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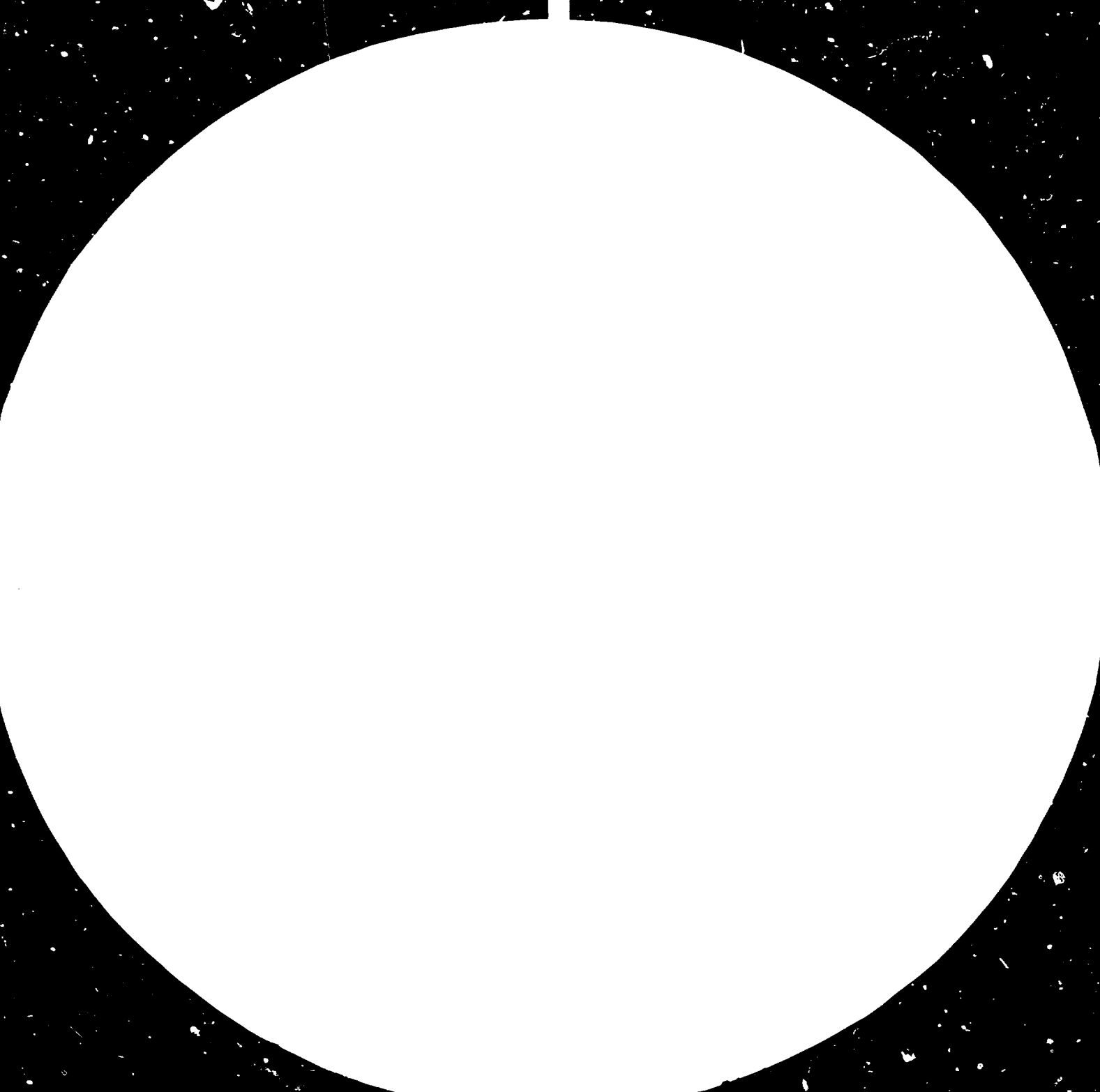

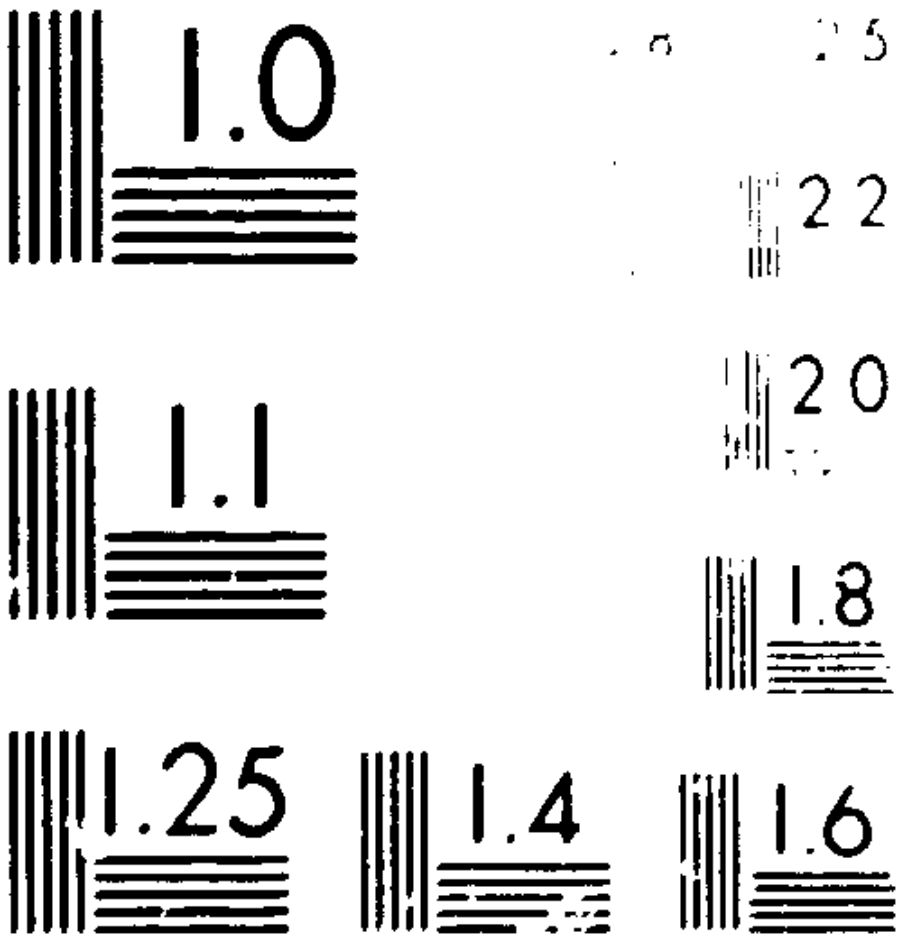
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Contract UD-K-17023-048

11477

"STUDY ON EXPANSION OF REPAIR AND MAINTENANCE FACILITIES AND PROGRESSIVE PRODUCTION OF PARTS, COMPONENTS AND SIMPLE MACHINE TOOLS IN DEVELOPING COUNTRIES"

FINAL REPORT "THE CONCEPT OF COMPLEX SYSTEM OF PREVENTIVE MAINTENANCE OF CAPITAL GOODS INDUSTRIAL PLANTS IN DEVELOPING COUNTRIES

Prepared by the Research Institute of
Engineering Technology and Economy
Prague.

December 1981

STUDY ON

EXPANSION OF REPAIR AND MAINTENANCE FACILITIES AND PROGRESSIVE PRODUCTION OF PARTS, COMPONENTS AND SIMPLE MACHINE TOOLS IN DEVELOPING COUNTRIES

The Final Report

The Concept of Complex System of Preventive Maintenance of Capital Goods Industrial Plants in Developing Countries

1. Introduction

The industrial plant is assumed as a production system. The Preventive Maintenance System / PMS / is one of the industrial plant's subsystems. In accordance with the system approach in introducing the PMS it is necessary, already in the technological design project of the PMS, to provide for the technical equipment and quality of staff at such level that is required by the most complex subsystem of the whole industrial plant.

The complex PMS does not cover solely the Capital Goods Industry, but is concerned with the entire industry of any developing country, as indeed of any highly industrialized country. In its principles the complex PMS is indispensable for simple industrial plants of any kind, in the same way as for the works turning out sophisticated products.

However, in the developing countries the PMS may, and most likely will have its peculiarities. These consist in the fact that in many instances even less complex capital goods will have to be manufactured on a sophisticated production equipment.

Though the principles of PMS apply generally, consideration will have to be given to the necessity of preparing a specific project of a complex PMS for each individual industrial plant.

The origin of maintence system.

Alone with the development of industrial level in the individual countries, the maintenance level has been developing, too.

A. First generation - maintenance to remedy faults

B. Second generation - Preventive maintenance was generated as a system at Ford Motor Company in 1910. Under various modifications it has been widely used in industrial countries till late fifties to beginning sixties.

C. Third generation - Differentiated preventive maintenance discriminating as for the importance amongst the individual items of equipment. The PMS takes care of the production means in a differentiating way according to their importance and is coming into use since the end of sixties.

D. Fourth generation - This is a self-diagnostics of faults and the PMS, with automatic protection of the equipments against defects. It is developed on highly complex and expensive equipments within an automated production system.

Generally, it may be said that the second and third generation subsystems are prevailing till the present time in all industrial brenches and in all countries.

Definition of Preventive Maintenance

Although there is no universally applicable single definition of preventive maintenance, regardless of the achieved standard of PMS, it should involve, at any rate, the following targets and actions:

1. Periodic inspection of Plant Assets and Equipment to uncover conditions leading to production breakdowns or harmful depreciation.
2. Upkeep of plant to sterilize such conditions, or to adjust or repair such conditions while they are still in a minor stage.

3. Differentiation of machinery and equipment importance thereby differentiating the maintenance modes.
4. Complexity of preventive maintenance.
5. Planning and control.
6. Economic effectiveness.

In the introductory part of this draft report the necessity of the PMS for every industrial branch and every plant has been stressed. In his book "Factory Management and Maintenance", Mr. G.C.Kyker gives a very precise answer to the question "Why Industry needs PMS?"

Preventive maintenance is not a cure-all for excessive downtime or high maintenance costs. There are other maintenance functions with which PMS must be integrated to achieve an efficient plant - maintenance program, a good paper work system, work planning and scheduling, training, work measurement, control reports and good shop and tools.

The major returns with which PMS has rewarded its users:

1. Less production downtime, with all its related savings and customer benefits, because of fewer breakdowns.
22. Less overtime pay for maintenance men on ordinary adjustments and repairs than for breakdown repairs.
3. Fewer large-scale repairs, and fewer repetitive repairs, hence less crowding or maintenance manpower and facilities.
4. Lower repair costs for simple repairs made before breakdowns, because less manpower, fewer skills and fewer parts are needed for planned shutdowns than for breakdowns.
5. Fewer product rejects, less spoilage, better quality control, because of properly adjusted equipment.
6. Postponement or elimination of cash outlays for premature replacement of plant or equipment, because of better conservation of assets and increased life expectancy.
7. Less standby equipment needed, thus reducing capital investment.
8. Decline of maintenance costs - labour and material - on asset items in the program.
9. Identification of items with high maintenance costs, leading to investigation and correction of causes such as /1/ misapplication, /2/ operator abuse, and /3/ obsolescence.
10. Shift from inefficient "breakdown" maintenance to less costly scheduled maintenance, hence better work control.

11. Better spare parts control, leading to minimum inventory.
12. Better industrial relations because production workers don't suffer involuntary layoffs or loss of incentive bonus from breakdowns.
13. Greater safety for workers, and improved protection for plant, leading to lower compensation and insurance costs.
14. Lower unit cost of manufacture.

The activity of PMS is not only to prevent breakdowns or cut operating costs but also PMS will improve output and quality of product.

In Czechoslovakia, a systematic research and application of PMS in the engineering and other industrial branches is carried out by VUSTE since 1965. Our PMS are being applied abroad now for more than ten years.

Inspite of the fact that the PMS principles are basically the same, the complex PMS method offers still a number of progressive elements of which the following five are the most important ones, while all the remaining elements are dealt with in the following chapters of the present draft report.

1 - complex maintenance scheme
2 - methods of maintenance planning, control and organization
3 - technical normatives including:
    - design-operational characteristics of machines and equipments
    - repair characteristics of machines
4 - technical preparation of repairs
5 - human factor in PMS

One of the most progressive elements, which forms the base of the whole complex PMS, is the technique of evaluating the complexity of machines and equipments with respect to the complexity based on the number of assemblies, mechanization and automation levels, accuracy class, weight and size. The number of evaluation points indicates the level of maintenance complexity. The Czechoslovak evaluation technique works with 13 evaluation degrees.

Another progressive element is the evaluation of preventive repairs of each piece of equipment which enables to establish an optimum organization of the PMS on every plant.

Last but not least factor of PMS to be mentioned is the evaluation of economical effectiveness of the performed preventive maintenance

of the individual equipments, as well as of the whole PMS. The method of economical evaluation involves both physical and moral wear. The economic evaluation of the PMS is an important instrument for the management of economical effectiveness of the entire production process.

Preventive maintenance of automatic capital goods

Automated technological equipments are installed in many developing countries. It is assumed that the automation will continue and the methodology of preventive maintenance of automated machines and equipment will thus require some attention.

The basic principles of the PMS have a general validity, yet it must be said that specific views have to be applied for automated equipment and it would not be expedient to bring together the methodology of conventional and automated machines to form one whole.

The priority in the processing is given the "methodology of Complex System of Preventive Repairs of Capital Goods in Industrial Plants in Developing Countries", which is applicable in every industrial plant.

The methodology of complex system of preventive repairs of automated production equipments is specifically focused at the engineering production equipped with NC machine tools.

2. Analyses of Capital Goods Maintenance System

2.0 Basic terms

The term Capital Goods designates equipments used in the production, i.e.

- machines including their outfit (accessories)
- technological equipments
- auxiliary equipments

Not only engineering production as such, but also other types of production which are using Capital Goods of lower up to medium complexity, fall under this term /textile mills, food industry etc./.

The basic evaluation factor to measure the effectiveness of capital goods utilization is the utility value. Applied to a given working equipment the utility value is the quantitative expression of its technical and other parameters describing its capability of

of fulfilling a particu. function in the production process over a given time. The utility value is naturally subject to a decrease through the entire duration of the exploitation period, i.e. from the moment of acquisition and installation of the production equipment till the time of its full depreciation and scrapping, with a varying decrease gradient at different periods of the whole exploitation time.

The Maintenance of Capital Goods is an organized process which in its results acts against the natural decline of utility value. The methods of Capital Goods Maintenance result altogether in a momentary increase of the utility value. The gradient of utility value decline cannot be directly affected by the maintenance - being largely dependent on the machine design and on its operational load. A repair of the machine causes, however, its utility value to jump up. Talking about the methods of increasing the effectiveness of Capital Goods Maintenance, we have in our mind the exactly fixed time and conditions under which a given maintenance action will bring optimum results.

The complex analysis and subsequent project of Capital Goods Maintenance System therefore have to originate from the following basic analytical steps:

- technical analysis
- general scheme and organization
- analysis of realization conditions in the specific plant of the developing country

2.1 Technical analysis of Capital Goods Maintenance

The technical analysis of Capital Goods Maintenance is aimed at the following problem groups:

- capital goods fund - groups
- specific properties of capital goods groups
- differentiation of capital goods with regard to labouriousness of maintenance
- normatives of maintenance labouriousness
- technical means of maintenance and realization terms

The technical analysis is thus focused at the acquisition and evaluation of data which will have to be considered when answering the following questions:

- what is the object of maintenance
- how much time is taking the maintenance
- what means are needed to relioze the maintenance

2.1.1 Capital Goods Fund

With respect to their position in the production process the Capital Goods may be classed into:

I. tight - their breakdown may jeopardize the plant production since the given technology cannot be replaced by another one. These are e.g. high-precision machines, machines of outsized parameters, also of high investment cost.

II. common - the most numerous group - majority of production machines, technologically replaceable

III. auxiliary - production means of high technological replaceability, at which mostly of a low exploitation coefficient and low investment cost

IV. special - production means requiring combined maintenance - e.g. electrical, mechanical and electronic - of which a typical example are the NC machine tools

In evaluating the Capital Goods the overall layout of the technological process is to be considered as well: In a common shop-floor set-up of conventional machine tools, to which the stock is to be delivered, e.g. by means of an electric truck, the question of maintenance of conveying means does not call for any special attention, a replacement transport means being readily available. In contrast to this are the Flexible Manufacturing Systems where the inter-operational transfer equipment forms the backbone of the system thus falling into the group of tight items of capital goods and, consequently, its maintenance is of high grade importance.

From the above said follows that the capital goods can be approached and dealt with:

- individually
- as groups
- grouped in flexible production systems
- incorporated in CAM-type systems

2.1.2 Specific properties of groups with regard to maintenance

Fig. 1 gives a rough comparison of technical structure of demand for maintenance of the above mentioned groups of capital goods. From this figure follows that some groups are not requiring all types of maintenance and, moreover, that the technical structure of some types of maintenance varies within one group of capital goods.

Fig. 2 gives a comparison of the mentioned groups with regard to their exploitation in work and their maintenance time. The latter figure shows that in addition to [redacted] higher utilization of tight and special machines employed in higher levels of exploitation, the maintenance time is cut down, too. Total down-times of these capital goods groups are lower, notably in the case of automated systems.

2.1.3 Capital goods differentiation with regard to labouriousness of their maintenance

In differentiating the capital goods, the basic criterion is to be seen in their operational readiness, i.e.

- admissible degree of production outage due to repairs
- degree of utilization
- allowable failure rate
- degree of prevention

The above mentioned indexes are qualified by means of classifying attributes /signs/ - see Table 1, column 4 - which are applied to designate:

- degree of technological replaceability
- requirements re degree of dependability
- aspects of machine utilization related to time
- requirements re accuracy of machines and equipments
- bearing of investment costs upon classifying mechanism
- influence of frequency of equal type machines with a profound knowledge of their wear and tear process
- and assumption produced by low technical status of machines, etc.

For the classifying attributes - signs - see Table 1.

Table 1. Classifying signs of labouriousness of capital goods maintenance.

Item No. 1	Group 2	Serviceability demand 3	Typical representants 4	Classifying characteristics 5
1A	tight machinery and equipment	21 - maximum serviceability irrespective of costs	31 - tight machines and equipment	41 - technological replaceability of machines exists in rare cases, defect means a direct disturbance in production process /notably machines for specialized technology/
		22 - production outages due to scheduled repairs kept at min., repairs done on non-working days /shifts/	32 - production lines	42 - maximum demand on dependability, cost of repair unimportant /repair systems with highest prevention share employed/
		23 - absence of breakdowns except for unforeseeable reasons /material, attendance or sim./	33 - transport equipment	43 - other signs for choice of machines and equipts. fall especially into the sphere of high utilization of machines /3-shift run/; requires individual approach according to specific conditions and amount of influence by other signs
				44 - high-precision demands both with special machines and conventional machines adapted for high-precision production
				45 - costly m/cs calling for economical payback - unless otherwise classed
				46 - unique machines acquired to solve bottlenecks in production technology
				47 - other signs aimed to achieve maximum serviceability
1B	important objects	21b - dependable technical condition	31B - boiler houses, water treatment plants, cleaning, sewerage	41B - key importance for object technology
2A	common	21 - admissible calculated outage of production due to scheduled repairs		42B - hygiene-epidemiological importance
				43B - exceptional working-environment or object-serving equipment
				44B - extra-safety requirements

Table 1 /ctd./ Classifying signs of labouriousness of capital goods maintenance.

Item No.	Group	Serviceability demand	Typical representants	Classifying characteristics
1	2	3	4	5
		22 - assumed optimum failure rate within planned limit 23 - extra costs of unplanned repairs to be covered from savings on economical utiliz'n of tight machines repair systems 24 - substitute technology mostly bringing about reserves in capacity of machinery equipment - one of the limiting factors	31 - common machines and equipment mostly replaceable	41 - technological replaceability of machines and equipments 42 - average degree of utilization related to time 43 - dependability degree limited /reduced/ by the applicability of a substitute technology 44 - machines expected to render common production precision 45 - important factor often ranking also exacting machines into this group is the frequency aspect, high skill of maintenance staff, availability of spare parts etc.
2B	operational	21B - co ..n degree of serviceability	31B- production halls of common technology	41B- permissible level of allowable w ear 42B- r duced demands of internal equipments

ctd ...

Table 1 /ctd./ Classifying signs of labouriousness of capital goods maintenance.

Item No.	Group	Serviceability demand	Typical representants	Classifying characteristics
1	2	3	4	5
3A	auxiliary machines and equipment	21 - lower exploitation rate 22 - economical methods of maintenance 23 - justified percentage of failures /unplanned repairs:	32B - administrative objects 33B - works road systems 34B - water system 31 - auxiliary mcs and equipt. 32 - common machine tools in subsid. shops with low expolit. rate	43B - common working environment 41 - easy replacement and substitution 42 - utilization of machines irregular, occasional 43 - dependability practically not required 44 - lowest technical standard considered to be rebuilt or disposed of
3B	auxiliary	21B- low demands on service	31B-storehouses with conventional equipment	41B- objects to be reconstructed or demolished in near future 42 - subsidiary stores, penthouses, sheds 43B- fencing 44B -canalizations and sim.

2.1.4 Labouriousness normatives of Capital Goods Maintenance

The indispensable scope of maintenance of machines and equipments - M+E - for the calender year is defined as a function of so called "Labouriousness degree of operational maintenance". This degree not only expresses the annual volume of maintenance jobs, but also their character and scheduling with regard to the importance degrees of each M+E item. The technically substantiated process of establishing the labouriousness degree emanates from the selected characteristics:

I. Design-operational M+E characteristic - exposes for each M+E item the criteria of design and operation:
   A - complexity
   B - technical standard
   C - weight and size
   D - degree of required accuracy

II. Repair characteristic - outlines the repair conditions of M+E systems
   a - labouriousness compared with preceding period
   b - level of reperability
   c - professional specialization of maintenance men, capacity and qualifications of repair staff
   d - technical outfit of maintenance staff
   e - availability of spare parts
   f - location of production and maintenance organizations

The evaluation of the mentioned characteristics enables each of the M+E item to be assigned one of the 13 stimulating degrees of labouriousness of operational maintenance /see Table 2 "Repair characteristic" next page/.

Based on the method applied by VÚSTE for the differentiated maintenance, tables were prepared differentiated according to the importance of Capital Goods for the given degree of labouriousness. The latter is then defined directly by the respective normative data for the purposes of annual schedule of operational maintenance activities.

Table 2. Repair characteristic

Degree	Level: low															Points arrived at		
					medium						high							
	labouriousness compared with preceding repair period		level of reparability		degree of repair staff skill		degree of mechanization req'd	availability of spare parts	labouriousness compared with preceding repair period		level of reparability		degree of repair staff skill		degree of mechanization req'd	availability of spare parts	labouriousness compared with preceding repair period		level of reparability		degree of repair staff skill		degree of mechanization req'd	availability of spare parts	boundary interval	average	resulting real degree of labouriousness
0	3	6	3		3	9	2	3	2	2	4	1	2	1	1	1	6 - 24	15	
2	3	7	3		3	9	2	3	2	2	4	1	2	1	1	1	6 - 25	15	
3	3	8	3		3	10	2	3	2	2	4	1	2	1	1	1	6 - 26	16	
4	3	8	3		3	10	2	4	2	2	5	1	2	1	1	1	6 - 27	16	
5	3	9	3		3	11	2	4	2	2	5	1	2	1	1	2	7 - 29	18	
6	3	9	3		3	11	2	5	2	2	6	1	2	1	1	2	7 - 30	19	
7	3	10	3		3	12	2	5	2	2	6	1	2	1	1	2	7 - 31	19	
8	3	10	3		3	12	2	6	2	2	6	1	2	1	1	2	7 - 32	20	
9	3	11	3		3	13	2	6	2	2	7	1	2	1	1	2	7 - 33	20	
10	3	11	3		3	13	2	6	2	2	7	1	2	1	1	3	8 - 33	20	
11	3	12	3		3	14	2	7	2	2	7	1	2	1	1	3	8 - 35	21	
12	3	12	3		3	14	2	7	2	2	8	1	2	1	1	3	8 - 35	22	
13	3	13	3		3	15	2	7	2	2	8	1	2	1	1	3	8 - 37	23	

I. Explanation of Design-Operational Characteristic of Capital Goods

A - Complexity of machines and equipments

When stipulating the criteria of maintenance labouriousness the complexity of production equipment can be comprehensively characterized by the number of essential functional units, i.e. assemblies, from which the evaluated machine is composed.

The applied C.G. classifications according to design, assembly, technology or function are not uniform, nor do they precisely express the maintenance and repair aspects. The number of these basic functional machine-and-equipment systems may be established from the machine data chart, from the description of machine and production equipment, or from other technical documentation, technical terms or standards. Usually, a separate technical documentation is prepared on these sectional functional systems or mechanisms to be at hand for maintenance and repair planning.

The number of assembly groups or assembly components remains thus as the riterion expressing the degree of complexity of the individual machines and equipments.

Definition:

An assembly group is such part of the production capital goods that forms a self-contained, detachable and reparable or replaceable assembly group ensuring a given basic function of the M+E.

These are e.g. the following mechanisms:

- s u p p o r t i n g /bed, column, block, box, cutter, baseplate, pallet/
- d r i v i n g /motors, gearings, couplings, distribution systems and s'n./
- w o r k i n g /with main working, or auxiliary feeding and approaching motions/
- m a n i p u l a t i n g /handling of blanks, tools, swarf etc./

and systems of

- c o n t r o l /mechanical, hydraulic, pneumatic, electric/
- c h e c k i n g and s o r t i n g .

The assembly group may be also regarded as an ingeniously arranged functional part of M+E, system or mechanism, i.e. assembly

group consisting of subassemblies of lower order including all systems and mechanisms composed of functionally associated members and assembly replacement parts /spare parts/ and components associated in various ways.

Example:

Assessment of number of assembly groups of a universal lathe.

Function systems or mechanisms of C.G. /E+E/	Assembly group	Number of assemblies
1. supporting	machine bed incl. tailstock	1
2. driving	electric motor	1
3. gear drives	gearbox	1
4. distributing	apron and threadcutting box	1
5. working with main motion	headstock including controls	1
6. working with auxil.motion	carriage and slides including control mechanisms	1
7. manipuleting	-	-
8. operating	-	-
9. controlling	-	-
10. auxiliary	cooling	1
11. inspection	-	-
12. additional	-	-
13. outfit	-	-
	Total number of assemblies	

On technological machines or other production equipment, the number of assemblies may go as high as to 20. In grouping the machines and the mechanisms in series /tandem-like/, or parallelly, or in some other kinds of groups or compounds to form a complex working centre, also in modular or production-line set-up, it is necessary to judge every machine on its own merits.

Likewise in case of Integrated Production Systems /IPS/, Automated of Flexible Production Systems /APS or FPS/ it is necessary for the evaluation of maintenance labouriousness by estimating the degree of complexity of mentioned production systems,

first to dissociate them according to sectional production systems to individual production units which can be judged each on its own merits.

B - Technical level - mechanization and automation level

The technical level is characterized by the objective codes which are classing the machines and equipments into 7 groups:

1- machines and equipments with solely manual operation
2 - mechanized machines and equipments
3 - machines and equipments partly automated with work cycle initiated by means of control mechanisms
4 - machines and equipments partly automated with program-controlled work cycle by means of control mechanism
5 - machines and equipments fully automated with work cycle actuated by means of control mechanisms
6 - machines and equipments fully automated with work cycle controlled from control programs
7 - machines and equipments fully automated with work cycle controlled from control program with automatic organizatica of control process - program
8-9- not yet classed

The mentioned code numbers designating the degree of technical level of capital goods are compulsory for nos. 3 and 4 classes to be specifically mentioned in supplier's packing lists, invoices and other documentation used in the communication between purchaser and seller.

In establishing the degree of technical level of a particular machine or equipment, it is to be considered for which purpose the machine or the equipment has been designed and what is it expected to perform. The technical level degree is in proportion with its capability of replacing human labour /manual, control, inspection work/.

The design-operational characteristic is fixed according to the machine or equipment value expressed in classifying points. The table 3 on next page may assist as an aid for the evaluation by points.

Table 3. Design-operational characteristic.

Complexity of Capital Goods		Degree of mechanization and automation		Weight and size of C.G.		Precision degree of C.G.		Points total	Degree of labo'ness of C.G.
Number of assemblies	Points	Degree of technical level	Points	Tons	Points	Precision required	Points		
0	0	1	1	1	1	less impor't.	1	3-4	1
1	1	2	5	2	4	common prec'n	5	5-7	2
2	4	3	10	3	6	prec'n m/cs	25	8-15	3
3	9	4	20	4	8	extra prec'n	100	16-25	4
4	16	5	40	5	10			26-40	5
5	25	6	80	6	12			41-60	6
6	36	7	100	7	14			61-83	7
7	49			8	16			84-105	8
8	64			9	18			106-135	9
9	81			10	20			136-245	10
10	100			•				246-330	11
11	121			•				331-400	12
12	144			•				401 and more	13
•				•					
•				•					
15				•					
•				•					
•				•					
18	324			•					
•				•					
•				•					
20	400			100					

Tables 2 and 3 contain source data for the evaluation of Capital Goods with regard to the labouriousness of maintenance operations in view of their design-operational characteristic. The resulting total number of points can be expressed and assigned to a given machine as a normative of maintenance for the current year as well as the normative of major overhaul labouriousness. The tables offer other data useful not only for specifying the required material and personnel, but also for the maintenance planning. The normatives are prepared in form of tables with a simple clue and are used by the head of maintenance staff.

2.1.5 Technical conditions and prerequisites for realization of Capital Goods Maintenance

The maintenance of machinery and equipment consists of the following basic activities:

- before failure - singular preventive inspection
  - continuous diagnostics
- after failure - detail inspection
  - repair of defective component
  - replacement of defective component
  - long-range evaluation of failure conditions

The singular preventive inspection is commonly performed on lower and medium complexity capital goods, e.g. after discovering a reject product. This type of inspection mostly requires only common maintenance tools and a skilled maintenance man.

On tight and special machines the inspection is sometimes rather complicated and it pays to provide for a continuous diagnostics. This is done with the aid of a special section of the electronic control unit. This unit is capable of evaluating and indicating an overstepping of permissible limits of given parameters, or of transferring the measured values to a higher /master/ computer - as is the case with the FMS. The controlled parameters are e.g. vibration, pressure of lubricating oil, power consumption, and sim. The respective pick-ups, transducers, evaluation circuits and operating instructions are to be supplied, in this case, by the machine builder. Subsequent diagnostics means completed by the user are inefficient and unreliable.

The detailed inspection follows the aim of ascertaining the real status of such parameters which are to be measured in a more complex technique. An example of this type inspection is the test of geometrical accuracy of the machine, alignment of guideways for sliding assemblies, accuracy of coordinate measuring and positioning, rigidity, etc. In this case the accuracy of the measuring technique is stressed, the testing and measuring instruments are to be one accuracy class higher than the rated accuracy of the tested machine. An example to illustrate this statement: Measuring of lathe accuracy by laser and evaluation of measured values in test chart print-out.

The repair and possible replacement of faulty component is a relatively common affair as far as mechanical parts of machines are concerned. In this case the remedy leads to material and spare parts stores. Understandably, these maintenance jobs may be performed only in observing detailed documentation supplied by the machine maker. To some extent more exacting is the repair of hydraulics, or electrical and electronic circuits. The difficulty lies in the amount of necessary more profound knowledge of the principles that are not commonly inherent in the engineering trade. The documentation is much more complex and so is the repair technology /e.g. replacement of an integrated circuit in printed circuits/. From these reasons a detail training of maintenance staff is here an inevitable prerequisite. The best suitable place for the training is with the supplier or builder of the machine.

The long-range evaluation of failure conditions is substantial on more complex production systems, such as FMS and CAM. On these systems it proves effective to have the evaluation solved on a computer which is continually acquiring the data from the production system and effects their preliminary classification. In this case the "Post mortem" recording technique finds its application. The analysis of these data enables the critical data of the production system, not only with respect to the production but also to the maintenance, to be discovered. In addition to this it is possible to obtain source documents for the scheduling of preventive inspections. The job is solved by suggesting the data

acquisition system /what kind of data, how frequently, what input devices to be used for their storage, etc./, hardware data acquisition system /computer, interface, memory type, channels/ and software data acquisition and evaluation /interruption system, peripheral drivers, file management, sorting, grouping etc./.

The technical prerequisites of capital goods maintenance may be briefly summarized as follows:

primary

- basic documentation of machine
- maintenance documentation on machine
- instrument and tool outfit to test operating parameters of machine
- spare parts
- disassembly and reassembly instruments and tool outfit
- technological equipment for the repair of defective components and material for repair or production of components

secondary

- stocks of spare parts and necessary material
- transport
- organization of distribution
- organization of maintenance and repair technology
- planning and securing of maintenance and repairs
- faults recording and evaluating devices
- record on realized maintenance of capital goods
- financial backing
- personnel backing
- training of maintenance staff
- contract terms from suppliers

The primary prerequisites for the realization of Capital Goods Maintenance are indispensable. The effectivity of Capital Goods Maintenance depends, however, on a complex provision of the secondary prerequisites as well.

2.2 General scheme and organization of Capital Goods Maintenance

The term "maintenance" involves a regular care aimed to ensure a full serviceability, or to remove minor defects. As a rule, while being maintained, the capital goods are generally not rendered inoperable.

The term "repair" involves remedy of partial wear and tear as well as of major faults. During the repair the machine is out of service.

The Capital Goods Maintenance includes following activities:

planned activities

- daily maintenance - checking and superficial treatment performed by the machine attendant
- inspection - to supplier's instruction and inspection data sheet, capacity planned with timetable /short intervals/ carried out by maintenance staff
- survey - an inspection of not firmly fixed scope, capacity planned with timetable, applied for common machines and auxiliary equipt. carried out by maintenance staff
- operational repair - removal of shortcomings caused by wear, technically not stipulated beforehand capacity planned beforehand, term fixed depending on amount of wear carried out by maintenance staff
- major overhaul - largest action aimed to remove effects of wear or damage and so to bring machine parameters to the original or predetermined level capacity planned, term fixed by the operational period since last major overhaul carried out by specialized repair centre

unplanned activities

- minor repairs - non-scheduled repairs taking less than 2 hours, technical procedure and time not fixed beforehand carried out by maintenance staff
- other unplanned repairs - demanding repairs in case of breakdowns carried out by specialized repair centre

The technical planning of repair activities is based on the normatives of labouriousness /see para 2.1.4/. Another factor in the planning is the operational aspect - long downtimes of machines may result in unacceptable production outages. It is therefore preferable to practice better shorter yet more frequent repairs to keep the operating parameters of machine within its permissible limits, than to postpone the repair action till the term of the necessary major overhaul.

The technical care system is aimed at:

- specialization - aggregating capital goods into groups according to maintenance characteristics and demands for the material backing of maintenance needs. Specialized maintenance systems are organized for these groups of capital goods.
- algorithmization - Trend to limit the intuitive approach to work, following the aim of convincing the personnel about the effectiveness by virtue of observing justified technical procedures.
- adaptability - A necessary change in maintenance activities under different conditions, e.g. ageing of machines.
- recorded information - Technical sheets on sequence of maintenance operations take in account systematically acquired data over a long period of time, which are stored in the information system data bank.
- integration - The technical care control is an integral part of the production process management.

Economical analysis of Capital Goods Maintenance

Capital goods are subjected to wear in the production process, namely:

- physical wear - material wear and tear due to physical and chemical influences
- moral wear - economical wear due to the ever growing trend of productivity and technical progress

In its results the technical care acts against the effects of physical wear /while new investments are the answer in matching the effects of moral wear/. From the economical point of view the condition of capital goods is measured by the value of production losses caused by downtimes /production outages/. Fig. 3 indicates the time course of the production losses in relation to the maintenance costs parameter. Fig. 3 proves convincingly that the production losses tend to grow starting from a certain moment. This moment is given by the statistical analysis of machine faults in relation to the intervening period of time. A suitable organization of maintenance is capable of deferring such moment quite considerably.

As mentioned in para 2.0 the physical wear results in the decline of utility value. The maintenance including diagnostics, inspections, etc. enables the repairs, causing the utility value to increase in a jump to the original or at least admissible level, to be planned more accurately. This fact is illustrated in Fig. 4.

The purpose of the technical care planning is to schedule the repairs at optimum intervals with regard to the mentioned course of the utility value tendency, to the increments of utility value due to repairs within limit costs at which the capital goods final depreciation is economically justified. Another factor included in the maintenance plan is the operational aspect of the given production unit, e.g. in agriculture or season-bound processing industries the repairs are scheduled outside the main activity period. In the engineering industry the repairs are scheduled for the time of factory holiday, etc.

There are several methods how to optimize the timetable of repairs.

Along with the timetable of repairs other problems associated with the maintenance have to be solved:

- financial costs planning
- material and spare parts purchasing list
- renewal scheme of maintenance centres outfit
- calculation of space required by maintenance
- storage and transport planning
- demand for personnel to secure maintenance and auxiliary services
- scheme of personnel qualification growth.

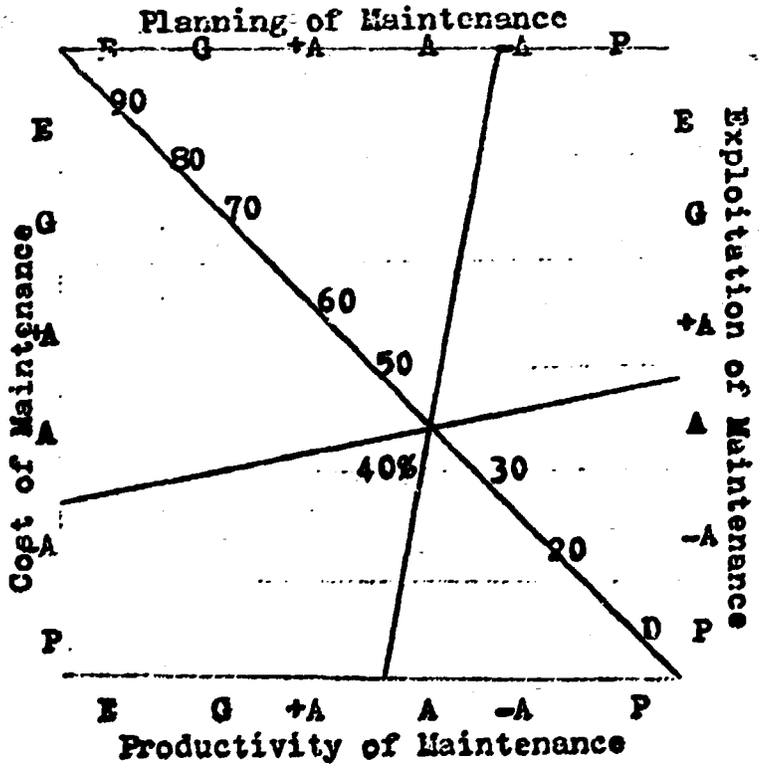
The evaluation of maintenance effectiveness is acting as a feedback in the management process. Once again, there is a number of exact methods based on specific indexes. The Luck graphic method is an example of them. Here is its brief description.

The Luck method is working with sixteen indexes divided into following four groups:

- planning
- work utilization of maintenance
- costs of maintenance
- working productivity of maintenance staff

Enlisted in a table are the planned and actual values of the mentioned indexes. Compiled from them are then the four graphs, each one for a group of four indexes. These values are plotted at the sides of the square graph. The values at the opposite sides of the square are interconnected by lines and the point of intersection of both connecting lines falls into a specific field marked from the best result down to the worst one as follows:

E ... excellent
G ... good
+A ... above average
A ... averege
-A ... under average
P ... poor



The results from the four graphs are transferred into the resulting graph in which they are marked always at one side. The main scale ranging from 0 to 100 forms the diagonal of the resulting square graph. On it, by means of a normal which is dropped from the intersection point of lines designating actually obtained values, it is possible to assess the aggregate realization of all the sixteen indexes.

Xt

3. Human Factor

In the developing countries the essential problem of development of capital goods production is the preparation and training of skilled employees for the production plants.

For the realization of PMS the problem of skilled staff is of a still greater importance. This is because of the fact that while it is possible to replace a skilled worker by automated equipment in the production process, such possibility does not exist in the PMS which can be materialized only through skilled technicians and workers.

Qualities required from the PMS team:

a/ capability of understanding the functional concept of production equipment

b/ qualification in specialized professions: engineer, electrician, electronic

c/ capability of locating the source of failure /trouble-shooting/

d/ technical intelligence and manual skill

The multi-professional working team for the preventive maintenance of capital goods consists of managers, graduated engineers, technicians and experienced workers.

For each specific industrial plant in the developing country a project of PMS is to be elaborated with detail plan of education and training of the required specialists.

An important factor in the staff preparation for PMS is the motivation, personal evaluation and financial incentives system.

4. Preventive Maintenance Projects - PMS

The project of preventive maintenance of capital goods in new plants is an integral part of the complex works project. The PMS projects in the existing plants will bear the character of rationalization projects.

Irrespective whether new or already existing plant is in question, the project must be based on the principles of a complex Capital Goods PMS.

Observing the mentioned principle means, in case of a specific project, to emphasize especially:

- definition of PMS complex methodology of maintenance concept
- specification of technical equipment of maintenance shop, i.e. diagnostics equipment, technological equipment of the repair of damaged components, and possibly manufacture of spare parts
- elaboration of the organization project of management and planning of maintenance in connection with the production process
- elaboration of the project of unification and standardization of components and instruments from the technical equipment, to facilitate their maintenance. E.g. one type of electrical equipment, one approach to standardization according to one system of standards- ISA, DIN - , one kind of electrical cycle etc.
- stipulation of PMS rationalization terms which are to be projected into the technological project of production, i.e. installation and layout of machines with respect to the production needs as well as to the maintenance needs. Machines must be accessible for maintenance purposes, hoisting equipment must be provided in the shops, space must be left for the transport of heavy and bulky components, etc.
- preparation and education scheme of PMS staff

Rationalization projects of PMS

In elaborating the rationalization projects for PMS introduction the principles of the accepted PMS methodology under specific conditions of a given industrial plant have to be observed.

On the basis of PMS methodology standard schemes, both of basic as well as rationalization projects, will have to be prepared.

The projects of rationalization and application of PMS are verified in practice and produce in all events an improvement in the production process economy of 15 to 25%.

A specific part of the rationalization projects is the strategy of rationalization, i.e. identification of conditions on a specific plant under which the PMS can be successfully introduced.

5. Preventive maintenance problems-capital goods producers' side

The complex methodology of preventive maintenance of capital goods in the production plants is a very important base also for the manufacturer of capital goods, in their designing as well as marketing and servicing with the user.

On the basis of PMS it is possible to design the structure of commercial and technical services with the maker, i.e.

a/ marketing

assistance to user in pre-project and project activities

b/ sales service

- maintenance manuals
- training of operators
- deliveries of spare parts

c/ after sale service

- diagnostics - inspection service
- preventive service calls, etc.

d/ PMS documentation

- manuals on diagnostics
- shop drawings of spare parts
- technological documentation of the production of spare parts
- machine data chart

e/ deliveries of spare parts

- first standby set supplied with the machine
- set to cover a long-term service
- set for major overhaul

f/ information service

- training of client's techniciens and workers
- various forms of training
- completion and updating of operating and maintenance manuals
- special forms of service

g/ cooperation of manufacturer with user

An economically effective exploitation of the production equipment depends largely on a good cooperation between the machine builder and user. The cooperation is to be precisely agreed beforehand and possibly confirmed in a contractua- form. The cooperation mostly concerns the following fields of activity:

Field of activity	Maker's share in %	User's share in %
Maintenance documentation	70	30
Spare parts and assemblies	90	10
Service diagnostics	90-100	0-10
Repairs and operational diagnostics	10- 40	60-90

Practical experience in the Czechoslovak industry witnesses that in the industrial plants working with an established P M S some 80-85% of all repairs, except for general overhauls effected by specialized centres, can be covered by the plant itself using their own forces. A precondition of this, however, is a preceding close cooperation with the supplier.

CAPITAL GOODS: I. BOTTLE-NECK II. CURRENT III. AUXILIARY IV. SPECIAL

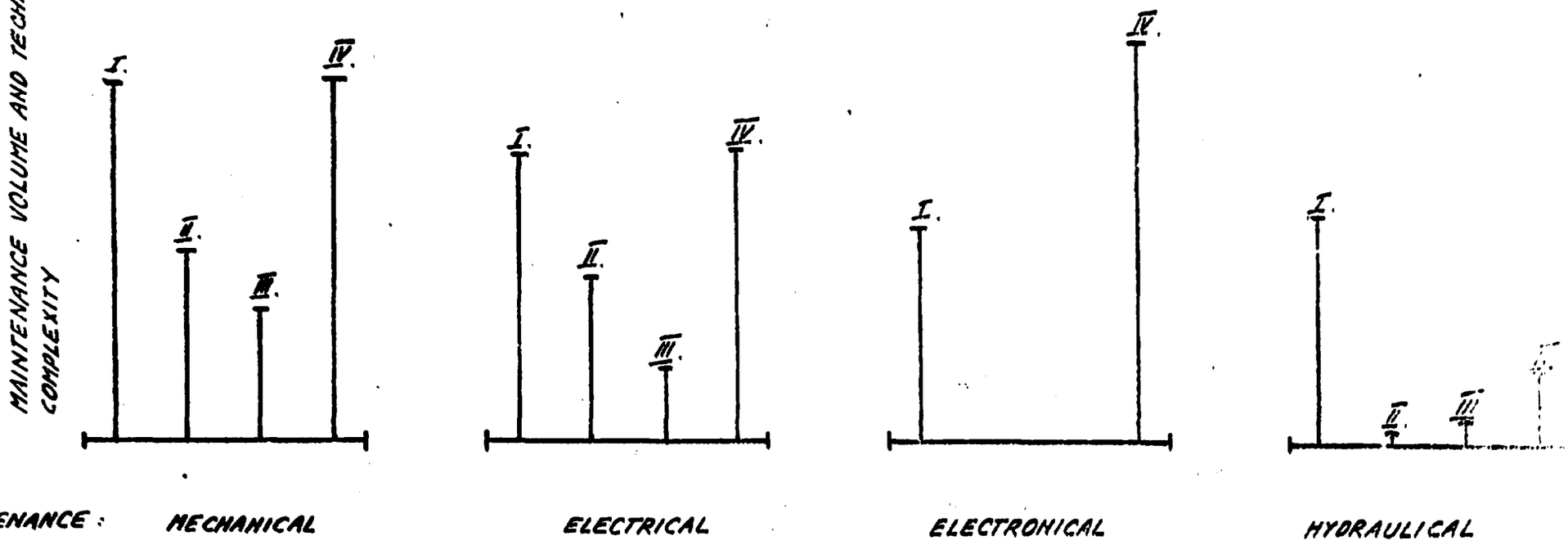


Fig. 1 GROUPS OF CAPITAL GOODS - DEMANDS TO DIFFERENT KIND OF MAINTENANCE

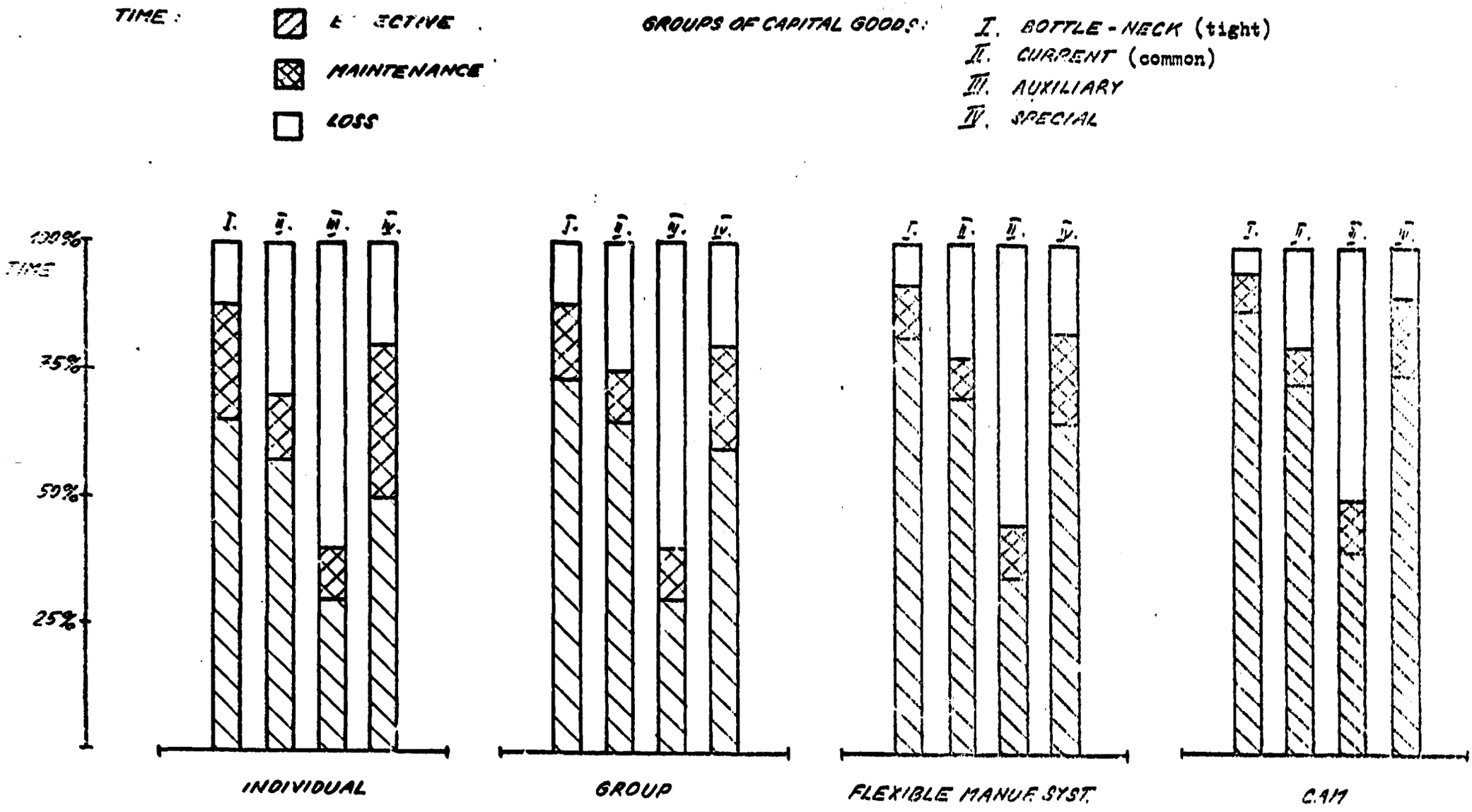


Fig.2 GROUPS OF CAPITAL GOODS - TIME DISTRIBUTION IN DIFFERENT MODE OF EMPLOYMENT

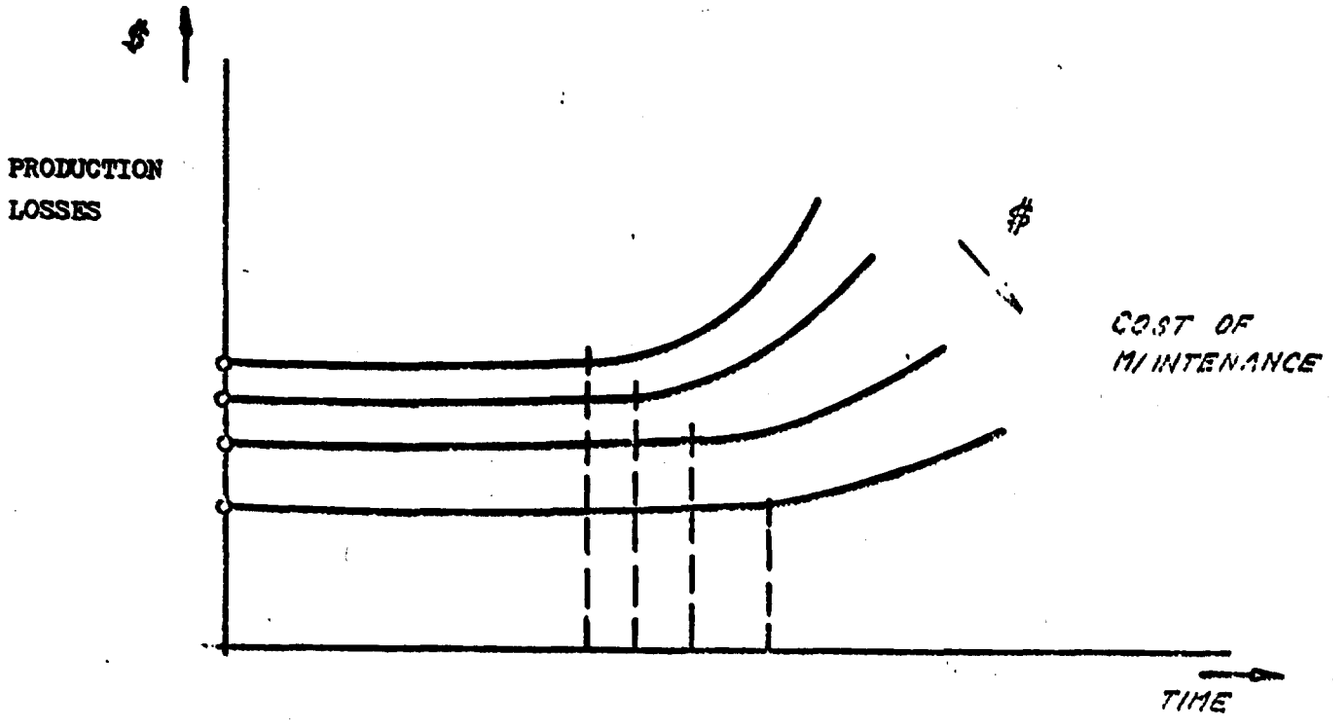


Fig.3 RELATION BETWEEN PRODUCTION LOSS AND MAINTENANCE COSTS IN TIME

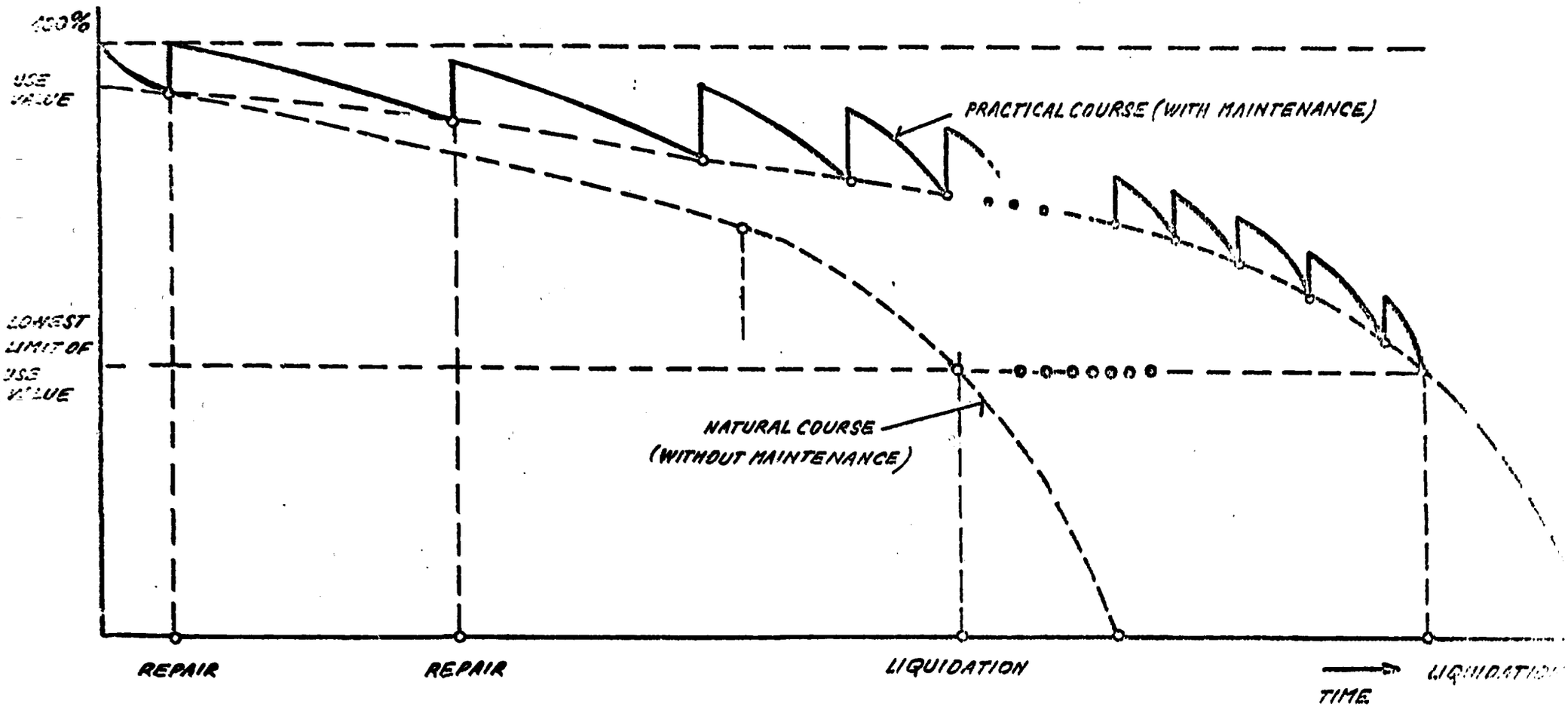


Fig 4 EFFECT OF MAINTENANCE ON THE USE VALUE DECREASE

EVALUATION OF MAINTENANCE EFFECTIVENESS
LUCK'S METHOD

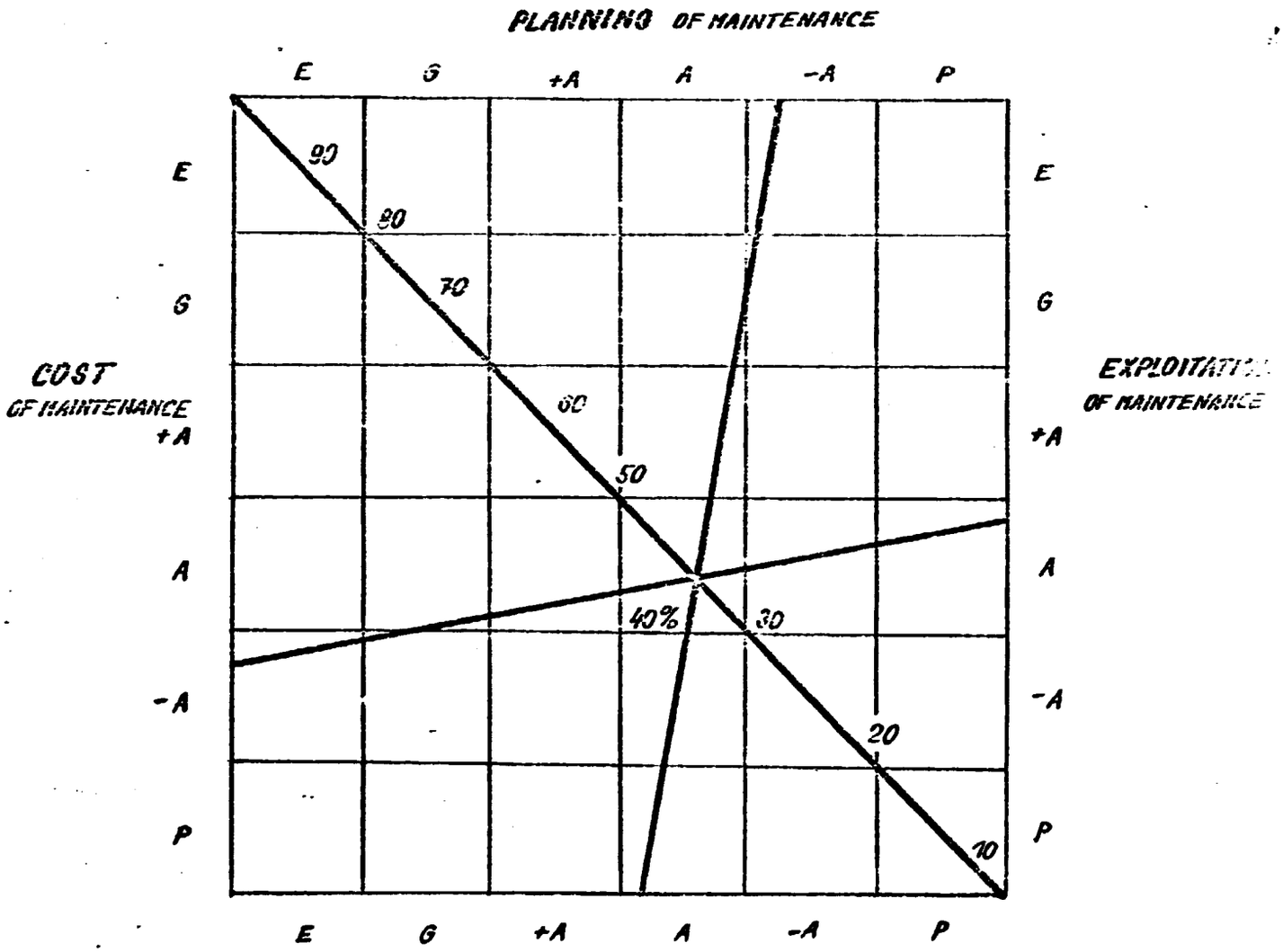


Fig.5 PRODUCTIVITY OF MAINTENANCE