation).

System of maintenance

Technical basis - Maintenance workshop with departmental competence for the machining centre. This also includes the available capacity for the said line. The workers are partly specialized.

Preventive mode - Prior to start of a workday (with one hour anticipation), revision according to a prescribed programme, including tribotechnical servicing attendance (lubrication).

Inspection - Once a month on a day of rest (e.g. Saturday or Sunday).

Routine repairs - Once a year at the time when the plant is inoperative (all-factory holiday).

Secondary repairs - For machining units and some other assembly elements, reserves are provided. In the event of a breakdown or major wear, the dismantled assembly elements are repaired in the workshop.

Liquidation of failures - If necessary, a competent repairman is summonned from the workshop.

Repairs which exceed the capacity of the maintenance service are carried out as part of the centre's maintenance service for the production of gearboxes, that is, within a system of a higher category.

Capacity demands of maintenance system

Category I	Degree of labour input	Hours
Vertical unit	3	400
Washing machine and tunnel	3	400
Checking machine	4	500
Conveyor between operations	4	500
Rotary table	2	300
		2,100
	Reserve for failures (20 per cent)	420
	Total I	2,520

Category II	Degree of labour input	Hours
Manipulators	2	450
Milling units	3	600
Drilling units	3	600
		1,650
	Reserve for failures (50 per cent)	825
	Total II	2,475

Category III	Summarized degree of labour input	Hours
Disposal of chips, lubrication and hydraulic circuits, other equipment	5	100
	Reserve for failures (80 per cent)	80
	Total III	180

Total labour input in maintenance of line - 5,175 hours

Self-sufficiency - 80 per cent

Internal labour input in maintenance - 4,140 hours

20 per cent of this total (828 hours) for electrical equipment.

Maintenance of the line calls for a theoretical year-round capacity of 2.17 workers. In practice, this capacity is naturally distributed into a system of short-time maintenance operations of both a preventive and an emergency nature.

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