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Maintenance Systems

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Preface

Nowadays, we are witnessing an ever increasing social expectation in relation to the maintenance. Its legal and economic regulation is done with direct and indirect methods in law, but realization is locally and practically. The Faculty of Engineering at University of Szeged includes vary applied engineering sciences in BSc and MA-courses either as a separate material or as a part of a subject, specified on a given profession. **By that time** the students **have known** the basic concepts and more significant details embedded in other subjects, which then are complemented with the trends of the changes in maintenance, **knowledge** on maintenance economics, the goals of sustainable technology and economy. This teaching material serves to complement their knowledge and to enwiden their horizons with no claim of being exhaustive. After a general overwiev, **our aim** is to emphasise the characteristics of maintenance systems to show the pecularities of some fields of application and to assist in the practical application of theoretical knowledge.

This teaching material keeps in view the correspondence with the **learning outcome-based approach**, the prescribed and expected professional competencies, competence-elements, and the formation of which the subject typically contributes to, thus the student:

Skills of a logistics studying in the

***a)* regarding knowledge, the student**

- knows and keeps the rules and ethical norms of cooperation and leadership as part of a project, a team and a work organisation;
- has a clear idea of the basic concepts and methods of founding institutions along with managing and altering their structure and organisational behavior;
- is familiar with the concepts and methods of controlling, organising and performing economic processes along with the methodology of analysing said processes, preparing and supporting decisions;
- is familiar with the basic principles of other professional fields connected to his/her own field (engineering, law, environmental protection, quality control, etc.);
- possesses the know-how required to complete basic leadership and organisation related tasks and is capable of preparing, launching and leading small to medium sized projects and enterprises;
- has mastered the professional and effective usage of written and oral communication along with the presentation of data using charts and graphs;
- has a good command of the basic linguistic terms used in economics both in his/her mother tongue and at least one foreign language.

***b)* regarding skills, the student**

- is capable of planning, organising,

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leading and overseeing economic activities, projects, minor enterprises and economic organisations;
- can uncover facts and basic connections, can arrange and analyse data systematically, can draw conclusions and make critical observations along with preparatory suggestions using the theories and methods learned. The student can make informed decisions in connection with routine and partially unfamiliar issues both in domestic and international settings;
- follows and understands business processes on the level of international and world economy along with the changes in the relevant economic policies and laws and their effect. The student considers the above when conducting analyses, making suggestions and proposing decisions;
- can employ techniques and methods of solving economic problems regarding to their application requirements and limits;
- can cooperate with others representing different professional fields;
- assumes the role of leader and organiser in project- and group-work after acquiring the necessary practical know-how and experience while also carrying out assessment and evaluation tasks;
- is capable of leading small and medium sized enterprises or an organisational unit within an economic institution after acquiring the necessary practical knowledge and experience;
- can present conceptually and theoretically professional suggestions and opinions well both in written and oral form in Hungarian or in a foreign language according to the rules of professional communication.

***c)* regarding attitude, the student**
- behaves in a proactive, problem oriented way to facilitate quality work. As part of a project or group work the student is constructive, cooperative and initiative;
- is open to new information, new professional knowledge and new methodologies. The student is also open to take on task demanding responsibility in connection with both solitary and cooperative tasks. The student strives to expand his/her knowledge and to develop his/her work relationships in cooperation with his/her colleagues;
- keeps the principles of lifelong learning inside and outside the world of labour.

***d)* regarding autonomy and responsibility, the student**
- conducts the tasks defined in his/her job description independently under general professional supervision;
- takes responsibility for his/her analyses, conclusions and decisions;
- completes his/her tasks independently and responsibly as a member of certain projects, team tasks and organisational units;
- takes responsibility for his/her work and behaviour from all professional, legal and ethical aspects in connection with keeping the accepted norms and rules.

Regarding maintenance management, including engineering, the authors intend to emphasise that it requires a creative way of thinking, from both the lecturer teaching the given subject and the student, to get to know and acquire more study materials, to weigh carefully how to use them in practice.

the Authors

1. THE IMPORTANCE AND EVOLUTION OF MAINTENANCE WITHIN INDUSTRIAL COMPANIES

1.1. Importance, place and role of maintenance activity in industrial companies

The complex character of the industrial production activity, the considerable increase of the value of the new equipment, the high costs due to the accidental interruptions in the manufacturing processes have led to the development of new researches in the field of maintenance and repair of the machines. Since the years 1970-1975, in many European countries, it has been concluded that some names referring to the specific works of maintenance, repair, and execution of the spare parts, to maintain the technical-functional parameters of the machines, no longer correspond. Thus, a new field of scientific approach, generally called **maintenance**, has emerged.

The average operating time of the machines between faults, the duration, and the quality of the maintenance and repairs operations are critical elements for the available time of the machines and the profitability of the company. Maintenance and repairs should be considered as a present investment made for the future.

Conscious of the rising costs due to neglecting maintenance activities, in recent decades, in many market economy countries, studies have been elaborated on the role that the maintenance and repair of machines should have. Thus, in the U.S., the specialized works on industrial development and engineering, addressed maintenance practices publish useful data and recommendations. In England, the researches have highlighted the deficiencies in maintenance and the potential sources of increasing the productivity of work on account of maintenance. In Japan, studies have been carried out, highlighting the impact of the maintenance and repair activity on the safety in the functioning of the production systems and on the quality of the products.

The change in the last decades of the role and importance of the maintenance activity was determined by the following factors:

1. The considerable increase in the value of the new equipment purchased, due to their constructive and functional improvement;
2. Increasing the complexity of the equipment by increasing the degree of mechanization and automation of the processes;
3. Increasing losses caused in case of equipment damage or their stationary repair;
4. Continuously increasing maintenance costs and increasing their share in product costs; a critical cause in the increase of the maintenance costs is the activities of

training - training of the personnel in the maintenance field.

5. Increasing the number and weight of the personnel employed in the maintenance activity.

The organization on economic principles of the maintenance and repair works is an essential objective because, for these works, critical quantities in materials are consumed, and labor and important quantities of money are spent.

A well-organized and adequately implemented system brings economic benefits, by reducing the stationing of machinery and production losses, with implications for obtaining lower-cost products. In this connection, two distinct aspects, but which depend on each other, are noted:

1. The factors that determine the increase of the efficiency in the maintenance compartment generate, in their turn, the diminution of the global costs, related to the manufacture of a product; for example, the higher the quality of the oil used in the operation of an engine, the higher the number of operating hours (20,000 hours instead of 10,000 hours), the lower the hourly costs associated with running the engine. This is because the expenses related to the oil will be spread over a higher number of operating hours.
2. Increasing the efficiency of the industrial unit can only be ensured by better equipment maintenance; for example, a maintenance program made according to the quality and time requirements imposed by the documentation elaborated for this purpose, and respecting a required protocol, allow the operation of equipment for a longer time, at the nominal parameters imposed.

Solving the first problem is the task of the maintenance compartment manager (elaboration of maintenance programs specific to each machine, carrying out training for the maintenance operators, to reduce the fault diagnosis times), and the second is the responsibility of the unit manager, who must engage and coordinate the different existing factors, among which the maintenance compartment is the main factor. The collaboration between these compartments (production - technical compartment - supply - technical and quality control - human resources - accounting - maintenance department) will become effective, as long as:

- The barriers that may exist between the different compartments are eliminated;
- There is an information system that can be used by all compartments, which is an essential fact because the information is a fundamental factor in making management decisions.

Organizing and carrying out maintenance on economic principles, performing short and quality repairs, applying the most efficient solutions for reconditioning used parts for their use, can generate a "**conflict**" between the maintenance and financial compartment, as well as with the production compartment.

There is sometimes a tendency to reduce the financial resources for preventive maintenance activities. In reality, the effect of this policy is not the

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one expected, with an increase in costs with corrective maintenance, as a result of the rise in the frequency of accidental falls (failures).

At the same time, increasing the number and value of corrective maintenance works will result in a reduction in the resources available in the future for preventive maintenance, and the industrial unit enters a vicious circle from which it will be difficult to leave.

To reconcile the two points of view, which are opposed only in appearance, the maintenance activity of the equipment must be located at the place that belongs to them within the industrial unit, and define the responsibilities. At the same time, the organization of the maintenance activity must be carried out in a way that allows solving all the maintenance problems in the most efficient way possible (the economic criteria will have to become a priority, in most cases).

In the Romanian industry - we can say under crisis conditions, that started with the transition to the market economy, being reinforced today by the specific disruptive factors of the global crisis - with all the difficulties arising due to the accelerated development of the private sector and the process of restructuring the industry in a final phase, the place and the role of the maintenance activity are reconsidered; from an ancillary activity, it becomes a strong technical and logistical service, having a positive effect on the overall efficiency of the enterprise.

1.2. History, definition, evolution and objectives of maintenance

The concept of "**maintenance**" in the industry has emerged in the U.S. in the 1950s, and later it gradually entered Western Europe, where it overlapped that of "**service**" and "**repairs**." The two terms have similar content but are not identical, because

- To "**service**" means to perform a set of activities on a machine (periodic or accidental checks, regular reviews, repairs of various types) to ensure the continuity of the operation of the machine in the production process;
- "**Maintenance**" involves the elaboration of a complex program, which includes the means of detecting the level of wear, concrete ways of preventing malfunctions, developing technologies of repairs, calculating the stock of spares and spare parts, training the personnel involved in the maintenance activity, activities of correction or renovation aiming both at widening the range of operations, intensifying the processing regimes and the economic efficiency of the machine at the workplace, to optimize the manufacturing costs.

A philosophical approach to the concept of **maintenance** highlights the fact that it can be considered the "proximate genus" of such activities, having a more comprehensive sphere, and

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T is the "specific difference" included.

Currently, at the company level, most of the service and repair compartments are in "transfer" to maintenance, due to the following arguments:

- The high level of equipment automation and their complexity implies a high level of competence for carrying out interventions to eliminate defects;
- The cost of purchasing the equipment is placed on an upward curve;
- Production costs are influenced by the time of unavailability of the equipment, price that tends towards critical values, especially in industrial units with a continuous production process.

The evolution from service to maintenance is determined by the following factors:

- Increased **financial resources** for investments in high productivity equipment;
- **Maintenance is preferable to service** in conditions of a homogeneous fleet of machines;
- **Maintenance is indispensable** in situations where accidental malfunctions can cause accidents at work or endanger the lives of production operators;
- **Maintenance is the imperative of environmental protection and conservation** because certain defects can be accompanied by emissions of pollutants, gases, etc. which endanger the health of operators;
- **Consistently applied, long-term maintenance** leads to lower production costs.

The place that the maintenance compartment occupies within the structural organization of industrial enterprises differs depending on the existence of the above criteria, as follows:

- **Fundamental position** - for nuclear power plants, flying machines, and other products that require a high safety coefficient;
- **Important position** - for industrial units with continuous processes, in which the interruption in operation generates significant losses/damages (metallurgy, chemistry, power plants, etc.);
- **Secondary positions** - for companies with a relevant contribution of manual activities related to mechanized, automated processes
- The transfer of the concept of "service" to that of "maintenance" is presented in table 1.1.

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Table 1.1. The transfer of the concept of "service" to that of "maintenance"

No	The defining parameter	SERVICE	MAINTENANCE	OBS
1.	Structure of the equipment in the manufacturing process	Machine tools specialized in operations	Aggregates, complex, multi-operational equipment	
2.	Structure of the processes undergoing repairs / maintenance.	Mainly manual processes; use of tools, testers, simple devices.	Mechanized, automated processes, users of complex equipment	
3.	Product safety level	Low, medium	High, important for human life	
4.	Human resources involved in the process.	Teams specialized in the categories of RU interventions in the company	Specialized personnel by categories of activities RU from specialized structures	
5.	Cost structure	Specific costs of repairs	Costs specific to maintenance processes	
6.	Strategy	Short term	Medium and long term	
7.	Process attitude of the operators involved	Uncertainty, waiting, frustration	Control, process control, programmed / controlled intervention	
8	Process planning	According to the conditions in the documentation prepared by the manufacturer	Elements of the repair program structure at the production system level	
9.	Specific elements	The activity oriented towards repairs	The activity oriented towards the management of repairs	

Source: our elaboration

Analysing the evolution of maintenance, we find that it is not limited to the development of its content, but also refers to the modernization of the concepts regarding the reliability, maintenance, availability, and redundancy of the equipment. In the contracts regarding the purchase of industrial equipment, clauses are provided regarding the reliability and compliance with the maintenance program to ensure availability and the set of spare parts required for the warranty period.

The Larousse dictionary defines **service** as "the act of keeping a thing in good working order," and **maintenance** as "the assembly of everything that allows the maintenance or restoration of a system or part of it, in working order."

Analysing the definitions above, we draw the following conclusions:

- "**Service**" has a limited area and is oriented towards concrete, physical repair and other activities related to it;
- "**Maintenance**" has a more comprehensive area, in that it includes, together with repairs and diagnostic analysis, the preparation of records regarding the condition/level of wear of the equipment, the calculation of the necessary spare parts, reliability calculations, cost tracking, measurements, and calculations with a predictive character, etc.

In the specialized literature [22], there are cases of analogy, in the aspect of the type of activity related to the lifetime of the machine, when evaluating the health of the machine (its technical state) compared with the health status of a biological organism. Table no. 1.2 reflects these activities.

The French Association of Standardization "AFNOR" defines maintenance [5] as "the set of actions allowing the maintenance or restoration of equipment in a specified state or able to provide a specific service." The definition covers the essential aspects of the maintenance activity but omits the preventive side and the economic component related to costs.

A definition accepted by most specialists is as follows: *Industrial maintenance is a set of measures and actions that allow the prevention, good maintenance or restoration of equipment in a predicted state or able to provide a determined service under the conditions of minimizing maintenance costs.*

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Table 1.2. The analogy between the health of the biological organism and the "health" of equipment

HEALTH OF THE BIOLOGICAL ORGANISM		"HEALTH" OF EQUIPMENT	
SPECIFIC ACTIVITIES	STATUS	STATUS	SPECIFIC ACTIVITIES
Knowledge of the human body and knowledge of certain types of diseases	Birth and growth of the organism.	Putting in function	Knowledge of technology and causes of falls.
Medical record, health book, diagnosis, analysis, periodic visits	Ensuring longevity of functioning of the mature organism	Durability	The equipment file, reports, diagnostics, expertise, periodic inspections.
Knowledge of treatments. Preventive treatment Curative treatment	Good health	Reliability Redundancy	Troubleshooting, periodic technical revisions, current 1st-degree repairs, 2nd-grade current repairs.
Surgery, recovery therapy, training.	Eliminating disease-causing causes.	Maintenance	Renewal, modernization, restoration of new functions
Self-knowledge, self-adaptation to external environmental conditions	Adaptability, resistance to the action of the environment	Availability	Operators training for the efficient use of the equipment
Cessation of vital functions to the body	Death	Scrap	Recovery of subassemblies.

Source: [22]

The following conclusions are drawn from the scope of this definition:

- **To restore** has the meaning of "correction," imposed by the change of the initial value of the operating parameters of the equipment;

- The **predicted state** or the **determined service** implies the predetermination of the operating parameters or the service to be reached, with the quantification of the characteristic levels;
- **To minimize maintenance costs** reflects the economic aspect of the activity;
- **Prevention** - the set of operations that avoids the unavailability of the equipment;
- **The good maintenance in a foreseen state** consists of the implementation of methods, procedures, measures, and actions that contribute to the progress of the maintenance in the four priority directions. The maintenance function evolved within the industrial units, being subjected to a continuous refining process, taking into account the compromise that had to be made between needs and demands from a technical, economic, and human point of view.

Historically, up until the 1960s, maintenance activity remained synonymous with repair, with equipment improvements being made whenever possible. Systematic maintenance is only applied to equipment with an impact on human security, and their stops are performed for the simple reason of analysing the level of wear, and it is completely abandoned in cases where the safety of persons was not put at stake.

In its evolution, the notion of industrial maintenance was enriched during the period 1960-1970 with the following new elements:

- The maintenance of the diagnosis appeared, using the non-destructive control techniques for the control of the vibrations resulted in the operation process of equipment; the analysis of the action of fluids, made the use of the supervision technique necessary, which led later to the *conditional maintenance*;
- The research on the *theory of reliability* and the way of processing the experimental data regarding the relationships between the demand, wear, deterioration, and service life of a product have been expanded and deepened.
- The way of assessing the risk and the probability of the occurrence of defects of the economic effects due to the decrease of the quantity or quality of the products, including the hidden costs of the maintenance activity, reflected in the notion of the *cost of the fall* has been improved.

The progress made in the maintenance activity has concrete results, from which concrete solutions and proposals can be deduced, as shown in figure no 1.1.

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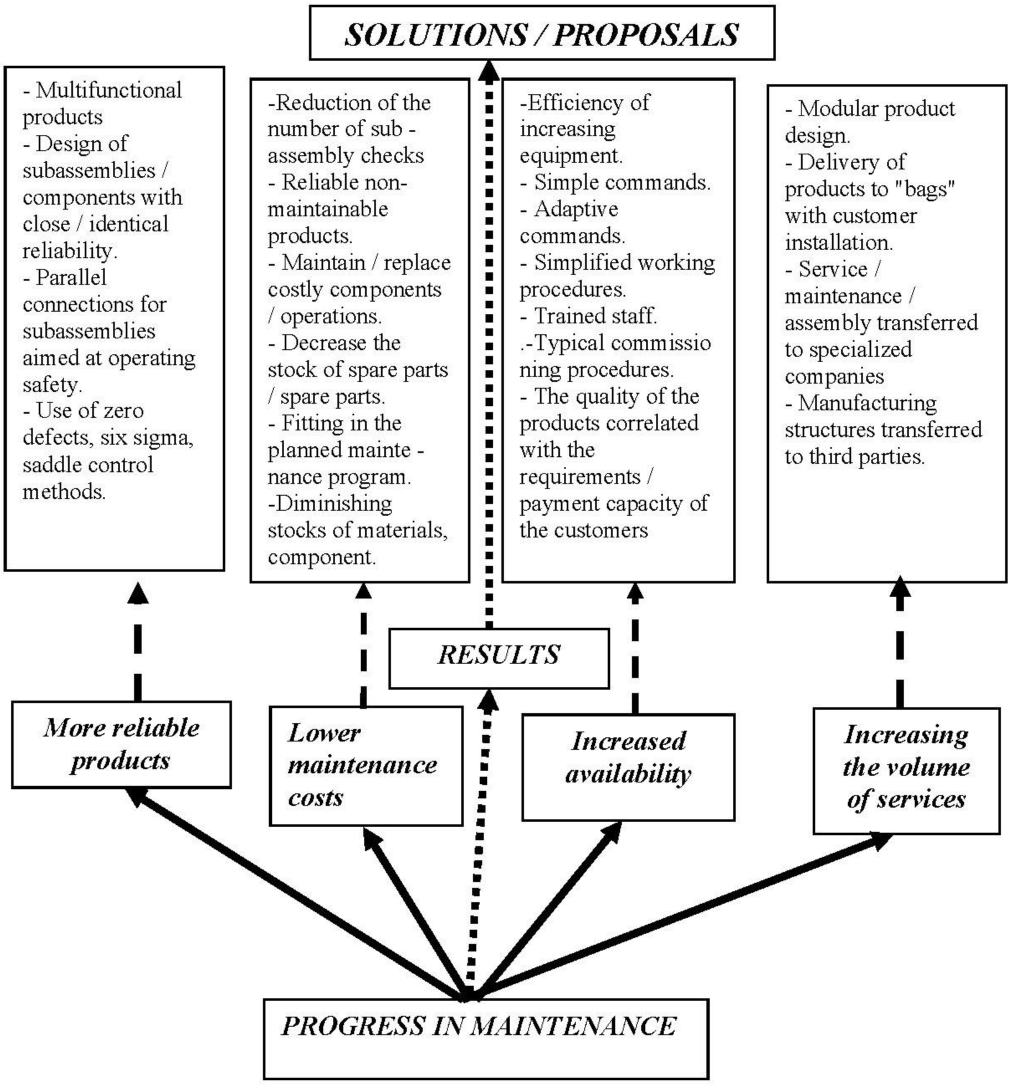

Figure no. 1.1 The progress achieved by applying maintenance processes

Source: [8]

In the field of industrial maintenance, two new concepts emerged after 1970:

➢ To minimize maintenance costs in the US, **The Life Cycle Cost (L.C.C.)** concept, which consists of highlighting all the costs related to the research, design, manufacture, operation, and maintenance throughout the life of a

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machine, has been implemented.

- Unlike LCC, which expresses an economical approach to maintenance, in Japan, the concept of **Total Productive Maintenance (T.P.M.)**, which represents a behavioural approach to maintenance, has been implemented. This concept aims to obtain maximum efficiency for machines by involving all the compartments in the maintenance activity, and in particular, by increasing the autonomy of action of the employees during the development of manufacturing and maintenance processes.

1.3. Factors influencing the maintenance process

The factors that determine the evolution of the maintenance activity, within the industrial enterprises can be grouped into:

1.3.1 Technical/technological factors;
1.3.2 Economic factors;
1.3.3 Factors related to human behaviour.

1.3.1. Technical / technological factors

Ensuring the dynamism of the development of industrial enterprises over time, as a basic requirement the introduction of technical progress in all their fields of activity, was generated.

Increasing the competitiveness of industrial enterprises could only be ensured based on scientific research and technological development.

In the research/design phases, the new strategies approached had as main elements the orientation towards new product projects, which would include in their structure both novelty elements, but also performing elements of the existing components/products, respecting the principles of the quality spiral elaborated by J. M. Juran.

The redesign of existing products has become a continuous process over time, being a source of supply for manufacturing processes with new products.

There has been a reduction/diminution of the time affected by the research-design processes, by intensifying the own research activities, by the reuse of components and sub-assemblies of the existing products already on the market, by the preparation/use of specialized design programs, by the use of supplier databases for components/subassemblies and not least by applying some performance standardization procedures (MTM, MOST, and so on).

The raising of the technical and qualitative level of activities in industrial enterprises was achieved by introducing new technologies, based on recent developments in computer science, microelectronics, nanotechnologies, and bionics. The new production strategies take into account:

- The introduction of specialized aggregates instead of the classic machine tools,
- The use of specialized equipment in welding processes instead of manual welding,
- Use of plastic injection equipment with programmable control,
- Diminishing the efforts of the operators in the assembly activity, and the use of robots/manipulators instead of the human resource,
- Introduction of automated control/selection technologies, capable of making a rapid selection in terms of quality of the processes performed and the products resulting from the process.

Automation processes are developed in flexible manufacturing workshops. There are more and more companies where the computer using the archive of programs of the production sector programs the assembly line. This way, the manufacturing (in whole or part) is assisted by the computer. There are two aspects worth noting here:

- From the design phase of the manufacturing line, a calculation of the reliability of the components is required, but also of the line itself, related to the operating parameters imposed on it, and
- It is necessary to develop a program of preventive/corrective maintenance, to avoid the installation of the "dead times" due to the stoppages of the assembly line from various causes.

Due to advances in component technology, electromechanical subassemblies require fewer maintenance and troubleshooting interventions due to the increased reliability of electronic circuits. At the same time, the fall of this equipment can be prevented by new fault detection techniques (sonic analysis, vibration analysis, etc.).

Modern electronic equipment allows the use of the surveillance technique of new equipment and the application of conditional maintenance, in which:

- It is necessary to elaborate and strictly observe the inspection program to verify the observance of the operating norms, the control of the technical state of the equipment, whose complexity is increasing;
- The diagnostic operations regarding the functional state of the equipment must be performed within the stipulated time intervals, with accuracy as close as possible to the legal requirements.

1.3.2. Economic factors

The importance of the maintenance activity is determined by the major influences it has on the most important economic indicators that characterize the activity of an industrial enterprise. The size of the expenses incurred by the maintenance and repair of the machine is influenced by two essential factors:

- **Number/structure of repairs performed and**
- **The volume of prophylactic maintenance works during operation.**

To obtain the overall reduction of the expenses with the maintenance and repair of the machine, it is necessary to act on the two factors above.

The following directions can be used more frequently to reduce the cost of maintenance and repairs:

1) Centralization and at the same time, the specialization of the repair works;
2) Improvement of repair methods and forms, using advanced technologies;
3) Scheduling the maintenance and repair work in such a way as to reduce the stoppage time of the machine;
4) Ensuring the repair with spare parts through centralized manufacture, which allows reducing their cost;
5) Establishing the optimal number of maintenance operators to reduce the consumption of labour force;
6) Reducing the consumption of materials used for repairs;
7) Constructive improvement of the machines to make the detection of defects, their removal and the control of the technical state in operation more comfortable and operative.

Reducing maintenance and repair costs requires liquidation of poor quality repairs, as lower quality leads to increased maintenance. The inferior quality of the repairs can be due to the inadequate technical control, as well as the poor endowment of the repair unit with cars and S.D.V., necessary to perform quality repairs.

One factor by which the increase of the economic efficiency is realized consists in the appearance and development of the companies specialized in maintenance, capable of carrying out numerous activities instead of the traditional maintenance compartments within the industrial units.

With the development of specific maintenance services, two essential considerations are ensured:

- **The beneficiary** (the user of the maintenance process) is not required to keep in “standby” teams of specialists; as a result, a reduction of maintenance costs takes place, together with an increase in the quality level of maintenance processes, being performed by specialists.
- **Specialized training may be set up** for

maintenance operations that operate both in the own enterprise and in other enterprises.

The determination of the optimal number of interventions takes into account the total costs incurred by providing the interventions, face to face with the tariffs for the provision of maintenance services, of the specialized providers, as it results from figure no. 1.2.

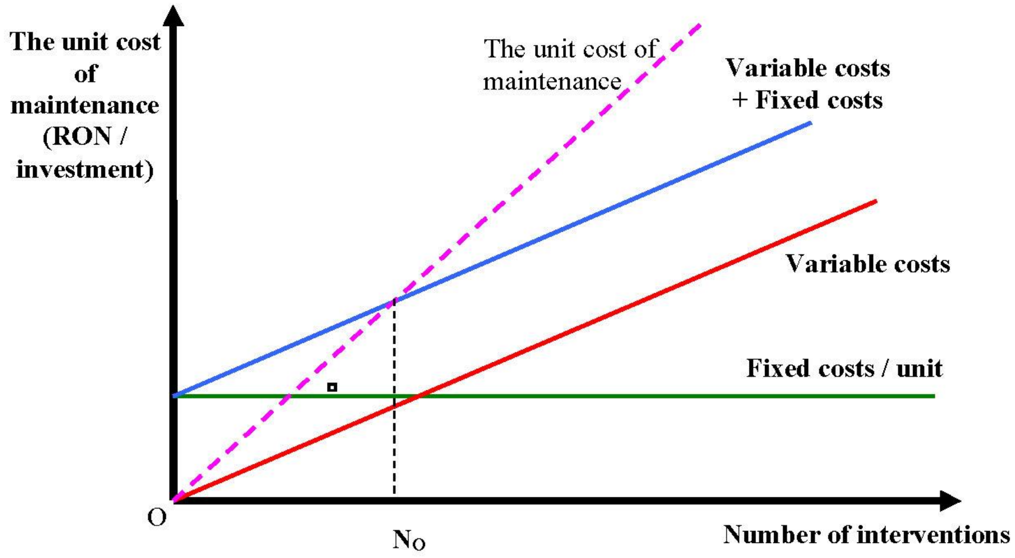

Figure no.1.2 Determining the optimal number of interventions

Source: our elaboration

The option of the management team with reference to the solution used to ensure the operation of a manufacturing system, considers the comparison between the costs incurred by the maintenance team/maintenance with the own staff and the option to contact a specialized service provider. It is observed that for a number of interventions smaller than the optimal number (No) **it is recommended to call a specialized service provider**, while for a number of interventions greater than (No) **it is recommended to carry out interventions in their own regime.**

Performing maintenance work through specialized companies is one of the fundamental changes that are registered in the industrial maintenance activity. They are more supple, flexible, able to adapt to the new requirements, they can periodically provide specialized services for which it is not economically justified to maintain within the traditional maintenance compartments new maintenance capacities.

Any manager who wants to solve the specific issues about total maintenance cannot ignore the costs that accompany the maintenance processes. Thus, if the needs of the maintenance process (preventive/corrective) are represented, related to the maintenance costs, the optimal values of the total costs related to maintenance can be determined, as shown in figure no. 1.3.

From the figure it is observed that to solve the needs related to the faultless operation of an equipment, a solution would be preventive maintenance. Its costs increase with the need to ensure a continuous operation of the equipment. On the other hand, the costs with the corrective maintenance ensure and solve the aspects related to the faultless operation of the equipment. As a result, the total maintenance costs, aimed at the operation of an equipment, admit an optimum (corresponding to minimum total maintenance costs.)

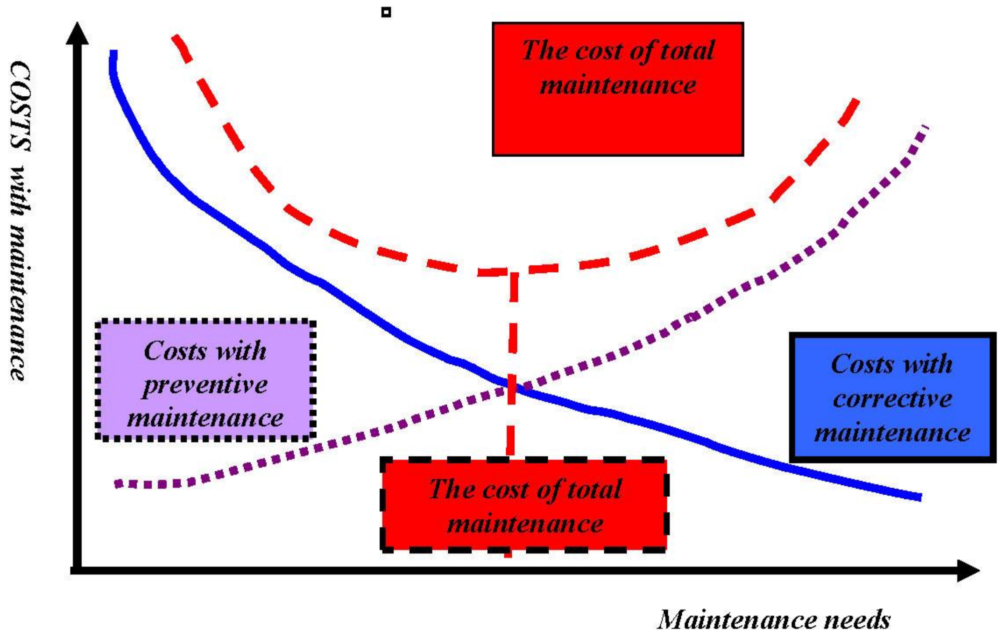

Figure no.1.3. Determining the minimum cost of the total maintenance according to the maintenance needs of the equipment

Source: our elaboration

1.3.3. Behavioural factors

An important factor in ensuring the efficiency of the maintenance and repair activity is the maintenance and operation personnel, as well as the nature of the relationships between them.

In plan of human relations, the organization of the total maintenance activity, at the level of a manufacturing structure, involves the following distinct activities:

❑ Drawing up forecasts regarding the labor force needs by levels/categories of qualification, for medium / long periods of activity;

❑ The selection of the available human resources, to specialize them, to ensure the quality of the tasks according to the existing documentation for this purpose;

❑ Clear definition of the tasks on the workstations, in terms of structures of activities, but also terms of the duration of the operations, and the terms of execution, and their planning in space and time;

❑ The correct evaluation of the results of the activity, the elaboration of a professional training program, the application of participatory methods, of stimulating the voluntary employment of the production operators to the maintenance activities, and the improvement of the working conditions.

1.4. The dimensions of the maintenance system

The development of these activities at the level of complex structures will amplify the maintenance function, acquiring a new dimension characterized by:

1.) A transfer of tasks aimed at maintenance partially to the production process and another part to specialized maintenance companies. The optimal maintenance policy adopted for this purpose, aims to establish the set of measures that must be adopted to ensure the functioning of the existent equipment park in optimal conditions, based on technical and economic criteria set, among which the most important, as a result of the previous presentation, are the safety in operation and the minimal maintenance and repair costs.

These objectives can be achieved by transferring to the production personnel some **maintenance activities of level I** among which we mention:

- ***Cleaning the machine and the work area,***
- ***Keeping order at work,***
- ***Lubrication of guides and structures in relative motion,***
- ***Setting some operating parameters of the machine,***
- ***Checking the level of the cooling-lubricating fluids used,***
- ***Checking the tightening voltage of the different components (screw/nut assemblies, conical assemblies),***
- ***Checking the extent of the transmission belts,***
- ***Signalling the malfunctions in the operation of various equipment necessary to be solved by specialists or complex teams.***

These activities, which traditionally belonged to the maintenance operators, do not require special skills and training, which is why they can be transferred to the production operators.

The complex maintenance works **of level II** will be executed by specialized companies that have equipment with SDVs, technological equipment, and performance control, as well as specialized personnel, for the complex repair activities. Repair units specialized for machine types, perform all kinds of repairs, but only for certain types of machines, such as lathes, mills, drills, etc. The personnel of the specialized units knows better the equipment to be repaired, the specifics to the repair, the causes of defects, and has the possibility of liquidating the defects in a short time.

The implementation of this maintenance policy will lead to the gradual reduction of maintenance personnel within the companies.

The preventive maintenance program, for complex type systems, represents a special case:

- *Vehicles used in the sporting activity (special speed, endurance, or traction races on various circuits). Here, depending on the specific requirements imposed by the designer of each brand, a set of specific, well-structured activities is required, both as a structure, but also as a procedure, time of action and deadlines; such a set of activities may refer to* ***fuel supply*** *(operation performed according to the strategy adopted by the team during the race),* ***simultaneous change of the four tires*** *(dictated by the level of tire wear, accidental failure of them, or weather conditions),* ***the change of the pilot*** *during the race, according to a graph imposed by brand strategist, etc. The "Team Manager" selects an active team, instructs him in sense of detailed assimilation, to perfection, of the imposed requirements, analyses these requirements together with the pilot/pilots of the race, so that the classification of the activities is achieved in a minimum time scale, regardless of the level, tendency and value of the disturbing factors, which may occur during a race.*
- Complex products such as locomotives, car heads, *are maintained at a level of reliability required by preventive maintenance programs performed by mechanics or drivers on machines.*
- *In case of ships, the personnel employed during the sail perform the preventive maintenance works. Preventive maintenance has as specific elements maintenance activities of the ship (exterior, interior cleaning, painting, checks of the specialized equipment provided to keep them in working order, oil changes to engines, simulation and installation of protective equipment for various situations.*

2.) Assigning new tasks to the maintenance compartment

The cooperation with specialized units and the transfer of maintenance activities to the production personnel lead to a limited reduction of the maintenance personnel, but not to the termination of this compartment.

The tasks of the maintenance compartment will be oriented in the following main directions:

a) formation of mixed teams made up of production and maintenance personnel with foresight and consulting tasks to diagnose the most difficult situations;

b) the selection of specialized units for cooperation, according to the economic and quality criteria, in order to contract the interventions;

c) collecting, systematizing and exploiting the information regarding the behaviour of the equipment in operation, in order to improve the diagnostic process in the maintenance programs, to reduce the consumption of materials, to optimize the stock of spare parts, to determine the optimum moment for the replacement of the machines.

These activities can be carried out by a maintenance department with a small number of employees, but with a high level of professional competence, consisting of:

• **experts**: personnel with versatile training made up of engineers and technicians able to contribute to the effort of the compartment, to provide specialized technical assistance to the production teams and to evaluate the quality of the works performed by third parties;

• **agents of methods** whose attributions are: establishing and monitoring maintenance programs, drawing up maintenance specifications, analysing information from equipment history, etc.

From the figure, it can be seen that in the structure of the concept of industrial maintenance, concept used mainly at level of complex manufacturing structures, there are accepted:

Considering the ones presented above, the evolution of the industrial maintenance function is presented in fig.1.4.

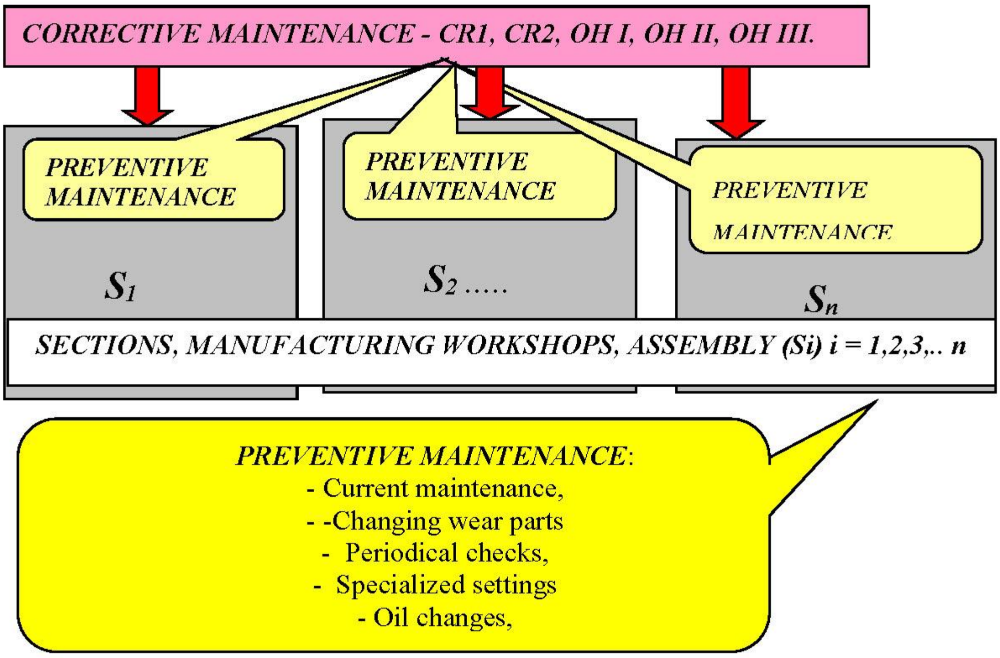

Figure no. 1.4. The evolution of the concept of industrial maintenance

Source: [9]

The corrective maintenance, through which current repairs of degree 1, of degree 2 are carried out, followed by capital repairs of degree I, degree II, and degree III, which aims to bring the equipment in working condition, close to the initial state, or its vicinity.

Preventive maintenance, which ensures the maintenance of the machine in working condition, through regular maintenance operations, periodic checks, periodic oil changes, special liquids used in the operation of the machines, changing the wear parts, replacing the spare parts according to the initial stability program, making special adjustments to maintain the operating parameters at constant levels.

The industrial enterprises, through the management teams, are oriented towards ensuring the profitability of productive activities through:

- Maintaining the production potential,
- Efficient exploitation of the technical infrastructure,
- Economic growth,
- Security of persons and property,
- Environmental protection, etc.

The organization of the maintenance activity requires from the management team the highlighting of the following aspects (fig. 1.5):

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a) The general objectives pursued concerning the maintenance activity;

b) Restrictions to be observed and, in particular, regulations related to security;

c) Action variables available to achieve the objectives;

d) Evaluation and control variables.

The activity of the management team has a strong cyber tempt, based on the processing of the reverse connections to restore the operating conditions.

The general objectives of maintenance directs the whole activity of the unit for a more extended period, depending on the level of development reached by the unit, and can be:

a) *Security-related objectives*. With the increase of the technical level and complexity of the equipment, as well as with the increase of the economic implications of their use, a particular qualitative characteristic such as reliability, acquires special importance, being followed with priority throughout its entire life cycle. These objectives can be quantified by a high-reliability coefficient of equipment susceptible to critical failure.

b) *Availability objectives*. The availability of the equipment is affected by two probabilities:

– on the one hand, the probability of malfunctioning for a particular duration;

– on the other hand, the probability of falling and restoring the ability to function properly over some time.

1.5. The objectives of the maintenance system

The objectives refer to the key equipment, as well as to the whole enterprise.

Objectives for a particular maintenance budget, which aim to allocate a specific budget and even the financial autonomy of this compartment, as well as to empower managers to justify all maintenance expenses. The objectives also aim to reduce maintenance costs, non-efficiency costs of equipment and long-term equipment management. A problem of first-order economic decision is to determine the optimum moment for the replacement of the machines, considering that in conditions of increase of the degree of wear, the expenses for the repairs are increased. Replacement with new machines with higher efficiency is accompanied by lower maintenance costs.

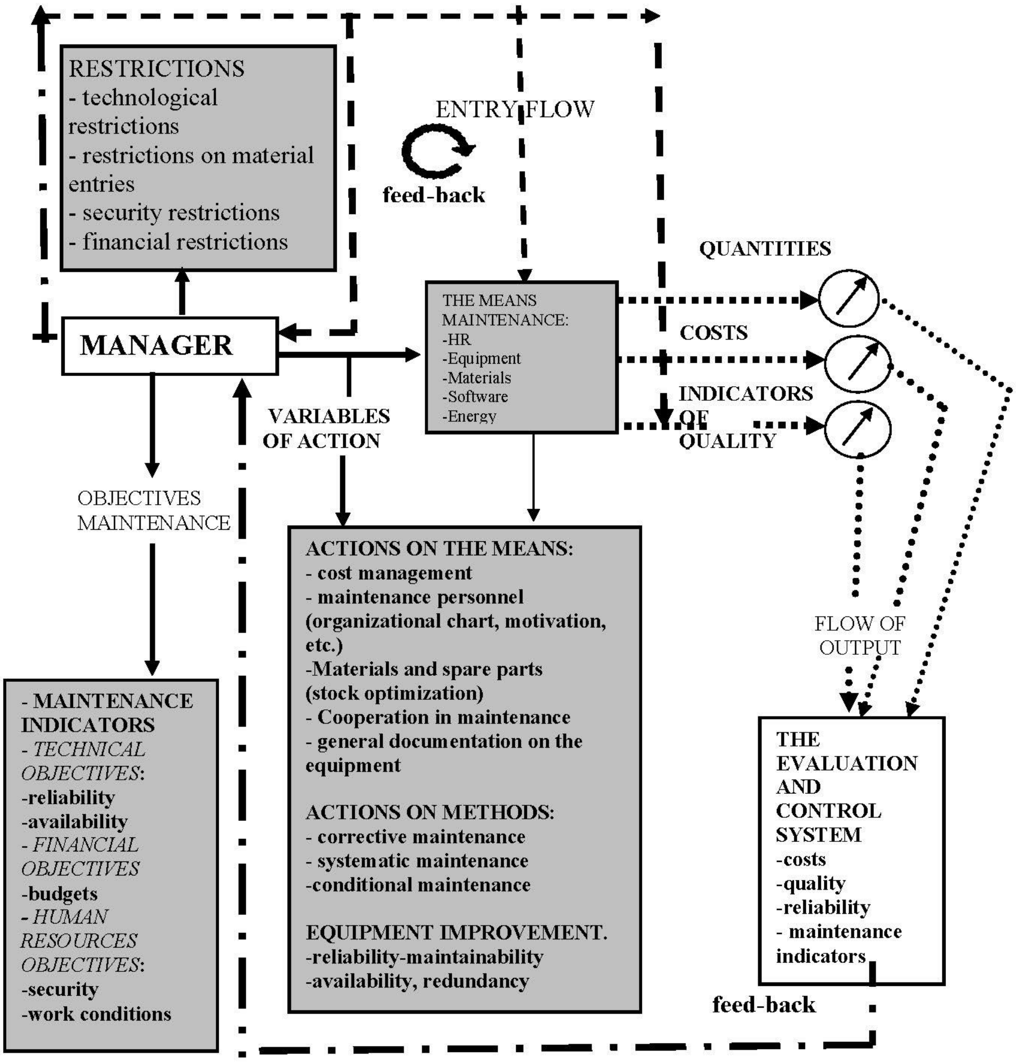

Figure no 1.5. Systematic analysis of maintenance management

Source: [3]

Increasing the availability of a technological line can be done in several ways: maintaining the equipment performing maintenance activities, but with increasing maintenance costs and non-efficiency costs, upgrading the equipment, replacing it with improved equipment, or with new technology.

S. Nakajima highlights five categories of measures for preventing accidental equipment malfunctions, measures in which the factors mentioned above are involved, and on which the maintenance objectives are depending (fig. 1.6).

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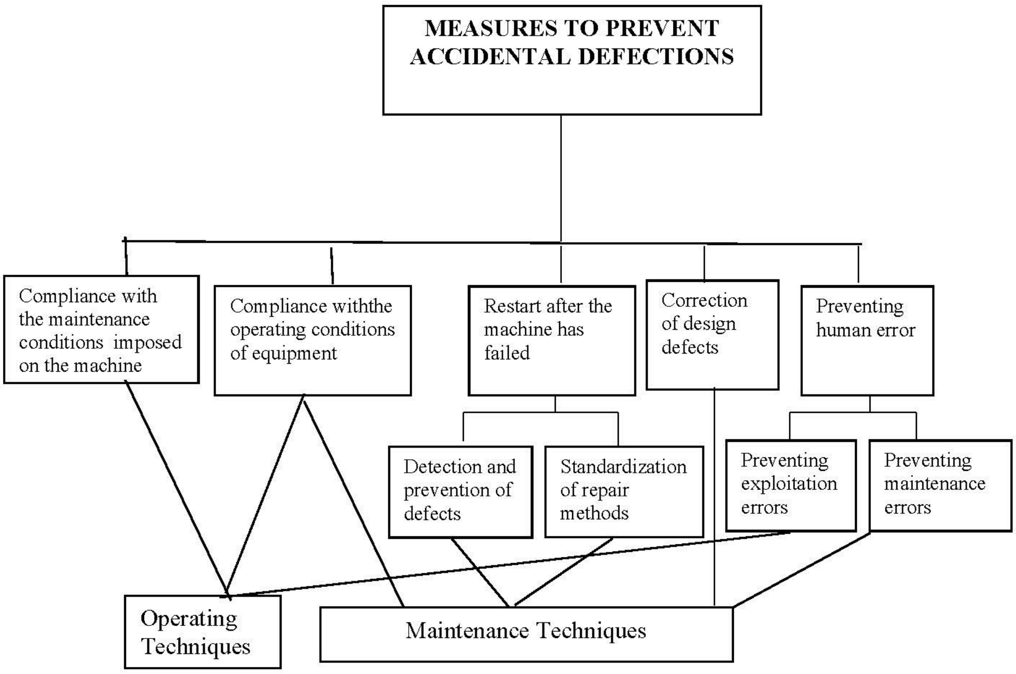

Figure no 1.6. Prevention measures for accidental failure

Source: [3]

Within the industrial units, the maintenance activity is directly or indirectly involved in the achievement of the five operational management objectives, called five Olympic zeros; goals that are difficult to achieve, namely:

1) Zero accidental falls;
2) Zero defects;
3) Zero stock;
4) Zero delays;
5) Zero paper.

1) The objective zero accidental falls. Its achievement is essential when the safety of the personnel or the environment is endangered.

2) The objective zero defects. In organizing the maintenance activity of the machine, it is essential to carry out rigorous verification of the quality of the works to prevent defects, especially to the automated and robotic ones, because the quality of the products is dependent on the technical state of the machines.

3) The objective zero stock. Some parts can be used throughout the life of

the machine, requiring only some adjustments, for example, the machine toolbar, gearboxes, etc. Through maintenance activities, the stocks can be considerably reduced, especially for the equipment with high reliability. This objective can be achieved within the organization of production in a **just in time** system.

4) The objective of zero delays aims at minimizing the duration of unavailability of the equipment, through an efficient organization of the maintenance activity.

5) The zero-paper-objective is achievable through the application of computer programs in the field of maintenance.

During the exploitation of the technological equipment the different parts of the kinematic chain, of the mechanisms and auxiliary installations are subjected to different degrees of application and wear, depending on the dimensions and nature of the material to be processed. As a result of the uneven wear of the component parts, they have a different operating life, requiring differentiated maintenance and repair measures. The risk of falling depends essentially on the reliability of the equipment. The consequences of the failures depend on their duration, related to the possibility of restart the operation, so maintenance.

Consequently, the achievement of the general objectives of the maintenance depends on several partners who intervene in the stage of conception and design of the equipment, use and maintenance.

1.6. The evolution of industrial equipment and the impact on maintenance

Within the industrial units, the production losses due to defects can be reduced to a minimum by keeping the machines in good working order. Since the maintenance and repair activity involves high costs, especially in the case of accidental stoppage of the equipment of high technical complexity, the maintenance activity will prove effective under the following conditions:

1. Improving the qualification, training, and forming of the personnel

The maintenance and repair norms include the constructive characteristics, and the degree of complexity of the repair works for each type of equipment, as well as the level of qualification for the maintenance personnel for each operation. Given the continuous increase in the complexity of the machines, and the cost of their stoppage, the interventions for the maintenance work require a high level of personnel qualification. The level of qualification can be increased through training courses and other means of information.

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2. The association of specialization with polyvalence

With the increase of the complexity of the equipment, the specialization of the maintenance operators is required, but at the same time, for carrying out particular works, it is also necessary to have polyvalent personnel. This can be achieved through the creation of multipurpose teams that meet the two requirements. The proportion between the two categories of personnel is determined by the degree of complexity of the machines and the size of the company.

3. Provide and control

In order to efficiently manage maintenance costs, it is necessary to develop forecasts in the following areas:

- The anticipated management of the personnel (number of employees, level of training, training courses followed, career evolution, necessary training, etc.);
- Estimating the expenses for establishing the budget projects;
- The elaboration of operational and technical documentation (databases on types of equipment, management of equipment history, booklet, logical troubleshooting schemes, etc.) for forecasting purposes;
- Applying the method of forecasting maintenance established based on measurements and calculations;
- Scheduling the work according to the size and complexity of the machinery park, by establishing the duration of repairs based on time regulations, etc.;
- Forecast management of spare parts.

In order to evaluate the obtained results and to improve the forecasts it is necessary to use the following means of control:

- equipment history to track and control its behaviour;
- analysis of the costs of the stoppage, to direct the action on the critical points of the equipment;
- Dashboard for controlling different aspects of maintenance, etc.

4. Increasing the speed of intervention

The level of production losses depends on the duration of unavailability of the machines, and this is influenced by the speed of the intervention, which can be increased by acting on:

- The functionality of the information system;
- The level of general training and specialization of personnel;
- Coordinating the personnel with maintenance tasks;
- The technical documentation, to be operational;

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- Management of materials and spare parts stocks;
- Material means, such as means of transport, maintenance equipment, etc.

An important objective of the maintenance activity is the assurance of the safety of the personnel and the equipment, as well as the protection of the environment.

5. Development and facilitation of production-maintenance links and transfer of certain maintenance operations to production

To fulfil the tasks assigned to it, the maintenance compartment enters into a series of functional relationships with the other compartments. The maintenance compartment establishes a special relationship with the production, meaning that the maintenance operations of level I can be transferred to the production operators to reduce the intervention time and the maintenance costs. In this respect, a list of level I maintenance operations will be established by a maintenance and production team, which can be taken over by the production or working operators and which does not require the maintenance operator to be moved. Also, the production operator can join the maintenance one to service it in case of complex works.

To ensure the management and supervision of the automated equipment with surveillance and operating systems, it is necessary to employ operators with a high level of training in the production compartment. They can receive, yet from their employment, specific training to be able to take over all the maintenance operations called *first rank* (or level 1), including troubleshooting and small maintenance operations. The taking over by the production personnel of the maintenance works of level I is favoured to the modern machines by the following factors:

- Equipping machines with maintenance surveillance systems, which allow the tracking and control of the critical components of equipment;
- The presence of self-diagnosis systems that allow the visualization of the defect points and the determination of the causes of the defect;
- Use of expert-information systems that allow automatic technical assistance to detect the defect and identify the causes that generated it.

6. Developing and facilitating the relationships between the research-design department and the maintenance department

To reduce the volume of maintenance and repair work in the company and therefor to reduce the maintenance and repair costs, it is necessary to improve the collaboration between the research-design and maintenance departments, by adopting the following measures:

- The purchase for production of equipment whose overall costs are as low as possible, especially in enterprises where maintenance costs are higher than the costs of processing operations;

- Participation of the maintenance department in designing and making investments;
- The compilation by the research and design department of a modernization program, by improving the technical and functional characteristics of the machine taken as a whole or of its different components, allowing to obtain performances comparable to those of the new machines;
- Designing the database regarding the number of operating hours, the frequency of falls and stops, the cost of maintenance interventions, the need for spare parts, the documentation provided by the equipment manufacturers;
- The research-design compartment will promote a policy of equipment standardization;
- In order to achieve the maintenance cooperation, the handbook for specifications of *maintenance and reliability* tasks will be developed.

7. Development of maintenance cooperation.

Depending on the complexity of the works, the endowment with control equipment, and means of maintenance, certain works that cannot be performed in the own maintenance compartment are recommended to be contracted with third parties. Maintenance cooperation is also required if the volume of works exceeds the capacity of the company if it is justified economically. Cooperation development requires:

- Analysing their resources to establish from the planning phase of the activity, which are the maintenance works to be executed through cooperation;
- The composition of the specifications containing all the quality prescriptions for each activity carried out by cooperation, it will be the primary document to which the reception of the work will be reported;
- Designating the persons from the maintenance compartment for choosing the partners and negotiating the contracting of the works;
- Coordinating the cooperation and establishing the responsibilities regarding the reception and the quality of the works.

8. Use of modern means of information

The complexity of organizing and planning the maintenance activity, especially in the case of large or long-term works, among which the capital repair works of the high complexity machines require multiple information, regarding the nature and function of the equipment, personnel requirements on the qualification levels, stocks of spare parts, possibilities of cooperation for certain activities, costs of works, etc. The operational computerization of the maintenance ensures the access in a short time to data, regarding the lifetime of machines, the number and degree of the interventions suffered, the cause of accidental falls, the components in critical condition, the duration of unavailability, the cost of the interventions, etc.

In conclusion, to meet the main demands of equipment evolution regarding maintenance, the organizational measures must include the following directions of action:

1) Ensure the compartment with qualified personnel, its improvement, and motivation.
2) Staff specialization and polyvalence. Create multi-purpose teams if needed.
3) Creation of a *maintenance-methods* compartment with the role of elaborating the maintenance regulations, technologies for the production and reconditioning of spare parts, development of forecasting, etc.
4) Establishment of the troubleshooting teams and the technical training of the staff to ensure the rapidity of the interventions.
5) Ensuring the cooperation, by transferring the maintenance operations of level I to the production personnel.
6) Development of cooperation between research, production, and maintenance to think about maintenance during the design phase of the equipment.
7) Development of cooperation with specialized maintenance companies.
8) Use of modern means of information.

1.7. Maintenance of the future

A well-organized maintenance activity contributes to the increase of the production of the industrial unit, for this reason, under the conditions of competition; this function tends to acquire an increasingly important role. In the future, the maintenance and repair workers will have another states, they will not only have the qualification of mechanics, but will acquire new qualifications in the field of electronics and information systems.

The development of new technologies will allow the increasing automation of the management, regulation, and supervision of the operation of the equipment in the process industries and the evolution of the manufacturing industries, by automating the processing and transport operations from one activity to another. This evolution has several major consequences, including:

- Maintenance will ensure the maintenance of more complex equipment;
- Increasing the qualification of the production personnel, which will have an increasing role in the supervision of the production equipment;

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- Reducing the number of workers.

In defining and characterizing the maintenance of the future, V. Deac [3] shows that "the maintenance function will have special importance in the management of the unit and, if the current structures do not evolve, this tendency will lead to the quantitative and qualitative growth of the maintenance compartment, of maintenance and maintenance costs".

According to the same opinions, based on the studies carried out and tested on specific industrial units, the main developments of the maintenance in the future are shown schematically in fig. 1.7.

The evolution of the maintenance will be carried out in the following directions:

1. Applying an operational computerized system of maintenance.

The information represents for the enterprise a resource as important as the energy and is an indispensable link between the management and operational staff. The information system will be an effective assistance tool in managing and controlling the equipment, the maintenance personnel, the supply of materials and spare parts, the maintenance costs, the cooperation, etc.

2. Better consideration of maintenance at the stage of design, procurement, and installation of equipment in the enterprise.

The reduction of the maintenance personnel is achievable through the acquisition of that equipment for which possibilities of rapid intervention and with reduced costs have been ensured, since the design phase; information that can be obtained from the maintenance database.

3. The transfer of the maintenance operations called level 1 to the directly productive workers whose training level will be higher.

Through the operational computerization of the maintenance, the production staff will be given access to the database, to document the information needed to perform the level I interventions on the equipment. Through this transfer of responsibilities, the production personnel are given responsibilities and motivations, having as result the reduction of the costs with the maintenance staff for the company.

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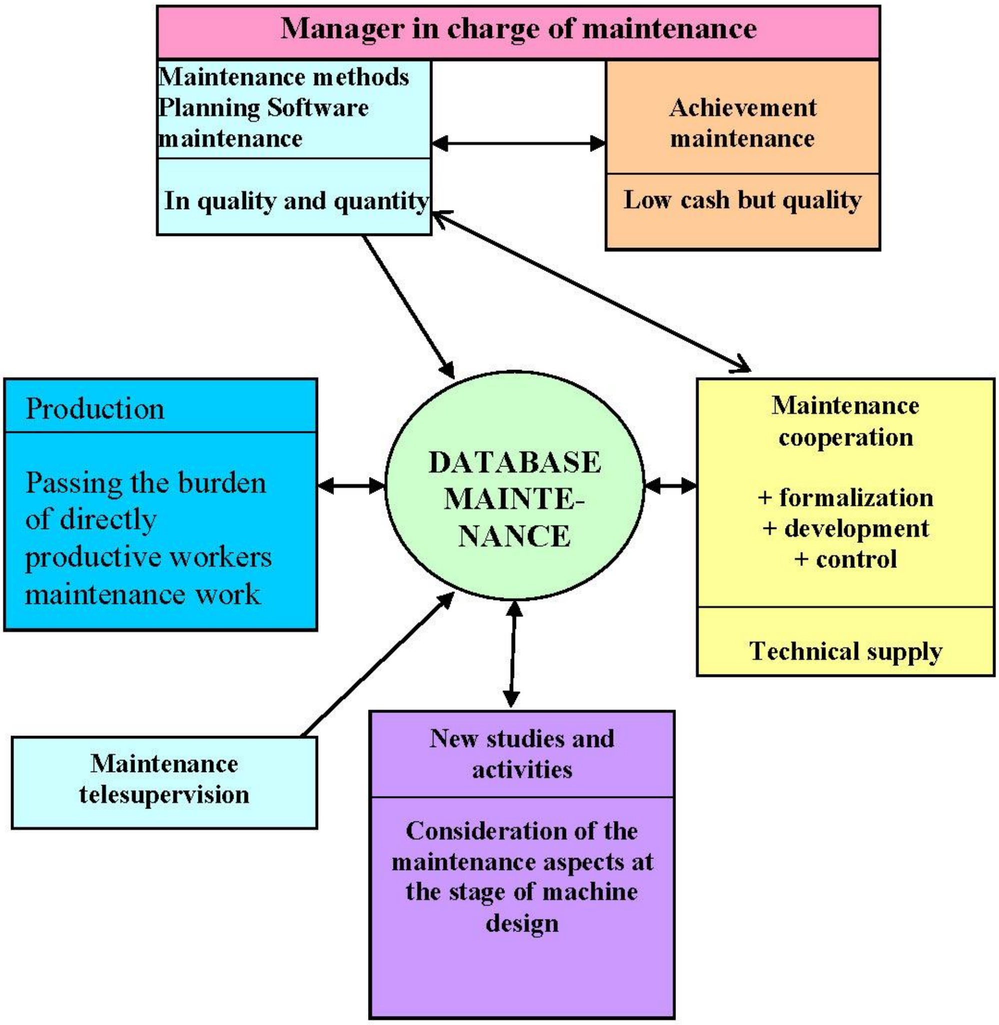

Figure no. 1.7. Maintenance evolution

Source: [3]

4. The development of maintenance tele-supervision systems will lead to the application of preventive or conditional maintenance systems.

The development of tele-supervision systems will facilitate the automatic updating of the maintenance database, and the application of conditional maintenance will lead to the reduction of maintenance costs and staffing.

5. Cooperation in maintenance will be developed through scientific foundation, control and good administration, which will allow:

- setting up within the enterprise a *method-maintenance* group;

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- improving the *technical-material supply* activity;
- operationalization.of *the maintenance computerization system*.

As a result of these developments, there will be a reduction of the maintenance staff, together with an increase in the level of qualification. It is estimated that **future maintenance will be zero-defect maintenance**! The achievement of this limit objective in the future will not lead to the termination of the maintenance compartment, but only to the reduction of the executive personnel. The rate at which this mutation will occur will be influenced by several factors, among which:

- The option of the managers to prepare this change and to engage the company in this way;
- The technical evolution of the equipment;
- The changes produced by the information technology revolution;
- The evolution of the human potential of the unit and its adaptability to these changes.

To make these changes, management factors have to elaborate a program of preparation of human resources, on which the speed to reach this objective will depend.

In our country, we are currently witnessing a division of large industrial units into smaller units, in which the maintenance activity has either been decentralized or has been transferred to production operators. This policy may bring results in the short term, but in the medium and long term, it will lead to equipment degradation.

1.8. Maintenance activity strategies

The organization of the maintenance activity can be done considering the following strategic alternatives (fig. 1.8):

Strategic alternative I: carrying out specific maintenance activities,

Strategic alternative II: subcontracting maintenance,

Strategic alternative III: purchase of new equipment,

Strategic alternative IV: transferring production to another producer.

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In the following, the types of strategies described in fig. 1.8 will be detailed:

1. *Total productive maintenance strategy* (S1) - is based on the concept of Total Productive Maintenance, which will be presented in detail in chapter 5.
2. *The strategy of the company's investment orientation* (S2) - involves the opinion of the maintenance personnel regarding investments in new equipment. This strategy aims to avoid investments in "second-hand" machines that financially benefit the industrial unit, but in the medium and long term leads to increased maintenance costs.

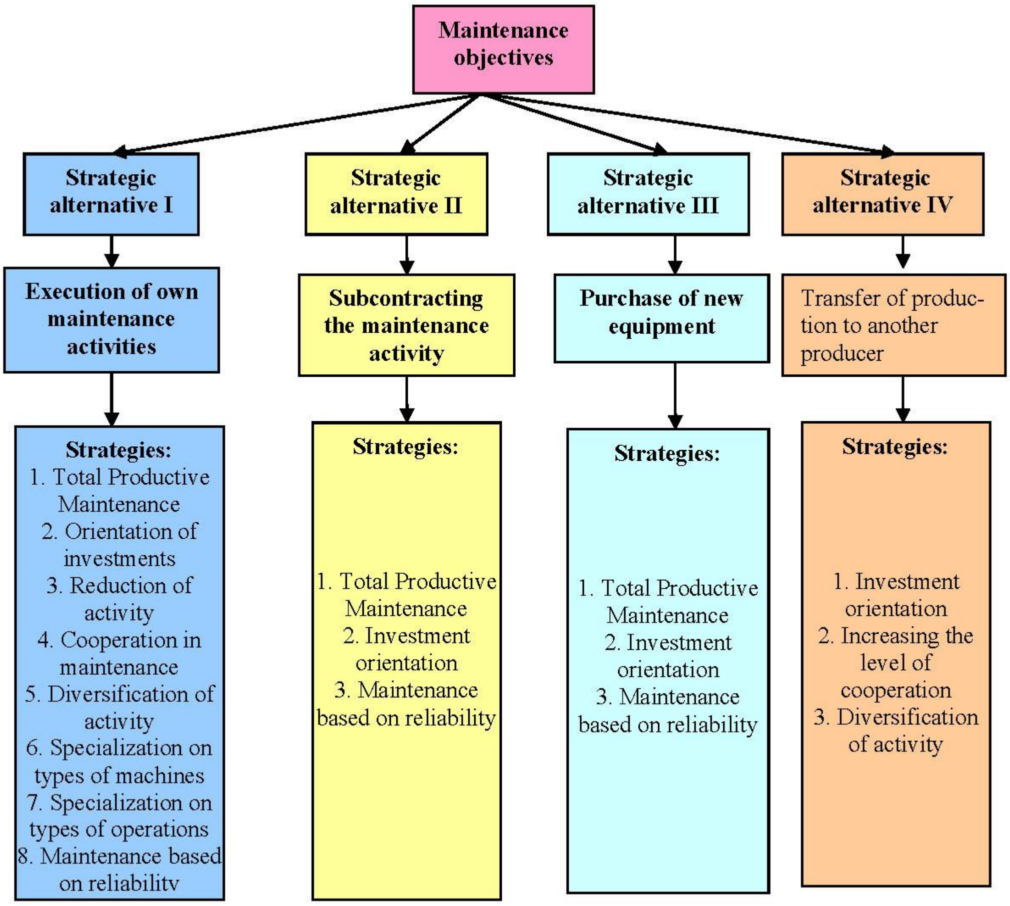

Figure no. 1.8. Maintenance activity strategies

Source: [9]

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3. *The strategy to reduce the maintenance activity* (S3) - consists of reducing or even ceasing the activity of the maintenance compartment. This strategy is applied by the units that go through periods of financial crisis and which lead to short-term economies, but which produce significant losses to the industrial unit in the medium and long term.
4. *Maintenance cooperation strategy* (S4) - consists of performing simple maintenance and repair operations by the own maintenance department, while the complex operations are done in cooperation with the specialized units. This strategy leads to a reduction in long-term maintenance costs.
5. *The strategy of diversifying the maintenance activity* (S5) - is applied by the units that have a reliable maintenance compartment and consist of carrying out maintenance and repair work not only in their unit but also in other units with a similar profile.
6. *The strategy of specialization on types of machines* (S6) - consists of forming teams of maintenance workers, each team is specialized in the maintenance and repair of certain types of machines. The advantages of this strategy are to increase the quality of maintenance activities.
7. *The strategy of specialization on types of operations* (S7) - consists of forming teams of workers, each team is specialized in performing certain types of operations (RC1, RC2, RK).
8. *New machines strategy* (S8) - consists of using the machines only while they are under warranty. This strategy applies only to industrial units with substantial financial resources. The advantages of this type of strategy consist of zero maintenance costs, high productivity, as well as good quality of the finished product.
9. *Maintenance strategy based on reliability* (S9) - involves using the funds allocated to the maintenance compartment to increase the reliability of the production system in the respective unit.

In practice, it is inefficient to apply a single strategy. Maintenance department managers need to find a combination of strategies that will lead to success quickly and effectively. Table 1.3 presents some examples of combinations of strategies commonly applied in the industry.

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Table 1.3. Some examples of combinations of strategies commonly applied in the industry

No. crt.	Field of activity	Alternative	1	2	3	4	5	6	7	8	9	Obs.
1	Mechanic	I										Company with tradition in the maintenance activity
2.	Rolling stock repairs	II, III										In the process of restructuring
3.	Energetic	I, III										Powerful research and design department in reliability and maintenance
4.	Transport	I,II,III										Car park systematically renewed
5.	Textile	II, III										Modern production management, prone to renewal of fixed assets
6.	Manufac-ture of pipes and welded profiles	I, II										Company with tradition in maintenance activities, equipment with advanced wear

Source: [9]

Questions to check understanding

1. What were the causes that determined the development of maintenance as a concept?

2. List five solutions / proposals applied to the maintenance processes that ensure the progress of the concept.

3. What are the main factors that influence the maintenance process?

4. What are the factors considered in the systemic analysis of maintenance management?

5. How many maintenance strategies do you know? Describe two of them, which you find more interesting.

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2. USE OF THE MARKOV CHAIN IN THE DEVELOPMENT OF DECISION PROCESSES IN MAINTENANCE ACTIVITY

2.1. Markov chains

In the real world, there are a multitude of phenomena from different fields such as management, economics, social structures that cannot be characterized deterministically, random walk is required. Therefore, stochastic processes are used in the study of these phenomena.

Definition 1. A **stochastic process** is called a random experiment that consists of a series of random sub-experiments. A special class of such processes is represented by the **Markov chains**.

Many random experiments are conducted in stages. Therefore, such an experiment can be considered as a sequence of sub-experiments and each result of the experiment is determined by the results of the sub-experiments (in order).

Thus, a stochastic process is a set indexed by random variables, $\{X_t\}$, where $_t$ runs through a set T called the set of positive indices $T = N$, and X_t represents a quantitative or qualitative characteristic of the system researched.

We have a succession of experiments with the same possible results. Therefore, $_t$ will be considered as a time point taking values 1, 2, 3, ..., n. This sequence gives the sequence of experiments. For each moment, the possible results will be noted 1, 2, ..., m (m = finite number). The best possible results will be called the states in which the system can be at any given time. The unit of measure for successive times t depends on the system studied.

Among the types of such sequences we can mention the one in which the probabilities of the results at one point are independent of the results of the previous experiments (for example: repeatedly throwing a dice, extracting a ball from the ballot box with a comeback).

Another type of sequence is one in which the probabilities of the results at a given time depend on the results from previous experiences (for example: successive extractions from the ballot without return). In this type of experiment two extreme sub-cases can be distinguished:

1. Extreme - is represented by the fact that the probabilities of the results at a given time depend on the results of all previous experiments in the sequence;

2. The other extreme - of the level of dependence is when the probabilities of the results at a given moment **depend only on the results of the previous experiment**. In this situation the sequence of experiments is called the **Markov process (chain)** [10]**.**

Definition 2. A Markov process or **Markov chain** is a succession of experiments in which each experiment

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has m possible outcomes E1, E2, ..., Em, and the probability of each result depends only on the result of the previous experiment. **Definition 3**. A stochastic process is said to have **Markov's property** if equality is achieved:

P (Xt + 1 = j / X1 = k1, ..., Xt-1 = kt-1, Xt = i) = P (Xt + 1 = j / Xt = i), for $_t$ = 1, 2, ...,n and for any sequence k1, k2, ... kt-1, i, j of states from the set of m possible system states.

Let 2 events, A and B. Note P (A / B) - the probability of event A conditioned by event B.

Markov's property shows that the conditional probability of any future event (X_t + 1 = j), given the past events X1 = k1, ..., X_t-1 = k_t-1 and the present state X_t = i, is independent of the past states and it depends only on the present state of the process.

There are a wide variety of phenomena that suggest behaviour in the manner of a Markov process. As examples, we have reproduced the following situations:

• the probability that a person will buy a product of a particular brand (detergent, beer, cosmetics, footwear, etc.) may depend on the brand chosen on the previous purchase;

• the probability that a person has a record may depend on whether or not the parents had a record;

• The likelihood that a patient's health status will improve, worsen, or remain stable in one day may depend on what happened the previous day.

The evolution of a Markov process can be described by means of a matrix.

The transition matrix is a very efficient tool for representing the compartment of a Markov process.

Definition 4. Let a Markov process that has m possible mutually exclusive results E1, E2,…, Em. The general form of a transition matrix for this kind of experiments has the form:

Future Status

$$\text{Current Status}\quad \begin{array}{c} \\ 1 \\ \vdots \\ m \end{array} \begin{array}{c} \begin{array}{ccc} 1 & \dots & m \end{array} \\ \begin{bmatrix} p_{11} & \cdots & p_{1m} \\ \vdots & \ddots & \vdots \\ p_{m1} & \cdots & p_{mm} \end{bmatrix} \end{array} = P$$

With system modelling, it can be in one of the most current possible states. A state corresponds to a result of the experiment. At the end of the experiment, the system may be in one of the states.

The transition matrix is made up of elements pij which represents the conditional probability that its system will change from the initial state to the future state j.

2.1.1. Observation

1. *Pij* with *i* = *j* represents the probability that the system will remain in the same state after the experiment is performed, and *Pij* with *i* ≠ *j* represents

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the probability that the system will change from one state to another.

2. The transition matrix is a square matrix of order m.

Properties

The elements of the transition matrix must satisfy the following:

1. $0 \leq pij \leq 1$, $i,j = 1,\ldots,m$ *(because it's all about probabilities),*

2. $\sum_{j=1}^{m} p_{ij} = 1$, i=1,2,…m. The line amount must give 1 because E1, E2, ... Em is a complete system of events. Property 2 ensures that, given a current state i of the system, the system will certainly move into a state j of the most possible after the experiment.

2.1.2. Regular Markov chains

Because Markov chains are stochastic processes, it is not possible to know exactly what is happening in each state; therefore, the system must be described in terms of probability.

Definition 6. Let a Markov chain with m states. A state vector for the Markov chain is a **probability vector** X = șx1 x2… xnț. The coordinates xi of the state vector X must be interpreted as the probability that the system is in state i.

When it is certainly known that the system is in a certain state, the state vector has a particular shape. Thus, if one knows for sure that the system is in the i-a state, the state vector will have an i-a component equal to 1, and the rest 0. X = [0 0 0 ... i ... 0].

The behaviour of a Markov chain can be described by a sequence of state vectors. The initial state of the system can be described by a state vector noted X0. After a transition the system can be described by a vector X1, and after *k* transitions, by the state vector *Xk*. The relationship between these vectors can be summarized by the following theorem:

Theorem 2.

Let a Markov process with the transition matrix *P*. If *Xk* and *Xk + 1* are state vectors that describe a process after *k* and *k + 1* transitions, respectively, then

$$X_{k+1} = X_k \cdot P$$

In particular:

$$X_1 = X_0 \cdot P$$

$$X_2 = X_1 \cdot P = X_1 = X_0 \cdot P \cdot P = X_0 \cdot P^2$$

$$\vdots$$

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$X_k = X_0 \cdot P^k = X_0 \cdot P(k)$

So the state vector *Xk* that describes the system after *k* transitions is the product between the initial state vector *X0* and the matrix *Pk*.

Observation. *X0, X1, X2, ... Xk, ...* are all 1 × m line vectors.

If you are interested in studying a stochastic process after a large number of transitions, then it is useful to study its general behaviour in the long term. For certain types of Markov chains this is possible.

Generally for a Markov chain with *m* states, the possibility that the system is in state *j* after *k* transitions depends on the state from which it started. Thus, *p1j (k)* is the probability that the system will be in state *j* after *k* transitions if it is initially in state 1. Similar meanings have for *p2j (k), ..., pmj (k).* There are no reasons that these probabilities are (or are expected to become) equal. But for some Markov chains there is a strictly positive probability *qj* associated with the state *j* so that after *k* transitions the probabilities *pij (k)* all become very close to *qj*. In other words, the expectation that the system will reach state *j* after *k* transitions (where k is sufficiently large) is about the same, regardless of the state from which it starts.

Markov chains that have such a long-term behaviour form a separate class that is defined as follows.

Definition 7. A Markov chain with the transition matrix *P* is called **regularly** if there is an integer *k* positive so that *Pk* has all the elements strictly positive.

2.2. Algorithm for solving a phenomenon played out by the Markov chain

1. The matrix of probabilities of transition from one state to another state is constructed.

2. Write the initial distribution in the form of a line vector, with the elements considered at time 0.

3. By multiplying the initial distribution by the probability matrix, the distribution for moment 1 is determined.

4. The evolution of the phenomenon is determined for 2, 3, 4 etc. desired moments.

5. The situation of the evolution of the phenomenon is prepared.

6. It specifies the situation of the product at the initial moment and establishes the policy of marketing its own product according to it, the situation of the competition and the technical-economic possibilities of the organization.

There are three travel agencies in the city of Vaslui: Atlassib, SmartInvest and ŞtefTurism. It has been observed that the choice of a travel agency is influenced by the last option that the consumer has chosen.

Table 2.1. It has been observed that the choice of a travel agency is influenced by the last option that the consumer has chosen.

Travel Agency	Atlassib	SmartInvest	ŞtefTurism	TOTAL
Atlassib	72	4	4	80
SmartInvest	12	102	6	120
ŞtefTurism	2	6	42	50
TOTAL	86	112	52	**250**

Source: Edited by the authors based on their own data.

The management board of the tourism agency ŞtefTurism would like to estimate the total market segment held. For this the Markov model was used.

To model this problem as a Markov process, the following states were chosen:

• Status 1: the consumer chooses Atlassib

• Status 2: the consumer chooses SmartInvest

• Status 3: the consumer chooses ŞtefTurism

The transition probabilities between the three possible states are as follows:

$$P=\begin{pmatrix} \frac{72}{80} & \frac{4}{80} & \frac{4}{80} \\ \frac{12}{120} & \frac{102}{120} & \frac{6}{120} \\ \frac{2}{50} & \frac{6}{50} & \frac{42}{50} \end{pmatrix} \Rightarrow P=\begin{pmatrix} 0{,}9 & 0{,}05 & 0{,}05 \\ 0{,}1 & 0{,}85 & 0{,}05 \\ 0{,}04 & 0{,}12 & 0{,}84 \end{pmatrix}$$

Observation:

The values on the main diagonal (0.9; 0.05; 0.05) are the probability that the consumer will opt for the same travel agency.

The transition matrix could also be represented as a graph:

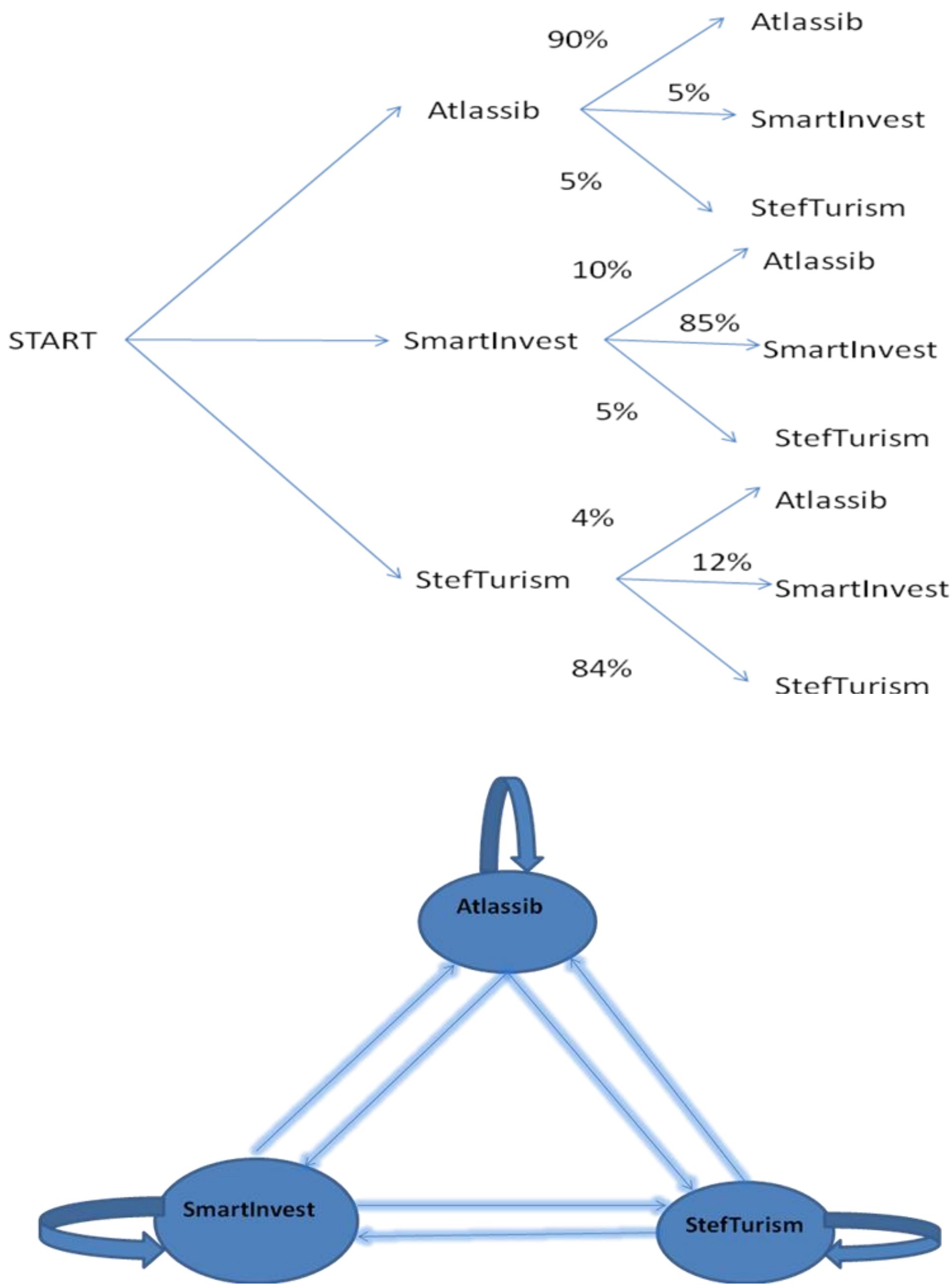

Figure no. 2.1. Transition matrix

Source: [10]

In particular, the fact that a consumer who last travelled with Atlassib to opt for the same travel agency has a 90% probability; the probability that he/she will go the next time with SmartInvest is 5%, and to choose ŞtefTurism is 5%. A consumer who last traveled with SmartInvest, will travel with Atlassib with a probability of 10%, will return to SmartInvest with a probability of 85% or will choose ŞtefTurism with a probability of 5%. The consumer who was a customer of the travel agency ŞtefTurism will choose Atlassib the next time with a probability of 4%, will go to SmartInvest with a probability of 12% or will return to ŞtefTurism with a probability of 84%.

As an application, in a western city, 250 departures are registered monthly to the three travel agencies. In January, they split their market shares as follows:

- Atlassib has a market share of 32%;
- SmartInvest has a market share of 48%;
- ŞtefTurism has a market share of 20%.

Market shares were calculated as a ratio between the clients of each travel agency and the total number of clients for the three agencies.

In February, the three agencies will split their market shares as follows:

$$(0{,}32 \quad 0{,}48 \quad 0{,}20) * \begin{pmatrix} 0{,}9 & 0{,}05 & 0{,}05 \\ 0{,}1 & 0{,}85 & 0{,}05 \\ 0{,}04 & 0{,}12 & 0{,}84 \end{pmatrix} = (0{,}344 \quad 0{,}448 \quad 0{,}208)$$

Accordingly:

- Atlassib Agency will own 34.4%,
- SmartInvest Agency will own 44.8%,
- ŞtefTurism Agency will own 20.8%.

In determining the effects of different marketing strategies on market shares, Markov processes have proven to be particularly useful. They help the management team in choosing promising decision alternatives.

ŞtefTurism has 10 employees, including a manager and an assistant manager. The average weekly salaries for the manager and assistant are 1200 euro and 800 euro respectively, and for each of the other 8 employees 650 euro each. For utilities, an average of 200 euro is paid, and the expenses for advertising are 420 euro, monthly. Excluding fixed costs, the agency estimates a net average profit of 200 euro per costumer.

According to statistics, on average 250 people travel monthly with the three travel agencies. In trying to increase its market share (from 20%), the manager of ŞtefTurism is considering the following strategies:

Option 1: If four people travel, they could be accompanied by a fifth person who would pay only 50% of the ticket price (couple package).

Option 2: For customers who opt for a ten-day stay with ŞtefTurism agency they will receive free transportation.

Option 3: Substantially increase the print advertisement and coupons in the local press.

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Table 2.2. Weekly fixed costs(euro)

Weekly fixed costs(euro)	
Manager	1200
Assistant manager	800
Staff (8 employees)	5200
Utilities	200
Publicity	300
Total fixed costs (euro)	7700

Source: Edited by the authors based on their own data.

The current situation:

As ŞtefTurism holds 20% of the market, the average number of customers in January is 250 * 0.20 = 50, and the average monthly net profit is:

50 * 200– 7700 = 10,000-7700 = **2300 euro**

For February, for a share of 20.8%, the average number of customers is 52, the average monthly profit being estimated at:

52 * 200-7700 = 10400-7700 = **2700 euro**

Option 1:

If ŞtefTurism offers the clients the couple package, the costs per client will increase by an average of 20 euro. It reduces the average profit per customer to 180 euro (not taking into account the fixed costs).

Table 2.3. Option 1.

Travel Agency	**Atlassib**	**SmartInvest**	**ŞtefTurism**	**TOTAL**
Atlassib	70	2	2	74
SmartInvest	9	99	3	111
ŞtefTurism	7	11	47	65
TOTAL	86	112	52	**250**

Source: Edited by the authors based on their own data.

Studies show that if the agency offered a 50% reduction to the fifth person, the matrix of transition probabilities would become:

$$P=\begin{pmatrix} \frac{70}{74} & \frac{2}{74} & \frac{2}{74} \\ \frac{9}{111} & \frac{99}{111} & \frac{3}{111} \\ \frac{7}{65} & \frac{11}{65} & \frac{47}{65} \end{pmatrix} \Rightarrow P=\begin{pmatrix} 0{,}94 & 0{,}02 & 0.04 \\ 0{,}08 & 0.89 & 0.03 \\ 0{,}10 & 0{,}17 & 0{,}73 \end{pmatrix}$$

Following the application of this option in January the market shares will be distributed as follows:

• Atlassib has a market share of 29.6%;

• SmartInvest has a market share of 44.4%;

• ŞtefTurism has a market share of 26%.

Following the application of this option in February, the market shares will be distributed as follows:

$$(0{,}296 \quad 0{,}444 \quad 0{,}26) * \begin{pmatrix} 0{,}94 & 0{,}02 & 0.04 \\ 0{,}08 & 0.89 & 0.03 \\ 0{,}10 & 0{,}17 & 0{,}73 \end{pmatrix} = (0{,}33976 \quad 0{,}44528 \quad 0{,}21446)$$

• Atlassib has a market share of 33.97%;

• SmartInvest has a market share of 44.52%;

• ŞtefTurism has a market share of 21.44%.

Since in January ŞtefTurism would hold 26% of the market, the average number of customers per month would be 250 * 0.26 = 65, and the average monthly net profit is:

52 * 200 + 13 * 100– 7700 = 11700–7700 = **4000 euro**

For February, the average number of people is approaching 54, and the average monthly net profit is:

44 * 200 + 10 * 100-7700 = **2100 euro**

Option 2:

If ŞtefTurism would implement the program for customers who opt for a ten-day stay, the advertising expenses will increase by 80 lei, and the average profit per client will decrease to 170 lei.

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Table 2.4. Option 2.

Travel Agency	Atlassib	SmartInvest	ŞtefTurism	TOTAL
Atlassib	71	3	3	77
SmartInvest	10	100	4	114
ŞtefTurism	5	9	45	59
TOTAL	86	112	52	**250**

Source: Edited by the authors based on their own data.

Studies show that if the agency were to provide free transportation to people opting for a ten-day stay, the matrix of transition probabilities would become:

$$P=\begin{pmatrix} 0{,}92 & 0{,}04 & 0{,}04 \\ 0{,}09 & 0{,}87 & 0{,}04 \\ 0{,}08 & 0{,}07 & 0{,}85 \end{pmatrix}$$

Following the application of this option, in January the market shares will be distributed as follows:

• Atlassib has a market share of 30.8%;

• SmartInvest has a market share of 45.6%;

• ŞtefTurism has a market share of 23.6%.

For February, the market shares will be distributed as follows:

$$\begin{pmatrix} 0{,}308 & 0{,}456 & 0{,}236 \end{pmatrix} * \begin{pmatrix} 0{,}92 & 0{,}04 & 0{,}04 \\ 0{,}09 & 0{,}87 & 0{,}04 \\ 0{,}08 & 0{,}07 & 0{,}85 \end{pmatrix} = \begin{pmatrix} 0{,}343 & 0{,}425 & 0{,}231 \end{pmatrix}$$

• Atlassib has a market share of 34.3%;

• SmartInvest has a market share of 42.5%;

• ŞtefTurism has a market share of 23.1%.

Since in January ŞtefTurism would hold 23.6% of the market share, the average number of customers would be 250 * 0.236 = 59, and the average monthly net profit of:

59 * 170- (7700 + 80) = 10030-7780 = **2250 euro**

For February ŞtefTurism holds 23.1% of the market share, the average number of customers reaching 58, and the average monthly net profit registering a value of:

58 * 170 - * (7700 + 80) = 9860-7780 = **2080 euro**

Option 3:

This strategy will increase the monthly expenses with the advertising by

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120 euro, resulting in a fixed cost of 7820 euro per month.

Table 2.5. Option 3.

Traval Agency	Atlassib	SmartInvest	ŞtefTurism	TOTAL
Atlassib	71	3	3	77
SmartInvest	11	101	5	117
ŞtefTurism	4	8	44	56
TOTAL	86	112	52	**250**

Source: Edited by the authors based on their own data.

The management team from ŞtefTurism believes that the effect of increasing the advertising will lead to a 1.12% increase in the number of clients who choose to travel with this agency. This means an increase in the number of customers from 50 to 56.

$$P=\begin{pmatrix} 0{,}92 & 0{,}04 & 0{,}04 \\ 0{,}09 & 0{,}86 & 0{,}05 \\ 0{,}07 & 0{,}14 & 0{,}79 \end{pmatrix}$$

For January, the market shares will be distributed as follows:

- Atlassib has a market share of 30.8%;
- SmartInvest has a market share of 46.8%;
- ŞtefTurism has a market share of 22.4%.

Following the application of this option, in February the market shares will be distributed as follows:

$$(0{,}308 \quad 0{,}468 \quad 0{,}224) * \begin{pmatrix} 0{,}92 & 0{,}04 & 0{,}04 \\ 0{,}09 & 0{,}86 & 0{,}05 \\ 0{,}07 & 0{,}14 & 0{,}79 \end{pmatrix} = (0{,}34116 \quad 0{,}44616 \quad 0{,}21268)$$

- Atlassib has a market share of 34.11%;
- SmartInvest has a market share of 44.61%;
- ŞtefTurism has a market share of 21.26%.

Thus, in January the average number of customers will be 56, and the profit will reach the amount of:

56 * 200- (7700 + 120) = 11200-7820 = **3380 euro**

Compared to the current situation, there will be an increase of the monthly profit by 1080 lei.

For February, ŞtefTurism agency will have an average number of 53 clients in the database, which will lead to an average monthly profit of:

53 * 200- (7700 + 120) = 10600-7820 = **2780 euro**

The figure below shows the profitability of each strategy in January and February compared to the current situation:

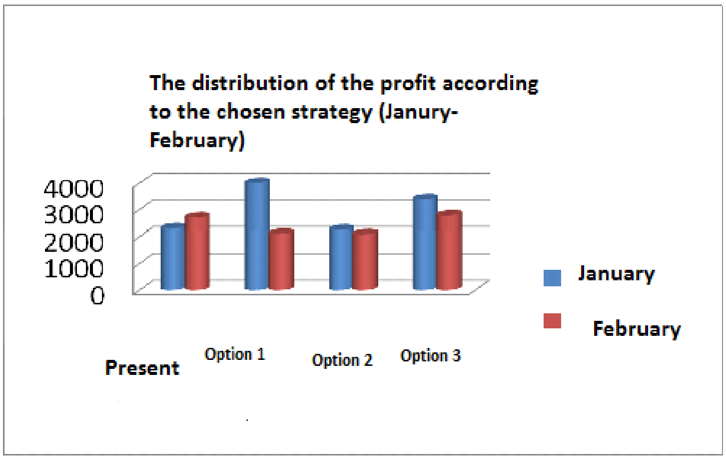

Figure no. 2.2. The distribution of the profit according to the chosen strategy

Source: Edited by the authors based on their own data.

CONCLUSIONS

According to the above study, the most profitable strategy for the month of January is the couple package according to which, when traveling four people, they could be accompanied by a fifth person who would pay only 50% of the ticket price. This policy will increase the monthly profit by 1700 euro compared to the current situation and the number of clients by 30%. The market share it can have under this strategy is 26%.

For February, the most profitable strategy is to substantially increase the print advertisement and coupons in the local press. This will increase the profit to 2780 euros, 80 euro more than the current situation, and the number of customers will increase to 53. The market share that can be achieved in this strategy is 21.26%.

2.3. Study of the reliability of systems based on MARKOV chain theory

2.3.1. The importance of the MARKOV chain method

The method that will be presented below, is used to solve the models of availability, respectively of the reliability and maintainability of a system, with time intervals between failures and durations of the repair times distributed according to any law and for any maintenance policy. The method is based on the Markov chain theory and was developed especially for use with the electronic computer, but for simpler systems a manual calculation can also be done.

2.3.2. Notions underlying the MARKOV chain method

The operation of a system is characterized by a succession of states that describe its normal or fault regimes. Given the probabilistic nature of the states through which the system goes, it can be admitted that its evolution is described by a random process. This process is defined by a family of random variables [x (t); t∈T] which describes the trajectory of the random process.

Knowing the system states at consecutive times t1, t2, t3, ..., tn-1, tn before t time, contributes to the knowledge of the state in which the system is at t time, by providing information collected from previous states, but all included in the most recent state, respectively the state corresponding to the moment tn. The system arrived at the moment tn in the state xn, state in which the past of the system is summarized, allows to predict its future evolution. The process specific to a system, which has such an evolution, is called the **Markov process.**

The Markov chain is a Markov process, defined by the random variables {x (t); t} which can take values belonging to an infinite or finite string.

A statistical process {x (t); t T} is called a multiple Markov process of order v, if it satisfies for any finite string t1 <t2 <... <tn, of values of parameter t, the condition: the distribution of the random variable x (tn) depends only on the values taken from the last ones variables, respectively x (tn-1), x (tn-2), ..., x (tn-v) and not by their distribution. We call a simple Markov process, that process described above, for which v = 1. A Markov process is said to be homogeneous over time, if the probabilities are not affected by a translation over time, that is:

$$P(t+\tau, e; \theta+\tau, \zeta) = P(t, e; \theta, \zeta)$$

where: P (t, e; θ, ζ) - represents the probability that the process is in state ζ at time θ knowing that it was in state e at time t, regardless of the value of τ.

A Markov process is called discrete, if T is a countable set.

2.3.3. The principle of the MARKOV chain method

A system consisting of a certain number of subsystems, can be characterized by:

- all possible or presumed states, which may be favourable or refusing states;
- all the initial states;
- probabilities of transition between states;
- the nominal mission of the system.

In terms of reliability, a system can only be in two distinct states: one in good operation and one in defect. The time evolution of the two states, can be highlighted by the operating profiles of the systems without redundancy (Figure 2.3.), respectively with redundancy (Figure 2.4.).

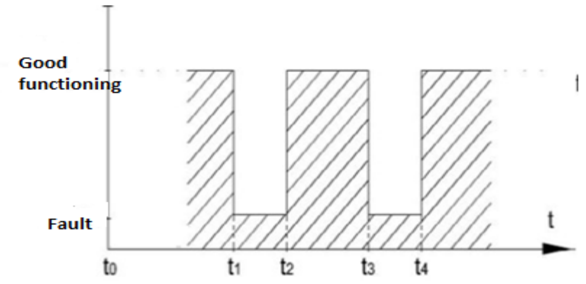

Figure no. 2.3. Systems without redundancy

Source: [10]

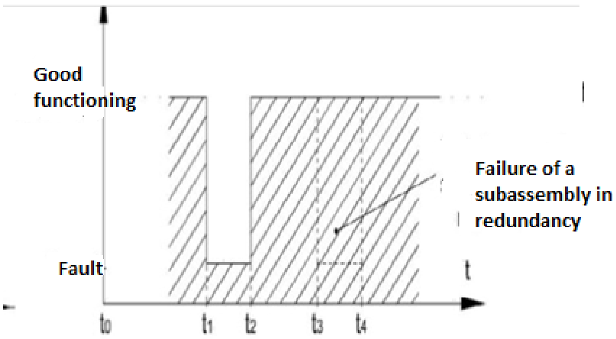

Figure no. 2.4. Redundant systems

Source: [10]

Based on the formalism in the figures, the following sizes can be defined:

- Pi

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- A (t), instant availability, which represents the probability that a system will (t), the probability that the system will be in the "i" state at the time "t" (the "i" state may be a defective state or a good one operation); either in good working condition at time "t", whatever the state in which it was initially;

- AF (t), instant availability, for the system that is initially in good working order;

- AD (t), the instant availability for the system that is initially in a default state.

The probable states of a system can be represented at discrete or continuous intervals, by means of an oriented multi-graph, named after the Markov diagram. For a system without redundancy, the Markov diagram is shown in the figure:

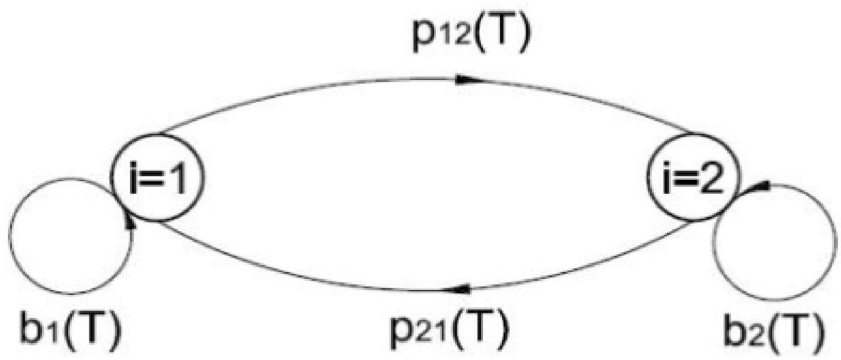

Figure no. 2.5. MARKOV chart

Source: [10]

The nodes in the Markov diagram represent the possible states of the system (i = 1, i = 2).

The oriented arcs, between the nodes, represent the transitions between the system states characterized by the following probabilities:

- p12 (T), represents the probability that the system will change from state 1 to state 2, during period T;

- p21 (T), represents the probability that the system will change from state 2 to state 1, during period T.

The loops attached to the nodes in the Markov diagram have the following meaning:

- b1 (T) = 1-p12 (T), represents the probability that the system will remain in state 1 during the period T;

- b2 (T) = 1-p21 (T), represents the probability that the system will remain in state 2 during period T.

If the failure rates and the repair rates (λ and μ) are constant over time, the process is stationary, and the availability curves evolve as in the Figure 2.6.:

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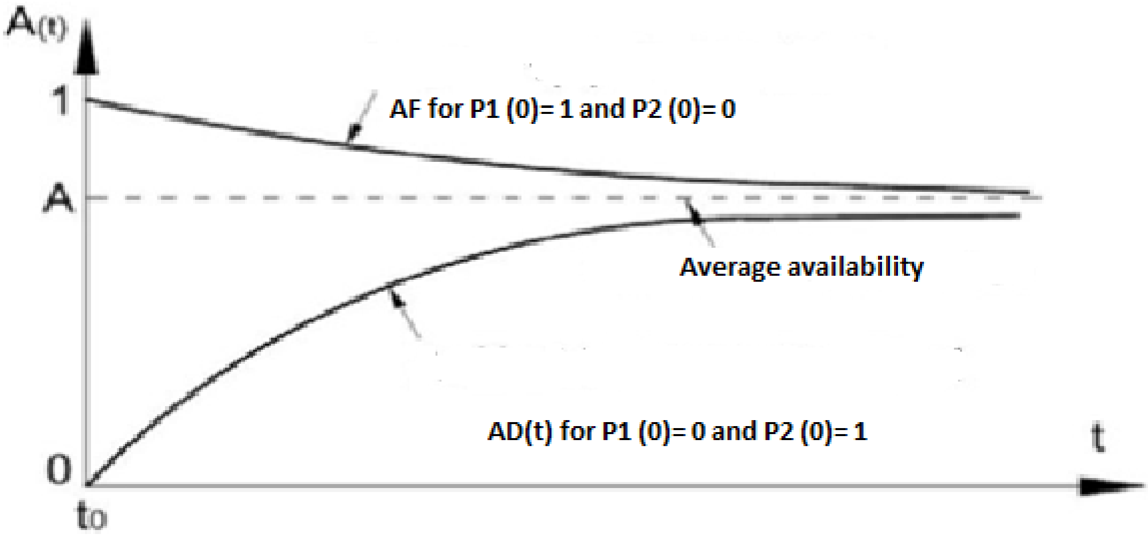

Figure no. 2.6. Availability evolution

Source: [10]

If the process is non-stationary, the availability curves take different forms, for the period of the system's youth, or for the one of wear / aging (Fig.2.7/ Fig.2.8)

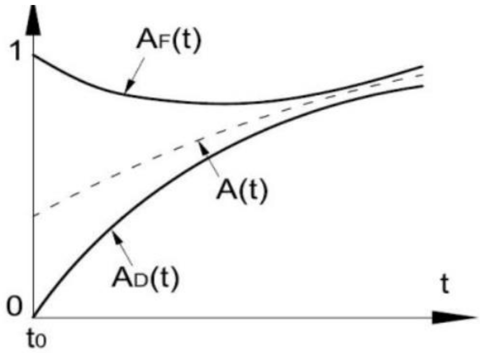

Figure no.2.7. Availability for youth period

Source: [10]

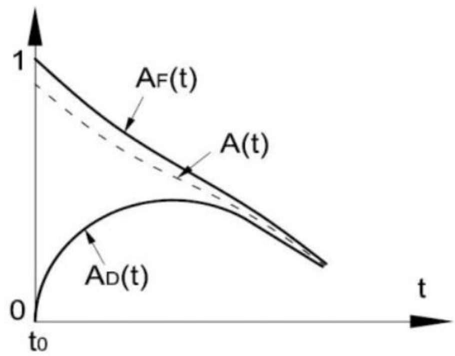

Figure no.2.8. Availability for wear period

Source: [10]

Availability over an interval (t1, t2) is given by the area under the availability curve, as shown in the figure for the stationary regime case (Fig.2.9.)

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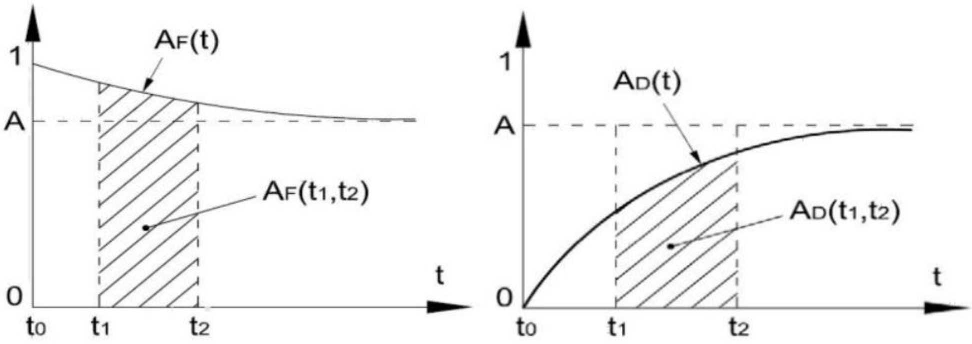

Figure no. 2.9. Availability on a range

Source: [10]

Of course, as has been shown, availability takes into account both reliability and maintainability, and their Markov diagrams are particular cases.

Thus, the Fig.2.10. and Fig.2.11. shows the operating profile of the reliability and respectively in the Markov diagram for a system without redundancy:

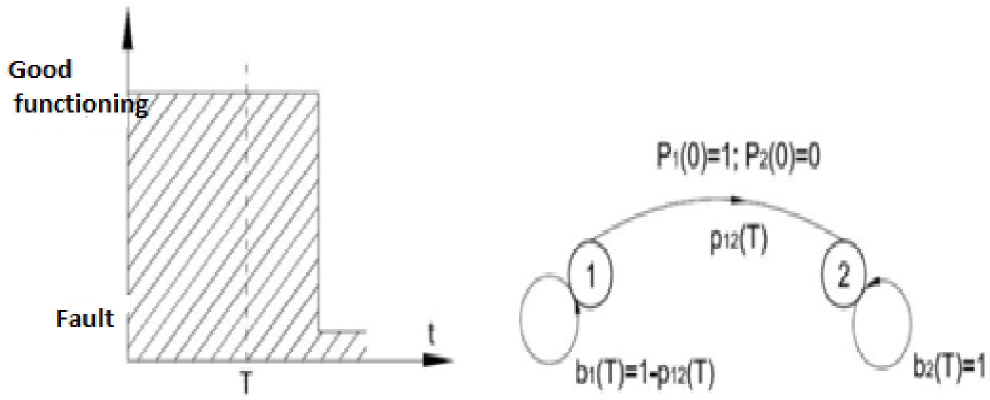

Figure no. 2.10.

Reliability operating profile MARKOV   Diagram of reliability

Source: [10]

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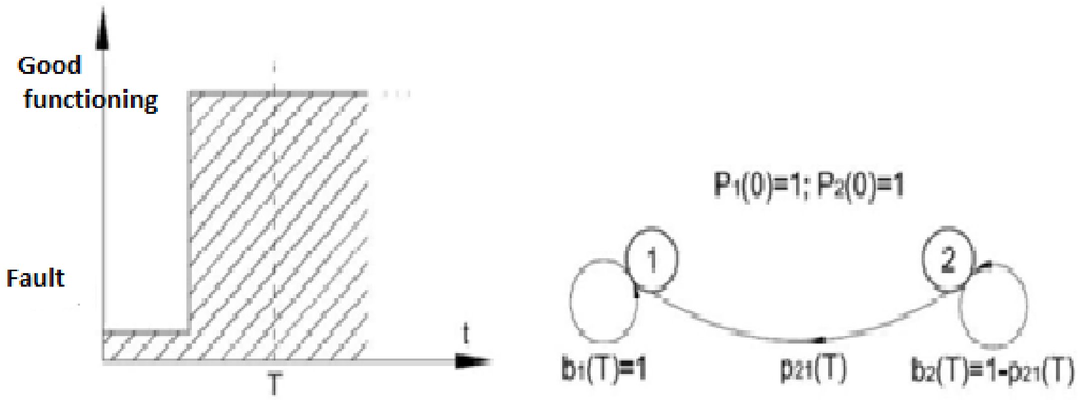

Figure no. 2.11.

Maintenance profile MARKOV ***Diagram of maintenance***

Source: [10]

So the mathematical model of instant availability can be written from the Markov diagram in the figure:

[Pi (nT + T)] = [q (t)] * [Pi (nT)].

where:

T = the sample size in the computer algorithm;

n = the number of iterations that apply;

nt = T - the duration of the mission for which the availability of the system is calculated.

From the previous relation it can be seen that the sum of the elements on the columns of the matrix q (T) is equal to the unit.

2.3.4. Conclusions

As a result, the behaviour of the equipment until failure, respectively the function of reliability, will be influenced by the renewal probabilities of the elements. Reliability analysis can only be performed by using the Markov process model. The set of equipment states is S = {0, 1, 2} in which "0" represents the state in which both components operate, "1" represents the state in which only one component works, and "2" represents the state in which none works. The "0" and "1" states are the operating states of the equipment as a whole, and the "2" state is the fault state. It is assumed that the two elements of the equipment are characterized by exponential distributions of operating and

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renewal times, with parameters λ and p respectively.

Questions to check understanding

1. Define the Markov Chain as a stochastic process.

2. What are the basic properties of the Markov Chain?

3. Study the application on tourist transport by the three travel agencies, and seek to understand how the transport matrix and the corresponding graph are drawn up.

4. What are the principles to be observed in the Markov Chain?

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3. MAINTENANCE CONCEPT IN THE SYSTEMIC CONTEXT

3.1. Primary data processing

3.1.1 Collecting reliability data

The information on the reliability of the products is mainly obtained either by following the behaviour of the products in actual operation or during tests.

Each of the two paths presents both advantages and limitations. In the pursuit of real exploitation, all the phenomena that occurred during the use of the product are detailed. However, a study based only on this information is a "historical" study, the value of which is the collection of statistical data or the detection of factors that lead to poor security. It should be added that the information from the real exploitation often refers to machines, aggregates, etc., in course of moral wear. At the time of drawing the conclusions, they may be of only historical importance, but the purpose of the reliability studies is to raise the level of performance of the current production. To these limits of the method of tracking in exploitation are added also the difficulties related to accurate and precise data collection, the stem sometimes deficient information system, etc.

Without excluding this process, which also has several advantages, it is necessary to use the test method. During these tests, it is tried, as far as possible, to "imitate" the conditions of real exploitation, both by reproducing the range of internal demands and the environment.

During the tests for the fault-free operation, a sample of elements (or systems) works until the moment of putting out of order of the entire assembly (or most of it). These tests sometimes take quite a long time (tests to determine the wear and tear), with the need for special equipment: assemblies, equipment, and a highly qualified workforce. For these reasons, the tests involve quite high costs.

As a possibility to remedy these difficulties, the **modelling of the use process** appears. Through this procedure, the duration of the experimentation is significantly shortened; it is possible to repeat and permanently modify the experimental conditions.

In figure.no 3.1 the procedures for collecting information according to different criteria are presented. Since the observation of the behavior in the real exploitation still represents the most used way in collecting the information to estimate the reliability, we will proceed to the development of this method.

If the projected reliability results from engineering calculations, the experimental reliability and the operational reliability are determined based on statistical information collected on the behaviour of the product under operating conditions or experimental tests.

Depending on the nature of the product (single copies, batches, large or mass series), observing its behaviour and collecting the necessary information can be organized according to different schemes. In any case, it is necessary that the operations of collecting the information are conceived and carried out in a systemic vision, respecting the following requirements:

- Each product is regarded as a complex system with a hierarchically ordered structure, having in its composition numerous subsystems components - parts, details, elements, etc.;

- For each product or component thereof, all the information is collected, essential for the detection of the factors that determine their level of reliability;

- The observation and collection of information are organized for a specific purpose; based on their proper processing and analysis, the decisions regarding the high level of reliability of the product are fundamented. The necessary data are collected to ensure maximum efficiency within the integrated information system of production quality management.

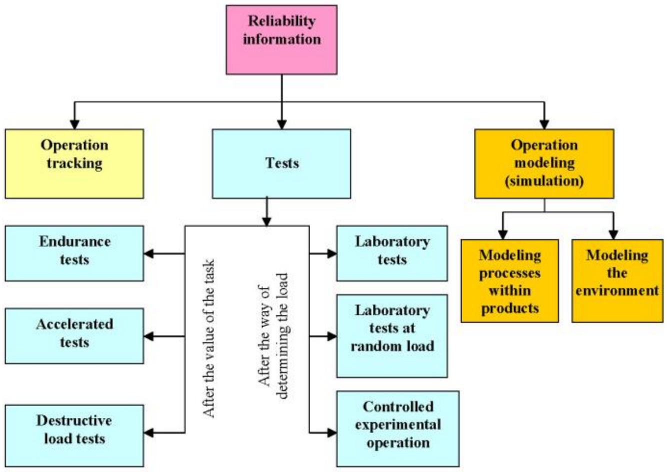

Figure no. 3.1. Ways to collect reliability data

Source: [2]

The collected data is organized in form of files, which include two types of data:

1.) **Descriptions of the product identification elements**, with the necessary detail for achieving the specified objectives (modular connection to the other subsystems of the enterprise

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information-decision system, serving the needs to improve projects, manufacturing and operating technologies, analysis and synthesis at any constructive level, etc.). The identification at each step is done using the machine code system. This information is supplemented by the technical-constructive, performance parameters, etc., necessary for complex analyses;

2.) **The observation program** of the machines represents the enumeration of the information that is collected for each element (observation unit) of the production system. The program is concrete, and local character is made up for each type of machine according to the concrete operating conditions, information needs, purpose pursued, etc.

The data on the following cannot be missing from the program:

a) the time moments in which changes in the state or behaviour of the device occur:

- the moment of commissioning;

- the moment of interrupting the operation;

- the moment of restart;

- the moment of the fall;

- the moment of restart after removing the causes of the fall;

b) the causes of falls by classes (total, partial, parametric, etc.);

c) the primary source of the fall (fallen elements);

d) who is responsible for the fall, etc.;

e) expenses related to the restoration of the fallen element (labour costs, spare parts, materials, penalties, etc.);

f) data on indirect losses due to the fall (production losses to the user, to its beneficiaries, etc.).

The main document through which the information is collected is the **exploitation report**, having to provide data on the use, defect, preventive maintenance, etc., which concern the behaviour of the products considered either individually (symbolized by letter I) or in groups of products of the same type (symbolized by the letter G).

Observation of product operating times. As it turns out from the very definition of reliability, an essential feature of this concept is the time interval during which the product was functioning until a failure.

The defective product can be:

- Replaced with a new copy of the same product;

- Repaired (restored), operation after which the cause of the defect is eliminated, and the repaired product resume its operation, generally as a new copy.

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a). Replacing the defective product that is no longer repaired is usually done at the moment. Therefore, the whole life of the product consists of the interval of good functioning, beginning with the moment of putting into use and ending with the fall of the copy i, at the moment of t_i.

If the product being researched is a mass product, then a sample of N identical specimens is formed, the use of which is initialized at the same time t_o. Starting with this moment, the time of each specimen in the sample $t_1, t_2, \ldots, t_i, \ldots, t_N$ is recorded.

The entire volume of data collected is ordered in the form of a graph called **the survival curve**. From the interpretation of the form of the survival curve and based on the prior knowledge of the concrete nature of the researched product, one can make appraisals on the theoretical law that models the reliability of the respective product.

b.) The product that, after failure, is restored (repaired) has a more complex behaviour, has a true "history" of operation along the time horizon of the observation. The life of the product consists of different periods corresponding to the states in which the product is (figure.no. 3.2.):

- Time of proper functioning t_i,
- Maintenance time t'_i (repair, restoration, troubleshooting, etc.),
- Interruption time I_i (backup).

Therefore, observing the functioning regime, in this case, must ensure the recording of the data on the operation or malfunction of the product.

Schematically, the succession in time of these moments and stages in the life of the product can be presented as follows: on the axis of time T, the moments of the beginning of observation and those of passing from one state to another are marked: 0, 1, 2, ... Durations of intervals during which the machine is in a certain state are represented on three levels, namely: at the basic level - the times of proper functioning, at the lower level - the maintenance times, at the upper level - the interruption times (backup).

c.) After collecting the necessary information about the behavior of the product that after the failure is restored, according to the rules described in (b), the problem is gathering the collected data in a unitary whole that is forming a homogeneous sample of data that will be the basis for further processing and analysis.

If the machine operates in stationary mode, it is possible to combine the collected data, whether they refer to the same copy of the product along a registered, sufficiently long "history" ("longitudinal summation"), or to a composite sample from a sufficiently large number of homogeneous N specimens that work in parallel over the same period ("transverse summation").

The total service life of the machine is calculated with the relation:

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$$T_{tot} = \sum_{i=1}^{N} t_i + \sum_{i=1}^{N} t'_i + \sum_{i=1}^{N} I_i \qquad (3.1)$$

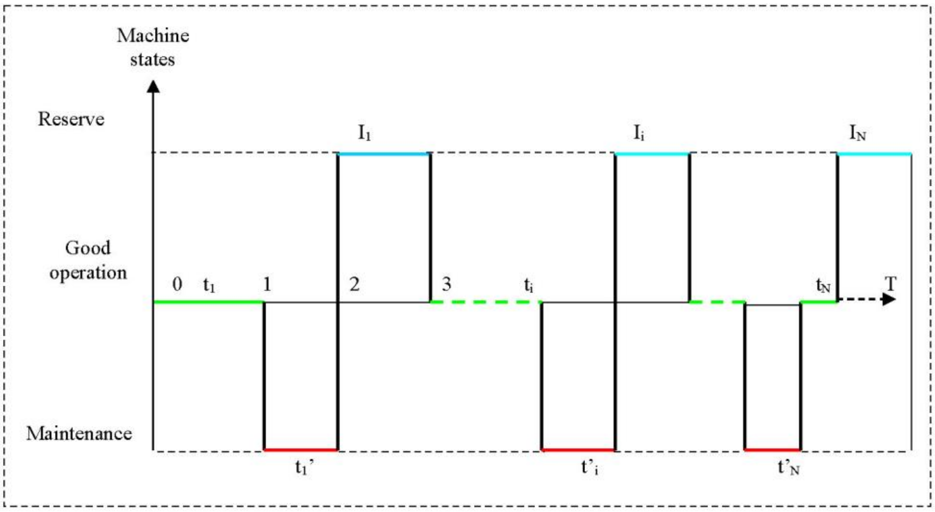

Figure no. 3.2. Events in the functioning of a product with restoration

Source: [7]

For the operating mode to be considered stationary, the following conditions must be met:

- The product is in the standard exploitation period, that is to say, the run-in period is exceeded and the wear (aging) period is not reached;

- The frequency of the defects should be constant and relatively low during each observation interval; the errors must be of the "sudden type," not preceded by symptoms, resulting by the sudden concentration of the tasks that act inside and on the element, the concentration of random character;

- The faults occur at long intervals and relatively equal between them;

- The behaviour regime should be "memory-free," i.e., the state and mode of operation of the machines at a given time will not depend on the past; future failures will not depend on the previous ones; the product restored following a malfunction will be capable of functioning and a new product. Each restart is treated as if it was a new machine.

Historical (longitudinal) data are, therefore, homogeneous over time and are considered as the elements of a homogeneous population. In the same

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way, the data ("longitudinal") of other specimens belonging to the same type of machine are treated, so that from the gathering of the recorded data, a homogeneous mass of information results about all the specimens observed in parallel ("transversely").

3.1.2. Systematization of reliability data

Data processing regarding the operating behaviour of the machines obtained according to the observation program described in 2.1 and organized in form of files and is differentiated according to the purpose pursued.

A first group of applications is made using the means of descriptive statistics. Thus, it is possible to group the faults by causes (up to the primary, generating cause), thus obtaining the distribution series. This is analysed later to highlight the comparative importance of the different causes. For more in-depth knowledge of the causes of the faults, combined groups and/or correlation tables are created. Also, a series of statistical indicators can be calculated that allow a more in-depth analysis of the phenomenon of the operating behaviour of the machines.

If observations are made on a sample of identical products that are functioning and the time of proper operation until the fall is recorded for each copy, the most appropriate procedure for synthesizing the collected mass information is the **composition of the survival curve**.

The design of the survival curve implies the continuous observation of the behaviour of the specimens in the sample, which - without special facilities for automatic recording of the times of proper functioning and the failures - is practically difficult to achieve. To overcome this methodological shortcoming, observation intervals are formed on the axis of time about which the number of falls that occurred during them is recorded. The collected statistical material is presented in the form of **experimental statistical distribution**. The survival curve is then based on it, and the reliability indicators are calculated.

Before moving on to the actual construction of the statistical distribution, we remind you that the breakdown series consists of two rows of data:

- the first one, regarding the **n** intervals of time of proper functioning (of product effect, of a fulfilled task, km travelled, etc.), delimited by the moments (i = 0,1, ..., n.);

- the second, to the number of faults recorded during the respective intervals ki (i = 1, ..., n.).

If we note with i = 1, 2, ..., in the intervals of the observation time, with ki (i = 1, 2, ..., n) the number of failures within the intervals, and with N the initial number of the sample examined, the parts remaining in operation at the end of each interval shall be:

$$N_1 = N - k_1$$

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$$N_2 = N_1 - k_2 = N - k_1 - k_2$$

$$N_i = N_{i-1} - k_i = N - \sum_{1}^{i} k_i$$

$$N_{n-1} = N - N_{n-1} = N_{n-1} - k_n = N - \sum_{i=1}^{n} k_i = 0$$

the notations can be identified through the graph in figure no.3.3.

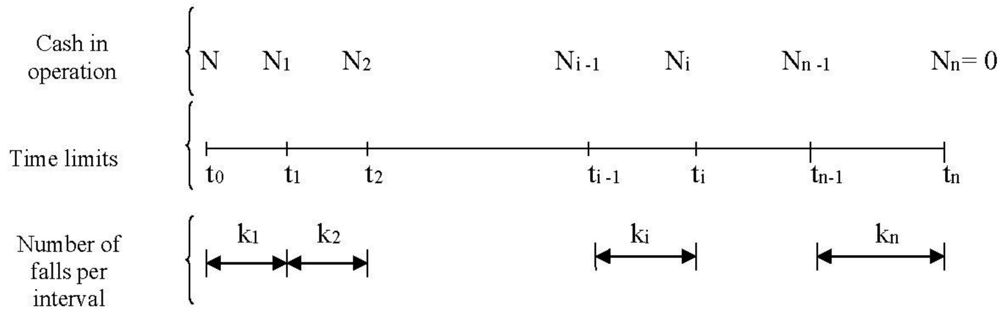

Figure no. 3.3 Observation intervals and the reduction of functioning assets

Source: [7]

In the graph of the survival curve, on the abscissa, there are represented the time moments t_o, t_1, … , t_n which delimits the **n** intervals of the observation time, and on the ordinate - the values of the functioning asset N, N_1, ... , N_i,...,0.

With the increase of the technical level and complexity of the products, as well as with the increase of the economic-social implications of their use, certain qualitative characteristics have acquired special importance, being followed with priority throughout the whole life cycle of the products. Thus, features such as reliability, maintainability, availability, assurance of work safety and environmental protection were imposed as notions of their own nature within the wider category of quality.

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3.2. Product reliability

Reliability represents the probability that a product, under well-defined conditions of use, operation or storage, will still be in functioning condition after time t.

Reliability can be expressed in five distinct forms:

- *The projected reliability* (*preliminary, predictive)* represents the reliability of a product determined based on its conception and design considerations, as well as on the reliability of its components under prescribed operating conditions.
- *Experimental reliability* represents the reliability of a product determined experimentally, in laboratories, test stations, test stands, where conditions (requests) similar to those in operation have been created.
- *Operational reliability* (*effective at the beneficiary*) represents the reliability of a product determined based on the results regarding the behaviour in exploitation for a certain period, of a large number of products used at the beneficiary.
- *The nominal reliability* represents the reliability of a product prescribed in specifications (standards, technical norms, contracts, etc.) or inscribed on the product.
- *The estimated reliability* represents the reliability of a product determined with a confidence interval based on the results from tests in laboratory conditions or the basis of the operating information obtained from several identical elements.

The steps that are taken to collect and process the data to obtain the reliability indicators are shown in figure 3.4. Also, here is the phenomenon of the impairment of reliability between the design and the operation stage.

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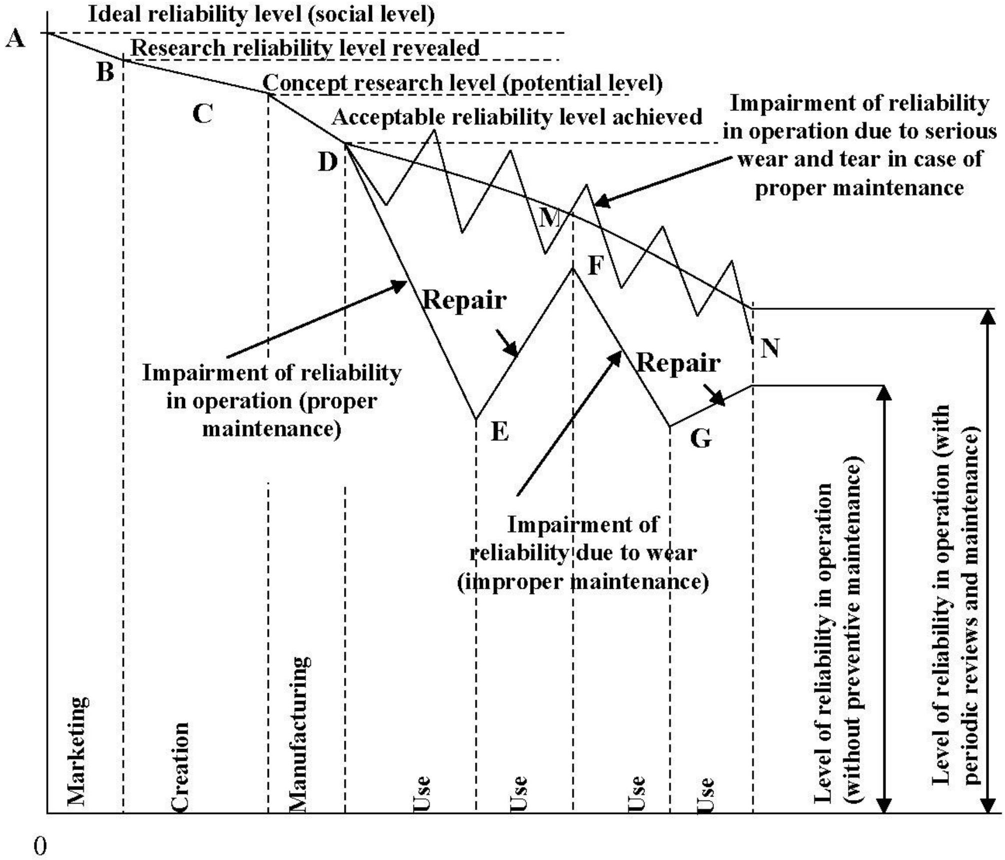

Figure no. 3.4. Impairment of reliability between design and operation

Source: [2]

3.2.1. The main indicators for calculating reliability

To further characterize the information on reliability, systematized in the form of the distribution of defects or the form of a series on decrease of the number, a series of statistical calculations is performed.

In the beginning, usually, calculations are made regarding the structure of failures at intervals of proper functioning, namely*:*

a.) The relative frequency of defects is defined by the relationship

$$\hat{f}\,(t_i) = \frac{k_i}{\sum_{i=1}^{n} k_i} \qquad (3.2)$$

as a ratio between the number of failures recorded in range **i** and their total.

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b.) The cumulative relative frequency of defects

$$\hat{F}(t_i) = \frac{1}{N}\sum_{1}^{i} k_i \qquad (3.3)$$

which expresses the weight of the defective products until the end of the interval **i**. Its value is increasing and becomes equal to 1 at the last interval of the series.

c.) *The relative frequency of the specimens in operation*, which is calculated as a complement to 1 of the cumulative relative frequency of the defects.

$$\hat{R}(t_i) = 1 - \hat{F}(t_i) = \frac{N_i}{N} \qquad (3.4)$$

The relative frequency of the specimens in operation is also called the **experimental function of reliability** because it shows the weight of the products that did not fail until the end of the interval **i** and which will deteriorate during the next ranges.

The calculations presented are complemented by those designed to reflect the central tendency of the distribution and the degree of spread of the defects towards this central tendency.

From the series of fault distribution, we calculate:

d.) The average running time or, as they say, the average time of proper functioning MTBF.

$$\bar{t} = \frac{\sum_{1}^{n} t_i k_i}{\sum_{i=1}^{n} k_i} = \frac{\sum_{i=1}^{n} t_i k_i}{N} \qquad (3.5)$$

The MTBF shows the average time of proper operation that returns on a failure, or more concretely, the average time of proper operation until failure or between two successive failures. MTBF is a direct indicator because its size is directly proportional to the reliability of

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the product: a higher degree of reliability means a higher MTBF and vice versa.

3.2.2. The reliability matrix

The information on the reliability of the machines, collected according to the procedure described above, can be systematized in the form of the so-called "Lexis graph" [B.02].

It offers new possibilities for analysing reliability, non-reliability, and maintenance activity, under the following aspects:

- for each generation of machines put into operation (batches, periods of purchase, etc.),
- for each working-age category,
- for each period of operation.

This way of tracking reliability has similarities with the cross-sectional analysis (moment analysis or synchronous analysis), and longitudinal (cohort or diachronic analysis) performed in demographics using the Lexis graph. Compared to the demographic analysis, the reliability tracking presents some essential features, of which we list:

- If the generations in the demographic are permanently reduced by the phenomenon of mortality, a population of machines can practically remain constant, because through repairs one can theoretically extend their "life" as much as we wish;

- If in the demography the study extends to the disappearance of the generation, in reliability it is done until the products are in operation, moment fixed at the limit of rational, economic use;

- If in demographics, the emergence and disappearance of generations is an uninterrupted process, in the economy, that process is discontinuous. A generation of machines appears with the launch in the manufacture of a new type, which incorporates the results of scientific and technical progress while removing another out-dated, worn-out moralistic type. The new generation, in turn, is produced only until the emergence of a new type, even more refined, and will end its "life" when consuming its optimal operating time from an economic point of view.

To build the matrix, we will consider two axes of time: one to represent the moment when the machine is put into use and the second to follow the life process (maturation, aging), etc. We will consider a one-year interval, divided into monthly periods. On the horizontal, we represent the service life in months, and on the vertical, the time elapsed from the moment of putting into service or the "age" of the machine.

The aging of the machine put into use at time 0 is shown with diagonal I; the one was given in use at time 1, with diagonal II, etc. Each "X" symbol on the "lifeline" of the machine marks the production of a malfunction, after which the repair operation restores its proper functioning. The copy given in use at the time "0" reaches the age of a period (month, year, etc.) when its "lifeline" intersects the point (1;1) the one used in time 1, when its "lifeline" intersects point (2; 1) and etc. (figure no. 3.4).

On the vertical "0," the number of machines used during the successive periods 80, 75, 90, etc. is entered.

Each herd used during a period is called a *generation*, which reaches the age of one year when the "lifeline" of the component copies intersects the vertical of the age of 1 year.

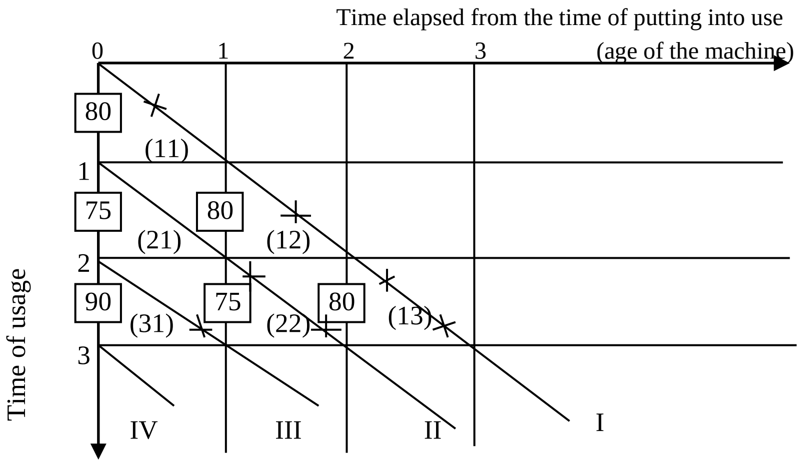

Figure no. 3.5. The "generation analysis" scheme

Source: [2]

The parallelogram thus delimited (for example for the machines used during the period 1 until they reach the age of 1 year, the parallelogram (11) is used to record all the events regarding the operation, maintenance, etc., such as the number of defects in the copies of that generation, the working time consumed for maintenance activities, the cost of these activities, other expenses related to ensure a functioning, operating expenses and so on.

We will show how to aggregate the detailed data in the synthetic tables for more extended periods of time. Suppose that the 3 periods in fig. 2.5 represent the months of a quarter, and we want to summarize the monthly data into quarterly data. In the figure, we find two types of data:

- Stock sizes, such as the number of copies in operation (the number or fleet of machines);

- Flow rates, such as a number of defects, working time and financial funds, etc.

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According to the general rule, the number of machines in operation during the quarter results as the sum of the corresponding monthly numbers. In the example considered this number is 80 + 75 + 90 = 245. As a rule of algorithmic calculation, it can be shown that the quarterly number results from the sum of the monthly numbers on the line corresponding to the last month of the quarter.

The reliability matrix method can be used today to characterize the reliability of the products during the warranty period, for which the information is registered with the manufacturer since he bears the costs with the repairs during the warranty period.

3.2.3. Product reliability parameters

Reliability parameters mean a measure by which the reliability or one of its characteristics is expressed quantitatively. Given the statistical nature of the failures, it turns out that the reliability parameters are statistical sizes. There are a large number of reliability parameters, which is explained by a large number of factors on which the reliability of a product depends. None of the factors that reliability relies on can fully be measured, but only estimate one side of it. [B.02]

As it is known, depending on their destination, the products can be divided into two categories: 1) products of long use (repairable or with restoration) and 2) products destined to a single-use (non-repairable or without restoration). If for the products of the first category the reliability represents, in short, the probability of functioning without defects within a certain period, on the other hand, for the products of the second category the reliability is reduced to the probability of functioning without defects, under the conditions provided, at the time of consumption. Consequently, reliability can be studied in the following situations:

1) If the product is repairable, its operation is expressed by three kinds of parameters: the parameters of the fault-free operation, the parameters of repair (restoration), and the availability parameters.

2) If the product is not repairable, its operation is expressed only by the parameters of the fault-free operation.

Of the parameters for fault-free operation, the most used in practice is the *reliability function* (the probability of malfunctioning), *the non-reliability function* (the probability of failure), *the intensity* (rate) *of the failure* (out of operation), and *the average operating time without faults*. Also, the parameters of repair (restoration) most commonly used in practice are *the maintenance function* (repair or restoration), *the non-maintenance function*, *the intensity* (rate) *of repair* (restoration), and *the average repair time* (restoration).

Regarding the availability parameters, they are: the availability function, the stationary availability and the stationary non-availability.

The reliability function of a product. Let T be the random variable that represents the defect-free operating time of a product and R (t) the probability that the product will operate without

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defect within the time interval (0, t). It follows:

$$R(t) = P(T > t)$$

The above expression whose curve is illustrated in figure no .3.5. is the reliability function (probability fault-free operation) of a product in the time interval (0, t). The function R (t) is a decreasing, positive and continuous function throughout the time interval (0, ∞). When t = 0, R (0) = 1 and when $t \to \infty$, $R(t) \to 0$/

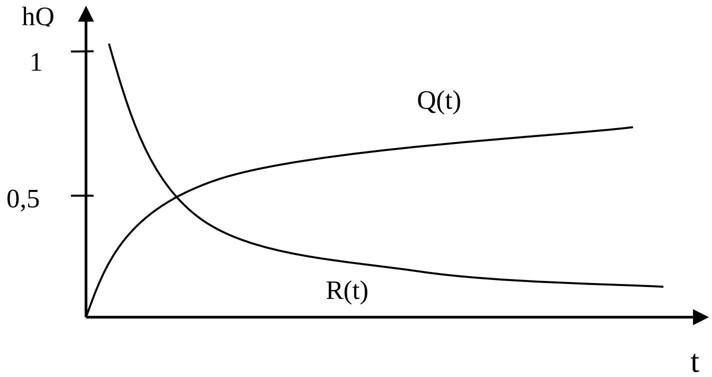

Figure no. 3.6. Graph of reliability and non-reliability functions

Source: [2]

The non-reliability functions of a product. Knowing that the event (T≤t) is opposite to the event (T>t) it can be deduced that P (T≤t) is the probability of failure of the product up to the time t, ie Q(t) =1- R(t)= P(T ≤ t)

The function Q (t) is an increasing, positive, and continuous function throughout the time interval (0, ∞). When t = 0, Q (0) = 0, and when $t \to \infty$, $Q(t) \to 1$

Failure intensity. Let be two-time intervals (0, t) and (t, t1). Assuming that R (t) = 1, that is, the product worked without defects in the time interval (0, t) the probability that it will function without defects and in the time interval (t, t1) is:

$$R(t,t_1) = \frac{R(t_1)}{R(t)}$$

where R (t1) is the probability of fault-free operation in the range (0, t_1). Also, the probability that the product will fail over time (t, t_1) is Q (t, t_1) = 1– R (t, t_1). If $t_1 = t + \Delta t$ and $\Delta t \to 0$, then:

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$$Q(t, t + \Delta t) = \frac{R(t) - R(t+\Delta t)}{R(t)} = -\frac{R'(t)}{R(t)}\Delta t + 0(\Delta t) \qquad (3.6)$$

By entering the notation z(t), we obtain:

$$z(t) = -\frac{R'(t)}{R(t)}$$

or writing as a derivative, it turns out:

$$z(t) = - [\ln R(t)]'$$

The parameter (size) z(t) is *the intensity* (*rate*) *of failure* (out of operation) of a product and represents:

- In a technical sense, the probability that a product that? has worked without defects until the moment t will fail during a subsequent unit of time (if this unit is small);
- In a probabilistic sense, the conditional probability density of product failure at time t, knowing that it has worked without fail until this moment.

If the equation of z(t) is solved with the initial condition R(o) = 1 is obtained:

$$R(t) = \exp\left[-\int_0^t z(u)du\right] \qquad (3.7)$$

Thus, knowing the defect intensity z(t), one can calculate the reliability function of a product in the time interval (o, t). Considering that z(t) = λ = constant, the reliability function follows the negative exponential repair law, that is:

$$R(t) = e^{-\lambda t} \qquad (3.8)$$

The average running time without faults. It is a parameter by which one can assess the reliability of products of the same kind with the duration of operation until the first failure, which is determined as a mathematical expectation of the random variable T according to F (t):

$$M(t) = \int_0^\infty [1 - F(t)]dt \qquad (3.9)$$

or based on probability density f(t):

$$M(t) = \int_0^\infty t f(t) dt \qquad (3.10)$$

by the reliability function, M (t) is set:

$$M(t) = \int_0^\infty R(t) dt \qquad (3.11)$$

and finally by the failure rate:

$$M(t) = \int_0^\infty \left[\exp - \int_0^t z(u) du \right] dt \qquad (3.12)$$

3.2.4. Models of product reliability

3.2.4.1. The model of exponential distribution

A continuous random variable X follows the **exponential distribution** if its probability distribution is defined by:

$$f(x) = \begin{cases} 0 \quad \text{când} \quad x \le 0 \\ \lambda \cdot e^{-\lambda x} \quad \text{când} \quad x > 0 \end{cases} \qquad (3.13)$$

The probability density f(x) of the exponential distribution depends on the parameter λ, which represents the **density of the event flow**, and this distribution is generated, moreover, by an elementary flow of homogeneous events.

If an initial arbitrary moment (in which the given events take place) is chosen as the origin of the events, then

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the time X of the occurrence of the next event - which is a continuous random variable - follows the exponential distribution. A similar distribution follows the duration (or time interval) between two successive elementary flow events.

The exponential distribution is found in the theory of reliability of technical installations and characterizes the relative frequency of falls. The mean value, the dispersion, and the mean squared deviation of the continuous random variable following the exponential distribution are:

$$\mathrm{M(X)} = \frac{1}{\lambda} \qquad (3.14)$$

$$\mathrm{D(X)} = \frac{1}{\lambda^2} \qquad (3.15)$$

$$\sigma(X) = \frac{1}{\lambda} \qquad (3.16)$$

The average duration (or average time interval) between the occurrences of two successive events is:

M (X) = m.

Between the density of the event flow λ and the average time interval m there is a connection relation:

$$\mathrm{m} = \frac{1}{\lambda} \qquad (3.17)$$

λ and m are the "failure rate" and "average proper functioning time" (MTBF), respectively.

The distribution function F(x) of the continuous random variable that follows the exponential distribution, respectively the probability that a (next) event will occur within the time interval (0, t), is:

$$\mathrm{F(x)} = \int_R f(x)dx = \begin{cases} 0 & \text{când } x \le 0 \\ 1 - e^{-\lambda x} & \text{când } x > 0 \end{cases} \qquad (3.18)$$

$$\mathrm{P(X > t) = 1 - F(x)}$$

$$= \int_t^{\infty} f(x)dx = e^{-\lambda x}$$

represents the probability that the given event will not occur within the time interval (0,t); it expresses the reliability R(x) of an installation, respectively the

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probability that it works without defects in the given time interval (0,t), that is R(x) = P (X).

The probability of occurrence of an event (next) in the time interval (x,x+ Δx), conditioned by the non-occurrence of this event in the time interval (0,x) is equal to λΔx, and the unconditional probability of occurrence of an event (next) in the time interval (x,x + Δx) is f(x) Δx. Between λf (x) and F(x) there is the following connection relation:

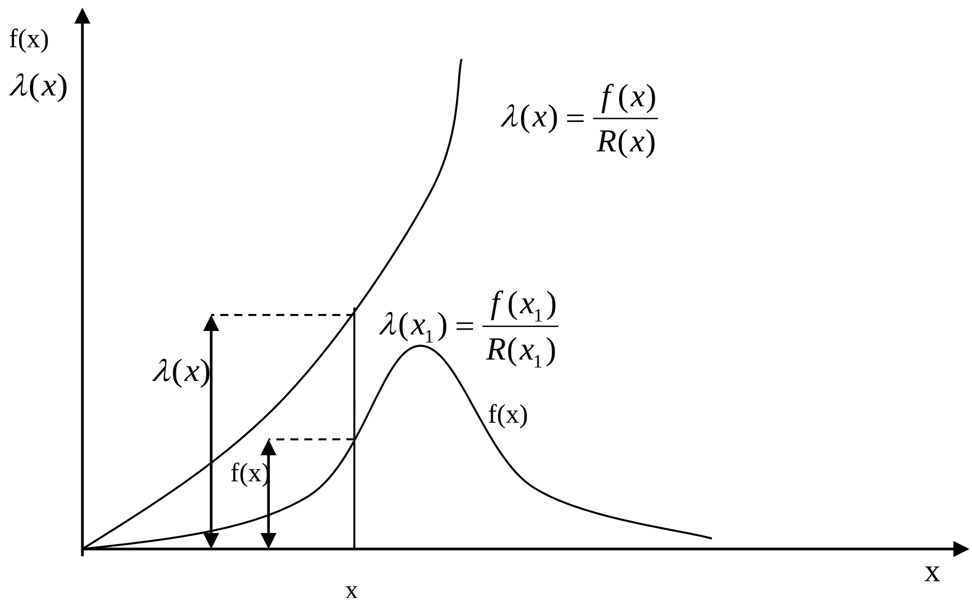

Figure no. 3.7. Graphical representation of the indicators λ(x), f(x) and R(x)

Source: [2]

$$\lambda = \frac{f(x)}{1 - F(x)} = \frac{f(x)}{R(x)} \qquad (3.19)$$

The probability density f(x), the reliability function R(x), and the failure rate λ(x) characteristic of the exponential distribution is graphically represented in figure no. 3.7.

The exponential model is used when the failure rate is constant. For many production equipment, there is a period of constant rate failures, following a period of early failures (with increasing failure rate) and before reaching the late failure period (with increasing failure rate).

A relatively constant failure rate can be obtained through a series of permanent preventive maintenance operations, through successive replacements of worn components, or with the increasing failure rate.

3.2.4.2. The Weibull distribution model

If the bearing period is ignored, the period after which the normal operation begins, the survival curve of the products with wear undergoes a "deformation" related to the exponential curve corresponding to the operation in a stationary regime. The deformation is done as follows, until the beginning of the period of degradation; the curve decreases slowly, remaining almost horizontal, due to the small number of failures that occur during normal operation. After the critical moment of entering the period of degradation the life regime of the equipment changes suddenly, the defects appear at a dizzying rate, until the stoppage of the entire equipment fleets in a relatively short time.

Weibull's law of distribution is used to model such survival processes. Weibull law has several analytical forms, of which we will present the two-parameter and three-parameter law.

The two parametric Weibull distribution. The treatment of the two-parameter variant is necessary because, in this way, the connection with the exponential law can be made, being considered even a generalization of it.

The probability density of the Weibull law is shaped

$$\mathrm{f}(\mathrm{t}, \beta, \lambda) = \begin{cases} 0, & dacă\ t \le 0 \\ \beta\lambda t^{\beta-1} e^{-\lambda t\beta} & dacă\ t > 0 \end{cases} \qquad (3.20)$$

where β> 0, λ> 0 and t is the time variable.

From the expression of density, it is observed that for β = 1, the Weibull distribution becomes an exponential distribution. For β> 1, the distribution curve is concave, and the larger the β, the graph of the function has an increasingly pronounced bell shape. For β <1, the distribution curve is decreasing, its convexity is increasing with a smaller β. The parameter β, therefore, determines the shape of the Weibull distribution. In figure no. 3.8.a for the parameter λ = 1 the graphs of the frequency function of the Weibull law are plotted, for the case when β = 1 (the curve corresponds to the exponential law) and for β> 1 and β <1 and in figure 3.9.b we specialize this construction for four values of parameter β.

The distribution function for the Weibull law is:

$$\mathrm{F}(\mathrm{t}; \beta; \lambda) = \int_{-\infty}^{T} f(t,\beta,\lambda)dt \begin{cases} = 0 & dacă\ t \le 0 \\ = 1 - e^{-\lambda t^{\beta}} & dacă\ t > 0 \end{cases} \qquad (3.21)$$

and expresses the probability that the next event (e.g. failure of a technical installation) will occur in the range (0,t).

As for the exponential law, the rate (intensity) of failure is defined in the case of the Weibull law:

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$$z(t) = \frac{P'(t,\beta,\lambda)}{P(t,\beta,\lambda)} = \beta\lambda t^{\beta-1} \qquad (3.22)$$

which in reliability theory expresses the failure rate. The shape of the rate curves according to different values of β can be seen in figure no. 3.8.

The ratio:

$$R(t;\beta,\lambda) = 1 - F(t,\beta,\lambda) = e^{-\lambda t^{\beta}} \qquad (3.23)$$

expresses the probability that the event will occur in the time interval (0,t) or - as it is said in the reliability theory - is the *probability of the faultless operation* of the technical installation until the moment t.

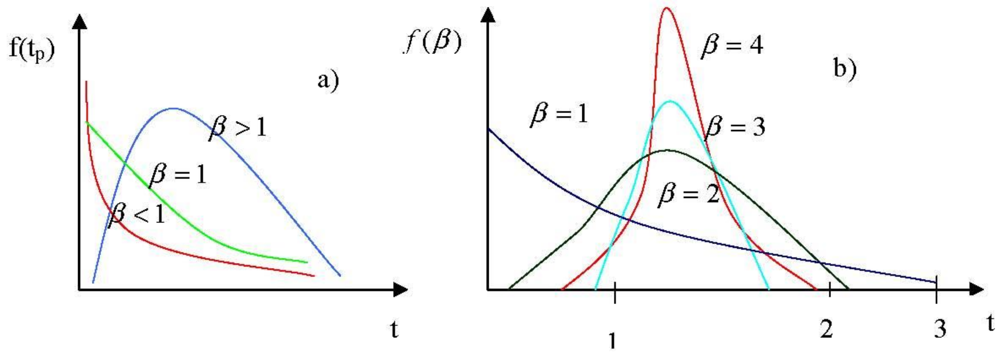

Figure no. 3.8. The frequency function graph for the case $\lambda = 1$

and different shape parameter sizes β

Source: [7]

In the case of Weibull distribution, the average proper functioning time is calculated as follows:

$$\text{MTBF} = \int_0^{\infty} \beta\lambda t^{\beta-1} e^{-\lambda t^{\beta}}\, dt = \frac{\Gamma\left(\frac{1}{\beta}+1\right)}{\lambda^{\frac{1}{\beta}}} \qquad (3.24)$$

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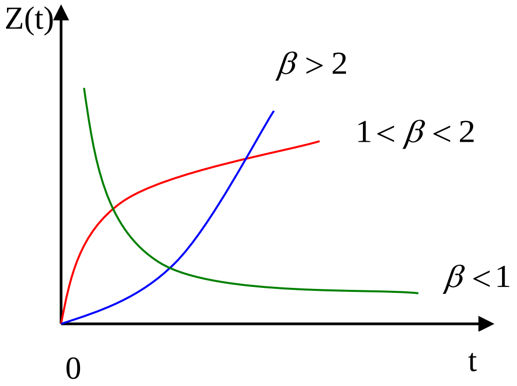

Figure no. 3.9. The evolution of the failure rate according to the parameter β

Source: [2]

The dispersion of the proper functioning time is:

$$D(t) = \frac{\Gamma\left(\frac{2}{\beta}+1\right)-\Gamma^2\left(\frac{1}{\beta}+1\right)}{\frac{\lambda^2}{\beta}} \qquad (3.25)$$

In the situation where we follow the reliability of components that in the first period of life have hidden defects, but then for a relatively long time does not suffer from "aging", the probability of failure at first is very high, after which it stabilizes around a constant level. The reliability function R (t,β,λ) approximates well in this case with the Weibull law of parameter β <1.

In the situation in which the components tracked are characterized by the absence of hidden defects, but the aging phenomenon manifests with increasing time, the intensity of the defects increases monotonously, and the safety function is approximated by a Weibull law with β> 1.

Estimating the parameters of the Weibull law. The determination of the β and λ parameters of the two-parameter Weibull law is made based on the observation of the operating regime, at the time of commissioning, of a batch composed of N products. The survival curve is constructed and the values of the relative frequency of the products in operation for i = 1, 2, ..., n are calculated.

$$R_N(t_i) = e^{-\lambda t_i^{\beta}} \qquad (3.26)$$

The estimation of the parameters β and λ of the distribution is done using the least squares method. Logging in the previous relationship results:

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$$\lg R_N (t_i) = -\lambda t_i^{\beta} \lg e \qquad (3.27)$$

or written in an equivalent form:

$$\lg\left[\frac{1}{R_N(t_i)}\right] = \lambda t_i^{\beta} \lg e\,. \qquad (3.28)$$

Repeating the logarithmic operation is obtained:

$$\lg\left\{\lg\left[\frac{1}{R_N(t_i)}\right]\right\} = \lg(\lg e) + \lg\lambda + \beta \lg t_i$$

Entering notations:

$$a = \lg\lambda + \lg(\lg e)$$

and

$$y_i = \lg\left\{\lg\left[\frac{1}{R_N(t_i)}\right]\right\}$$

Applying the method of least squares, the following system of equations results for the estimation of the parameters a and β:

$$\sum_{i=1}^{n} y_i = na + \beta \sum_{i=1}^{n} \lg t_i \qquad (3.29)$$

$$\sum_{i=1}^{n} y_i \lg t_i = a \sum_{i=1}^{n} \lg t_i + \beta \sum_{i=1}^{n} (\lg t_i)^2$$

where n is the number of time intervals included in the calculation.

Weibull law standardized (transformed). We can express the Weibull law in a more advantageous form, in some practical cases, by substituting the value of the defect rate and the time normalisation with a constant η, which represents the real scale parameter. Thus, if we introduce the notation:

$$\lambda = \frac{1}{\eta^{\beta}} \qquad (3.30)$$

Hence $\eta = \frac{1}{\sqrt[\beta]{\lambda}}$ the expression of the density distribution of the two-parameter Weibull law becomes:

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$$f(\frac{t}{\eta},\beta) = \frac{\beta}{\eta}\left[\frac{t}{\eta}\right]^{\beta-1} \times e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad (3.31)$$

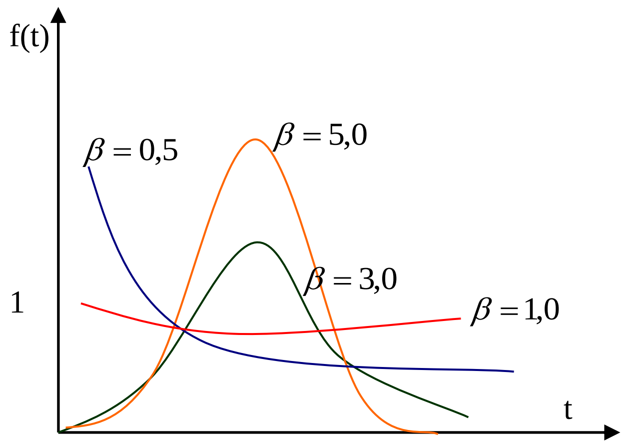

Figure no.3.10. Evolution of probability density

for β =0,5; β = 1,0; β = 3,0; β = 5

Source: [2]

The graphical representation (figure no 3.10) of this function for different values of the β-shape parameter indicates the possibility of its use in other particular laws, such as exponential, normal, etc.

The three-parameter Weibull law. It represents the complex variant of this law, and is presented in a way that connects with the exponential law. The probability of survival, or the function of reliability, is according to this law:

$$R(t, \beta, \eta, \gamma) = e^{--\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \qquad (3.32)$$

where:

β - is the shape parameter;

η - the scale parameter (the characteristic life parameter),

γ - the position parameter (location or initialization).

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If the parameter β = 1, the expression of the probability of survival becomes:

$$R(t,\beta,\eta,\gamma) = e^{--\left(\frac{t-\gamma}{\eta}\right)^{1}}$$

If in this case we take into account that, $\frac{1}{\eta} = \lambda = \frac{1}{MTBF}$, and we initialize it at the zero moment $\gamma = 0$, then the relation $R(t,\beta,\eta,\gamma)$ becomes:

$$R(t) = e^{-\frac{t}{\eta}} \cdot e^{\frac{\gamma}{\eta}} = e^{-\lambda t}$$

in which we easily recognize the function of reliability in the exponential case.

The shape parameter β defines the allure of the curve. Its influence is significant if we follow the evolution of the distribution density of the Weibull model as a function of β values. The probability density equation is:

$$f(t,\eta,\beta,\gamma) = \frac{\beta}{\eta} \cdot \left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \cdot e^{-\left(\frac{t-\gamma}{\eta}\right)} \qquad (3.33)$$

It should be noted that the parameters η and γ are expressed in the same units of measurement as t. In order to simplify the working procedures, it is generally assumed that η = 1 and γ = 0.

The initialization parameter (position, location, marking) γ performs a translation operation on the t-axis. If we assume the parameter η = 1, the probability density can be written:

$$f(t,1,\beta,\gamma) = \frac{\beta}{1}\left(\frac{t-\gamma}{1}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{1}\right)^{\beta}} \qquad (3.34)$$

an expression in which making a variable change:

$$(t-\gamma) = T \ cu \ (t-\gamma) > 0$$
(3.35)

we obtain:

$$f(t,1\,\beta,\gamma) = \beta T^{\beta-1} \cdot e^{-T^{\beta}} \tag{3.36}$$

This parameter indicates the survival time between 0 and γ. If γ <0 this would imply the situation where at the beginning of the initialization time of the observation, the elements are already "exhausted".

In the practical studies regarding the operating behaviour of the technical systems the initialization time (γ = 0) can be introduced as the moment of commissioning of the system. It should be noted that the average lifetime is equally increasing in relation to γ.

The scale parameter η completes the form of the three parameter model, for which the probability density equation becomes:

$$f(t,\eta,\beta,\gamma) = \frac{\beta}{\eta} \cdot \left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \cdot e^{-\left(\frac{t-\gamma}{\eta}\right)} \tag{3.37}$$

and the distribution function is:

$$F(t,\eta,\beta,\gamma) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \tag{3.38}$$

wherein η represents the actual scale parameter. If we calculate f(t) for η = 1, and then compare the results for case η = 5, we will notice that in the latter case, the values of f(t) must be divided by 5, and the values of t will be multiplied with 5, the total area under the curve remains unchanged and equal to 1.

The defect rate z(t) is thus calculated:

$$z(t) = \frac{d}{dt}\frac{(t-\gamma)}{\alpha} = \frac{\beta}{\alpha}(t-\gamma)^{\beta-1} \tag{3.39}$$

α representing the scale parameter. Between η and α there exists the relation $\alpha = \eta^{\beta}$ where η = $\eta = (\alpha)^{1/\beta}$.

$$z(t) = \frac{\beta}{\eta^{\beta}}(t-\gamma)^{\beta-1} \tag{3.40}$$

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Graphical estimation of the Weibull distribution parameters. The most convenient procedure is represented by the Weibull or A. Plait diagram [1], in figure 2.11, such a diagram is presented, constructed by performing double logarithms on the reliability function.

$$\ln\ln\frac{1}{1-F(t)} = \beta\ln(t-\gamma) - \ln\alpha \tag{3.41}$$

For γ = 0 the previous relation becomes:

$$\ln\ln\frac{1}{1-F(t)} = \beta\cdot\ln t - \beta\ln\eta \tag{3.42}$$

Between $ln\ ln\frac{1}{1-F(t)}$ and $ln(t)$ a linear type relation is identified, which allows the representation by a line in a system of conveniently chosen orthogonal axes.

A point in the Weibull graph (3.7) has the coordinates:

- ➢ abscissa: on A, time t is represented; and on ? a, lnt
- ➢ ordinate: on B, F(t) in %, and on *b*, $ln\ ln\frac{1}{1-F(t)}$

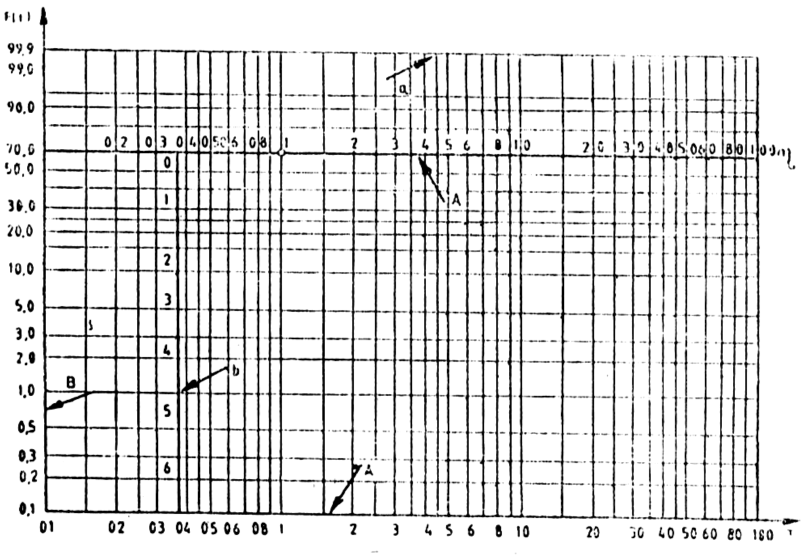

Figure no. 3.11. Weibull network

Source: [2]

Therefore, the ordinate represents the cumulative relative frequencies of the defective components at the moments of time t, and on the abscissa the moments $t_1,\dots,t_2,\dots,t_n$ (other cycles, maneuvers, drives, km travelled, etc.).

Estimation of the initialization parameter γ. The graph shows the points that correspond to even values of moments in time and the corresponding relative frequencies. It should be noted that the tests (observation of the behaviour) can be stopped before the sample is exhausted, for a good estimation, the failure of at least half of the observed elements is sufficient. If a line aligns the points, the parameter γ is zero. If the points do not line up with a line, the following situations may arise:

a) The curve obtained to have the shape of figure no 3.12. Generally, such forms are encountered if the observed technical system is at the end of the running period.

b) The curve obtained to have the shape of figure no 3.13. Such a form appears when the products subject to observation have some degree of wear before the start of the study.

To obtain in these cases a straight line on the Weibull graph, a change the variable T = t-γ is performed.

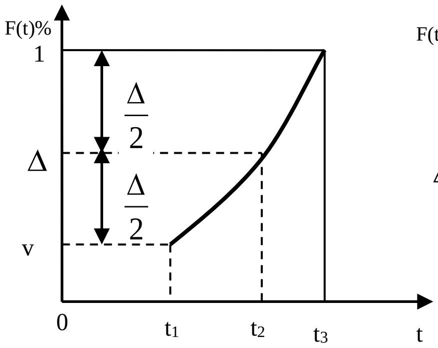

Figure no.3.12. A variant of placing the points of the experimental line on the network

Source: [2]

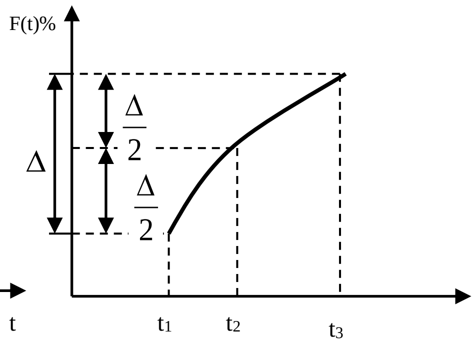

Figure no. 3.13 Another variant of placing the points of the experimental line on the network

Source: [2]

In the graph, this represents a translation to the left or right of the curve, a fact made by subtracting or adding (depending on the shape of the curve) a same value to a number of 5-6 points on the curve. Obviously, in order to find the optimal solution, the operation is performed by several explorations.

The value of γ can be read directly on the graph after performing the curve translation operation, or an interpolation form can determine it as follows:

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$$\gamma = \frac{t_1 \times t_3 - t_2{}^2}{(t_1 + t_2) - 2t_2} \tag{3.43}$$

where t_1 and t_3 represent the abscissae of the extremes of the curve and t_2 - the abscissa of the median point of the cumulative relative frequencies.

The estimation of the real scale parameter η is performed on the Weibull network, if it is identified on the line marked "η" which corresponds to the ordinate 63% (considering t = η, the expression of the reliability function is R (η) = $e^{-\left(\frac{\eta}{\eta}\right)^{\beta}}$ = $e^{-1^{\beta}} = e^{-1} \approx 0{,}37$ the specific weight of the components with a lifetime shorter than η is 1- 0.37 = 0.63), the point at which it intersects with the experimental straight line. By calculation the value of η is obtained as follows:

$$\hat{\eta} = \left(\frac{\sum_{i=1}^{n} t_i}{n} \right)^{\frac{1}{\beta}} \tag{3.44}$$

Two confidence limits can be set for the parameter η so that it belongs to the determined interval with a sufficiently high probability, respectively:

$$P(\hat{\eta}_1 \le \eta \le \hat{\eta}_2) = 1\text{-}\alpha \tag{3.45}$$

It is known that $2n\left(\frac{\hat{\eta}}{\eta}\right)^{\beta}$ follows a law χ^2 with $\gamma = 2n$ degrees of freedom. The confidence interval is constructed as follows:

$$\frac{\hat{\eta}}{C_1} \le \eta \le \frac{\hat{\eta}}{C_2} \tag{3.46}$$

where:

$$C_1 = \left(\frac{\chi^2{}_{2n,\frac{\alpha}{2}}}{2n} \right)^{\frac{1}{\beta}} \tag{3.47}$$

and:

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$$C_2 = \left(\frac{\chi^2{}_{2n,1-\frac{\alpha}{2}}}{2n} \right)^{\frac{1}{\beta}} \tag{3.48}$$

The estimation of the shape parameter β is easy if the coordinate point (1; 63%) draws a parallel to the right of the experimental values. The value of β is read at the intersection of this parallel with the axis noted b.

3.2.5. Validation of reliability models

In the experimental studies regarding the reliability of the machines, severe problems raise the processing and statistical interpretation of the collected data. Essential is the identification of the theoretical law, after which the regime of operation or failure of the machines is carried out.

The suitability of the models is made using either graphical or analytical methods, which obviously offer a higher degree of accuracy.

1) **Validation of the exponential model**. It can be carried out through several adequacy tests. A simple solution offers Hahn and Shaphiro [B.02], who proposed for the density of the exponential distribution the substitution $1/\theta = \lambda$, obtaining $f(t;\lambda) = exp. (-\lambda t)$, $t \geq 0$, $\lambda >$, variant used for suitability. If the observations on the behaviour are materialized in the form of operating times $t_1, t_2, \ldots, t_n$, we calculate the test statistic (W_0):

$$W_0 = \frac{\sum_{i=1}^{n} (t_i - \bar{t})^2}{\left(\sum_{i=1}^{n} t_i \right)^2} = \frac{\sum_{i=1}^{n} t_i^{\ 2} - \frac{\left(\sum_{i=1}^{n} t_i \right)^2}{n}}{\left(\sum_{i=1}^{n} t_i \right)^2} \tag{3.49}$$

t representing the average of the values $t_1, t_2, \ldots, t_n$. The decision is made by comparing the calculated Wo statistics with the table values. If W_{inf} calculated $< W_{sup.}$ the hypothesis of exponentiality is accepted (obviously in the conditions of the admitted decision risk).

The Kolmogorov-Smirnov test is a "distance test" highlighting the magnitude of the distance between the experimental distribution function and the theoretical function.

Stages of test application:

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➢ the experimental values $F(x_{(i)})$ and the theoretical values $F(x_{(i)})$ are calculated at points $x_{(i)}$, $i = \overline{1, n}$;

➢ the size is identified:

$$k = \max_{1 \le i \le n} \left| \hat{F}(x_{(i)}) - F(x_{(i)}) \right| \tag{3.50}$$

➢ the value is calculated.

$$\lambda = \frac{k}{\sqrt{n}}$$

➢ P (λ) is determined - the probability of concordance between the experimental and the theoretical functions. It is estimated that for P (λ)> 0,05 the agreement is satisfactory.

2). **Validation of the Weibull model**

Practical considerations, knowledge of the physical basis of a phenomenon or process, previous experience, comparisons with similar situations, etc. can lead us in a study to the hypothesis of a Weibull behaviour. However, it is required that, before proceeding with the actual calculations, the inference operations, the formulation of conclusions or decisions, and the validation of the model should be carried out. In most cases, in practice, we do not have global information on the behaviour of all elements of a population, but information obtained either through statistical survey, statistical experiment, or limited observation as duration. For this reason, it is necessary to check whether there is reason to suppose that the experimental data do not contradict the hypothesis formulated on the behavioural model.

The test built to validate the model requires the following calculation steps:

➢ The experimental data $t_1, t_2, \ldots, t_n$ are recorded,

➢ The values $x_i = \ln t_i$ are calculated,

➢ The statistics are evaluated:

$$l_i = \frac{x_{(i+1)} - x_{(i)}}{E(z_{i+1}) - E(z_i)} \tag{3.51}$$

where:

$z_i = \dfrac{x_{(i)} - \eta}{\xi}, \quad \eta = \ln\theta, \quad \xi = 1/k; \quad E(z_i)-$ average

➢ the statistics of the test is built:

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$$S = \frac{\sum_{i=\frac{n}{2}+1}^{n-1} l_i}{\sum_{i=1}^{n-1} l_i}$$

The acceptance of the Weibull model takes place when $S_{calculat} \leq S_{tabelar}$, the critical values are represented in the tables.

3) Discrimination between exponential and Weibull models. It has been shown that the Weibull model, by its high degree of generality, also includes the exponential model as a particular case, for which the shape parameter β = 1. The problem is therefore reduced to the verification of the statistical hypothesis H_0: β =1, with the alternative H_1 : β>1, i.e., the adequacy of the exponential model to the Weibull hypothesis.

Billman Antle and Bain solve the problem, based on the statistic $\beta/\hat{\beta}$ in which $\hat{\beta}$ is the value of the maximum likelihood estimator of β, which depends on the volume of the sample (n) and the number of observations made until the end of the experiment (r). The values of statistics:

$$V = \sqrt{n}\left[\frac{\hat{\beta}}{\beta} - M\left(\frac{\hat{\beta}}{\beta}\right)\right] \qquad (3.52)$$

were tabulated for the probabilities P=1 - α, n şi r:

$$P\left\{\sqrt{n}\left[\frac{\hat{\beta}}{\beta} - M\left(\frac{\hat{\beta}}{\beta}\right)\right]\right\} = 1-\alpha \text{, null hypothesis } H_0\text{: } \beta = 1 \qquad (3.53)$$

being rejected when, for the level of significance established:

$$V_{calculat} > V_{1-\alpha\,;n;r} \qquad (3.54)$$

The working stages can be systematized as follows:

- The experiment is performed to obtain the data;
- Because the table values are set only for the ratio sizes (r / n) = 1;

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0.75 and 0.50 it is necessary to take this into account when conducting censorship;

- The parameter of the β form is estimated using the maximum likelihood procedure;
- The V statistics are calculated and compared to the corresponding table equivalent.

3.3. Product maintainability

Maintainability is the likelihood that a system will be up and running within a given period of time.

Maintainability quantifies the quality of maintenance actions and requires, for this purpose, to determine:

1**. The possibility of occurrence of maintenance activities**.

There are two maintenance methods:

a.) ***Corrective maintenance*** *is the set of activities performed after the failure of a means of production, or after the degradation of its function in an unexpected way*. These activities consist of the localization of the defects and their diagnosis, the restart of operation, with or without changes, and the control of the proper functioning. Corrective maintenance takes two forms:

- ***Curative maintenance*** *represents corrective maintenance activities, which aim to restore production to a specific state of operation, which allows it to perform its functions.*
- ***Palliative maintenance*** *involves corrective maintenance activities, intended to allow a means of production, provisionally, to fulfil all or part of its functions.*

b**)** ***Preventive maintenance*** is maintenance that aims to reduce the probability of damage or degradation of a good or service. Preventive maintenance can be presented in three subtypes:

- ***Systematic maintenance*** *is the maintenance carried out through maintenance activities, current repairs, overhauls, and capital repairs, built in a technical plan, standardized by interventions specific to each type of machine.*
- ***Conditional maintenance*** *is the maintenance carried out by following the wear parameters of the elements or the key subassemblies of the machines using specific tools (wear, vibration, oil analysers, etc.).*
- ***The previsionary maintenance*** *represents the preventive maintenance subordinated to the evolution analysis, followed by the significant parameters of the degradation*

of the good, which allows the delay and the planning of the interventions.

2.) The availability of the necessary time for carrying out these activities, namely:

➢ The average time for performing different maintenance activities,

➢ The frequency of occurrence of the need for maintenance actions depends on the reliability of the system (structure); therefore, on the quality of its design and execution.

Maintainability is determined as:

1.) Experimental; through simulation in laboratory, on the test platform of the different categories of defects and recording the intervention times to eliminate the deficiencies.

2.) By following the behaviour of the systems, structures, or products to the beneficiaries (organization "banks for technical data").

2.3.1. Maintainability indicators

a.) The average frequency (number) of failures over an observation interval calculated as the sum of the failures over a time interval:

$$N = \sum_{i=1}^{n} k_i \qquad (3.55)$$

and the total running time of all specimens in the sample $\sum_{i=1}^{n} t_i k_i$

$$\bar{k} = \frac{\sum_{i=1}^{n} k_i}{\sum_{i=1}^{n} t_i k_i} \qquad (3.56)$$

As the reliability of the product increases, the value of the indicator $\bar{k}$ decreases, and vice versa. Obviously, between MTBF and k, there is an inverse proportionality ratio MTBF = 1 / k.

b.) To characterize the degree of manifestation of the defects, respectively, the times of proper operation, the *standard deviation* of the values to the average is calculated.

To be able to surprise the change of the regime of stoppage of the machines, we will determine the *local*

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characteristics of the reliability. Thus, one can calculate:

c.) *the defect density*, calculated as a ratio between the number of defects recorded in an observation interval and the length of this interval. If the observation interval has the same length over time, this length can be taken as a unit of time, and then the density of faults is confused with the number of faults. On the other hand, if the observation intervals have different lengths, the density of faults will show how many faults within the interval return per elementary time unit (hour, day, etc.) and become analogous to the experimental distribution density;

d.) *the failure rate*. This indicator shows the weight of the defective specimens during the observation interval, compared to the number existing at the beginning of the respective interval:

$$\hat{z}(t) = \frac{k_i}{N_{i-1}} \tag{3.57}$$

where N_{i-1} is the number of units in operation at the beginning of interval i. If the machine is operating in stationary mode, the rate of defects throughout the sample is equal to the average frequency of falls.

The demonstration of this density is as follows; it is considered that the observation time interval is equal to a unit of time $\Delta t = t_{i+1} - t_i = 1$.   .

During the time intervals i = 1,2,…,n there are recorded respectively k_1, k_2,…, kn faults. It is assumed that the interval n is the interval in which the last samples of the range fail. So:

$$k_1 + k_2 + ... + k_i + ... + k_n = \sum_{i=1}^{n} k_i = N$$

It has been shown that the number observed at times 0,1,2, ..., n is respectively:

$$N_o, N_1, N_2, ... , N_n = 0$$

As it is known [B.02], the local failure rate at intervals is:

$$\hat{z}_i = \frac{k_i}{N_{i-1}} \tag{3.58}$$

In the case of stationary operating mode, the local failure rate is the same for any interval.

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So:

$$\frac{k_1}{N} = \frac{k_2}{N_1} = \dots = \frac{k_n}{N_{n-1}} = \frac{\sum_{i=1}^{n} k_i}{N + \sum_{i=1}^{n-1} N_i} \tag{3.59}$$

In this relation we have: $N = \sum_{i=1}^{n} k_i$.

The denominator of the report can be developed as follows:

$$N + \sum_{i=1}^{n-1} N_i = N + N_1 + N_2 + \dots + N_{i-1} + \dots + N_{n-1} = k_1 + 2k_2 + \dots + (n-1)k_{n-1} + nk_n \tag{3.60}$$

On the other hand, being determined that $\Delta t = 1$, the total operating time of all the specimens in the sample, $\sum_{i=1}^{n} t_i k_i$ considering that $t_i = i\Delta t$, is :

$$\Sigma t_i k_i = \Sigma i k_i = 1k_1 + 2k_2 + \dots + (n-1)k_{n-1} + nk_n$$

Thus, the $N + \sum_{i=1}^{n-1} N_i = \sum_{i=1}^{n} t_i k_i$, identity results and each member of the identity represents the total operating time of all the copies in the investigated population.

Consequently, the rate of failure, constant over time, results in:

$$\hat{Z}(t) = \frac{\sum_{i=1}^{n} k_i}{N + \sum_{i=1}^{n-1} N_i} \tag{3.61}$$

and is confused with the average frequency.

2.3.2. Maintainability parameters of products

Let T be the random variable representing the recovery time of a product in the event of failure and G (t) the probability that the product will be restored within the time interval (0, t). Resulting:

$$G(t) = P(T < t) \qquad (3.62)$$

The expression G (t) is **the maintainability (repair) function** of a product in the time interval (0, t).

The intensity of the restoration. Let it be two time intervals (0,t) şi (t,t_1). Proceeding as in the case of determining the failure intensity, one obtains:

$$\mu(t) = \frac{G'(t)}{1-G(t)} \qquad (3.63)$$

The parameter μ(t) is the repair intensity of a product, that is, the conditional probability density of the completion of the repair in the time interval (t, t_i) in case the product was in repair in the interval (0, t). If the equation μ (t) is solved, whether the hypothesis G (0) = 0, it is obtained:

$$G(t) = 1\text{-}\exp\left[-\int \mu(u)du\right] \qquad (3.64)$$

Thus, knowing the restauration intensity μ (t,) one can calculate the maintainability function of a product in the range (0, t).

Average recovery time. Proceeding as in the case of the average operating time without faults is obtained:

$$MTR = \int_0^\infty e^{-\mu} dt = \frac{1}{\mu} \qquad (3.65)$$

where MTR is the average time to restore a product. The MTR parameter is usually expressed in hours and can be used to make comparisons regarding the maintainability between similar products.

3.3.3. Calculation of the maintainability of a product

For calculating the maintainability of systems, as a basis of calculation, the actual repair times t'_i extracted from the technical data bank corresponding to accidental faults are used. The values t'_i are ordered ascending, and the cumulative frequencies are calculated as well as the calculation of the main reliability indicators (see 2.2.1).

In case the law of distribution of the actual repair times t'_i has been

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verified, by using an exponential graph test, the maintainability is determined from the relation:

$$M(t) = 1- e^{\mu t} \qquad (3.66)$$

where μ represents the repair rate and $\mu = \frac{1}{MTR}$

If the exponential test for your distribution t'_i is not verified, Weibull's law is used. The average repair time (MTR) is determined in this case by following formula:

$$\text{MTR} = \frac{\eta}{\beta}\Gamma\left(\frac{1}{\beta}\right) + \nu \qquad (3.67)$$

where:

$$\Gamma\left(\frac{1}{\beta}\right)s \qquad (3.68)$$

is an Eulerian function, whose values are taken from the tables. In this case, the maintainability will take the form of Weibull's law:

$$M(t) = 1- e^{-\left(\frac{t-\chi}{\eta}\right)^{\beta}} \qquad (3.69)$$

Parameters β, η, γ are similarly determined according to the method described in the previous paragraph.

3.4. Availability of products

The notion of *availability* means the probability that the system will be able to operate after a time consumed for repairs, imposed by the fall that occurred after a certain period of proper operation.

Availability is affected by two probabilities:

- On the one hand, the probability of operating without fail for a specified duration;
- On the other hand, the probability of failing and restoring the ability to function properly over a period of time.

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Quantitatively examined, the availability has different meanings:

- Availability (time) is the percentage of time in which a product is in working order;

- Availability (the machine) represents the percentage of machines available after a running time, due to the cumulative effect of the units that have not failed and those units that have been put back into operation within a preset maximum interruption time;

- Availability (mission) represents the percentage of tasks within a certain period that has no faults that? cannot be fixed within a specified interruption time.

Availability can be maintained by 4 different means:

- reliability,
- maintenance,
- correct use,
- renewal.

Availability by reliability is easy to understand: it has long been known that it is cost-effective to pay something more expensive to have fewer fails. The main difficulty arises when the limit has to be set. Highly reliable parts cost 5 to 10 times more than ordinary parts, and often no profit is obtained in this way. If the annual maintenance expenses represent 10% of the purchase price of equipment, an increase of this price by 10% - 20% appears advantageous. In practice, a compromise is sought between the purchase price, the requested service, and the accepted risk.

Availability trough maintenance - results from the fact that reliability is a probability. Reliability is technically and financially limited. The defects in the initial period of bearing, as well as those of the subsequent period, of wear (corresponding to the aging of the material), derive from inevitable physical phenomena, and the defects during the period of use (intermediate, corresponding to the maturity) have an accidental regular character. Also, reliability can deteriorate over time, even during the storage period, thus generating additional failures. Reliability is restored to its normal level by troubleshooting or preventive maintenance, as defects are predictable or unpredictable. It can be noticed, from the above, that the maintenance does not always correspond to a real intervention on the equipment, and that it can exist in the form of static security that gives a quality guarantee to the eventual troubleshooting. Maintenance is the extension of reliability, and the two are mutually supportive.

Availability by proper use of the machines is often ignored; machines, appliances, and installations are abused by mounting them in inappropriate environmental conditions or by overloading. This is why modern equipment is designed so that it can survive such abuses, and this not so much by their robustness but, above all, by the automatic control of the functional parameters and by the safety protection with which they are equipped. This is a design problem that is properly resolved by engineers only through their direct contact with users and maintenance managers.

Availability through renewal is the only way when the equipment and materials age, the many defects requiring important maintenance operations, sometimes economically expensive, to obtain the necessary availability. We are dealing with a vicious circle that can only be removed by replacing it with other new equipment.

Availability indicators

The average time of proper functioning is expressed by the relation:

$$\text{MTBF} = \frac{\sum T_i}{n} \qquad (3.70)$$

where T_i is the faultless operating time intervals and **n** is the number of t_i intervals.

a) **The rate of defects (falls)** is defined by ?

$$\lambda = \frac{1}{MTBF} \qquad (3.71)$$

c) **The average repair time** is expressed by the ratio:

$$\text{MTR} = \frac{\sum t_i}{n-1} \qquad (3.72)$$

where t_i are intervals of repair time, and n is the number of intervals t_i.

d) **The repair rate** is given by the formula:

$$\mu = \frac{1}{MTR} \qquad (3.73)$$

e) **Availability** is expressed through relations:

$$\text{D} = \frac{MTBF}{MTBF + MTR} = \frac{\mu}{\mu + \lambda} \qquad (3.74)$$

$$\text{D}(t_i, T) = \text{R}(T) + \text{Q}(T) \times \text{M}(t) \qquad (3.75)$$

where R(T) is reliability at time T and Q(T) is non-reliability at time T and M (t) is maintainability at time t.

As it results from the above relations for calculating the availability of a system it is necessary to calculate the

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reliability of the system as well as its maintainability.

3.4.2. Availability parameters

The operation of any repairable product (such as a machine, an installation, equipment) during the normal operating period (useful life) is characterized by a succession of states in which the operating periods alternate with those of failure (stoppages or forced shutdown), or with planned shutdown states. Planned stoppage states are influenced by deterministic events (human decisions); these states are not random.

If the operating status is noted with 1 and the malfunctioning state with 0, then the operating behaviour of the product is a two-state Markov stochastic process:

$$\{x(t) = i; i = 0;1\}$$

If the product is in working order at time t, the probability that it will fail in the elementary time interval (t, t+Δt) is z(t), where z(t)Δt is the product's failure intensity.

Also, when the product is in a defective state at time t, the probability of it being put back into operation within the elementary time interval (t, t+Δt) is μ (t) Δt, where μ (t) is the intensity of restoration.

If it is admitted that the functions z (t) and μ (t) are constant over time, then the possibilities of transition (transition) of the process are:

$$P_{01}(t, t+\Delta t) = \lambda \Delta t \; ; \quad P_{00}(t, t+\Delta t) = 1 - \lambda \Delta t \qquad (3.76)$$

$$P_{10}(t, t+\Delta t) = \mu \Delta t \; ; \quad P_{11}(t, t+\Delta t) = 1 - \mu \Delta t$$

Also, for the fault-free operating time (T_f) and the repair time (T_r), the fundamental assumption is accepted that they are random, independent and identically distributed variables.

In order to determine the absolute probabilities of the process, the system of differential equations is obtained:

$$\left.\begin{aligned} P_0'(t) &= -\lambda P_0(t) + \mu P_1(t) \; ; \quad & P_0(0)=1 \\ P_1'(t) &= \lambda P_0(t) - \mu P_1(t); \quad & P_1(0)=0 \end{aligned}\right\} \qquad (3.77)$$

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Solving this system of equations results:

$$P_0(t) = P_0(0)e^{-(\lambda+\mu)t} + \frac{\mu}{\lambda+\mu}\left[1-e^{-(\lambda+\mu)t}\right] \tag{3.78}$$

Respectively:

$$P_1(t) = 1 - P_0(t) \tag{3.79}$$

If the state 0 is considered as the initial state of the process, then $P_0(0)= 1$and results:

$$P_0(t) = \frac{\mu}{\lambda+\mu} + \frac{\lambda}{\lambda+\mu}e^{-(\lambda+\mu)t} \tag{3.80}$$

$$P_1(t) = \frac{\lambda}{\lambda+\mu}\left[1-e^{-(\lambda+\mu)t}\right] \tag{3.81}$$

If the state 1 is considered as the initial state of the process, then $P_0(0)=0$ and it results:

$$P_0(t) = \frac{\mu}{\lambda+\mu}\left[1-e^{-(\lambda+\mu)t}\right] \tag{3.82}$$

$$P_1(t) = \frac{\lambda}{\lambda+\mu} + \frac{\mu}{\lambda+\mu}\left[e^{-(\lambda+\mu)t}\right] \tag{3.83}$$

Replacing $P_0(t)$ with D(t), respectively $P_1(t)$ with U(t), assuming that state 0 is the initial state of the process, i.e the product is in working state at time t = 0, the respective expressions become:

$$D(t) = \frac{\mu}{\lambda+\mu} + \frac{\lambda}{\lambda+\mu}e^{-(\lambda+\mu)t} \tag{3.84}$$

$$U(t) = \frac{\lambda}{\lambda+\mu}\left[1-e^{-(\lambda+\mu)t}\right] \tag{3.85}$$

The expression D(t) is the *availability function* of the product, that is, the probability that the product is available (in working order) at time t. The availability function D(t) is a monotonically decreasing function of time, with an initial value D(0) = 1 and with asymptotic value:

$$\lim_{t\to\infty} D(t) = D = \frac{\mu}{\lambda+\mu} \tag{3.86}$$

The above expression is the *stationary availability* of the product, that is, the probability that the product will be available at times away from the initial moment. By entering the value D in the expression of the availability indicator, the obtained formula is:

$$D(t) = D + (1\text{-}D)\exp\left(-\frac{t}{D \cdot T_r}\right) \tag{3.87}$$

where:

$$\frac{t}{D \cdot T_r} = (\lambda + \mu)\, t = \left(\frac{1}{T_f} + \frac{1}{T_r}\right) t \tag{3.88}$$

The variation of the availability function D(t) can be represented graphically as in figure no. 3.14. From this variation one can deduce the speed with which the function D(t) approaches its asymptotic value D. It is observed that this function decreases exponentially, having the time constant D.Tr.

If t =D.Tr then the expression of availability becomes:

$$D(D.Tr) = D + (1\text{-}D)e^{-1} = D + 0{,}368\ (1\text{-}D)$$

On the contrary, if t = 0, then the expression becomes:

D(0) = D + (1-D) =1

which can still be written:

D(0) – D =1-D

In other words, the difference between the function D(t) and its asymptotic value D is maximum at the initial moment, but it decreases quite quickly becoming null.

These findings are valid not only for the exponential distribution but for any kind of distribution of the operating time without faults (T_f), respectively, of the repair time (T_r). The expression U(t) is the *unavailability function* of the product U(t), that is, the probability that the product will be unavailable (in defective state) at time t.

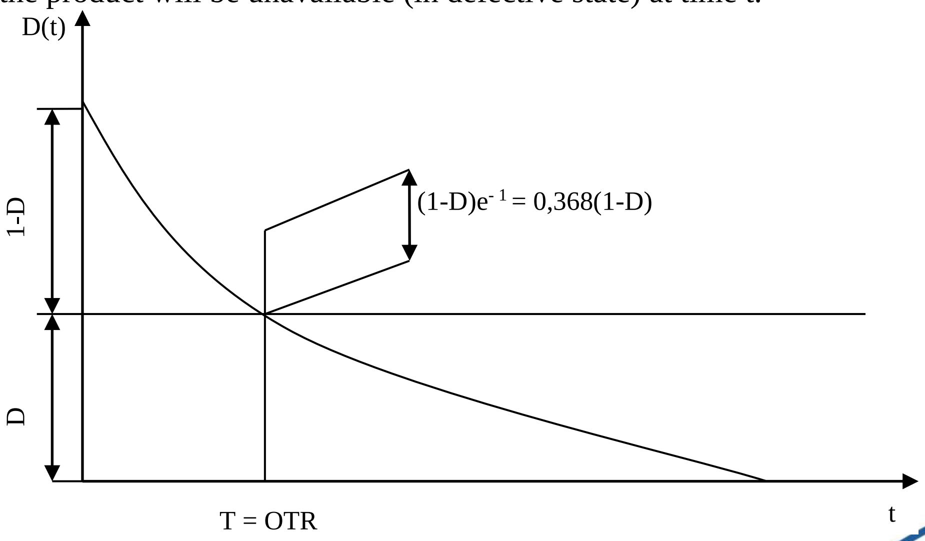

Figure no. 3.14. Graphic expression of the availability function

Source: [7]

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Because at a time t a product is - according to the accepted hypothesis - either in working condition or defect, it turns out that between D(t) and U(t) there is the relation:

D(t) + U(t) =1 sau U(t) = 1-D(t)

The unavailability function U(t) is a monotonically increasing function of time, with an initial value U(0) = 0 and with an asymptotic value:

$$\lim_{t \to 0} U(t) = U = \frac{\lambda}{\lambda + \mu} \tag{3.89}$$

The above expression constitutes the *stationary unavailability* of the product, that is, the probability that the product will be unavailable (in defect state) at moments away from the initial moment.

If the product is not restored, it is obvious that μ = 0 and then the expressions D(t) and U(t) become:

$$D(t) = e^{-\lambda t} = P(t) \tag{3.90}$$

$$U(t) = 1 - e^{-\lambda t} = Q(t) \tag{3.91}$$

In other words, in this case, the availability function is exactly the reliability function, and the unavailability function is exactly the non-reliability function.

Because the asymptotic value D is constant, the stationary availability is also called the *availability coefficient*, and noted K_d, and it is calculated as follows:

$$K_d = \frac{\frac{1}{n}\sum_{i=1}^{n} t_i}{\frac{1}{n}\sum_{i=1}^{n} t_i + \frac{1}{n}\sum_{i=1}^{n} t_i'} \tag{3.92}$$

where t_i is the faultless operating time intervals, t'_i is the repair time intervals, and n is the number of intervals, t'_i is respectively t_i. Using other common notations, the above expression can be written:

$$K_d = \frac{MTBF}{MTBF + MTR} \tag{3.93}$$

in which MTBF is the Average Time of Proper Functioning, and the MTR is the Average Time of the Restoration (repair).

Taking into account the above expressions it is observed that the availability of the product is the result of two events: reliability and maintainability.

Noting with P(E) the probability of performing at least one of the two events (that is, the probability that? the product will be in working order at any given time), the expression is obtained:

$$P(E) = P(E_1 \text{ U } E_2)$$

where E_1 is the proper functioning event and E_2 is the repair event. The events E_1 and E_2 being independent and knowing that $E_1 \cap E_2 \neq \Phi$, one can write:

$$P(E_1 \cup E_2) = P(E_1) + P(E_2) - P(E_1 \cap E_2)$$

So:

$$P(E_1 \cap E_2) = P(E_1) \cdot P(E_2)$$

from which it is obtained:

$$P(E_1 \cup E_2) = P(E_1) + P(E_2) - P(E_1) \cdot P(E_2)$$

or:

$$P(E_1 \cup E_2) = P(E_1) + [\ 1 - P(E_1)\ ] P(E_2)$$

Repacing:

$P(E_1 \cup E_2) = D$ – availability

$P(E_1) = R$ – reliability

$P(E_2) = M$ – maintainability

We obtain:

$$D = R+(1-R)\cdot M \qquad (3.94)$$

If D, R and M depend on time, then the above expression takes the form of:

$$D(t) = R(t)+[1-R(t)]M(t') \qquad (3.95)$$

From the above expressions, it can be deduced that the *availability* of a product (element or system) is determined by two probabilities:

a) The probability that the product will work without fail within a time interval t (reliability);

b) The probability that the product that fails in the time interval t will be put back into operation within the time interval t'(maintainability).

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In other words, with these expressions one can find the economic optimum between the expenses for reliability and those for maintenance, in order to obtain a required level of availability of the product, that is to say, to fulfil the requirements for the product to fulfil the service for which it was intended, with minimum overall cost.

The expressions D(t) and U(t) correctly represent the availability, respectively the unavailability of the product, both at moments close to the initial moment and at moments distant from the initial moment.

The expressions of D (as an asymptotic value of D(t)), correctly render the availability, respectively the unavailability of the product only for moments far away from the initial moment.

Availability is the most complex form of manifesting the quality of the products in the process of their exploitation, as it includes both their reliability and their maintainability.

Another availability parameter is the *average number of restores over a period of time*. Being an availability parameter specific to repairable products (with restoration), the average number of product recoveries in a given time interval T can be calculated either based on the availability function D(t) and the failure intensity λ, or on based on the unavailability function U(t) and the restoring intensity μ. Consequently, this reliability parameter can be obtained using the expression:

$$\eta = D(t)\lambda T \qquad (3.96)$$

or:

$$\eta = U(t)\mu T \qquad (3.97)$$

3.5. Typology of the industrial production

The concrete organization of the production processes in various forms is directly dependent on the number of product names that are manufactured in the respective link, with the volume of production that is manufactured from each type of product, with the establishment of the manufacturing nomenclature. All these parameters are therefore linked to the typology of industrial production.

The type of production can be defined as the total of the technical-organizational factors that characterize the stability of the nomenclature of the manufactured production, the volume of the production, the degree of specialization of the jobs, of the sections or companies and the way of the movement of the material factors for production on the jobs. The practical importance of the structuring by types of industrial production consists in fact of

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the type of production that is part of an organizational link of the company and determines the management methods used, the technical preparation of the manufacturing, the records, and control, etc.

There are theoretically three types of production, namely *mass, serial and individual production*, although in practice none of them exists in pure form. Therefore, the classification of an organizational link of the company in one or the other of the three types of production must take into account not one criteria, but a set of criteria that characterize each of the three types of production separately.

The existing differences between different types of production influence the workload of the jobs and, therefore, the degree of specialization of each job. In this respect, we distinguish the following jobs: jobs in which a certain operation is carried out permanently at the same part (characteristic for mass production); jobs where several types of operations are carried out permanently on several part and which are repeated after certain periods (characteristic for serial production); jobs at which different operations are performed on a variety of parts, which are repeated for indefinite periods or which are never repeated, unfolding without having a certain succession (characteristic for individual production).

The type of production influences not only the degree of concentration of the manufacture of one or another of the parts but also the size of the workload coefficient, which can take the following values: below 0.1 for the individual production; between 0.11 and 0.8 for series production; between 0.8 and 1 for mass production. The type of production exerts an important influence on the costs of production, in the sense that, if the organization of production is closer to the mass type, the cost is lower due to the reduction of the share of wages as a consequence of the increase of specialization and labour productivity. Otherwise, the closer the production organization gets to the individual production, the higher the costs are.

Each of the three types of production has certain characteristics and conditions of organization as follows:

3.5.1 Mass production type

The organization of this type of production occurs only when the permanent loading of each job with the execution of the same part is ensured, that is when the volume of production and the labour costs necessary to execute it satisfy for each operation of the technological process or all the operations performed by an executing, successively on each product unit, the relation:

$$Q \cdot t \geq F^t \tag{3.98}$$

where: Q represents the production volume of the respective part during the period considered;

t - the time required to execute the respective operation or the total operation on a product unit;

F^t - the time fund of the work place at which the respective operation is performed for the period considered.

From the analysis of this formula it results that the volume of work on each technological operation or on total operations must ensure full employment during the period considered, that is:

$$t \geq \frac{F_t}{Q} \tag{3.99}$$

If we note $\frac{F_t}{Q}$ = C (the cadence), that is, the period of time between obtaining on the flow line of two consecutive products of the same kind, it results:

$$t \geq C \quad \text{or} \quad \frac{t}{C} \geq 1 \tag{3.100}$$

Therefore, the main condition of mass production organization is that the ratio between the time spent on the part of reference for a particular operation and the cadence of the line is over unitary. The ratio between t and C serves as an indicator for determining the degree to which a particular production has a mass character or not. With the help of this indicator, the number of jobs is calculated, which must be organized for the continuous execution of a certain operation, i.e., a rhythmic production is ensured under certain conditions.

The characteristics of this type of production are:

- The specialization of each performer or workplace in the execution of a certain technological operation during the considered period, which leads to the creation of the necessary premises for the increase of labour productivity;
- As a result of the full specialization of the jobs, it is possible to distribute a complex of machines to execute products of the same type size and thus to create specialized sectors or technological lines on landmarks or parts. This is possible by placing the machines, installations, and equipment in the sequence of the operations provided for in the technological flow of manufacture of the respective product or part. The parts and subassemblies move rectilinearly, which creates the necessary premises for the proper ordering in time of the production. The tasks of the operative management of the respective production are greatly simplified;
- The movement of the parts and subassemblies ensures the rapid development of the technological process, the transformation of the production material into finished product, in the shortest possible time. Continuous execution of the same part or product avoids the formation of products batches, because each product, after completing a particular operation, immediately goes to the workplace where the next operation is performed;
- The production cycle has a minimum duration as a consequence of

the rectilinear and individual displacement of each product:

$$D_{cip} = t_l + t_2 + \ldots + t_n = \sum_{i=1}^{n} t_i \tag{3.101}$$

where: D_{cip} is the duration of the production cycle on the part or product i;

t_i - the unit time of the operation of the technological process on the part or product i;

- For the production of the same product or part in large quantities, appropriate expenses for machinery, equipment, and work installations are properly admitted. That is, the specific weight of the specialized equipment with a high degree of technical endowment is high, and the S.D.V.'s can be specialized to the maximum, which allows the optimal execution of each operation;
- The norms regarding the duration of the operations, due to the continuous repetitions on the same workplaces, can be studied and established with special attention, as they are much closer to the actual duration of their execution, so the calculations for their foundation are more precise;
- Daily, each job consumes the same type and size of raw materials, materials and semi-manufactured goods, which makes the organization of the auxiliary activity not dependent on the production needs as is the case with the mass production and the individual production.

The basic condition for mass production can be satisfied with different products to a different extent. At a certain volume of labour costs of the operations, the production volume of the respective product can be so large, so that at each operation the mass character of the output (I_m) is equal to one.

Depending on the extent to which the volume of production and the volume of labor costs of the operations as a whole satisfy the relation $I_m = 1$, we distinguish the following variants:

- *Automated flow mass production (automatic flow lines*) characterized by complex automation of the production process in the sense that all technological operations are performed with machines and equipment, all in an automatic line, with minimal human effort;
- *Mass production in non-automated flow*, which is characterized by the continuous movement of natural production factors in the production process, that is, each part after being processed at one operation is transmitted to the next operation, the transport is continuous. This variant assumes that the I_m indicator for all operations must be expressed in whole numbers, i.e. the duration of the operations must be multiple or equal to

the cadence of the line, according to the relation:

$$t \times Q = N_{lm} \times F_t \quad \text{sau} \quad I_m = \frac{t}{C} = N_{1m} \qquad (3.102)$$

where: N_{lm} represents the number of workplaces or machines from a given operation, expressed in whole numbers;

- *Mass production in intermittent flow*, characterized in that a part of the operations or all the operations have a duration that is neither equal nor multiple to the cadence of the line. It is frequently encountered in the mechanical processing units, and the inequality of the report is caused either by the reduced quantities of products that are executed from each kind, or by the impossibility of dividing and regrouping the related operations, or by the constructive and technological instability of the products to be executed, which limits the use of specialized technological equipment. To minimize the possibility of wasting time under the conditions of this variant, it is necessary to use a special form of work organization.

3.5.2. Series production type

This has as main feature the repetition of the executing the same production as in the mass type. The essential difference between the two types of production is given by the fact that the volume of unit labour costs correlated with the quantity of production to be executed in a given period in the case of serial production, is insufficient to ensure the loading of each workplace only with the execution of a particular job and therefore does not allow the manufacture of the same product to be permanently extended for a longer period.

The mathematical restrictions that must be met by the series production are:

$$Q \times t > F_t \quad \text{şi} \quad O > N_u \qquad (3.103)$$

where: O represents the number of operations through which the different parts to be executed during the given period pass;

N_u = number of machines or equipment (workplaces) required in a given period to perform the production task Q.

The full use of an executor's time fund is accomplished by improving the various operations of the technological process related to the different parts or products. The more different the terms of inequality, the greater the number of different operations that must be performed on a particular workplace to ensure the full use of the time fund of that job are.

The full use of the working time fund in this type of production is realized when:

$$Q \times t = F_t \qquad (3.104)$$

where: F_t represents the total working time fund;

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Q,t = the quantity of products respectively the time required to perform all the operations at the considered workplace.

This type of production has the following characteristics:

- Due to the lack of a full specialization of the workplaces, it is not possible to separate a particular machine or production sector in which only products of a certain type and size can be executed. Because each position in the production program occupies only part of the time fund of the job, of the machine or the operator, after performing the tasks that refer to this position, the operator will do tasks related to another position in the production program, and the machine will be stopped and subjected to a new adjustment. Otherwise, both the operator and the machine will be waiting for a long period of time until they will again receive tasks related to the same position;
- The technological flow of several products is often different, for which the composition of the jobs that are performed on different workplaces is not the same at all workplaces. For these reasons, in the series production sections, the location of the machines is usually done not according to the technological flow, but according to the characteristics of their constructive and technological homogeneity;
- The passing of the parts and products from one operation to another, from one workplace to another is done in batches of parts or products. This is because it is not possible to execute the production piece by piece, executing each product copy individually, which would require considerable time for preparation and completion. To reduce the weight of this kind of spending of time in total time per piece, products or parts of a certain type size are organized into groups of n products and pass through such batches through all technological operations;
- Substantial increase in the duration of the manufacturing cycle following the execution of the parts or products on batches:

$$D_{cip} = n\,(t_1 + t_2 + \ldots t_n) \qquad (3.105)$$

where: n represents the size of the batch of parts or products.

This increase is determined by the fact that at the execution of each operation on a certain workplace, there is not one product at the same time, but a batch of n products:

- The batch size is an important factor to increase the productivity of the work and to improve the use of the machine. The lower the weight of the preparation-completion time in the total time per piece is, the better both the working time of the operator and the time background of the machine is. The size of the batch is in turn influenced by the volume of unitary expenses of workforce and materialized by the complexity of the technological process, etc. The efficient use implies two conditions: for each part of the product that is executed, it is necessary to establish and determine the necessary sizes of the batch; different parts of the finished product are repeated in series production with different frequencies, meaning that the parts produced in larger batches are repeated less often, and those in smaller batches, more often;

➢ The incomplete specialization of the workplaces reduces the technical-organizational basis of the company with serial production, fact materialized in the variable character of the loading of workplaces and, related to it, the need to systematically change the adjustment of the machines - in case of transition to the execution of another job - makes it difficult to use the specialized, automated and semi-automated machinery in mass production. The possibilities of technical standardization of work and of a well-established determination in duration of the technological processes are reduced, the smaller the quantities of products that are executed of each kind and the more frequently the production schedule changes. The systematic change of the production tasks and of the conditions of production at workplaces, make the auxiliary and service activities, the technical quality control, the organization of the records, etc. to be much more complicated than in the case of mass production.

Depending on the degree of fulfilment of the characteristics specified above, we distinguish three forms of serial production, namely: *serial production in flux* (large series production); *series production* (medium series); *series production with a nomenclature of products that are not systematically repeated* (small series).

3.5.3 Individual production type

This type has obvious differences from the previous types and is characterized by the following features:

➢ The instability of the nomenclature and the great variety of the production that is done in small quantities. Although the manufacture of each product or part, in this case, requires high costs, however, limiting the production to these products in a certain period of time would not ensure full loading of the existing machinery and equipment in the company. For these reasons, in such companies, a large variety of products are produced in parallel, but in small quantities, sometimes unique;

➢ The technological specialization of the workplaces or permanent parts and details on certain workplaces are impossible. This is because a large variety of products are manufactured, but in small quantities;

➢ Universal machines and SDVs are used, due to the variety of manufactured products and the lack of repetition of these products;

➢ The production cycle has a relatively long duration. The wide variety of the nomenclature of manufactured products, the high frequency of changes in the manufacturing nomenclature, the use of universal machines and SDVs, determines a relatively long duration of

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the production cycle and the form of successive joining of operations;

➢ The proximity of the operative management to workplaces, because on these there is at the same time a large number of constructively and technologically special parts, which makes the operation of centralized management difficult.

The situation of the Romanian industry during the transition period is characterized by restructuring and reconversion, by switching to the most efficient form of industrial management. This passage must be a continuous line of the development of the main industrial branches, which is why the classification of production by types has not only a theoretical character but also a practical one, even prospectively, which will lead, according to the characteristics of each type of production, to the choice of the type that will allow to increase production, improve its qualitative parameters, and increase the contribution of industrial production in increasing macroeconomic indicators.

Questions to check understanding

1. What are the possibilities for collecting data regarding the maintainability of a product?

2. Choose an equipment / product that you have; establish for it, the indicators that define maintainability - the relative frequency of defects, the cumulative frequency of defects, the average time of good operation and the average time of repairs.

3. Describe the model of the exponential function in the maintenance of a product.

4. Describe the Weibull distribution model for evaluating the maintenance of a product.

5. List the relationships for calculating / evaluating the maintainability of a repairable / irreparable product.

6. How many types of production do you know? State the characteristics for each type of production.

4. FREQUENCY, USE AND LUBRICATION OF COUPLES FREQUENTLY

4.1. The connection between the wear process and the defects

In order to increase the reliability of the technical systems for long durations, it is necessary to eliminate the defects from the "youth period" and to strictly apply the procedures regarding the preventive replacement of the elements, in order to exclude the influences due to the wear. A technical system subjected periodically and systematically to revisions carried out at appropriate time intervals, does not practically age. The elements not having the weather to wear out, the failure rate, reduced in size, will only reflect the phenomenon of accidental damage. In such cases, the behaviour of the products does not depend on the history of their previous evolution, the current state and mode of operation do not depend on the past, the current defects are not influenced by the past ones, and the future ones do not depend on the past ones, the repaired product can be considered as performing same service as a new product. In these circumstances, we have to deal with the so-called "memory-less processes".

Generally, the reliability calculations during the normal operating period are performed using exponential or Poisson distribution laws, but it is necessary to take measures to prevent the occurrence of wear phenomena, by programming the replacement of the elements towards the end of the normal operating period, in order to see elimination of aging and wear drops.

However, the studies to estimate the reliability cannot be carried out solely on the basis of the data related to accidental malfunctions, neglecting those of wear.

The study of wear is particularly useful for establishing the preventive maintenance regime, for sizing the stock of spare parts and other specific activities.

The use of these studies is more obvious for complex systems consisting of tens of thousands of elements, where the probability of wear failure can reach values that affect the degree of reliability even when the accidental failure rate is close to zero. The mission of the "Challenger" cosmic shuttle was compromised by the lack of quality of a sealing seal, which did not resist the temperature changes during the shuttle launch.

In [2] the following experimentation model is proposed: a number of identical products are subjected to observation until all the elements are damaged or a significant percentage of the volume of the observed ones is detected. Information regarding "youth defects" and "wear defects" will be excluded. It is assumed that the rate of accidental defects remains constant during the normal lifetime, so the probability of accidental defects also remains unchanged, but increases the probability of wear defects as time progresses. Fix or exponential? From the studies on the wear process and the fall regime, the idea of a well-defined tendency in the evolution of these phenomena emerges.

Modelling such behaviour must take into account this particularity. Different solutions are envisaged: some authors recommend the use in these cases of normal or non normal law, and others consider that the description of these phenomena is done with the help of Weibull distribution.

4.2. The friction-lubrication relationship

Rubbing and its effects.

Friction can be defined as a complex process of molecular, mechanical and energetic nature, which takes place between the contact surfaces of two or more bodies in relative motion with each other.

The rub may be:

- harmful, due to the occurrence of heating and wear phenomena leading to the removal of the friction subassembly (bearings, piston-cylinder, gears, etc.), or due to the occurrence of vibrations (shaking movement that appears in the guides of the machine tools, presses, etc.);
- useful, when it appears on clutches, brakes, wedge joints, friction variants, etc., although it may be accompanied by heating, vibration and wear phenomena.

Rubbing can be of several types:

1. Dry rubbing occurs when no lubricant layer is interposed between the surfaces of the contacting bodies, except for the films absorbed from the ambient gas environment (O2, N2, H2O molecules). The size of the frictional force depends on the pressure, the nature, the degree of finishing, and the relative speed of the surfaces in contact. This type of friction causes the phenomenon of oscillation to occur, which converts mechanical energy into thermal energy, followed by wear of surfaces and even rapid bending of contacted parts. Good lubrication totally or partially removes these consequences, function and operation, roughness of the surfaces and materials used.

2. The fluid and semifluid rubbing (figure no. 4.1) occurs when between the contact surfaces there is a layer of fluid composed in turn of three parts: two of them adhere to one surface, and the third is between the two. Friction occurs due to the exchange of molecules at different speeds. Due to this fact, there is an increase of the molecular disorder and therefore the heating, which depends on three factors:

- the relative velocity between the fluid layers;
- the thickness of the fluid layer between the two surfaces;
- the nature of the fluid, characterized by the viscosity coefficient, which leads to a semi-fluid friction when it is very fluid.

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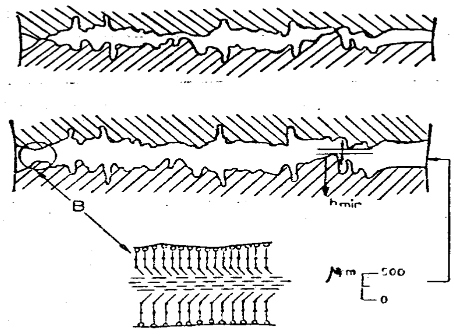


Figure no.4.1. Sketch of the semifluid a) and fluid b) friction regime

Source: [13]

3**.** Limiting or unctuous rubbing (Figure no. 4. 2.) occurs when the pressure between the contact surfaces is high and the fluid layer between the surfaces is rapidly removed, leaving only the fluid adhering to the surfaces, but sufficient to prevent direct metal-metal contact, and possibly the flu. The layer of lubricant adhering to the friction surface is connected to it by strong molecular adhesion forces, making a greasy lubrication. Under very severe conditions, the absorbed layers can be removed from the friction surfaces. In these situations, either a solid lubricant (graphite) or a chemical reaction layer (metal oxide or sulfide) is required.

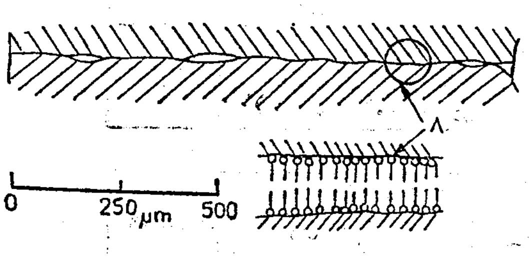
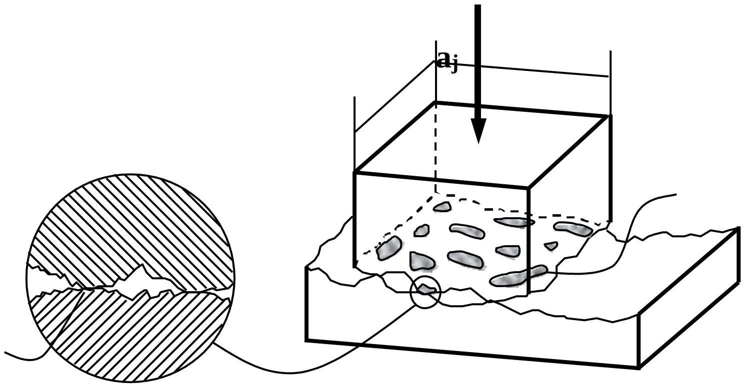


Figure no. 4.2. Sketch of the contact of surfaces in the limit friction regime

Source: [13]

The real contact surface is the sum of the micro-surfaces obtained by the mutual deformation of the bodies, with the area given by:

A r = ∑ci. The apparent area can be calculated according to Hertz's theory, if the equations with pyramids, hemispheres, etc. are equated.



As size order: Ar ~ 10-4 Year.

Figure no. 4.3. Calculation of the real surface

Source: [8]

The real area is calculated on simplified models taking into account the elastic contact theory and the asperity distribution laws. The results are controversial.

4.2.1. Theories of dry rubbing

The mechanical theory explains the existence of the friction force by the energy consumed for the asperities escalation.

Molecular adhesion theory considers that friction occurs as a result of the need to overcome intermolecular forces. Thus, it is assumed that in the case of contact between bodies with surfaces with reduced asperities (fine, polished surfaces) adhesion forces appear which generate the friction.

The welding bridge theory (Bowden, Tabor, 1939) considers that the friction is due to the breaking of the welding bridges (micro-suddles as in figure no. 4.4.) that are instantaneously formed at very high temperatures (800 ... 1000 C). The micro-suddlers are made and unfolded consecutively in movement. Although the mentioned temperatures could not be measured, it was found that the average temperature of the parts rarely exceeds 80-100 0 C.

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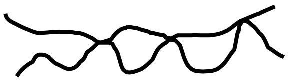

Figure no.4.4. Ruptures of micro-cracks in welding bridges

Source: [8]

The elastic and plastic deformation theory states that such deformations of the contact asperities occur resulting in friction. The quantum energy theory claims that friction occurs due to energy exchanges at the atomic and subatomic levels, between the contact materials.

Mixed molecular-mechanical theories try to approach complex the occurrence of friction, by simultaneously considering several of the aforementioned theories.

4.2.2. Dry friction laws

Coulomb, continuing Amontons' research, outlined four laws of dry rubbing:

a) The frictional force is proportional to the normal load on the contact surface: Ff ~N;

b) The frictional force depends only very little on the relative speed;

c) The friction force does not depend on the nominal contact surface;

d) The frictional force depends on the nature of the body of the coupling and on their degree of processing.

This resulted in the first mathematical expression of the frictional force:

Ff = μa N (4.1) , where μa is the coefficient of friction at slip.

Much later, Bowden and Tabor [1], using the theory of micro-junctions and considering the dry contact of two metal surfaces under normal load N, they hypothesized that the real contact area Ar is created as a result of the transition of the asperities from the elastic deformation regime to the plastic regime. Thus, the real area Ar can be expressed:

$$A = \frac{N}{r} \times \sigma_c \qquad (4.2)$$

where σc - the flow voltage for the weakest material.

In this case, the friction force is precisely the shear force required to shear the micro-junctions:

$$F_f = A_i \, \tau r \qquad (4.3)$$

where τr - the shear breaking voltage of the micro-junctions.

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From the relations (4.2) and (4.3) a new relation for the coefficient of friction results:

$$\mu = \tau r / \sigma c \qquad (4.4)$$

It follows that to have a low coefficient of friction it is necessary that τr be small and σc very large, which cannot occur simultaneously in a common material.

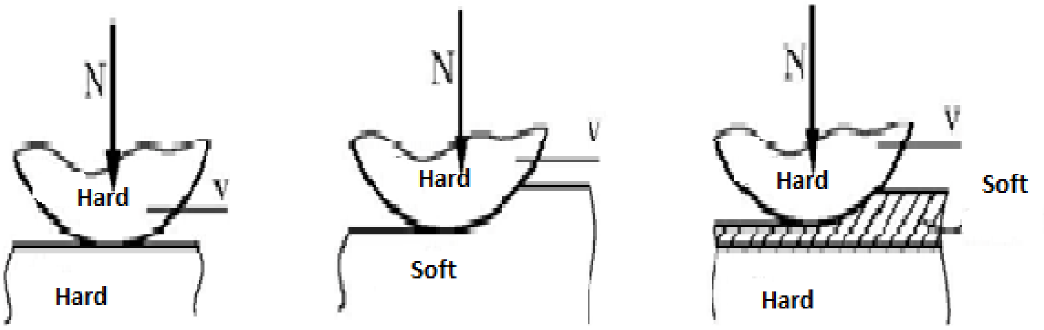

Figure no 4.5.a Couple of hard/hard materials
Source: [8]

Figureno.4.5.b Couple of hard/soft materials
Source: [8]

Figure no.4.5.c Couple of hard/soft hard materials
Source: [8]

For couplings of hard materials (Figure no.4.5.a) it is observed that both materials are worn out. In the case of couples with a harder and softer material (Figure no.4.5.b), softer material is worn.

A better solution is the one, in which two hard materials are used, one of them being covered with a soft layer (Figure no.4.5.c) which will be the worn one.

Table 4.1. presents the values of the friction coefficient for different pairs of materials that operate in two friction-lubrication regimes.

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Table 4.1. The values of the friction coefficient for different pairs of materials that operate in two friction-lubrication regimes.

m	OL / Bz phosphours	OL / Bz synthesizd	OL / OL	OL / Fc	OL / Graphite	OL / Composition (others softly infernal) (aliaj moale neferos)	OL/ferodo (asbestos impregnated with resins)
Regime dry	0,7	0,28	0,6÷1,2	0,18÷0,6	0,08÷0,1	0,15÷0,18	0,3÷0,4
Regime limit or mixed	0,1÷0,2	0,11÷0,25	0,1÷0,25	0,1÷0,2	-	0,08÷0,1	-

Source: [8]

In general, it is unacceptable to use rubbing couplings made of the same materials.

Friction limit (to the limit)

The terminology and conditions for the emergence of the friction regime at the border are not yet unanimously accepted.

The actual operating conditions of a coupling lead to the decrease of the slip friction coefficient (μ ak) relative to the theoretical dry regime, due to dust, oxides, unctuous layers, water, etc. It is accepted that there are several cases of occurrence of the friction regime at the limit, these manifesting separately or concurrently.

I. The bodies are separated by molecular thin layers of absorbed or chemisorbed lubricant (Van der Waals bonds). The adhesive layer is bonded to the metal by strong adhesion forces (Figure no.4.6.). Only under severe conditions this layer is torn. At very high loads the oily layer is pierced.

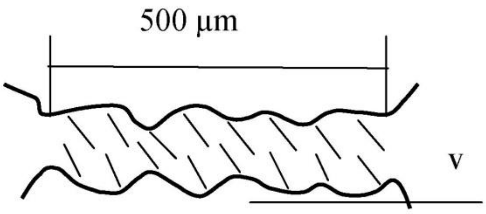

Figure no. 4.6. Strong adhesion forces.

Source: [8]

II. The bodies are separated by solids (powders) with lamellar structure (graphite or MoS2 - molybdenum bisulfide) (Figure no.4.7). The added substance is usually incorporated into an epoxy resin.

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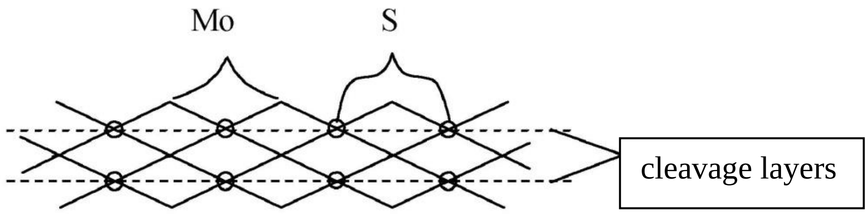

Figure no. 4.7. Occurrence of cleavage layers

Source: [8]

In this case, although the coefficient of friction decreases only a few times, the wear is reduced thousands of times compared to the dry friction.

III. Extreme pressure lubrication (EP) occurs when a solid layer is formed as a result of the chemical reaction between an inorganic substance and metal. As a result of the reaction, a product with a solid lubricant (e.g. chlorine, sodium, phosphorus) is obtained. This release also occurs at the high temperatures produced by the contact of the coupling.

IV. Lubrication with a thin metal layer deposited prior to operation (lead, iridium).

V. Lubrication with layers of oxides, sulphides or chlorides.

All these aspects appear as technically dry rubbing regimes.

Table 4.2 presents the values of the friction coefficient of several rubbing couplings lubricated with various lubricants.

Table 4.2. the values of the friction coefficient of several rubbing couplings lubricated with various lubricants

Friction couple	**Layer type**	**The coefficient of friction**
OL / OL	Molecular oil	0,1 ... 0,16
OL / Fc	Fatty acids	0,05 ... 0,12
OL / OL	Stearic acid	0,1 ... 0,11
OL / Cu	Stearic acid	0,09

Source: [8]

Semifluid or mixed rubbing

Semifluid (mixed) rubbing is a complex phenomenon that occurs at the limit of fluid friction, when the thick layer of fluid breaks and successively recovers. In the bags between the pieces there is fluid lubrication (HD) and on the tips in contact, lubrication at the limit (Figure no.4.8.). The regime is characteristic of starting and stopping the car or in the case of couples with alternating-symmetrical movement.

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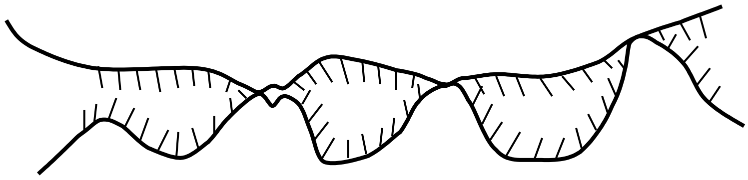

Figure no. 4.8. Lubrication at the friction limit

Source: [8]

When the loads increase, the friction regime is reached strictly "to the limit".

The transition from the fluid or mixed lubrication state to the boundary lubrication state can be materialized by a diagram (Figure no. 4.9.) in which the friction coefficient increases simultaneously with the increase in temperature, the lubricant being gradually expelled, from the thick layer remaining only the greasy layer.μ.

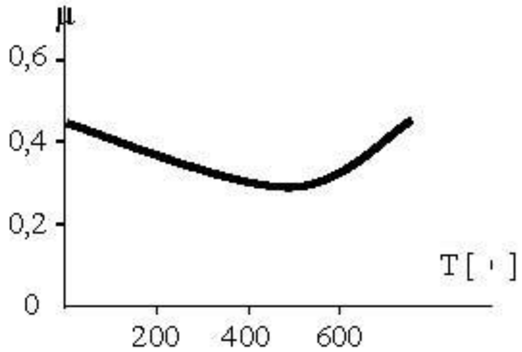

Figure no. 4.9. Change of friction coefficient with respect to temperature

Source: [8]

Table 4.3. shows the orientational values of the friction coefficient, depending on the type of lubrication regime.

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Table 4.3. the orientational values of the friction coefficient, depending on the type of lubrication regime

The type of friction	The type of lubrication	The coefficient of friction
Dry	No greasing	>0,3
Limit	Lubrication to the limit	0,1
Mixed	Mixed lubrication	0,005
Fluid	HD or HS lubrication	0,001

Source: [8]

In order to determine the conditions for the mixed and boundary friction, a Stribeck high curve will be used initially for flat sliding bearings (Figure no. 4.10.) - where μ is the coefficient of friction, h is the thickness of the film, ή is the absolute viscosity of the lubricant, v is relative speed and N is the normal charge.

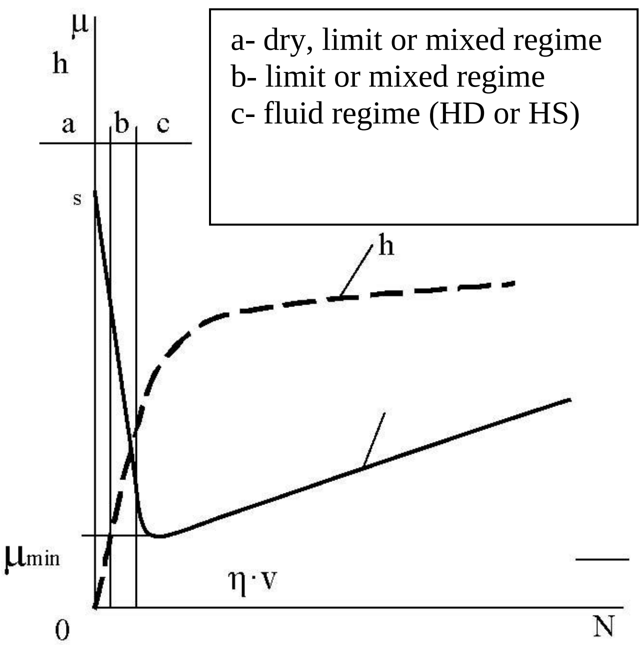

Figure no. 4.10. Stribeck's Curve

Source: [8]

Dry, limited or mixed speeds (zones a and b, Figure 4.10.) lead to operating instability: thus, when the speed or speed decreases, the friction coefficient increases and the machine stops. The fluid lubrication regime (zone c, Figure 4.10.) shows the optimum operating range, in which the coefficient of friction is minimal and the wear is practically zero, as a result of a continuous film of lubricant that completely separates the surfaces of the friction joint. If the speed increases, although the thickness of the lubricant film will increase, the coefficient of friction will also increase, due to the appearance of turbulence in the film.

Fluid rubbing

Fluid rubbing occurs when the film thickness is large enough to avoid contact between the peaks of the asperities. The lubricant adheres to the metal and the phenomenon of friction at the limit or mixed appears only when starting and stopping. In fluid mode, the friction is generated by the internal stresses in the fluid, given by its viscosity. The wear is practically zero, when the pressure in the film (insured internally or externally) ensures the lifting of the load. Even if there are still some touches of the peaks of the asperities, the friction is predominantly fluid.

If Ra <0.2 m, when the speed or viscosity is reduced, the film stops and the regime becomes limited (unctuous).

If the film has a thickness of 10 ... 100 μm, the fluid friction is thick film. If the film has a thickness of 1 ... 10 μm, the fluid friction is thin film.

4.3. Process Wear and Wear

Crudu [12] defines the notion of tribo-system related to wear, which is a process that accompanies rubbing most of the time. The wear leads to the modification of the initial state of the surfaces of a tribo-system, as a result of the material detachment, being an undesirable phenomenon.

Process Wear represents the effects of wear: traces of deterioration on surfaces and products coming off surfaces.

Wear (loss of material) can be expressed [4] by weighing (gravimetric wear, Ug), measuring the thickness of the lost layer (linear wear, Uh) or as volume of lost material (volumetric wear, Uv).

The wear volume increases with time (the wear is cumulative), it is inversely proportional to the hardness of the tested material. It depends directly on the lubrication regime, the operating temperature and the load.

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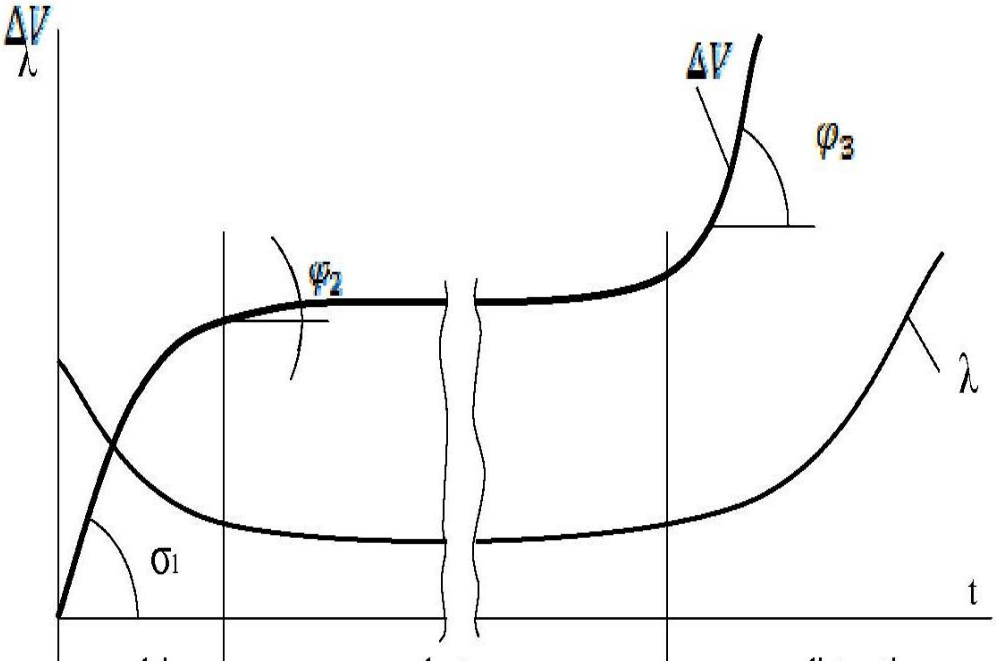

grinding exploitation destructive wear

Figure no. 4.11. The evolution of the volumetric gravimetric wear

Source: [4]

Figure no.4.11 shows the evolution of the volumetric gravimetric wear (V) and the failure intensity (λ).

It distinguishes the three periods of operation of a machine: running, operation, out of use. It can be observed that the bearing is characterized by the intense wear with the large angle slope and the high intensity of the failure. In this phase the peaks of the asperities are levelled, the real area increases and the real pressure decreases.

The operating period is much longer, the wear is minimal and occurs with a very small slope with an angle φ1 << φ2, the failure intensity being constant and almost zero.

In the last phase (destructive wear, the period of wear and tear), irreversible wear occurs which results in removal from use.

4.3.1. Wear types

It is admitted that there are four fundamental types of wear: adhesion, abrasion, fatigue and corrosion. In addition, other derivative or particular forms are mentioned.

Generally, in operation, two or more types of wear appear: adhesion-abrasion, abrasion-corrosion, fatigue-corrosion, adhesion-abrasion-corrosion, adhesion-abrasion-fatigue-corrosion, as is the case of wear by collision.

Table 4.4 [19] presents the main types of wear, the nature and examples of rubbing couplings affected by wear.

Abrasive wear is a process of destroying surfaces by scratches and loosening of roughness, by shearing or fatigue or by the presence of foreign particles carried by the oil.

The broken particles carried by the oil have an aggravating effect, therefore the oil must be filtered. Cars must be watertight in the area of the kinematic couples. After the set-up, the oil will be changed with the asperities off.

The volume of material used by abrasion (UV) can be calculated with the relation [1]:

$$U_v = K_u \frac{N \times L_f}{HB} \tag{4.5.}$$

where Ku = 10-2 1 is a wear coefficient dependent on the materials participating in the wear, N is the normal load [N], Lf = v t is the friction length [mm], HB the softness of the body (usually HB≈3 • σc) and Uv results in mm.

It should be noted that for Ku = 1 the wear occurs from the first displacement of the surfaces. It has been experimentally proved that hardness is an important parameter on which wear depends, so that abrasion resistance increases with increasing hardness. Certain alloying elements (Mn, Cr, Mo) reduce abrasive wear of steel surfaces.

Contact (adhesion) wear occurs due to the short-term disappearance of the lubricant, leading to local plastic slips, local melts, ruptures and shears of micro-joints (micro-welds). The process can degenerate leading to the flu.

Gripping means performing welds on larger surfaces (very high speeds and loads in the absence of lubricant) leading to material dislocations - deep curls, following the deterioration and permanent locking of the coupling. Materials of the same name (steel / steel, cast iron / cast iron, etc.) grip faster, as opposed to pairs of materials of different chemical composition (steel / tin, steel / lead).

The volume of material used by abrasion (Uv) can be calculated with the relation (4,5.). But with a much lower wear coefficient, $K_u = 10^{-7} \quad 10^{-4}$.

Table 4.4. The main types of wear, the nature and examples of rubbing couplings affected by wear

Types of wear	Nature of wear	Types of rubbing couplings
Adhesion Incipient grip. Material transfer. Moderate adhesion. Severe adhesion: total swelling	Mechanical, metallurgical and thermal	Most friction couples, bearings, removable assemblies, slide rails, guides, piston-cylinder, gears, variators, cutting tools, etc.
Abrasion. Micro-aşchiere. Authorization. Abrasive erosion. Coulters. scratch	Mechanics	Machine parts operating in abrasive environment, drive chains, insufficiently protected rubbing couplings (piston-cylinder, bearings with sliding, bearings, gears, etc.).
Fatigue Mechanical fatigue. Pitting. Exfoliating. Thermo-mechanical fatigue	Mechanics. Thermo-mechanical	Lubricated hertzian couplings (gears, bearings, ball screws, camshafts, chain rollers) Hertzian couplings with dry rubbing or undergoing defective heat treatment (roller, bandage rail, gears, etc.)
Corrosion Chemical corrosion rusty	Chemical	Machine parts in corrosive environments, unprotected or in the presence of degraded lubricant, water (piston-cylinder, sliding bearings, bearings).
Galvanic corrosion Electric pinching	Electrochemical	Friction joints greased and under the action of electric current: The flanks of gears, bandage-rail, electrical contacts.
Biochemical corrosion	Biochemical	Guides and pipes for lubricating-cooling fluid from machine tools.
Tribocoroziune? Fretting corrosion	Mecanochimică?	Friction joints in the presence of the lubricant Degraded: piston-cylinder, guides, bearings, etc. Friction joints with small displacements in corrosive environments: rockets, bearings, grooves, threaded assemblies, etc.
Cavitation impact	Mechano-thermal chemistry	Surfaces subjected to gas implosion, in water or oil (turbine blades, pumps, ship propellers, slide bearings, gears, etc.). Grinding bodies, gears, etc.
Peel Cold deformation		The surfaces of some parts of machine parts deformed by plastic due to strong mechanical stresses (gears, bearings, shredding members, etc.).

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	Mechanics	
Frizz		Required and imperfectly greased sidewalls.
Deformation		Bearing paths, gears flanks.
Interference		Gears not displaced or imperfectly displaced.
Rectification crack	Thermo-mechanical	Machine parts with grinding defects, gear etc.
Treatment cracking Thermal		Poorly treated machine parts (gears, rollers, shafts, etc.).
Hot deformation	Thermal	Machine parts strongly required mechanically and thermally: bearings, gears, guides, brake discs, etc.
Discoloration (staining)		Overheated surfaces: cylinder liners, gears, brake discs, etc.

Source: [19]

The intensity and speed of wear are given by the relationships:

$$I_{uh} = \frac{U_v}{L_f} \times \frac{K_u}{HB} \ \min \qquad (4.7.)$$

$$V_{uh} = \frac{U_v}{T} \times \frac{K_u \times N}{HB} \qquad (4.8.)$$

The value of the wear coefficient can be obtained from the tables [4.3], for example for hard steel / polyethylene, K_u = 1,3 · 10^{-4} and for steel / Cu-Pb, K_u = 0,1 · 10^{-4}. For the increase of the resistance to the grip, additive oils of extreme pressure and hardened steels are used.

For the increase of the resistance to the grip, additive oils of extreme pressure and hardened steels are used.

Superficial contact wear is caused by fatigue and occurs due to repeated loading and unloading (> 106 loading cycles), in the presence of normal hertzian voltages σH and tangential τH voltages in the superficial layer. Due to these efforts, micro-cracks and microscopic dislocations appear. The union of several micro-cracks leads to cracks. Under the action of the oil pressed into cracks (breakdown effect) they increase, leading to material dislocations; so pits, punctures appear. The phenomenon is known as pitting. When 1% of the nominal surface is covered with pinches, the couple is compromised. The phenomenon is aggravated by the existence of geometrical slips.

The incipient pitting (appeared during the shoot) may cease, disappear (favourable case) or may advance leading to exfoliation. The phenomenon occurs mainly in untreated or improvement steels (HB 350 MPa).

Pitting is avoided by using viscous oils, hardening and grinding surfaces.

Figure no. 4.12. shows pitting appeared on the side of a tooth of a gear.

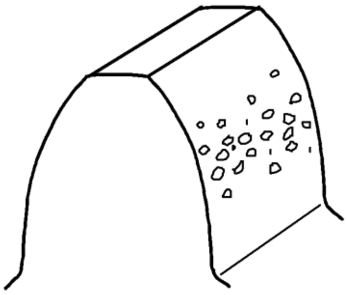

Figure no. 4.12. The phenomenon of pitting.

Source: [8]

The wear of freight occurs in contact regimes with moving surfaces of small amplitude at which micro-slip occurs at atomic distances. In the contact area there is also a chemical reaction that generates charter corrosion. The freight appears at presses assemblies or at slip bearings transported over long distances.

Corrosion occurs due to the action of some active chemical factors. The best known case of chemical corrosion is rust and it occurs under the action of oxygen in the humid air. Inside the cars a chemical tribo-corrosion occurs due to the acidity of the oils.

Cavitation wear occurs on the pallets or rotors of the pump, on the propellers of the vessels and is manifested by the appearance of deep punctures of irregular shapes that evolve over time. Itching occurs due to the "explosion" of the bubbles of gas and gas that form on the surfaces of bodies moving at high speeds in liquid environments.

Bending is the plastic deformation in the form of spherical caps that appear on the surfaces in contact with spherical pieces (ball bearing rings). Impact wear occurs on surfaces that are in contact with shock and has several forms simultaneously: abrasion, adhesion, plastic deformation, etc.

4.3.2. The importance of lubrication in the operation of machines, machines and installations

Any maintenance program must include the lubrication activity, the way of its creation and organization, in order to be carried out with minimal costs but to have maximum efficiency.

Lubrication, as an operation, is important for machinery and aggregates, for their proper functioning, and as an activity it is important through the logistics that are carried out for the supply, storage of lubricants and by the self-lubrication of each machine, installation or aggregate. The lubrication is mainly due to the extension of the service life and the preservation of the machines. A machine, an installation, needs lubrication, without which it cannot operate. Therefore, it is necessary that, from the purchase date, a program of organizing the lubrication activities should be elaborated, which will include all the specific works of supply with all types of lubricants, the form of supply, the storage mode, the elaboration of the lubrication instructions, the technology of making the lubricant, by whom, when, how, with what, how much.

The lubrication operation can be performed by the production operator or by specialized persons, depending on the complexity and specificity of the machine, the aggregate or the installation. The practice has shown that performing the lubrication work by specialized personnel is preferable, as it creates the possibility of combining the cleaning activity with the lubrication, and the lubrication duration is reduced

The problem of lubrication acquires different values, depending on the size of the unit, the structure and the degree of complexity of the machines. The problem is easier for companies that have a relatively small number of groups of machines of the same kinds, it becomes a complex one for those units that by their specific production have a wide range of types of installations, machines and aggregates.

Due to the complexity of the lubrication operations and their implications on the normal operation of the machines, worldwide, there is a tendency to typify the lubrication materials and to symbolize the periodicity of the lubricants: daily, weekly, monthly, etc., after a certain number of operating hours or as scheduled. Based on the typing of the lubrication and auxiliary materials, the determination of the lubrication periodicity is made "lubrication sheet" of each machine and aggregate, a file that represents a basic document in the system of maintenance and repair of the machines. In practice, the lubrication sheet is prepared monthly, 10 days in advance for the following month, by the maintenance and repair department. The file contains data on:

- the lubrication points,
- the lubricants used,
- the lubrication system,
- periodicity of lubrication.

The file is used to schedule the maintenance work of the machines and to determine the lubricant requirement.

Regarding lubrication, it is necessary to strictly respect the types of lubricants indicated by the manufacturer of the machine and if there is no recommended assortment, it will be replaced with another one that has similar properties, found by laboratory analysis.

The storage of lubricants, their distribution, their use, as well as the determination of the frequency and methods of the most effective lubricants, are important tasks for the good maintenance of the machines.

In the case of a large number of lubricant assortments, a large number of lubrication places, especially when the lubrication frequency is different, in practice a color code and geometric shapes applied to both the vessel in which they are stored or in which they are stored are introduced. The lubricant is handled as well as at the lubrication point. This simplifies the work of choosing the lubricant for the respective lubrication point, while reducing the number of errors (lubrication with a different lubricant than the one provided).

The lubrication program, no matter how well organized, is only effective as long as it is respected, and this depends on the level of responsibility of the lubricant, and the quality of the lubricants used.

In the paper "Organization and management of maintenance and repair activities" I. Ceauşu presents the consequences of the studies carried out in the highly industrialized countries, in case of non-observance of the lubrication program; thus "in England 44.66% of the amounts allocated for this activity are spent to repair and replace defective parts due to the lack of lubrication; In Germany the studies were oriented towards the evaluation of energy losses due to wear, and in the United States similar studies revealed that 50% of the cases of machine failures are caused by lubrication errors ”[12].

4.4. Lubricants

Lubricants are fluid, viscous or solid materials that can extend between the contact surfaces of two solid bodies in contact with rubbing, both to replace the dry rubbing between the two bodies by a fluid rubbing, thus reducing the friction and thus reducing prevent overheating.

Depending on their state of aggregation, lubricants can be: liquids, solids and gasses.

Lubricants play a multiple role:

- protects the kinematic surfaces of the coupling against direct contact;
- makes the supporting film in the case of fluid friction;
- contributes to the evacuation of the heat produced by friction;

- prevents the penetration of impurities from the outside.

Lubricants are: liquid, semi-solid (plastic), solid or gaseous.

Liquid lubricants are: oils, water, molten metals, dissolved salts, etc.

4.4.1. Liquid lubricants

Two types of oils are used in industrial practice:

1) Mineral oils are mixtures of aromatic, naphthenic, paraffinic hydrocarbons with a mixed structure, with a certain content of oxygenated combinations, or with sulfur. Mineral oils are mainly used because they have a stable structure and can be used at high speeds, at high temperatures and at low temperatures. The behavior of the lubricant as an anti-freeze and anti-wear element is dictated by the chemical nature and molecular structure of the constituent hydrocarbons. For example, cyclic hydrocarbons (naphthenic, aromatic and mixed) play an important role in raising the viscosity.

2) Synthetic oils (esters, polyglycols). Synthetic oils have higher chemical stability than mineral oils. Synthetic oils have the property that they have a linear variation of viscosity with temperature, as opposed to the mineral ones which, at high temperatures and pressures, have a rheological, nontontonian behavior in the operation of modern machines (high pressures and temperatures, lubrication of nuclear equipment, etc.). Thus, synthetic oils with better viscosity-temperature dependence, with higher resistance to oxidation, thermal decomposition, etc. were obtained. The most well-known synthetic lubricants are: acid esters, diabases?, uranophosphates, silicone esters, polyglycols, esters and fluorinated or chlorinated hydrocarbon compounds. Silicones can be used between -500, + 4500C and have an effective anti-foaming character, and at high load their viscosity increases rapidly with pressure. Synthetic oils are much more expensive than mineral oils.

The maximum weight in the production and consumption of lubricants is held by synthetic oils, which can be non-additive and additive compounded.

The classification of oils is standardized by taking over the classification of SAE (Society of Automobile Engineers of the USA), which establishes ten areas of use symbolized by one or more letters. Some of the most popular areas are:

- M - for thermal engines (MAS - for spark ignition engines, MAC - for compression ignition engines, Diesel); example: 20W40

- AVI - for aviation;

- T - for vehicle transmissions. Example: SAE 10 W, M;

Other types of oils are: G for guides; K for compressors; H for hydraulic drives; L for bearings; F for refrigeration machines.

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4.4.2. Consistent greases

Consistent greases are dispersions of metal soaps in mineral oils (naphthenic oils) or oily liquids. From the point of view of internal friction, the consistent greases belong to the category of Newtonian environments (plastic or quasi-plastic media). The operation of the lubricated lubrication joint is limited by the temperature, which must be lower than the drip point (the temperature at which the grease begins to drop under its own weight).

The most commonly used greases are: general purpose greases, bearings greases, lighter greases for open bearings, LDE graphite greases, lithium-calcium-lead greases, barium greases, lithium-calcium greases, low temperature greases, barium-aluminium greases, etc. Consistent greases have good adhesion to metal surfaces

In addition to the greases mentioned above, in certain conditions, synthetic greases are used, greases that have different chemical compositions (esters, fluoresters, polyglycols, polymers and silicones). These greases correspond to synthetic oils with a higher temperature range compared to mineral lubricants, also having high chemical stability and low viscosity-temperature sensitivity.

4.4.3. Solid lubricants

Under certain friction conditions (pressure, temperature, working environment), liquid lubricants can no longer be used effectively. They are replaced with solid lubricants.

The conditions that solid lubricants must meet are the following:

- reduced shear strength and reduced hardness to have a low coefficient of friction;
- good adherence to the basic material, the continuity of the film and the durability through the possibility of regeneration;
- elasticity, good conductivity and thermal stability, low density;
- electrical conductivity;
- reduced and uniform granulation, as well as lack of abrasive particles;
- lack of corrosivity.

The weight of one or other of these requirements depends on the friction regime and the nature of the lubricant used. The efficacy of the same lubricant is given by the micro-geometry of the support surface and its preparation technology.

4.5. Solid lubrication materials

They can be used between surfaces in relative motion, between which there is a very high pressure, as well as in high temperatures. The use of these lubrication materials implies a reduction of the running time of the mechanism and a rapid release of the heat resulting during operation.

Among the solid lubrication materials are graphite, talc, molybdenum bisulfide, metal soaps such as: calcium stearate, magnesium, Teflon (synthetic material).

Depending on their nature, solid lubricants can be added to oils or greases, incorporated into the bearing material or applied to the spindle by chemical or mechanical means.

If coatings with thin layers of solid lubricants, such as graphite or molybdenum bisulphide, to apply on both surfaces in relative motion, the durability of the milling torque increases by 2-3 times compared to the case of coating only one surface.

Viscosity is the basic quality of lubricants and represents the resistance that their particles offer when subjected to a slip. By viscosity it can be seen whether a lubricant is suitable for a particular purpose, certain operating conditions.

The viscosity decreases considerably with increasing temperature. Therefore, it is necessary to assess the temperature at which the given viscosity value is valid.

Preferably, the oils with the smallest variation of viscosity in relation to temperature are preferred, as they can work in a wide range of temperatures with a stable regime.

The lubricating capacity is the property of the lubricant to adhere to the metal surface in difficult friction situations or at very high pressures.

Flash point

It is the temperature at which the oil heated in an open shell, at atmospheric pressure, ignites under the action of a flame. For mineral oils the flash point is 150-200 ^{0}C. The flash point is more interested in choosing oils for internal combustion engines, compressors, etc.

The point of solidification (freezing) is the temperature at which the oil under the action of its own weight can no longer visibly flow. This phenomenon occurs not at a precise temperature, but within a temperature range.

Emulsionabilitate

It is the property of the oil to mix with hot water, forming an emulsion, and not to separate later, a property we especially want in steam turbines.

Foaming

It is due to the air bubbles dispersed in the oil whose release on the surface of the oil forms the foam, favouring the process of oxidation of the oil. At the same time, the thermal conductivity decreases which leads to the decrease of the cooling capacity of the oil and of the heat processing in the process of friction of the different machine organs. After use, the waste oils are collected for refining, to obtain basic oils.

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4.6. Additives for oils, greases and self-lubricating materials

Additives have the role of influencing the modification of certain lubricant properties. Depending on the nature of these properties, additives can be classified into:

a.) additives for increasing the viscosity and improving the viscosity index (polysobutylene, polymethacrylic acid, paraffin and chlorinated naphthalene);

b.) additives with detergent-dispersive action (organo-metallic compounds of Zn, Sn, Ni, Ca, and phenolic derivatives, phosphates, sulfides);

c.) additives with antioxidant and antifoam action;

d.) additives for improving the conditions of rubbing and wear;

- additives for reducing and stabilizing the friction coefficient;
- additives for limiting progressive use to medium and high loads;
- additives with anti-grip or extreme pressure action.

The choice of one or the other of these additives should be made in close correlation with the particularities of the friction regime, since the same additive can have positive effects in one situation and negative in another.

Additives must meet the following requirements:

- it does not lead to intensification of the use (anti-grip additives) compared to pure oil. If the non-grip additive cannot meet this condition, then a special additive that prevents intensive use is introduced;
- it does not corrode the steel or the soft alloys at the operating temperature and does not lead to rusting of the steel surfaces under high temperature conditions. To avoid this, special anti-corrosive components are introduced;
- have stable properties in operation; have thermal stability in the operating temperature range, do not decompose and do not form deposits;
- be dissolvable in the base oil and set in the storage solution. If the additive gives a colloidal solution in the oil, it must be insoluble in water, especially when under operating conditions it can reach the lubrication system;
- not to destroy the sealing materials (rubber, leather, etc.);
- additives for improving the conditions of rubbing and wear must also have antifoam and antioxidant action;
- the additives required for severe friction conditions should have good properties at both low speeds and loads, and at high speeds and loads, for example for the lubrication regime of the hypo gears of cars.

As additives that reduce friction and wear and prevent flu, the following categories are used in pure form or in combination: animal fats, vegetables and fatty acids; organic sulfur bonds; halogens (especially chlorine); phosphorus; of nitrogen; various metal bonds (for example, lead soap, acid and bisulphide of Mo, W, organic bonds of Zn, colloidal Fe, etc.); links containing several active elements in the same molecule (S, CI, N and others); additives for combating the biodegradation of lubricants (under the action of bacteria).

Lubricating materials must meet the following conditions:

- It can form a layer of lubrication that reduces friction;
- Be adherent to the contact surfaces, do not leak in case of temperature rise and do not strengthen when the temperature drops;
- To ensure the transport of heat produced by friction or results from chemical reactions, outwards, both through the contact bodies and through the lubricant flow itself;
- To ensure the transport of the active chemical components, mainly oxygen, which produces the oxide layer;
- Sealing, respectively the protection against the penetration of impurities from outside; for example, the consistent grease forms at the exit of the flow from the bearing + r a protective collar; which ensures a more persistent maintenance of the lubricant layer in the case of shock operation and during periods of interruption operation; it does not require complicated seals, and the replacement intervals are relatively large (6-8 months).

The additives are also used to change the behaviour at temperature, pressure, speed, environmental conditions and are:

- enhancers of the viscosity index (A.I.V.);
- anticorrosive (A.C.);
- antioxidants (A.O.);
- anti-rust (A.R.);
- anti-foam (A.S.);
- antistickslip (A.S.L.);
- anti-wear (A.U.);
- anti-influenza (EP);
- depressants (freezing point decrease) (D.G.);
- detergents (prevent deposits on hot surfaces - tar) (D.T.);
- dispersants (keep the insoluble compounds in suspension) (D.I.);

- of unct polyfunctional (P.F.).

Example: for EP, S, Cl, P, compounds of Zn etc. are used.

Greases are Newtonian plastic or quasi-plastic media (Bingham media). They are produced by the dispersion of soaps (Na, Ca, Al, Ba, Li, Pb) in mineral oils.

The operating temperature must be lower than the drip point.

Compared to other lubricants, greases have the following advantages: better adhesion to metal surfaces, simpler seals, high chemical stability, and reduced viscosity variation with temperature.

Some of the disadvantages are: it is used at slow speeds, at the beginning of the movement additional effort is required, the operation being limited by temperature.

Under certain conditions, greases can be used throughout the life of the machine, without the need for replacement or filtering (for example, the capsule bearings are factory-lubricated).

Self-lubricating materials are some plastics:

- polytetrafluoroethylene (PTFE Teflon) has a low coefficient of friction in contact with steel μ = 0.04 ... 0.06;

- Polyamide has a coefficient of friction greater than Teflon, but is cheaper;

- sintered materials (Fe, Bz). Uosity (increase the molecular adsorption) (O.T.).

These materials are used especially for camp bearings. They can also be used as composite materials in the form of deposits on metallic materials, for example: Teflon (0.02 ... 0.2 mm) on sintered Bz adhering to steel (base material).

The correct choice of lubricants is based on: the relative displacement speed of the surfaces in contact; the specific pressure that appears on the slip surfaces; the thermal regime of the machine or the working temperature of the lubrication site and the environment; caliateta of the surfaces in contact; the type of friction (slip or roll); the lubrication system.

The oils are chosen taking into account the viscosity, the lubrication capacity (greasiness), physical and chemical characteristics, the operational stability of these characteristics for as long as possible, compatibility with other materials that inevitably come into contact during exploitation, etc. Higher greasiness, in the case of intermediate states of friction will result in reduced wear and safety in operation in relation to the danger of higher grip.

In the case of drip or wax lubrication, a special emphasis is placed on greasiness and this especially for the units that work with high contact pressures.

When lubricating with recirculation, when the same amount of oil is kept longer in the circuit, the chemical stability of the respective oil is of particular interest.

During the run-up period, more fluid oils are indicated, possibly with an additive, which reduces the danger of the flu.

Consistent greases have as their basic characteristic the dripping point, i.e. the temperature at which the grease starts to drop under the action of its own weight. A consistent grease is the better, the higher the drip temperature is but the grease remains secured at the operating temperature. Table 4.5. lists the types of greases consistent standardized in our country, indicating the area of use.

Table. 4.5. The types of greases consistent standardized in our country, indicating the area of use

Category	Type	STAS	Base (soap type)	Drop point ^{O} C min	Main uses
Lubricants consistent for general use	U 75 Ca 2	562-71	Calcium	75	Bearings, slides, etc.
	U 80 Ca 0			80	
	U 85 Ca 3			85	
	U 100 Ca 4			100	
Consistent greases for bearings	Rul 85	1608-72	Calcium and lead	85	Lubrication of bearings
	Rul 100		Calcium	100	
	Rul 145		Sodium	145	
	Rul 165		Sodium	165	
Lubricants consisting of briquettes for open bearings	LD 93 Ca 7	2721-71	Calcium	93	Open bearings working at high temperatures and high pressures (machines in the paper and cement industry, mills, etc.)
	LD 170 Na 7		Sodium	170	
Greases for temperature low	Tj 70	6320-68	Calcium	70	Lubrication and protection metal parts in winter according to special prescriptions
	Tj 60			60	

Source: [8]

Oils, as opposed to consistent greases, have the following advantages:

- They are used at any speed, even at very high speeds;
- They maintain their ability to lubricate at temperatures at which consistent greases either lose it - as is the case at high temperatures - or cause high energy losses - as happens at low temperatures;
- They have lower internal friction, which makes them usable in sensitive, precision devices;
- Allow complete lubricant replacement, without the need for the disassembly and prior washing of the lubricant elements;

The disadvantages of the oils are:

- Difficult and expensive sealing against lubricant losses;
- The need for more frequent completion.

4.6. Systems and methods of lubrication of machines and machines

The importance of lubrication

As careful as the contact surfaces of two pieces in relative motion with each other are processed, two frictional forces are created at this level.

Depending on whether or not there are lubricants between moving surfaces, the friction may be: dry; semifluid; fluid.

Normally, fluid friction occurs when the machines and machines are in the operating mode. Fluid rubbing can be maintained when moving at high speeds among surfaces, and the surfaces are subjected to a medium pressure and are continuously fed lubricants.

The semi-fluid friction may occur as a result of defective or insufficient lubrication, as well as when starting and stopping the machine when, due to the too low speed, the required oil layer between the two surfaces in relative motion cannot be introduced.

When parking the machine, due to loads on the shaft, the lubricant is removed between the two surfaces of the spindle and of the bearing, the contact being made directly on the tip of the asperities of the respective surfaces, leaving a very small amount of lubricant in the gaps among the asperities. Thus, when starting, the lubrication will be incomplete, semi-fluid or even dry, if the machine has been stationary for a long time (Figure no.4.13.).

At low rotational speeds, the shaft begins to carry under it a lubricant, which, having a wedge shape and some pressure, begins to lift it: in this case, the lubrication will be semi-fluid.

As the speed increases, the centre of the spindle approaches that of the bearing, to coincide with it at very high speed. In the latter case, theoretically, the thickness of the lubricant film becomes constant throughout the periphery of the spindle.

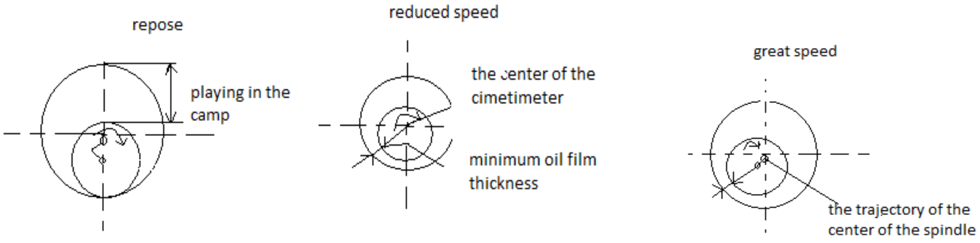

Figure no. 4.13. Bearing operation under semi-fluid conditions

Source: [8]

Under the conditions of fluid lubrication, it is realized:

- Reducing the use of friction surfaces;
- Reduction of energy consumption by friction;
- Increasing the permissible tasks;
- Increasing operational safety;
- Lubricant economy;
- The rational organization of the anointing should include;
- Choosing the lubricant, and storing it in optimal conditions;
- Determination of the required quantity of lubricant by quantities and of the cleaning material based on the consumption norms;
- Measures to reduce leakage and evaporation losses;
- Measures for the correct handling of the lubricant;
- Observance of the technical norms of the safety of the work and of the norms of prevention and extinguishing of the fires.

Depending on the number of lubrication places of the oil flow mode and the character of the oil circulation, there are several lubrication methods. Thus: according to the number of lubrication places, two are distinguished:

- Individual lubrication, when each lubrication site is served by its own lubrication system; centralized lubrication, as many lubrication points as possible are provided by a central lubrication system;
- After the oil cutting mode there is a pressure-free lubrication, when the oil reaches surfaces that must be lubricated due to gravity, capillary or molecular absorption; pressure lubrication when the oil is sent to the lubrication circuit by means of a pump;
- Depending on the character of the oil circulation, it is distinguished: greasing the closed circuit or recovering the oil. When the oil returned to the basin after oiling is put back into circulation; open circuit lubrication, in which the oil cannot be recovered (lubricating guides and screws);
- The system, lubrication method and lubricant for a car, machine or installation are established on the basis of the following criteria:
  - The importance of the body whose lubrication must be ensured in the

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functional assembly of the machine, the machine, the respective installation;

- The quality of the lubricant related to the functioning of this body;
- The amount of lubricant required per the amount of time (hour) and for a complete change (8h).

According to these three criteria it is established: centralized or not, with or without pressure (with or without recovery); the location of the lubrication devices through which the accessibility to the lubrication site must be sought and the ease of affecting it; ensuring the functioning of the lubrication system with the possibility of controlling this operation and, in some cases, with the automatic signalling of the lubrication stop.

Lubrication devices and installations, used in machines, machines and installations, must comply with the following conditions:

• The possibility to adjust the oil flow;

• Filling with lubricant can be made easy;

• The cleaning operation of the lubrication device can be done conveniently;

• Safety against penetrating into the device of abrasive dust, chips or tool cooling fluid;

• Easy control of the quality of existing lubricant at any given time;

• Safety in operation and the possibility of controlling it;

• Simplicity and low cost.

Knowing the lubrication methods, the lubrication conditions imposed on the lubrication devices and installations used allows the selection of the most suitable lubrication system, in relation to the particularities of each machine, machine and installation.

The lubrication systems are of several types:

• Systems for individual lubrication, periodic or continuous, with or without pressure;

• Periodic or continuous centralized lubrication systems, with or without pressure;

• Combined systems.

Consistent greasing. Greasing with consistent grease is applied to machines with low speeds or when the required amount of lubricant is reduced <bearings with bearings, the bearings of the aggregates working in the free atmosphere, in dust (forming protective collars against the penetration of various particles) some gears>. The lubrication is done with the help of ball greasers; can be used three types of ball greasers:

type A with head and tapered thread,

type B with flat head and cylindrical thread, and

type C with flat head fixed by pressing.

In these greases the lubrication hole is closed by a ball pressed by a spring. During feeding with this hand press, the grease overcomes the pressure

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of the spring and penetrates inside. The gears can also be mounted in an inclined position 45^0 or 90^0, using position pieces.

The centralized lubrication, realized by the simultaneous supply of several greasing points pressed in a cylinder, whose piston is manually or mechanically actuated, with the possibility of adjusting exactly the quantity required for each lubrication place, ensures an efficiency superior to the previous devices.

Oil grease. The individual lubrication performed manually applies to bodies with low demands and low speeds. Lubricants with flat or cylindrical cover, supplied with oil cup and ball greasers are used as lubricants, in which the oil is manually pressurized using a pump called Tecalemit.

Fatty lubrication systems are based on the phenomenon of capillary of cotton or hemp. Sometimes a central reservoir can provide the lubrication of several lubrication sites simultaneously, each fuse having its own vertical channel for dripping the absorbed oil and an individual connection to the oil pipe.

The ring greasers ensure the lubrication due to the adhesion of the oil on the ring. It is a very good lubrication device, economical, because the oil is not lost.

Individual lubrication in the oil bath is rarely used and especially for bearings. In this case, the oil level should not pass through the middle of the ball or the bottom roller, because a larger amount of oil leads to its foaming and, consequently, to a defective lubrication, immediately noticed by overheating the bearing.

Lubrication by bubbling consists of driving and impregnating a quantity of bath oil inside the car or machine housing, from where by pruning it is driven through collecting holes at the lubrication sites. The individual lubrication in the oil bath with intermediate element is used in the case of large length guides. The intermediate element consists of two conical rollers mounted on the axis, which rests on the spring, whose role is to keep in constant contact the rolls with the guide of the sled. The lubrication with a felt cushion that is in an oil bath and makes contact with the spindle, to be lubricated ensures by its capillarity the transmission of the required oil quantity.

Centralized pressure-free lubrication requires a hydraulic system consisting of an oil reservoir, a pump, which absorbs the oil from the reservoir through the filter, and sends it to a distributor, from where, through the pipes. In the oil it is directed under the action of gravity at the lubrication places.

The lubrication systems continue under pressure. The oil absorbed through the filter by the pump, which provides adequate pressure, is filtered a second time by the other filter, and directed to the dispenser, closed at the top; the oil is directed to the lubrication places through the pipes.

Making a correct lubrication involves:

• The removal of the bearings and the dismantling of the lubrication holes or

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channels before the beginning of the lubrication;

• The lubrication is done carefully, without wasting to avoid the oil leaking;

• The lubrication is performed only when the machine is stopped;

• After the lubrication is done, the drained oil is wiped off and the appliances are replaced.

The lubrication of the chain transmissions depends on the speed of the chain, the friction taking place between the drive wheel and the chain and among the chains. At speeds of displacement of 4-6 m/s, the lubrication is done by dripping, the oil being distributed through several pipes, at the untrained part of the chain.

The control of the lubrication operation is of particular importance and consists of: checking the pressure and continuity, checking the lubrication, etc.

The control of the oil circulation is made with the indicator; In this case, the oil flows or drips through the curve tube, which can be seen through the glass cylinder which forms part of the indicator body.

4.7. Rubbing and its effects

Rubbing can be defined as a complex process of molecular, mechanical and energetic nature, which takes place between the contact surfaces of two or more bodies in relative motion with each other.

The rub may be:

- harmful, due to the occurrence of heating and wear phenomena leading to the removal of the friction subassembly (bearings, piston-cylinder, gears, etc.), or due to the occurrence of vibrations (shaking movement that appears in the guides of the machine tools, presses, etc.);
- useful, when it appears on clutches, brakes, wedge joints, friction variants, etc., although it may be accompanied by heating, vibration and wear phenomena.

Rubbing can be of several types:

1. Dry rubbing occurs when no lubricant layer is interposed between the surfaces of the contact bodies, except for the films absorbed from the ambient gas environment (O2, N2, H2O molecules). The size of the frictional force depends on the pressure, the nature, the degree of finishing, and the relative speed of the surfaces in contact. This type of friction causes the phenomenon of oscillation to occur, which converts mechanical energy into thermal energy, followed by wear of surfaces and even rapid bending of contacted parts. Good

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lubrication totally or partially removes these consequences, function and operation, roughness of the surfaces and materials used.

2. The fluid and semifluid rubbing (Figure no.4.14) occurs when between the surfaces that are in contact there is a layer of fluid composed in turn of three parts: two of them adhere to one surface, and the third is between the two. Friction occurs due to the exchange of molecules at different speeds. Due to this fact, there is an increase of the molecular disorder and therefore the heating, which depends on three factors:

- the relative velocity between the fluid layers;
- the thickness of the fluid layer between the two surfaces;
- the nature of the fluid, characterized by the viscosity coefficient, which leads to a semi-fluid friction when it is very fluid.

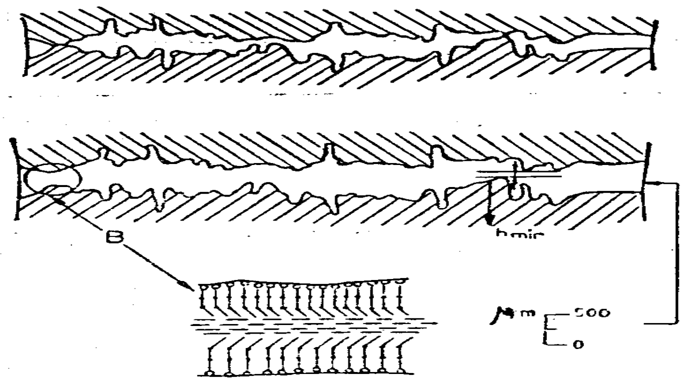

Figure no. 4.14. Sketch of the semifluid a) and fluid b) friction regime

Source: [13]

3. Limiting or unctuous rubbing (Figure no. 4.15) occurs when the pressure between the contact surfaces is high and the fluid layer between the surfaces is rapidly removed, leaving only the fluid adhering to the surfaces, but sufficient to prevent direct metal-metal contact, and possibly the flu. The layer of lubricant adhering to the friction surface is connected to it by strong molecular adhesion forces, making a greasy lubrication. Under very severe conditions, the absorbed layers can be removed from the friction surfaces. In these situations, either a solid lubricant (graphite) or a chemical reaction layer (oxide or metal sulfide) is required.

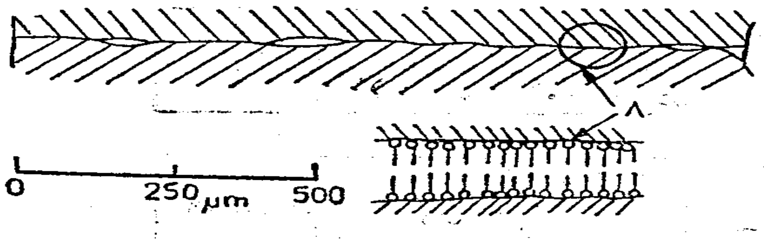

Figure no. 4.15. Sketch of the contact of surfaces in the limit friction regime

Source: [13]

Wear, consequence of rubbing

Wear is defined as a gradual modification of the dimensions accompanied by the loss of precision during operation, as a result of the friction of the contact surfaces.

Wear can wear the following shapes (Figure no. 4.15.):

1. The normal operating wear that is the result of the action of the friction, of the chemical and electrochemical phenomena, being conditioned by the quality of the materials, by the way of the processing, the type of maintenance and repair applied. It is normal if the prescribed maintenance and operation of the machines are complied with according to the rules and parameters of use.

Normal wear limit is considered to be reached when the quality of work done by a car, machine or installation begins to become inadequate.

In the friction-wear process they have an important influence: the working temperature, the friction components, the heat transfer processes that produce dimensional changes and cause the wear to vary widely, being even a component of the reliability projected throughout its life. Of the machine, wear that begins with the start of the machine, the machine or the installation and continues throughout the life of the machine, even if modern methods of maintenance and repair are applied to them.

2. Accidental wear or damage that is the result of the intensive increase of normal wear, as a result of the malfunction of the machine, the failure to observe the operating, maintenance and repair regime. Wear occurs quickly and has great effects on machines and inserts because it includes many systems.

The size of the wear depends on the following factors:

- The quality of the materials used,
- The roughness of the surfaces in contact,
- Quality and type of lubricant,
- Working regime of the parts in contact.

The existence of the wear can be highlighted with the author of the following criteria (Figure no 4.16.):

- Techniques and technologies that lead to the emergence of games, noise, decreased accuracy.
- Economical ones that generate excessive consumption of fuels, lubricants and high maintenance costs.

Wear can be of several types, namely:

1. The mechanical wear is the direct result of the friction of the surfaces of two parts and is found in the form of wear by abrasion and corrosion.

- Wear by abrasion is characterized by the appearance of micro-plastic deformations and by the cutting of thin

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metallic layers, by hard abrasive particles, which are between the friction surfaces. In terms of intensity, the abrasion wear depends on the physico-chemical properties of the materials from which the parts are made, on the properties of the abrasive particles, on the sliding speed and the pressure during the friction. As a physical phenomenon, abrasion can be considered as a cutting process, by applying these laws.

- Wear by erosion occurs due to the direct contact of the friction surfaces, that is, when the lubricant film is interrupted, or has not formed at all, the case of starting the machine, when the viscosity is too high or at too high temperatures, when the viscosity is very low.

2. The thermal wear occurs due to the friction that raises the temperature on the surface of the parts by changing the physical-mechanical properties, crushing or gripping the surfaces. Depending on the temperature, friction occurs in the pieces in contact phenomena such as: recrystallization, recovery, quenching and even melting.

3. Wear by corrosion is a process of degradation of the metallic surfaces under the action of the environment. It can also be chemical in nature when certain substances attack the parts and electro-chemical if local electric cells are formed under the action or in the presence of salts that act as electrolytes.

4. Wear by oxidation is determined by the penetration of oxygen into the surface layer of the metal. Wear in this way has two forms: in the first form oxygen enters the surface and decomposes it into powder form, and in the second form another structure appears which represents metal oxides characterized by high hardness and high brittleness.

5. Fatigue wear is determined by the action of the variable loads on the parts. This wear occurs in the form of rubbing, exfoliating surfaces and cavitation wear.

- Wear by rubbing is determined by the destruction of the metal surfaces due to the overlap of the effects of slip and oxidation. It occurs when unwanted travel occurs between two pieces in strong contact.
- The wear by exfoliation is characterized by the detachment of very thin surface layers (of the order of millimicrons) on the metallic surfaces. Exfoliation occurs especially in parts with residual stresses or in reliable materials.
- The cavity wear is caused by the cyclic loads acting on the metal surfaces that work in various environments (turbines, pumps, etc.).

4.7.1. Wear limits of parts

The wear limit of a piece constitutes, under normal operating conditions, the occurrence of the maximum allowable play. At this limit, the continued operation of the machine or the machine with maximum games leads to the occurrence of the damaged uses accompanied by the increase of the consumption of lubricants.

The limit of exploitation of the parts of machines and machines can be established according to the following basic criteria: the technical criterion, the technological criterion (operating) and the economic criterion.

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When setting the wear limit of the parts, one of these criteria will be considered, the other two serving as aiding or verifying criteria. For example, in the means of car transport, the technical criterion is applied to the car transmission bodies, the technological criterion to the gearbox (when the normal operating mode changes), and the economic criterion to the engine, based on fuel and lubricant consumption.

4.7.2. Wear measurement methods

Discontinuous wear measurement methods

Method of measuring dimensions. Measurements can be made with external micro-meters, with indoor micro-meters or with dial comparators, the accuracy of the measurements varying between $\pm 10\mu$ and $\pm 2\mu$. When using this method, it must be taken into account that the measurements are made in relation to a fixed base.

The evaluation of the uses by this method is only done approximately, because with equipment such as micro-meters and dial comparators, two measurements do not generally overlap on the same points. Also, there are a series of errors determined by the character of the micro-surfaces, the temperature difference between the piece and the measuring instrument, the non-uniformity of pressing the measuring instrument, etc.

Weighting method. This method consists in determining the difference between the initial and the final weight (after a certain operating time) of the part considered, thus determining the overall weight wear or the relative wear in percentages. The determination of linear wear is possible only in the event of a uniform distribution of the wear on the work surface of the parts, which in most cases does not correspond to reality.

The application of this method is indicated for parts where the determination of wear by micro-meters is not satisfactory and which have gravimetric sensitive wear.

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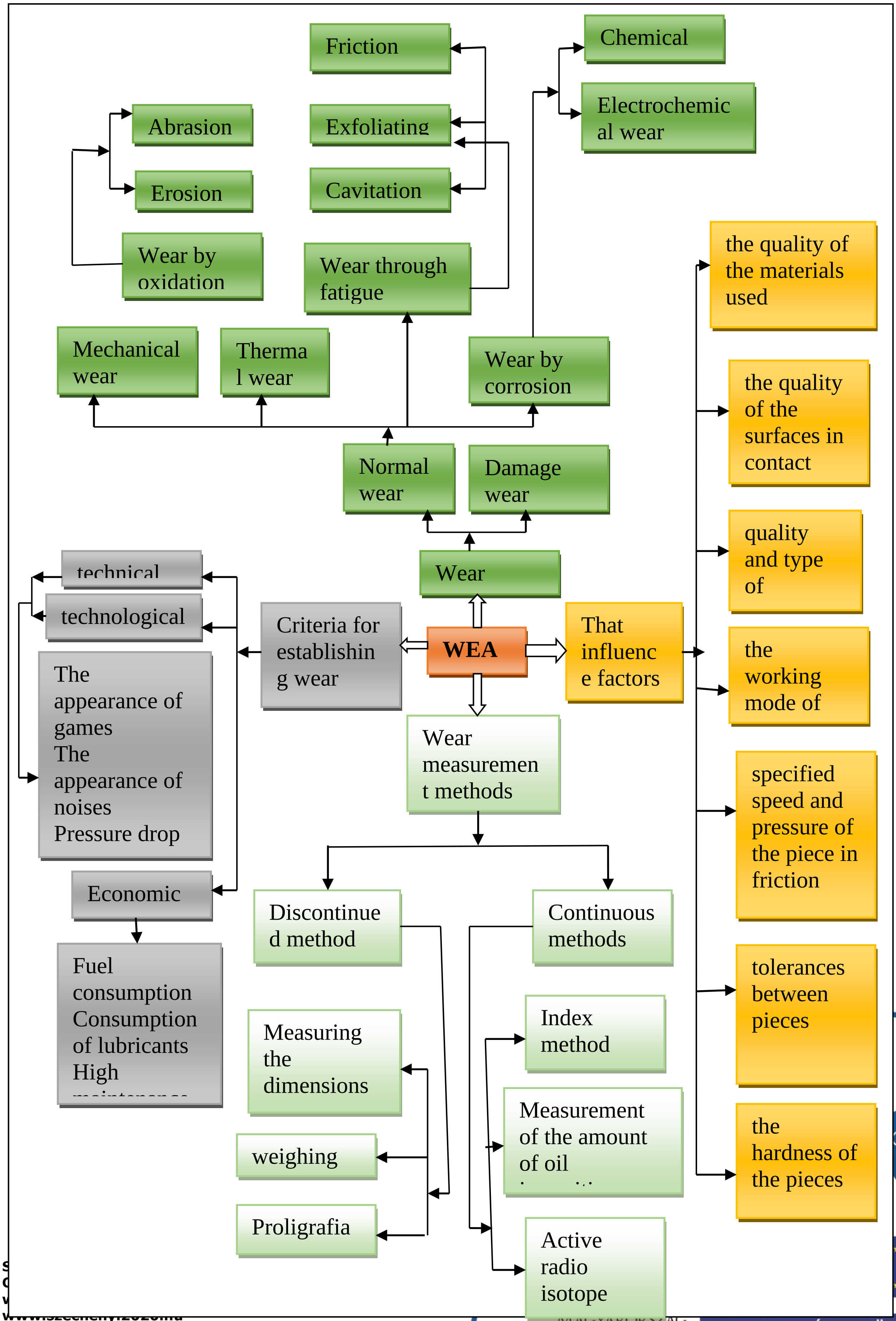
Figure no. 4.16. Block diagram of the wear of machines and installations Source: [13]



Profiling method. This method consists in lifting the profilogram of the working surface of one or more sections of a piece by means of a mechanical or electrical profilograph.

The method can be applied in two variants:

- by raising a single profilogram (for the same section), if the measuring base is an unused face of the part;
- by lifting two profilograms (for the same section), in case a cross-section is drawn with respect to the profiled section and whose maximum depth forms the measuring base.

The wear is determined by the distance between the two raised profilograms, before and after the operation of the considered part.

4.7.2.1 Continuous wear measurement methods

Functional indices method. The method consists in assessing the wear of the various organs during the machine's operation based on the working indices (for example, the power in the thermal motors). Applying this method gives satisfactory results only in the case of simple machines. In the case of complex machines, the use of functional indices to determine the wear of the whole machine gives only qualitative assessments.

Method of measuring the amount of oil impurities. The method is based on the hypothesis that, during operation, of the total metal taken up by the oil due to the wear of the parts by rubbing 90-95% come from the wear of the contact parts. The method can only have a comparative character and this is only when the conditions of similarity are respected.

4.7.2.2. Continuous wear measurement methods

Radioactive isotope method. With the help of the radioactive isotope method, the wear can be studied, thus giving the possibility to choose the appropriate materials for certain working conditions. Accidental wear can also be prevented. This method has a number of advantages compared to other wear research methods. Used together with one of these, the radioactive isotope method can obtain useful information for design and operation.

The main advantages of the radioactive isotope method are:

- the special sensitivity of the appreciation of wear, which reaches up to 10-12g;
- the possibility of simultaneous measurement of wear on several parts, without disassembling the machine, which allows to highlight the influence of different factors on the wear.

The determination of the wear with the help of radioactive isotopes consists in the introduction of radioactive substance in the investigated pieces and in the recording, by means of a meter, of the number of impulses produced by the

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particles of radioactive substance entrained with the products of the wear by the lubricant.

The increase of wear is proportional to the size of the radioactivity of the oil, the conversion being made by using a standard unit.

Using the radioactive isotope method, different systems can be created to automatically signal the maximum allowable wear of the aggregates. In this case, a radioactive substance is introduced at a certain depth from the surface of the work-piece. When the piece is worn to the depth marked with the radioactive substance, it starts to train from the radioactive substance. In this case, radioactive particles will appear in the lubricant, the presence of which will be immediately recorded by the signalling system.

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Questions to check understanding

1. Describe in detail the phenomena that occur in the process of wear.
2. How is the actual surface area evaluated in the wear process?
3. Describe the phenomenon of semi-fluid / mixed wear.
4. List the types of wear you know.

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References

1. Bowden, F. P., Tabor, D., The Friction and Lubrication of Solid, P. I-II, Oxford Clarendon Press, 1964.
2. Caubet, I. J., Théorie et pratique industrielle de frottement, Ed. Tehnic., Dunod. Paris, 1964.
3. Deac, V., Badea, F., Dobrin C., The organization, flexibility and maintenance of production systems, ASE Publishing House, Buchareșt, 2010.
4. Dumitrescu, C. D. ş.a., Calitatea, fiabilitatea, mentenanţa sistemelor complexe, Editura Politehnica, Timişoara, 2008.
5. Dumitrescu, C. D. ş.a., Ingineria și asigurarea calității, Editura Politehnica, Timişoara, 2008.
6. Dumitrescu, C. D. ş.a., Ingineria și managementul calității produselor și serviciilor, Editura Politehnica, Timişoara, 2008.
7. Dumitrescu, C. D., Țișcă, I. A., Conteptul de mentenanța în contextual systemic. In. Mentenanța Sistemelor. Editura Politehnica, Timișoara, 2017.
8. Dumitrescu, C. D., Țișcă, I. A., Frecarea, uzarea și lubrifierea cuplelor de frecare. In. Mentenanța Sistemelor. Editura Politehnica, Timișoara, 2017.
9. Dumitrescu, C. D., Țișcă, I. A., Importanța și evoluția mentenanței în cadrul intreprinderilor industrial. In. Mentenanța Sistemelor. Editura Politehnica, Timișoara, 2017.
10. Dumitrescu, C. D., Țișcă, I. A., Utilizarea lanțului markov în elaborarea processelor de decizie. In. Mentenanța Sistemelor. Editura Politehnica, Timișoara, 2017.
11. Constantinescu, V. N., Asupre vâscozității fluidelor la presiuni mari, I. Conferinta, VAREHD, Institutul de Învatamânt Supuerior, Suceava, 1980.
12. Cru, I., Încercarea materialelor la uzura, Vol. I, Editura Tehnică, București, 1983.
13. Flamand, L., Fonctinnement du contact elastohydrodynamique regueux, These de grade de docteur d'etat, INSA Lyon, 1989.
14. Filipoiu, I. D., Raseev, M., Voica, I, Organe de mașini, Vol. I, Universitatea "Politehnica" București, 1994.
15. Heizer, J., Rendre B., Operations Management, Sixth edition, Prentice-Hall. Inc., Upper Saddle River, New Jersay, 2001.
16. Khonsari M. M., Wang H. S., A theory of thermo-EHD Lubrication of lquid-solid lubricated cylinders, Journal of Tribology, April 1996, Vol. 112, 254-261.

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17. Panaite, V., Munteanu, R., Control statistic și fiabilitate, Editura Didactică și Pedagogică, București, 1982.
18. Pavelescu, D., Musat, M., Tudor, A., Tribiologie, Editura Didactică și Pedagogică, București, 1977.
19. Pavelescu, D., Tribotehnica, Editura Didactică și Pedagogică, București, 1983.
20. Pavelescu, D., Radulescu, Gh., Gafitanu, M. Gheorghiu, N., Organe de mașini, Editura Didactică și Pedagogică, București, 1985.
21. Popinceanu, N., Gafitanu M., Diaconescu E., Cretu S., Mocanu D. R., Probleme fundamentale ale contactului cu rostogolire. Editura Tehnică, București, 1985.
22. Renert, M., Oprișan, Gh., Fiabilitatea utilajelor și instalațiilor chimice, Editura Tehnică, București, 1980.
23. Seiciu, P. L., Contribuții la imbunătățîrea portantei elastohidrodinamice la angrenaje modelate prin role, Teza de doctorat, U. P. B., București, 1997.
24. Tudor, A., Frecarea și uzarea materiale lor, Ed. BREN, București, 2002.
25. Zand M., Thermal and Non-Newtonian Effects in Elastohydrodynmic Lubrication of Rolling-Sliding Contacts, North Carolina State University at Raleigh, 1990.
26. Zechel, R., Bartz, J. W., Pressure Viscosity of Multigrade Engine Oils and Different synthetic Lubricants, EUROTRIB’89, Vol. 4, Helsinki, 1989.