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Systems theory and system analysis in economy

Tutorial

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CONTENT

INTRODUCTION

Systems theory and systems analysis – methodology for the scientific study of any objects by presenting them as systems and analyzing these systems.

Methodology Sciences is a system of principles and approaches of research activity on which a researcher (scientist) relies in the course of obtaining and developing of knowledge within a specific discipline: physics, chemistry, biology, mathematics, economics, computer science and other branches of science.

For the first time, the term “***systems theory***” was used by the biological theorist and philosopher Ludwig von Beratlanfi at a philosophical seminar in the late 1940s twentieth century. He owes his existence to a field of knowledge called the "general theory of systems."

Aa 1948 the famous book by N. Wiener “Cybernetics” is published, which proclaims the unity of management principles in biological and technical systems, and later in socio-economic ones. This led to the emergence in the theory of systems of a scientific direction called "***system analysis***" - the most constructive of applied areas of system research.

You can give this definition of system analysis.

Modern ***systems analysis*** *is an applied science aimed at identifying the causes of real difficulties encountered by the “owner of the problem”* (*organization, institution, enterprise, team*), *and the development of options for their elimination.*

The purpose of system analysis consists not only in understanding the functioning of the system - tasks of a higher level are the *design, creation of the desired system and its management.*

The basis of systems analysis is a systems approach.

Systems approach *– it is a methodology of scientific knowledge and practical activity, as well as an explanatory principle, which is based on the* ***consideration of an object as a system****.*

An object – indicates something that the practical or cognitive activity of the subject (observer) is directed at. This something can exist both in reality (thing, process or phenomenon), and in a fictional world (for example, an object in programming, a mathematical object); and the subject can be the subject itself – a person, a social group, or the whole society.

A system approach is the rejection of one-sided analytical, linear-causal research methods. The main emphasis in its application is on the analysis of the integral properties of the object, the identification of its various relationships and structures. A systematic approach seems to be the most universal method of analysis and research of any complex technical, economic, social, environmental, political, biological and other systems.

The fields of application of the systems approach and systems analysis in the practical activities of people are extensive from technology to economics, from mathematics to social planning, from space research to learning processes. In modern society, systemic ideas have already reached such a level that thoughts about the importance and usefulness of a systematic approach to solving all problems are familiar or generally accepted. Not only scientists, but also engineers, teachers, lawyers and cultural figures have discovered a systematic approach in their work and are trying to consciously systematize their work. The higher the degree of consistency (in solving problems), the more effective is the solution to any practical problems, since the system approach is general theoretical in nature and reflects integration processes between elements of different sciences that permeate system logic as a whole. Moreover, the development is carried out at the level of new (synthesizing) knowledge, which is of a system-forming nature (the establishment of various connections, principles, laws). Mandatory signs of consistency in the practical activities of people are:

1) structured activities;

2) the interconnectedness of the components of the activity;

3) the subordination of the organization of all activities to a specific goal.

Now we turn to a consistent presentation of the basic concepts and provisions of system theory and system analysis. First, we consider the generally accepted concepts in this area, as applied to various areas of knowledge and activity, and then specifically as applied to the economy.

TOPIC 1. BASES OF THEORY OF SYSTEMS

1.1. The concept of the system, its properties and purpose.

In the scientific and educational literature there are a large number of explanations of the content of the scientific concept in the term "system". In addition, this term entered broadly enough to explain a number of generalizations – the economic system, the information system, the social system, the energy system, the secondary and higher education system, and so on. An important means of characterizing a system is its properties. The main properties of the system are manifested through the integrity, interaction and interdependence of the processes of conversion of matter, energy and information, through its functionality, structure, communication, and external environment.

Property – these are the external manifestations of the process by which knowledge about the object is obtained, and observation is carried out on it. The properties of the object are perceived using sensory organs and technical means. Properties provide the ability to describe the objects of the system quantitatively, expressing them in units, having a certain dimension. Properties of system objects can change as a result of its action.

You share the following ***basic properties of the system***:

1. The system is, first of all, a set of elements. Under certain conditions, elements can be considered as systems. The system exists among other material objects that are not included in it. They are united by the concept of “***external environment***”. In fact, the delineation or identification of a system is the division of a certain area of the material world into two parts, one of which is considered as a system – an object of analysis (synthesis), and the other – as an external environment. *The relationship of the external environment and the system* can be considered one of the main features of the functioning of the system, an external characteristic of the system, which largely determines its properties.

2. The presence of significant relationships between elements and (or) their properties, superior in power (strength) of the connection of these elements with environmental elements that are not included in this system. Significant relationships are understood to mean those that naturally, with

necessity determine the ***integrative*** (combined) properties of the system. The indicated property distinguishes the system from a simple conglomerate and distinguishes it from the environment in the form of an integral object. ***Integrity*** – this is a system-wide property consisting in the fact that a change in any component of the system affects all its other components and leads to a changesystem as a whole; and vice versa, any change in the system responds to all components of the system.

3. The presence of a specific organization, which is manifested in the structuredness of the system and its ***hierarchy*** – *a structure characterized by the presence of subordination*, i.e. unequal relationships between elements, when the impact in one direction has a greater effect on the element than in the other.

4. The existence of integrative properties, that is, inherent in the system as a whole, but not peculiar to any of its elements separately. Their presence shows that although the properties of the system depend on the properties of the elements, they are not completely determined by them. *Conclusion: the system is not reduced to a simple set of elements, and, dividing the system into separate parts, it is impossible to know all the properties of the system as a whole.* This property of the system is called ***emergence*** (arising, unexpectedly appearing) – the system has special properties that are not inherent in its elements, as well as the sum of elements not connected by special system-forming bonds; irreducibility of system properties to the sum of the properties of its components; a synonym is a ***systemic effect***.

5. The system has the property of developing, adapting to new conditions by creating new connections, elements with their local goals and means of achieving them. ***Adaptability*** – the ability of a system to change its structure and choose behaviors in accordance with the new goals of the system and under the influence of environmental factors. ***Adaptive system*** – one in which there is a continuous process of learning or self-organization.

A system can be any object of animate and inanimate nature, society, a process or a set of processes, etc., if they define elements that form a unity (integrity) with its connections and interconnections between them, which ultimately creates a set of properties inherent only this system and distinguishing it from other systems.

Thus, in the most general case, taking into account the above properties:

System *– this is the set of elements that make up the unity of elements, their connections and interactions between themselves and between them and the external environment, forming the integrity inherent in this system, qualitative certainty and purposefulness.*

Based on the tasks of managing and researching the laws of functioning of technical, organizational, economic and social systems and the problems that arise in them, we will accept for the following clarification of the term “system”: ***a system*** *is a complex of interconnected parts, elements or subsystems united by a researcher to achieve some goal or a set of goals. An additional feature of the system is the belonging of each element and each connection between the elements to the fulfillment of its target function.*

In other words, *any system must fulfill some functions*: it simply exists, is the area of another system, serves a system of a higher order, is a control for a certain class of systems, serves as a tool or material for creating a more complex or advanced system, and so on, which make up system goals. In systems analysis, the goal is central to the system analysis itself and begins with the formulation of goals.

Subsystem *– part of the system, which in turn acts as a system of a lower order, the purpose of which is determined by the functions of a system of a higher order and hierarchy*.

To quantify the effectiveness of the functioning of the system in achieving its goals, the system as a whole and each subsystem separately must have formal descriptors and indicators of their activities, including a measure of the achievement of the goals of the entire system. In system analysis and a number of other sciences related to management, *a meter or measure of fulfilling goals is called a* ***criterion.*** That criterion basically dictates the behavior of the system. Thus, *the functioning of the system has a purpose, criteria for evaluating its implementation and a strategy for its achievement.*

This definition makes it possible to begin consideration of the system from the point of view of the meaning of its existence – its functions and goals, it contains the idea of interconnection and internal development of the system. First of all, we do not ask ourselves how the system is organized and how it functions, but the question of *why it exists, what its purpose is, that is, the* ***goal***, devoting further research, mainly to studying how this goal is achieved, due to what resources and how it can be implemented. Based on the fact that the *goal of its activity* is decisive in the system, we thereby assume that the same goal, in principle, can be achieved in various alternative ways.

Together with the hierarchy of subsystems of different levels, a hierarchy of the corresponding goals and criteria of these subsystems arises. The goals and criteria of subsystems should not only be aimed at you completeness of the main goal as its component, but also to be linked to each other in time. Building a tree of goals or a hierarchical graph that establishes the significance and subordination of goals can serve as a good "implementation mechanism" for such a link.

System purpose *in accordance with its function main purpose defines, directs and regulates its actions.* However, it must be in mandatory agreement:

- with objective laws and requirements (tasks) of a higher order system;
- with the real possibilities of the world surrounding the system or the environment;
- with the possibility of a numerical (formalized) description (see section 1.8) and control of the goal;
- with real capabilities and resources of the system itself.

Correspondence of a goal to objective laws means, first of all, correspondence to its goals of a higher system. Often, such a correspondence when setting the goal of the system is either intentionally or erroneously absent, which quite often leads to the destruction of the entire system. For example, the experience of building a developed socialist society and the subsequent collapse showed that "... the interests of society as a whole, that is, the state, were always in the first place, and the personal interests of an individual member of the society were considered as secondary, and sometimes even ignored." Therefore, when setting goals within a system – in its subsystems, it is important that the goals of the whole system and the course of their achievement be consistent and known to a subsystem of any level.

So, the goal determines the meaning of the existence of the system, it must correspond to the goals of the higher system, the objective capabilities of the external environment, the internal capabilities of the system itself.

Thus, the main quality inherent in any system is its functions of the main purpose (goal), respectively, the system can be single-functional (single-purpose) or multi-functional (multi-purpose).

For further presentation, we will choose the following as the definition of the purpose of the system:

System purpose this is the desired state of the system or the results of its activities achievable within a certain time interval (real goal).

The objectives of the activity stem from objective needs and are hierarchical in nature.

The goals of the upper level cannot be achieved until the goals of the nearest lower level are achieved.

Goals should be concretized by time and performers.

Among the many goals, it is advisable to try to find or form a global goal.

Goals should provide the ability to quantify their achievement.

The choice of goals is decisively influenced by the value system that this goal adheres to, therefore, when setting goals, the necessary stage of work is the identification of the value system that the decision maker adheres to.

For example, a distinction is made between the technocratic and humanistic value systems. According to the first system, nature is proclaimed as a source of inexhaustible resources, man is the king of nature. Everyone knows the thesis:

“*We cannot wait for favors from nature. It’s our task to take them from her”***.**

The humanistic system of values suggests that natural resources are limited, that a person must live in harmony with nature.

The practice of the development of human society shows that following a technocratic system of values leads to disastrous consequences. On the other hand, the complete rejection of technocratic values also has no justification. It is not necessary to contrast these systems, but reasonably supplement them and formulate the goals of the development of the system, taking into account both value systems.

1.2. External environment and system resources.

External environment *is a set of objects (systems) existing in space and time that are supposed to act on the system.*

The external environment determines all the conditions and laws of the functioning of the system, all aspects of its activities. The external environment imposes most of the limitations on the system. The rules and laws of the functioning of the system are determined by external additions that form the external environment of each system, and control their implementation.

If we consider the process of the occurrence of a problem, then the environment is understood as the external conditions that caused it. From the point of view of a formal definition, an environment for a system means everything that creates the conditions for its operation.

No system can be considered without its connection with the external environment. The question is only in the direction of this connection. Some authors consider one of the principles of a systematic approach the principle when only such phenomena and processes are considered as an object of study, the course of which does not affect the nature of the environmental impact on them.

For some processes, and especially economic ones, such a restriction is unacceptable. So, if during the industrial process an excessive amount of harmful emissions into the environment is released, the relevant supervisory authorities will impose financial sanctions on the enterprise or force it to construct rather expensive treatment facilities, which in turn will be reflected in an increase in the cost of production and will determine a significant increase in the cost of production products.

Or another example. The development of coal deposits in an open way will be determined, first of all, by the conclusion from the useful circulation of vast areas of land. Until recently, this was not given due attention, the cost of land was not taken into account when forming payments for the use of natural resources. The current legislative framework forces us to review previous projects and provide for strict regulation and reclamation of used land.

And finally, the third example concerns intensive fishing processes in a number of seas and coastal zones of the oceans, as a result of which fish stocks sharply decreased and the catch of some fish species ceased due to its absence (for example, Black Sea salmon and light croaker in the Black and Azov Sea).

In the described processes, the effect of the process on the environment occurs with a significant lag in time, however, the large scale of modern activity makes us very attentive to the nature of the inverse effect of some processes on the environment, especially in the field of the use of natural resources. This applies not only to flora and fauna, but also to reserves of mineral resources - coal, iron and polymetallic ores, water and other resources.

System resources *– it's all that is at the disposal of the system and that which the management of the system can actively influence in the direction of its most efficient use in the process of its functioning to achieve the goal.*

In the broadest sense, the resources include the material, energy and information components consumed by the system. Undoubtedly, human resources should also be attributed to resources. For example, for a manufacturing enterprise it will be fixed and revolving funds, human resources, technological units and all equipment engaged in production.

The resources should also include the scientific, technical or engineering potential of persons participating in the functioning of the system. The availability of qualified engineers and managers in many respects decides the success of the business. For example, a qualified design bureau of the plant, initiative employees of the chief mechanic's department ensure timely replacement of obsolete products with more advanced ones, modernization of equipment and technology. Here, not only the quantitative, but also the qualitative side of the leaders and engineering workers is important. The resources should also include the cultural and general educational level of the work collective. We will talk more about the role of human resources in a systems approach a bit later.

1.3. The concept of system structure.

The concept of structure is one of the many-valued concepts. It, like any other concept of a sufficient degree of generality, contains various semantic levels that correspond to some extent to the stages of its historical development in human knowledge. It is impossible to even list all the meanings of the concept of structure in which it appears by different authors. We will adhere to the following definition:

System structure – a set of system elements and the relationships between them in the form of a set. The structure of the system means the structure, location, order and reflects certain relationships, the interposition of the components of the system, i.e. its device and does not take into account the many properties (states) of its elements.

Element is *an integral part of a complex whole. In our case, a complex whole is a system, which is a complex of interconnected elements.*

An element is an indivisible part of a system that has independence in relation to a given system. The indivisibility of an element is considered as the inadvisability of accounting within the model of a given system of its internal structure. The element itself is characterized only by its external manifestations in the form of connections and interconnections with other elements.

The system can be represented by a simple enumeration of the elements (Fig. 1), however, most often when exploring an object, such a representation is not enough, since it is necessary to find out what the object is and what ensures the achievement of the goals.

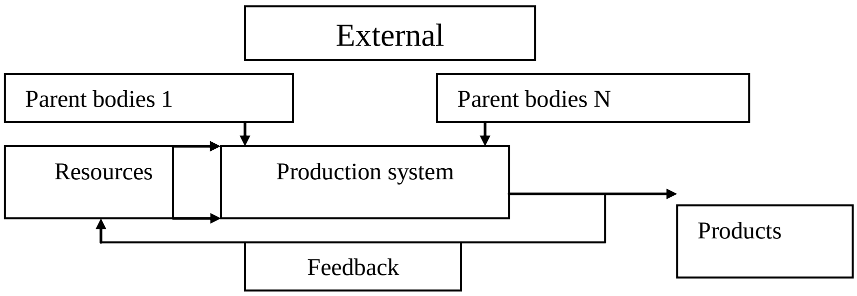


Fig. 1. System structure

One and the same object can be represented by systems with different structures depending on the stage of cognition of objects, on the aspects of consideration, on the goals of creation. Over time, the structure of the system can change - systems with *constant* and *variable* structures.

In a systematic description of organizational, economic, industrial and technical objects, *single-level* and *multi-level* structures are distinguished. Multilevel systems are characterized, as a rule, by a hierarchical structure; they are also characterized by *polystructure*, i.e., the interweaving of different-quality subsystems that form several hierarchical structures interconnected (production, technological, territorial, institutional, social, etc.).

Hierarchical structure was most widely used in the design of control systems, the higher the level of the hierarchy, the fewer links its elements have. All elements except the upper and lower levels have both command and subordinate control functions.

In the form of hierarchical structures, constructions of complex technical products and complexes, structures of classifiers and dictionaries, structures of goals and functions, production structures, organizational structures of enterprises are presented.

In general, the term hierarchy more broadly, it means subordination, the order of subordination of the lowest by rank and rank of higher, arose as the name of the "career ladder" in religion, is widely used to characterize the relationship in the apparatus of government, army, etc., then the concept of hierarchy was extended to any subordinate order of objects.

Thus, in hierarchical structures, it is only important to highlight the levels of subordination, and there can be any relationship between levels and components within a level. In accordance with this, there are structures that use the hierarchical principle, but have specific features, and it is advisable to highlight them specifically.

The structure may have a material, functional, algorithmic and other basis. An example of a material structure is the scheme of a prefabricated bridge, consisting of separate, assembled sections, which indicates the order of their connection. An example of a functional structure is the division of an internal combustion engine into power, lubrication, cooling, and torque transmission systems. An example of an algorithmic structure is a set of software tools that indicates a sequence of actions, or an instruction that defines these actions when troubleshooting a technical device.

In order to represent the object as a system at the first stage of cognition, it is necessary to dissect the object in one way or another, to reveal, for example, its spatially bounded parts, or to find other forms of dissection of the object, and then to state the existence of relations of these parts in a holistic picture of the object, i.e. carry out *decomposition* system. Thus, representing the object as a system, we give a preliminary picture of the component parts of the object in their mutual relations, i.e., we form the structure of the system. The definition of a system as some structure of the aggregate relations of parts or elements contributes to a more definite formulation of the research problem, so that in the future it would be possible to carry out a structural analysis of the system. In other words, *structural representations of systems can be a means of researching them*.

The system at its core is always structural. ***The structure is a system model***, and its formation – by ***modeling*** and characterizes only the structure of the system, not taking into account the many properties (states) of its elements. The concept of *model* and *modeling* in system analysis will be given by us in section 2.2.

1.4. Status and types of system behavior.

Each element of the system is characterized by specific properties (physical, chemical, economic, etc.) that define it uniquely in this system.

The set of all properties of an element will be called ***the state of the element,*** and the set of states of the elements and the relationships between them at a particular point in time will be called the ***state of the system***.

The state of an element, and, consequently, of the system as a whole, depending on various factors (time, space, external environment, etc.) can change. Successive changes in the state of an element (system) over time will be called the ***movement of the element (system).***

Considering the various modes of movement of the system, we can distinguish three different types of system behavior: equilibrium, transitional and periodic.

The state of the system is called ***equilibrium (stationary)*** if none of its essential variables changes in the considered time interval. Distinguish between ***static*** and ***dynamic*** equilibrium. **Static** equilibrium is the equilibrium of rest. In static equilibrium, the system in the absence of external disturbing influences or with constant influences retains its state throughout the entire observation time interval. The equilibrium state of the system in motion – ***dynamic*** equilibrium means that the transformations of its variables are identical, that is, they do not generate new images.

Transitional (***non-stationary***) is called this type of system behavior when it is in the process of transition from some initial state to any steady state.

If the system returns to the same state at regular intervals, then this behavior is called ***periodic***.

The equilibrium mode of system behavior is closely related to the concept of system stability.

Sustainability – this is the ability of the system to return to a state of equilibrium after it was removed from this state under the influence of external or internal disturbing influences. This ability is inherent in systems when the deviation does not exceed some established limit – the ***stability threshold***.

The concept of stability is one of the most important characteristics of system behavior. Under the stability refers to the constancy of the state of the system or the constancy of the sequences of some of its states in time during its transformations.

The concept of sustainability in living organisms is associated with the phenomenon of ***homeostasis.*** Homeostasis is the ability of living organisms to provide the optimal regime of the internal environment by maintaining the constancy of the essential parameters of the system (temperature, composition of the cell fluid, etc.). Ensuring the constancy of the essential parameters of the system is achieved through information management processes with feedback, which eliminates the consequences of disturbing random environmental influences on individual subsystems and elements of a living organism.

The principle of homeostasis is often used in the construction of various technical systems, which are called homeostatic.

The concept of stability in the strict sense does not apply to the system itself, but to some property of its behavior, moreover, the behavior of the system as a whole, and not any part of it. When combining a number of systems with unstable behavior, the new system may turn out to be stable. At the same time, aggregating several stable systems does not necessarily result in a system with stable behavior.

It should be noted that a system that is stable by some property of behavior, by another criterion, may be unstable. So, for example, the stability of productivity does not mean at all that the change in the cost of production will also be sustainable.

In specific studies, of undoubted interest is the change in the stability of the behavior of economic (economic) systems with respect to disturbances of a different nature, which we will discuss a little later.

1.5. Feedback system.

The concept of “connection” is included in any definition of a system and ensures the emergence and preservation of the integrity of its properties. This concept simultaneously characterizes both the structure (statics) and the functioning (dynamics) of the system. However, it is rather difficult to define this almost obvious concept - there are dozens of definitions. We will use the simplest definition, which sounds like this:

Communication *– a set of dependencies of the properties of one element on the properties of other elements of the system*. To establish a connection between two elements - this means to reveal the presence of dependencies of their properties. Any law of nature and society is an internal, stable, essential connection and mutual conditionality of phenomena. There is no law out of touch!

The dependence of the properties of elements can be *one-sided* and *two-sided*. Bilateral dependence of the properties of one element on the properties of other elements of the system is called the *relationship*. The set of interconnections and interrelations between the properties of elements, when they acquire the character of mutual interaction with each other, is called interaction.

First order bonds called connections functionally necessary to each other. Additional bonds are called ***second-order bonds***. If they are present, they significantly improve the action of the system (manifestation of the synergy effect), but are not functionally necessary. Excessive or conflicting relationships are called ***third-order bonds***. Sometimes communication is defined as restricting the freedom of elements. Indeed, the elements, entering into a relationship with each other, lose some of their properties, which they potentially possessed in a free state.

In the world around us, there are a very large number of different relationships – multidimensional, multifaceted, multivalued, multifaceted, which we must learn to learn. In the general theory of systems, special attention is paid to the following three types of connections.

Recursive connection – necessary connection between objects, in which it is clear where the cause and where the effect. For example, costs in the economy always act as a cause, and their results as a consequence. There is a recursive relationship between costs and results.

Synergetic relationship – it is defined as a relationship that, when combined with the actions of independent elements of the system, provides an increase in their overall effect to a value greater than the sum of the effects of these elements acting independently. Therefore, it is a reinforcing connection between the elements of the system. It is from synergetic relationships that the integral (emergent) properties follow, that is, the properties of a holistic system that are not inherent in its constituent elements considered outside the system.

Cyclic (feedback – it is a process leading to the fact that the result of the functioning of a system affects the parameters on which the functioning of this system depends. The only purpose of the feedback subsystems is to change the ongoing process. In this connection, feedback is the basis of the object of control, self-regulation and development of systems, their adaptation to changing conditions of existence.

To describe the principle of feedback, we restrict ourselves to considering the interaction of the system only with the external environment (Fig. 2).

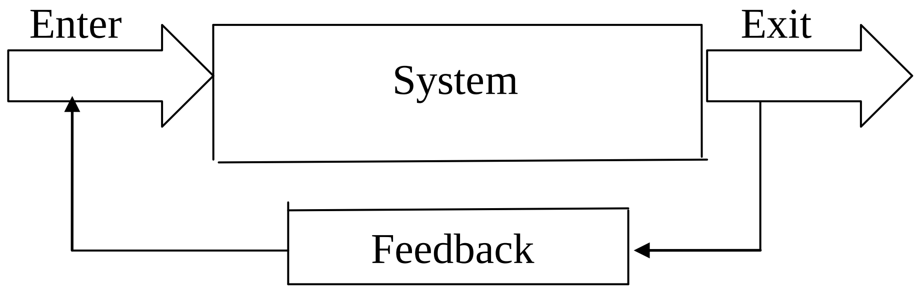


Fig. 2. The cyclic communication scheme

System inputs – these are different points of influence application (impacts) environmental system. System inputs may be information, substance, energy and so on, which are subject to conversion. Generalized input (X) call some (any) the condition of all r input parameters x_1, x_2,…, x_r the system, which can be represented as a vector $X = (x_1, x_2,\dots, x_r)$.

System outputs – these are different points of influence application (impacts) environmental systems. The system output (Y) is the result of the system converting the information, matter and energy.

In this case, the system behavior can be described by the law (function) F, reflecting changes in X at the input and Y at the output of the system: $Y = F(X)$. It also determines the state of the system at a certain point in time. To determine the function F, the methods of expert estimates, mathematical, simulation and stochastic modeling are most often used. A detailed analysis of these methods is carried out within the discipline "Operational Research and Optimization Methods".

Now, taking into account the above remarks, we can, in the general case, consider how feedback on the management of the system is organized. All methods of managing the system can be divided into two alternative classes.

- Management designed to ensure the *stability of the system in this state.* Let the system deviate from its current state as a result of some random impact, for example, from the external environment. We can judge this by *changing* the values of a number of output parameters. In this case, the feedback should change the input signal in such a way as to counteract the change in the output signal and return the system to its original state with the original output parameters. This feedback is called ***negative feedback.***
- Management designed to ensure the *transfer of the system from one state to another.* This is achieved due to the ***positive feedback***, which, through a controlled action on the input parameters, puts the system in the desired state with the given output parameters.

In fact, the *positive and negative* feedbacks thus form a *system control loop* that has a closed form (Fig. 2) due to the appearance of the possibility of dosing control actions on the input parameters of the system and analysis of their results by output parameters.

When developing models of the functioning of complex self-regulating, self-organizing systems in them, as a rule, both negative and positive feedbacks are present at the same time. So, for example, the production and needs of people form complex feedback, in which the need to meet the needs of people is driven by production, and the latter creates the basis for expanding the range of satisfied needs.

An example *A* complex self-regulating, self-organizing system is also any living organism in which feedback provides it with a stable development of its organism even with adverse interactions with the external environment. In more detail, systems with control will be considered by us in a separate section a little later.

1.6. Classification of systems.

Systems are divided into classes according to various criteria, and depending on the problem to be solved, one can choose different classification criteria:

1) by specificity constituting the system of elements (that is, by their nature) distinguish between ***material*** and ***abstract*** systems. Material systems are objects of the real world around us. Among the whole variety of material systems, there are ***natural*** ones that have arisen independently of man (for example, the solar system), and ***artificial*** ones, that is, created by man (for example, the goods circulation system). Abstract systems are a speculative representation of images or models of material systems, which are divided into ***descriptive*** (logical) and ***symbolic*** (mathematical). In the management of modern complex production, abstract systems play no less role than material ones.

2) by type of displayed object: technical; biological; economic, etc .;

3) by the nature of the interaction ***open*** and ***closed*** systems are distinguished with the environment. In an open system, there is a continuous exchange with the external environment of energy, matter, information. An open system interacts continuously with the environment. All biological, technical, economic systems are open systems. In a closed system, its elements interact only among themselves and are not connected with the external environment, that is, systems that do not exchange substances, energy, information with the environment. Any real systems are subject to the interaction of the environment and themselves affect it, that is, they are open.

4) by the nature of the causation of events in the process of interaction of elements, in particular, by the nature of the dependence of the output reactions of the system on input pulses, ***deterministic*** and ***stochastic*** (***probabilistic***) systems. Knowing the nature of the input pulses, one can accurately predict what the expected output response will be, such systems are called ***deterministic***. The connections in such systems are rigid, functional and her behavior can be absolutely accurately foreseen. For example, knowing the laws of motion of the planets of the solar system, you can accurately predict solar and lunar eclipses, etc.

Probabilistic (***stochastic***) call such systems in which the sequence of events in which is strictly not determined and is probabilistic in nature. That is, the system experiences effects that are uncontrollable, random in nature. For example, even in fairly clean experiments with fertilizers, introducing the same dose of the substance, we will get different results on different plots, although the conditions were as even as possible. Stochastic systems are also systems in which the human factor is present - factories, airports, shops, consumer services, etc.

5) by the nature of the movement of the system, i.e., changes in its states over time. In some systems, the transition from one state to another is carried out by instantaneous jumps, and then the system remains in this state for a relatively long time. Such systems are called ***static.*** In real conditions, the system cannot remain in a statistical state indefinitely. All real systems change over time. When talking about static systems, they mean that system variables remain unchanged for the duration of this study. Systems are called ***dynamic*** if the transition from one state to another is made not by instantaneous jumps, but during some time, that is, the transition processes can be observed and described. Dynamic systems characterized by the fact that their output signals at a given time are determined by the nature of the input influences in the past and present (depending on the background). Otherwise, the systems are static. An example of dynamic systems is biological, economic, social systems; artificial systems such as enterprise, production line, etc.

6) **the degree of complexity of the system** is usually divided into simple, complex and very complex.

Simple called systems consisting of a small number of elements, with simple relationships, unbranched internal structure, the purpose of which is to perform elementary functions. Examples of such systems are crop rotation in crop rotation, etc.

A system is called ***complex*** if the number of elements in it is significant, but still visible and calculable, the structure of relationships and interactions is branched, the functions performed are diverse. An example of a complex system is an agricultural enterprise.

Very complexed system is usually called a system, the essence of the relationship in which is not well understood and not fully understood. Examples of such systems are the universe, society, economics, and the brain.

Of greatest interest from the point of view of control are the patterns of behavior of complex and very complex dynamic systems in motion.

Classifications are always relative. So, in a deterministic system one can find elements of stochasticity, and, on the contrary, a deterministic system can be considered a special case of stochastic (with probability equal to one). Similarly, if we take into account the dialectics of the subjective and objective in the system, then we will understand the relativity of the division of the system into abstract and objectively existing: these may be the stages of development of the same system. Concerning other classifications of systems exist in the literature. For example: distinguish between **linear** and **non-linear** systems. For linear systems, the reaction to the sum of two or more different actions is equivalent to the sum of the reactions to each disturbance separately. For nonlinear – this condition is not satisfied; if the input and output of the system is measured or changes in time discretely, through the step Δt, then the system is called **discrete**. The opposite concept is the concept of a **continuous** system. So computers, electronic clocks, electric meters are discrete systems, and hourglass, sundials, heating devices, etc. are continuous systems.

1.7. Conceptual theory issues systems.

We formulate three main conceptual questions of the theory of systems.

First conceptual question is the internal variability of the system, which is caused by both the variability of the research objectives and the development of the system over time. *The same system, depending on the objectives of the research, may have a different internal structure, and the structure may change over time.* Thus, the system is not something once forever given. In accordance with its internal capabilities, requirements, conditions of a higher-level system and environment, changes can be made to it. It is important that these changes improve the effectiveness of activities to achieve the goals set for the system in question.

Second conceptual issue the question is who defines the goals of research, how to describe its functioning and criteria for evaluating the activities of the system. In principle, as follows from our definition, they are established by a superior system through the goals and strategy of the system under study.

Third conceptual issue the question is who should provide for the introduction of appropriate changes in the nature of the activity and structure of the system, who and how adjusts the goals of the system, determines the criteria, develops and implements a strategy for a dedicated (or predetermined) time interval.

The theory of systems is used in the study and study of a wide range of scientific, social, technical, economic and other problems, including in the formulation of the research problem itself in conditions of information uncertainty. Here, problems are understood as tasks whose solution has matured in society. Theoretical and cognitive approaches to the study of systems contribute to a clear definition of the main classes of systems, analysis methods, models and algorithms, to which it is advisable to apply the methodology of system theory, and provides a basis for developing common principles for formalizing the most heterogeneous objects and phenomena.

How to practically check whether the system in question is systemic? Using the method of control questions, we can offer the following sequence of questions, the answers to which will help us practically deal with our "system":

1. Is the set of elements of the system complete, that is, sufficient for the functioning of the system? Are there any extra or missing items?

2. What are the relationships between the elements? Are there enough of them, are there any extra ones? Do communications ensure system functioning?

3. Does the system possess qualities (functional properties) that are not inherent in any of its elements separately?

4. Is the interconnection of this system with the external environment ensured? Are all significant external relationships taken into account? Limitations?

5. What will the analysis of this system from the position of the subsystem, that is, from above, give? Are the laws of development inherent in the subsystem violated?

6. What will the analysis of this system give from the perspective of possible outcomes (final results), that is, a view from below?

7. Does this system as a part of matter possess all its inherent properties (materiality, objectivity, the transformation of matter from one species to another, etc.)?

8. Are the laws of materialistic dialectics preserved or violated in the system? Can a system evolve, what are the driving forces of development?

The variety and fundamental differences of objects, processes, problems to be considered from the perspective of systems theory, determined the diversity of the instrumental base and formulated the requirements for their application in the study of various economic, organizational, technical and other processes and phenomena called system analysis, which will be discussed a little later.

1.8. Methods of presentation and description of systems.

Obviously, the statement is that in order to effectively manage, you need to know what you are managing. In the theory of systems, an idea of a controlled object should be given by its systematic description, which is the first step in the process of forming managerial decisions.

1.8.1. Principles of system description.

The practical orientation of system research determines the whole specificity of concepts, approaches and methods and can be represented as a fundamental principle of system analysis – ***the principle of purpose***. This principle states that any complex object should be considered only from the point of view of solving a specific problem facing the researcher or decision maker. This means that *the description of the system must be focused.* The goal determines the method and form of description of the object. The purpose of the analysis is dictated by the choice of the level of generalization, on which the description of the system is based. This level is fixed by the choice of system elements whose integral properties constitute the boundary of the system description details. As already emphasized, the decomposition of the system, although it is of a targeted nature, is not determined by the arbitrariness of the researcher,

The properties of the integrity, hierarchy and infinity of the system made it possible to formulate one of the basic principles of system theory – ***the principle of multi-level description***, the number of description levels is determined by the goals and the depth of analysis necessary to achieve them. In a generalized sense, it states that any object should be described:

- as an element of a system of a higher order or level;
- as an integral structure that can be represented in the form of an associated set of parameters;
- as some complex structure, the internal structure of which must be presented with a sufficient detail to achieve the objectives of the study.

Thus, the minimum required number of levels of system description is three. In fact, when researching, for example, socio-economic and economic systems, a significantly larger number of levels of description are usually introduced.

The concept of *system description* is associated with the *concept of system description languages.* Description languages must correlate with each other in a certain way, forming a hierarchy of descriptions. The hierarchical system of languages that describes a system or object should be built on the principle of *information unity*, the essence of which is that each concept, each process in the description hierarchy is the result of a generalization of the concepts of a lower level of description.

In the light of the above principles, the description of the system at each hierarchical level should be appropriately structured and, in the general case, should reflect:

- goals and objectives of the study;
- numerical criteria for assessing the completeness and quality of the performance of the objective function (see section 2.2);
- the place of the system under study in a system of a higher order, the measure or degree of dependence on the external environment, the form and mechanism for the implementation of this dependence;

- the functions of the system in achieving the goal of a higher order system;
- main indicators of the system;
- the structure of the system and the functional purpose of the elements;
- content of information links;
- management structure and organization of targeted behavior of the system;
- goals of the system, decomposition of goals into tasks;
- a hypothesis about the mechanism of functioning of the system;
- analysis of the functioning and forecasting of the development of the system based on the identified goals and objectives of the system and the mechanism of its functioning.

The listed aspects should be contained in each level of the system description. However, in many cases, the principle of *information unity* is not maintained. For example, as the experience of a *substantive* study of various problems of the functioning and development of the system shows, in most works devoted to this problem, such structuring and strict orientation to the goals of the study are not observed. Usually, the presentation is carried out in free form, the levels of generalization are not fixed, the mechanism of functioning of the investigated object is not described explicitly. This circumstance extremely complicates the transition to the next level of description of formal methods of system research and the construction of mathematical models of the system. In most cases, you have to re-design structured, a multilevel system description of objects from the point of view of the questions being investigated, since formalization is based on a meaningful description and completely depends on its quality. This is an extremely important and crucial stage of system research, designed to generalize and systematize empirical and theoretical knowledge about the object from the standpoint of the goals of analysis, to develop a fundamental hypothesis about the mechanism of its functioning and build a meaningful, model of the system, which forms the basis of its formal theoretical representation.

1.8.2. Formalization of systems.

The transition from a *meaningful (verbal*) description of the system to a *formal* description is a complex problem, both theoretically and in applied terms. The origins of this problem lie in the difference in the natural language used for a meaningful (verbal) description of the system and formal languages that have their own specifics for various systems: economic, technical, social, environmental, etc. Any formalization inextricably associated with the construction of artificial, or formalized, scientific languages. Such languages are created to accurately express thoughts in order to exclude the possibility of ambiguous understanding. Formalization makes it possible to build scientific languages with a precisely established structure and given rules for converting some expressions into others.

Natural language is extremely rich in semantic nuances and has great flexibility in reflecting reality. Causal relationships of various nature in the system are easily interpreted by means of a natural language. However, his concepts are fixed implicitly and ambiguously. For example, the laws and relationships in the description of the system are given in a general, non-specific, qualitative form, allowing for various interpretations. The conclusion mechanism is based on the intuitive logic of communication and inference. As a means of expressing thoughts, natural language has an infinite variety of forms and makes extensive use of the deliberate ambiguity of meaning and almost always contains subtext that is clearly not fixed. That’s why natural language can convey the subtlest nuances of human thoughts,

At the same time, a quantitative analysis of the phenomena and processes of reality has its own laws, which contradict the properties of the natural language, and requires a special formalized approach to the description of the system. A formalized approach requires, first of all, the unambiguity of concepts, a strict logic of conclusions and conclusions, fixing the meaning of transformations that reflect the laws under consideration. Formal language is poor compared to natural language. It always simplistically reflects reality. The wealth of semantic nuances, concepts, intuitive-logical techniques, in principle, can not be formalized.

Therefore, in the context of systemic research, formalization should be associated with a meaningful interpretation of quantitative results, their comprehension and the addition of non-formalizable aspects.

***Formalization** – this is the stage of systematic research, at which the main hypothesis formulated in the content description about the mechanism of the studied process of the system's functioning and its regularities takes on a strict logical and quantitative form of cause-effect relations.*

The first stage of formalization is the construction (synthesis) of a *formal scheme of the structure of the system* containing a symbolic description of the system and the process of its functioning. The second stage is the construction of *system models*.

In the formal scheme, the connections between the elements, the description and functioning parameters of the elements of the system and the system as a whole, and the space-time dependencies are clearly fixed. The main transformations in this scheme are usually represented by some display operators, the internal mechanism of which may not be considered at the first ethane of formalization. The formal scheme, by virtue of its generality, allows one to interpret meaningfully in their terms all possible phenomena that take place in the system under study.

The formal scheme has a dual purpose:

- on its basis it is possible to develop both a substantive and a formal theory of the process under study;

- It serves as the basis for building a system of models.

The logic of relations of the formal scheme allows a meaningful analysis to be strictly and purposefully and makes its conclusions and recommendations more conclusive and unambiguous.

***Synthesis of a formal scheme** – it is nothing more than a process of cognition of a system, representing a certain stage in the general system research, and it is inextricably linked and determined by the structure of the system.* It can begin, for example, with the fact that the decomposition of the system given in the substantial description is presented in graphical form, the connections between the elements are drawn and their content is fixed, that is, the structure of the system is formed. This graphic display illustrates a meaningful diagram of the functioning of the system, fixing the sequence of actions of its elements and communication with a wider system.

A similar graphical diagram is built for each subsystem and further for all elements, that is, it is detailed down to the element whose internal structure at the selected level of analysis is indifferent to us. In other words, already at this stage, a hierarchy of system descriptions is introduced, in accordance with which the system description languages will be selected. In addition, here we select and fix the structure of the system as the basis of a formal description.

The next step in constructing a formal scheme is to translate a meaningful description of the relationships of elements within the system and the external relationships of the system to specific parameters of the system and its elements. These parameters should have a clear meaning, unambiguously reflect one or another characteristic of the state of the system and its elements, the relationships, factors and conditions that occur in the system. The choice of parameters for describing the system and its elements is a complex creative process, largely determined by the art and knowledge of the researcher.

The choice is usually made from above, first for the general graphic scheme, then for the schemes of subsystems and elements. When choosing system parameters, it is necessary to focus on the available information, clearly present the methods for obtaining each of them and their relationship with the parameters of a lower level system description.

The choice of parameters at each level of the system description - this is the compilation of formal system description languages, in terms of which its dynamics will be described in the future.

The correct choice of system parameters is helped by the consistent application of the ***classification principle***, which states that in order to build a formal scheme and a formal model of the process under study, it is necessary to classify the state of the system and its elements in accordance with the objectives of the study, necessarily taking into account the chosen levels of generalization. Next, for each class of system states, classify the values of the selected parameters.

In other words, for further consideration, *it is necessary to select only those states of the system under study that correspond to the objectives of our study, and to each of them to compare certain values of the parameters for describing this state.*

The state parameters of the system and its elements can be both quantitative, expressed as numbers, but also allow a meaningful description that allows its translation into quantitative scales and indicators.

The final step in constructing a formal scheme is to display the system's functioning scheme in terms of selected languages, that is, parameters of different levels of system description.

A formal diagram may have a tabular graphic or mathematical form. In the latter case, the tabular-graphical form can illustrate the provisions of its mathematical counterpart. The table-graphical representation of the formal scheme is convenient when analyzing poorly formalized objects, for example, such as social processes in systems.

To study material processes in the system, you can build a mathematical formal scheme, and, if necessary, provide it with graphic illustrations. Naturally, any formal scheme should be accompanied by a special description explaining the meaning of all the transformations performed.

The development of a formal scheme completes the systemic representation of the object of study.

TOPIC 2. BASES OF SYSTEM ANALYSIS

System analysis as a discipline was formed as a result of the need to research and design complex systems, manage them in the face of incomplete information, limited resources and lack of time. Due to fundamental considerations, the concepts and axiomatics used in system analysis are based on the axiomatics of control theory, information theory, theory of choice and decision-making. The widespread dissemination of ideas and methods of system analysis, and most importantly, their successful application in practice became possible only with the introduction and widespread use of computers. It is the use of computers as a tool for solving complex problems that allowed us to move from building theoretical models of systems to their wide practical application.

Today ***system analysis*** *is a section of systems theory, the methodology of which is a* ***systematic approach*** *and consists in the study of any objects by representing them as systems, their analysis and synthesis, identifying common properties and patterns for formalizing these systems.*

2.1. The concept and basic principles of a systems approach.

The study of objects as systems caused the formation of a new scientific methodology – a *systematic approach* used in various fields of science and human activity. The purpose of this science is to search for the structural similarity of laws established in various disciplines, based on which, system-wide laws can be derived. For example, in sociology, two main systemic approaches to the study of society can be distinguished. This is a *structural and functional analysis* that explores the features of a developed society, the determining role of the production method in relation to other aspects of social life, the contradictions between the material and spiritual phenomena of life, the specific features and complexity of expressing economic relations through the interaction of political, legal, family, emotional and other relations existing in society. Another approach to the study of social phenomena is a genetic analysis. Its tasks are understanding the society as a developing whole, highlighting the qualitative features of each stage of its development. Ultimately, these two methods of research are mutually complementary, allowing us to understand society as a whole.

Currently, many works are devoted to systems research. All of them consider the solution of systemic problems in which the object of research is presented in the form of a system.

System tasks can be of two types: ***system analysis*** and ***system synthesis.***

Analysis tasks – determination of the properties of the system according to a known structure, the study of the properties of an existing education, i.e. analysis, involves the process of dividing the whole into parts.

Synthesis tasks – determination of the structure of the system according to its properties, i.e., the creation of a new structure, which should have the desired properties - building a whole of parts.

In fact, in a system analysis, these two opposing approaches, the methods of analysis and synthesis are intertwined, while carrying out the analytical procedure, attention is constantly paid to the methods of combining, synthesizing individual results into a single whole and the influence, analysis of each of the elements on other elements of the system and the system as a whole.

Consider the basic principles of a systems approach.

First principle – this is a requirement to consider the totality of the elements of the system as a whole.

Second principle – this is recognition that the properties of a system are not just the sum of the properties of its elements. Thus, the possibility is postulated that the system has special properties that some elements may not have.

Third principle a systematic approach determines the hierarchy of knowledge, requiring a multi-level study of the subject: the study of the subject itself is an "own" level; the study of the same subject as an element of a wider system is the "higher" level and, finally, the study of this subject in relation to the elements making up the subject is the "lower" level.

This principle of a systems approach requires the study of integrative properties and patterns of systems and systems of systems, the disclosure of the basic mechanisms of integration of the whole.

Fourth principle a systematic approach is its focus on obtaining quantitative characteristics, the creation of methods that narrow the ambiguity of concepts, definitions, estimates.

Fifth principle the focus of the system approach on the effectiveness of the management system. It is theoretically proved that there always exists a function of the value of a system - in the form of a dependence of its effectiveness (almost always it is an economic indicator) on the conditions of construction and functioning.

In other words, a systematic approach requires considering the problem not in isolation, but in the unity of relations with the environment, comprehending the essence of each connection and an individual element, and conducting associations between general and private goals. All this forms a special method of thinking that allows you to flexibly respond to changes in the situation and make informed decisions.

With that said, we define the concept of a systematic approach.

Systems approach *– this is an approach to the study of an object as a system in which elements, internal and external relations, which most significantly affect the studied results of its functioning, are identified, and the goals of each of the elements are determined based on the general purpose of the object.*

In practice, to implement a systematic approach, it is necessary to provide for the following sequence of actions:

- the formulation of the research task, from which it should be clear what needs to be done and on the basis of what to do it;
- allocation of the object of study as a system from the environment. A feature of distinguishing an object as a system from the environment is that it is necessary to select its elements whose activities or properties are manifested in the field of research of this object;
- the establishment of the internal structure of the system and the identification of external and internal relations. The need to identify (or create) a particular connection is determined by the degree of its influence on the characteristics being studied: those that have a significant impact should be left behind. In cases where the relationships are unclear, it is necessary to enlarge the structure of the system to known levels and conduct research in order to further deepen the details to the required level. Elements that do not have connections with others should not be introduced into the structure of the system. From the foregoing, the conclusion follows: the establishment of the internal structure is not an operation only of the initial stage of research, it will be refined, and will change as the research is conducted. This process distinguishes complex systems from simple systems,
- the definition (or setting) of goals in front of the elements based on the manifest (or expected) result and the entire system as a whole. In any system, each element of its structure functions on the basis of its own

purpose. When identifying it (or setting it up), one should be guided by the requirement of subordination to the general goal of the system. It should be noted here that the particular goals of the elements are not always consistent with the ultimate goals of the system itself;

- development of a model of the system and conducting research on it. Complex systems are usually investigated on models. The purpose of modeling is to determine the responses of the system to impacts, the boundaries of the functioning of the system, the effectiveness of control algorithms. The model should allow the possibility of variations in the change in the number of elements and the relationships between them in order to study various options for constructing the system. The process of studying complex systems is iterative, and the number of possible approximations depends on a priori knowledge of the system and the rigidity of the requirements for the accuracy of the results obtained. Thus, a systematic approach involves research not on a real system-object, but on a system-model.

Model (in science) is a substitute object of the original object, a tool for cognition that the researcher puts between himself and the original object and with the help of which he studies some of the properties of the original. The model is another material or mentally presented object that replaces the original object in the process of research. Correspondence of the model properties to the original object is characterized by ***adequacy*** – information obtained during the study of the model can be transferred to the object with one degree or another degree of reliability. The mismatch between the properties of the model and the object may be due, for example, to the following reason. When constructing a model, the researcher endows the model elements with abstract, ideal, mental properties that may not fully correspond to the properties of a real object. Therefore, the results of studies on a model may not fully correspond to the results of the same studies on a real object. The process of building and researching a model is called ***modeling.***

In modern science, models are widespread in the form of a description of an object (object, process or phenomenon) in a formalized language designed to study its properties. Such a description is especially useful in cases where the study of the object itself is difficult or physically impossible.

Based on the studies, recommendations are made:

- by the nature of the interaction between the system and the environment;
- the structure of the system, types of organizations and types of relationships between elements;
- according to the law of system management.

The main practical task of the systematic approach to the study of control systems is to, having discovered and described complexity, justify additional physically feasible connections that, when superimposed on a complex control system, would make it manageable within the required limits, while preserving such areas of independence that contribute to improving the efficiency of the system.

The included new feedbacks should strengthen the favorable and weaken the adverse trends in the behavior of the management system, preserving and strengthening its focus, but at the same time orienting it to the interests of the supersystem.

2.2. Modeling as a method of system analysis.

On the one hand, the system is that physical reality in relation to which it is necessary to make decisions (any natural and artificial objects). On the other hand, in the process of system analysis, an abstract and conceptual system is created, described using symbols or other means, which is a certain structural and logical device, the purpose of which is to serve as a tool for understanding, describing and possibly more fully optimizing the behavior of connections and relations of elements real physical system. Such an abstract system can be a mathematical, machine or word model or a system of models, etc. In the physical and corresponding abstract model system, a one-to-one relationship between the elements and their relationships must be established. In this case, it is possible without resorting to experiments on real physical systems, evaluate various kinds of working hypotheses regarding the appropriateness of certain actions, using the appropriate abstract model system, and work out the most preferred solution. However, in this case, especially for complex models, the question of conformity of the used reality models arises reasonably. For example, without taking into account the external environment, conclusions about the behavior of the system, obtained on the basis of modeling, can be quite justified when viewed from the inside of the system. But a situation is not ruled out, when these conclusions have nothing to do with the system - when looking at it from the outside world. This is where a special modeling method comes to the rescue – the statistical test method. Existing modern methods of mathematical statistics allow us to answer the question - is it possible and, with what confidence, to use the simulation data. If these confidence indicators are sufficient for us, we can use the model to answer the questions posed above.

From the totality of research methods, experts distinguish two different approaches: mathematical and logical.

Supporters of the first of them emphasize mathematics, i.e., to describe a complex system using formal means (block diagrams, networks, mathematical equations). On the basis of this kind of formal description, the mathematical task is often posed to find the optimal system design or the best mode of its functioning, i.e., to find with the help of a computer the maximum (or minimum) of the target function of the system (for example, maximum profit, minimum cost, maximum reliability, etc.) under given restrictions on the values of controlled variables.

Three main directions can be distinguished in it. These three areas correspond to the three stages that are always present in the study of complex systems:

1) the construction of a mathematical model of the investigated object;

2) statement of the research task;

3) the solution of the mathematical problem.

Consider these steps.

1. The construction of a mathematical model (formalization of the studied system, process or phenomenon) is a description of the process in the language of mathematics. When constructing a model, a mathematical description of the phenomena and processes occurring in the system is

carried out. Since knowledge is always relative, a description in any language reflects only some aspects of the processes and is never completely complete. On the other hand, it should be noted that when constructing a model, it is necessary to focus on those sides of the process under study that are of interest to the researcher. In this way,

Mathematical model is an *approximate representation of real objects, processes or systems, expressed in mathematical terms and preserving the essential features of the original. Mathematical models in quantitative form, using logical-mathematical constructions, describe the basic properties of an object, process or system, its parameters, internal and external relations.*

Deeply erroneous is the desire in building a mathematical model of the system to reflect all aspects of the existence of the system. When conducting a system analysis, as a rule, they are interested in the dynamic behavior of the system, and when describing the dynamics from the point of view of the study, there are paramount parameters and interactions, and there are parameters and interactions that are not significant in this study. Thus, the quality of the model is determined by the correspondence of the performed description to the requirements that are presented to the study, the correspondence of the results obtained using the model to the course of the observed process or phenomenon. The construction of a mathematical model is the basis of the entire system analysis, the central stage of research or design of any system. The result of the entire system analysis depends on the quality of the model.

According to the principles of construction, mathematical models are divided into ***analytical*** and ***simulation.***

In ***analytical*** models, the functioning processes of real objects, processes or systems are written in the form of explicit functional dependencies.

However, there is a class of objects for which, for various reasons, analytical models have not been developed, or methods for solving the resulting model have not been developed. In this case, the analytical model is replaced by a simulator or simulation model.

In ***simulation*** modeling, the functioning of objects, processes, or systems is described by a set of algorithms. Algorithms imitate real elementary phenomena that make up a process or system while preserving their logical structure and sequence over time. Simulation allows you to use the source data to obtain information about the states of a process or system at certain points in time, however, predicting the behavior of objects, processes or systems is difficult. We can say that simulation models are computer experiments performed on computers with mathematical models that simulate the behavior of real objects, processes, or systems.

The basis for constructing a simulation model is a system analysis of the simulated object and a system synthesis of its model.

Depending on the nature of the studied real processes and systems, mathematical models can be ***deterministic*** and ***stochastic.***

In ***deterministic*** models, it is assumed that there are no random influences, the elements of the model (variables, mathematical relationships) are sufficiently accurately established, the behavior of the system can be precisely determined. When constructing deterministic models, algebraic equations, integral equations, and matrix algebra are most often used.

Stochastic model takes into account the random nature of the processes in the studied objects and systems, which is described by methods of probability theory and mathematical statistics.

According to the behavior of models in time, they are divided into ***static*** and ***dynamic***. ***Static*** models describe the behavior of an object, process, or system at any given time. ***Dynamic*** models reflect the behavior of an object, process, or system over time. In this case, the model parameters are functions of time and the objective function includes the coordinate of time.

2. At this stage, the purpose of the analysis is formulated. The purpose of the study is assumed to be an external factor in relation to the system. Thus, the goal becomes an independent object of study. The goal must be formalized. The task of system analysis is to carry out the necessary analysis of uncertainties, constraints, and formulate, ultimately,

some optimization problem $S_f = f(x) \rightarrow max$, $x \in G$. Here S_f is a number that displays a quantitative criterion for achieving the goal; f is the objective function, x is an element of a certain normalized space G, determined by the nature of the model, $G \subset E$, where E is a set that can have an arbitrarily complex nature, determined by the structure of the model and the features of the system under study. Thus, the task of system analysis at this stage is interpreted as some optimization problem.

Analyzing the requirements for the system, that is, the goals that the researcher expects to achieve, and those uncertainties that are inevitably present, the researcher must formulate the goal of analysis in the language of mathematics. The optimization language here turns out to be natural and convenient, but not at all the only one possible.

3. Only this third stage of analysis can be attributed to the stage itself, which fully uses mathematical methods. Although without the knowledge of mathematics and the capabilities of its apparatus, the successful implementation of the first two stages is impossible, since formalization methods should be widely used both in constructing a system model and in formulating the goals and objectives of analysis. However, we note that it is at the final stage of system analysis that subtle mathematical methods may be required. But it should be borne in mind that the problems of system analysis may have a number of features that lead to the need to use heuristic approaches along with formal procedures. The reasons for turning to heuristic methods are primarily related to the lack of a priori information about the processes taking place in the analyzed system.

Another approach puts the logic of system analysis at the forefront. In this case, the inextricable relationship of system analysis with decision making is emphasized, and that means choosing a specific image or course of action among several possible alternatives. Here, system analysis is considered, first of all, as a methodology for clarifying and organizing or the so-called structuring of a problem that must be solved with or without the use of mathematics and computers. At the same time, the concept of “structurization” includes both an explanation of the real goals of the system itself, alternative ways to achieve these goals and the relationships between the components in the process of implementing each alternative, and an in-depth understanding of the external conditions in which the problem arose, and hence the limitations and consequences of a different course of action.

Logical system analysis is supplemented to one degree or another by mathematical, statistical, and logical methods, however, both its scope and methodology are significantly different from the subject and methodology of formal mathematical system research. After some time, scientists came to the conclusion that strategic tasks are not easily qualified (i.e., quantifiable) due to the lack of an unambiguous optimality criterion for the system as a whole and require the development of decisions by attracting subjective judgments from experienced managers and experts. Even with a clear logical and structural basis for research and the use of formal methods for assessing alternatives and finding the best solutions, subjective judgments and intuition of experts and individuals continue to play a huge role at all its stages influence a role of decision makers. Therefore, the concept of such a system analysis began to be developed, in which the emphasis is mainly on the development of essentially new dialectical principles of scientific thinking, the logical analysis of complex objects, taking into account their interconnections and conflicting trends. With this approach, it is not mathematical methods that come to the fore, but the logic of system analysis itself, the streamlining of decision-making procedures. These methods are based on the identification and generalization of the views of experienced expert experts, the use of their experience and innovative approaches to the analysis of an organization's activities include: a brainstorming method, a scenario method, an expert assessment method, a Delphi method, methods of the type "Goal tree", "business game", morphological methods, SWOT analysis and a number of other methods (see special literature). And apparently, it is no coincidence that recently under the system analysis is often understood a certain set of system principles and the following definition corresponds to it.

***System analysis** - this is an interconnected logical-mathematical and comprehensive consideration of all issues related not only to the design,* *development, production, operation and subsequent liquidation of systems, but also to methods of managing all these stages, taking into account social, political, strategic, psychological, legal, geographical, demographic , military and other aspects.*

What is the main meaning of systems analysis?

System analysis allows an incomparably deeper and better understanding of the essence of the theory of systems, their structure, organization, tasks, laws of development, optimal paths and control methods. System analysis sharpens the intuition of the decision maker and thereby expands the basis for his judgment, thus helping to develop a better solution.

The trend towards a systematic analysis of major problems appears especially when their scale increases to such an extent that solutions become complex, time-consuming and costly. When substantiating such decisions, which become the subject of a system analysis, factors calculated ahead for a 10-15 year period are becoming increasingly important. Factors of this kind include, first of all, the huge increase in investment in large-scale programs covering a long period, and the growing dependence of these programs on the results of scientific research and technical developments.

Another important reason for the need to take into account a long-term perspective is the strategic nature of the goals themselves, which are set before a system analysis and which determine the policy of the government (or organization) for a long period. It is important to note that the more general and important problems arise for managers at various levels, the greater the importance of system analysis to solve them.

Where can and should system analysis be applied?

The main and most valuable result of a system analysis is not a quantitative specific solution to a problem, but the study of a problem situation, clarification of its causes, development of options for its elimination, decision making and organization of further functioning of a system that solves a problem situation. This, in turn, means that the application of system analysis is determined by the type of problems, therefore, we will consider in more detail what is understood in a system analysis as a problem.

2.3. Systematic understanding of goals and problems.

As already mentioned in the systematic approach, the object of analysis is represented by a system that performs the role of a model over which studies are conducted. The logical basis for the construction and consideration of any systems is to *accurately determine the purpose (function of the main purpose) of the system or to clarify the meaning of its existence.* In turn, the goal of the system is set by the subject conducting the analysis, or this goal is set by customers so that he develops an optimal solution to achieve this goal. In this case, a situation may arise when, *if there is a goal, it is not known how to achieve it or a discrepancy between the actual state of the object and the desired state of the object, which would ensure the achievement of the goal.* In system analysis, this situation is called a ***problem***, and ***target*** – *an image of a non-existent, but desired state of the object that would solve the problem.*

So in a systematic understanding of the problem and the goal can distinguish two participants - the ***subject*** and the ***object.***

Subject solves such problems as observation, analysis, description, design, operation of an object or its management.

The object the analysis can be a process phenomenon, object, device, problem, enterprise, etc.

Moreover, the goal can be viewed from the perspective of the subject and object.

2.3.1. Systematic understanding of the goal.

Target from the perspective of the subject defined as the goal of analysis, description, design (creation or reorganization) and management:

• *the purpose of the analysis of the object* is to identify the presence and place of contradictions (problem situations), the causes of their occurrence and methods of elimination;

• *the purpose of the description of the object* is to present the problem situation in a form convenient for analysis;

• *the goal of designing* (creating or reorganizing) an object is to resolve a problem situation by creating a new object or reorganizing an old one;

• *management objective* – maintaining the operation of the facility in accordance with the assignment.

Target from the position of the object it is defined as the purpose of the functioning of this object, which can be laid down by its creator or formed inside the object.

Consider some of the important features of the goal:

• *The choice of goal is purely subjective*, that is, based on specific knowledge of the individual or community (you cannot wish for what you don't know about) and are aimed at meeting a specific life need.

• *The goal is specific.* Satisfying the goal can bring only a specific result obtained by using specific means in specific conditions.

• The goal can be seen as a means of assessing future results.

• *The goal always carries elements of uncertainty*, which inevitably leads to some mismatch of the actual result and what was planned.

Even the ancient philosophers noticed the properties of any human activity: the results obtained always differ from the planned goals. In the process of carrying out activities, a person is usually guided by the principle of coincidence of goals and results, and often falls into a rush, being surprised that he planned one thing and got another. This is especially dangerous when organizing a business that could end in failure.

Modern ideas about the divergence of goals and results of activity are associated with the name of the Russian philosopher N.N.Trubnikov, who claimed that his reason was the "duality" of the means used. Indeed, when funds are selected to achieve the intended goal, for example, technology, personnel, etc., while not yet tested in real life, they represent ideal tools, that is, tools that are only mentally suitable for achieving goals. But in practice, they begin to manifest themselves as real objects with such properties, many of which were impossible to know in advance. After all, these properties are manifested only in interaction with other objects, therefore, until such an interaction was not, until the means were "built" into real systems, they remained abstract, ideal, mental means. And as ideal means, they seemed to be able to ensure the implementation of planned goals. But when they become real means, they give a result that in some ways does not coincide with the goals.

Rarely there are cases when the subject has only one goal - most often there are several (in particular, the higher the level of control, the more goals, even if they are textually united by one wording - “global goal”), and it is important not to miss any essential of them.

For example, in business, an organization (enterprise) is a means to an end in the interest of business owners. This goal is the main goal of the organization. However, it cannot be reduced only to maximizing profits; it must be the sum of the goals of all its employees, consumers, etc. Moreover, other business participants have their own goals. Typical interests of key business participants are shown in table 1.

Table 1.

Business member	**Typical Economic Interests**
Shareholder	The increase in the size of the annual dividend. Increase in stock value
Manager	Increase salaries and bonuses.
Employee	Increased job security. Raising the level of wages. Maximizing the social package.
Consumer	Minimization of prices. Improving the quality of products. Warranty service, maximizing the warranty period. Maximizing the term of a commodity loan.
Provider	Minimization of commodity credit. Creating a dependency relationship. Maximizing the contract period, lead time of the order.
Financier	Ability to repay interest loans. Quality cash flow management.
Government	The increase in the number of jobs. Maximizing tax payments. Maximizing contribution to economic growth and

	balance of payments.
Social group	Minimizing environmental risk. Social equity financing.

Thus, the subject at the first stage of system analysis has to solve three problems associated with the goal:

- formulation of the purpose of the analysis (in the broad sense);
- understanding of the purpose of the customer;
- understanding the internal purpose of the object of analysis.

To facilitate the goal-setting task, the goal is decomposed (detailed) in the form of an unordered or ordered set of interconnected sub-goals (structuring), which make it more specific and understandable for all participants in the goal-setting process.

The most popular goal structuring is the construction of the so-called "***goal tree***".

The fact is that *any system has duality, being both a goal and a means.* The purpose (role) of this system is the goal for which the system components are intended as means, and on the other hand, this system itself is a means to achieve a goal of a higher order. For example, the production of motors is a goal for employees of the engine shop, but a means for the enterprise as a whole.

A description of the relationship between goals and means can be reflected in a special scheme (graph), called the "tree of goals", which was proposed back in 1957 a group of American scientists. The term "tree" implies the use of a hierarchical structure obtained by dividing a common goal into subgoals. Then it was successfully used in a number of large military and industrial programs in the USA, and now it is a daily tool for almost any modern manager.

The construction of the "goal tree" begins with the process of structuring, dividing the main goal into components called subgoals, each of which is a means, direction or stage of its achievement. Then, each of the subgoals, in turn, is considered as a target and is divided into components. If all these elements are represented graphically, then we get the so-called "goal tree", facing down with a crown. In this case, the main goal is at the top level. The process of dismemberment should be carried out until at the very lowest level of the “tree” there are funds whose implementation does not cause fundamental difficulties and doubts.

A fragment of the "target tree" is shown in Fig. 3.

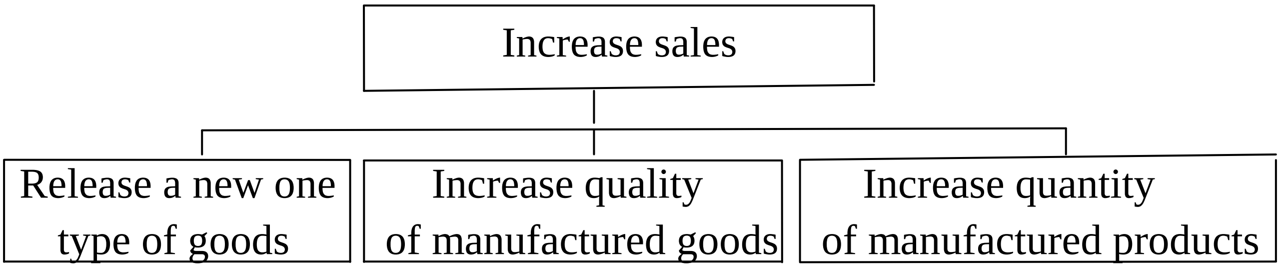


Fig. 3.A fragment of the "target tree"

To check the completeness and internal consistency of the “goal tree”, there are four simple rules:

• When reading from top to bottom, the subgoal should answer the question of what needs to be done to realize the goal of the previous level?

• When reading from bottom to top, a higher-level goal should answer the question, why is the goal directly below it necessary?

• When reading the subgoals necessary to achieve one goal, it should be clarified whether all the subgoals are really necessary to achieve it.

• When reading the subgoals necessary to achieve one goal, it should be clarified what other subgoals of this level are necessary to achieve the goal.

Criteria are used to quantify the degree of achievement of the goal. In this sense, *the criteria can be considered as quantitative models of qualitative goals*. The criteria should reflect the goal as fully as possible.

The need for criteria arises in the implementation of management tasks, in particular, optimization and decision-making tasks, when it becomes necessary to evaluate the available alternatives. Determining the value of a criterion for a given alternative is essentially an indirect measurement of the degree of its suitability (value) as a means to an end.

In order to achieve the completeness of the model of the situation under consideration, in addition to the criteria, it is necessary to take into account the existing ***restrictions*** or otherwise ***coercive relations*** –

conditions that limit and describe how the goal should be achieved. The fact is that the solution to any real problem is faced with ***limitations*** that can be divided into:

- objective – laws of nature and resource constraints;
- subjective – associated with the value system.

The target criterion, as it were, opens up possibilities for putting forward more and more new alternatives in search of the best of them, and the restriction deliberately reduces their number, prohibiting some of the alternatives. Some target criteria can be sacrificed for the sake of others, but the restriction cannot be excluded, it must be strictly observed. In this sense, restrictions simplify, rather than complicate, the work of a systems analyst.

In the practice of system analysis, there are cases when the imposed restrictions are so strong that they make achieving the goal unrealistic. Then the system analyst must raise the decision maker with the question of whether it is impossible to relax or remove these restrictions completely.

2.3.2. Systematic understanding of the problem.

In the general case, a ***problem*** *is understood as a discrepancy between the desired and actual state of affairs, requiring its resolution*. In the case under consideration ***problem –*** *the difference between the desired and actual conditions of the object, the elimination of which is not obvious.*

All problems, depending on the depth of their knowledge, are divided into three classes:

a) ***well-structured*** or quantitatively formulated problems in which significant dependencies are so well defined that they can be expressed in numbers and symbols, which ultimately receive numerical estimates;

b) ***unstructured*** or qualitatively expressed problems containing only a description of the most important resources, signs and characteristics, quantitative relationships between which are completely unknown;

c) ***poorly structured*** or mixed problems that contain both qualitative and quantitative elements, and the qualitative little-known and uncertain aspects of the problem tend to dominate.

A *well-structured* research methodology is used to solve well-structured problems. It consists in the application of mathematical models and methods (linear, nonlinear, dynamic programming, queuing theory, game theory, etc.) to find the optimal strategy for controlling targeted actions. The main problem of applying the methods of operations research is to choose the right type or develop a new mathematical model, collect the necessary initial data and make sure by analyzing the initial premises and the results of mathematical calculation that this model reflects the essence of the problem being solved.

In *unstructured problems*, the traditional is the logical-heuristic method, which consists in the fact that an experienced specialist collects a maximum of various information about the problem being solved, gets used to it and, on the basis of intuition and judgment, makes suggestions about appropriate measures. With this approach, there is no well-ordered logical procedure for finding a solution, and a specialist who puts forward certain proposals cannot clearly state the method on the basis of which he came to the final recommendations from the totality of scattered initial information. When solving a problem, such a specialist relies on his own experience, on the experience of his colleagues, on professional preparedness, on the study of similar problems by the method of situations, but not on a clearly formulated methodology.

To *poorly structured problems*, for the solution of which a system analysis is intended, providing for an interconnected logical-mathematical and complex consideration of all issues, includes most of the most important large-scale economic, technical, political and military-strategic problems.

Typical problems of this kind are those that:

a) identified for future decisions;

b) face a wide range of alternatives;

c) depend on the current incompleteness of technological achievements;

d) require a large investment of capital and contain elements of risk;

e) internally complex due to the combination of resources necessary for their solution;

When performing a system analysis in the process of structuring a problem, some of its sub-task elements get a quantitative expression, and the relations between all the elements become more and more defined. Proceeding from this, in contrast to the application of research methods of operations, when using system analysis, the initial clear and comprehensive statement of the problem is not necessary at all, this clarity should be achieved in the process of analysis itself and is considered as one of its main goals. The tasks of operations research methods can be posed in a quantitative form and solved on a computer. In contrast, the strategic problems of developing a long-term production policy, as a rule, cannot be formulated as tasks of operations research. Problems of this kind are the subject of system analysis.

In system analysis, the concept of a problem is defined and interpreted quite widely. This is due, on the one hand, to the formation of a system analysis as a science with its own subject and conceptual field, and on the other hand, to the presence of several alternative scientific schools working in a specific subject area of knowledge - in this case, in the field of economics, in the analysis of enterprise functioning, economic safety when analyzing the effectiveness of investment projects.

In a number of fundamental works on system analysis related to foreign works of the 70-60s of the last century, the following concept of the problem is given.

Problem *defined as some situation in a system in which there are two states*: *one is called existing, and the other is proposed, predicted or desirable, moreover, the transition of the system from the existing state to the predicted state cannot be performed without managerial influences on the system.* The existing state is represented by the existing system, the proposed state is represented by a hypothetical (or desirable, predictable) system.

Consider ***the way to correctly pose the problem***, which can be considered scientifically sound.

First, they get the answer to the question, is there a problem and what was its source (change in external conditions, change in the internal state of the system, negative effects of interference and disturbances, incorrect management decisions, etc.)? Further, its exact formulation and analysis of its structure follows. Then, the development of the problem (in the past and the future), the external relations of this problem with other problems are examined, and the question of the fundamental solvability of the problem is raised.

Consider some aspects of this method.

It is known that any task to improve activities in any field involves solving a number of issues.

Firstly, it is necessary to clearly establish the boundaries of the area being improved, which eliminates the tendency to "embrace the immense."

Secondly, conditions should be formulated that characterize the necessary or desired state of affairs in this area. Necessary it is called when it is objectively determined, and desired - with a subjective approach.

Thirdly, it is necessary to determine the actual state of affairs in the analyzed area and on this basis to identify shortcomings, that is, a mismatch between the necessary (desired) and actual state of affairs.

Fourthly, it is necessary to evaluate the consequences that the identified shortcomings lead to, if they are not eliminated, or otherwise, to assess the relevance of the identified problems. And if the problems are relevant, we believe that they require a solution.

Solution to the problem sets how the gap between the existing and the desired state will be filled. The ***solution***, therefore, is filling in the control actions between the existing and the desired state, performing a targeted conversion of one state of the system into another. *To build such a solution, it is necessary to analyze the causes of the identified shortcomings, as well as determine the means to eliminate these causes and then establish ways to implement the selected means. This solution to the problem is carried out using the learning process.*

Learning, in the theory of active systems, is defined as cognitive actions that ensure the recognition of present and future states of the system, as well as the construction of a feedback (control) communication model that transforms one state of the system into another. Feedback control fills the gap between the existing and the desired state and keeps the system functioning within the prescribed limits. ***This process is the process of solving the problem.***

When formulating a problem or analyzing the state of a system to identify a problem, first of all, clearly state the problem (the correct formulation of the problem is the key to improving the efficiency of public and private production) The purpose of formulating the problem is to establish the essence of the problem in known terms and parameters, and not in terms that are unknown, for which:

- determine or specify the goal, determine the state of the system at the time of the formation of the problem, identify and coercive ties;
- set the necessary conditions, determine the reliability of the conditions and their economic content, determine the relationship of economic parameters with organizational, technical and technological or other that are necessary to solve the problem;
- Establish the boundaries of permissible changes in the state of the system and the alternatives to be evaluated, arrange the alternatives according to their economic preferences;
- establish agreed criteria, determine the numerical values of the criteria, determine the admissible and most effective values of the criteria;
- formulate, where necessary, working hypotheses, assumptions, actions and their sequence to solve the problem, determine the necessary assumptions and their economic efficiency;
- determine the parameters and conditions that are the most risky, determine the nature of the risk and the economic consequences of risky decisions.

After the initial and substantive aspects of the problem become clear, when the problem is clear in structure, parameters and risk, it follows:

- identify the processes that will occur in the system when solving the problem;
- check the completeness and reliability of information about the state of the system, and if necessary, process all the information related to solving the problem;
- to develop directly the algorithm for solving the problem, based on an understanding of the problem and on the information available to solve it;

- get partial, experienced and / or preliminary solutions, if possible, get a complete solution to the problem;

- Based on the given values of the criteria, check the solutions received.

Implementation or implementation of a solution is invariably one of the critical checks of solutions, without which the solution can only be experienced. If trial implementation of a solution is not possible, conducting verification of decisions should play a more important role.

The time it takes to solve the problem, in the list of steps to solve the problem is not indicated. It is impossible to set the duration of the process to fully solve the problem. However, it is useful to imagine the relative amount of time that should be spent on each major area of problem solving. The time required for each area varies widely depending on the size of the problem.

A mirror image of the formulation of the problem is the development of a definition of the goal. The term goal is used here to describe the specific result to be achieved. Recall in a systemic sense ***target*** – *an image of a non-existent, but desired state of the object that would solve the problem.* The goal can take the form, which determines the achievement of the maximum (or minimum) of a function or quantity, moreover, this quantity must still be determined, or it must take the form of setting the range of values within which the solution should be located. In all cases, the goal is the desired result of the activity.

Goals and coercive connections should not be confused. ***Coercive relationships*** are conditions that limit and describe how the goal should be achieved. Their action limits the problem or introduces the problem into the boundaries.

The combination of goals that establish a course of action and coercive ties that limit goals forms a constraint at which the study of the problem begins. A ***restriction*** is the sum of the rules, regulations and guidelines put forward personally or externally that define the boundary of the problem. Each problem should have a definable limitation. The compatibility of purpose and coercive bonds is essential. Without agreement on restrictions, it is unbelievable that there is agreement on decisions. It makes no sense to talk about a "solution" if the groups of people interested in the situation are not able to agree on a problem or restriction.

When a specialist in systems analysis forms a ***condition for a problem***, he puts limits on the study of the problem and, therefore, the ***limits of the constraint***. In a mathematical sense, conditions can be defined as sufficient, redundant or contradictory, and they cannot take other forms.

The condition of the problem is ***redundant*** if it contains unnecessary elements. ***Unnecessary elements*** may be those that are not used in the analysis, do not affect the result, or, for example, in the economic sense, tend to cause losses or cost overruns. An example of a redundant condition: it is planned to study the automation of a large-scale inventory control system with coercive links consisting in the requirement that the existing manual information processing system continue to work in parallel with the automated system.

The condition may also contain a contradiction. A ***contradictory element*** is one that is closely related to other elements (parameters), and if one element or parameter is true, the other must be false. An example of a contradictory condition: the goal of a subcontractor is to draw up a monthly production growth schedule that is consistent with customer requirements. However, the rate of production by the customer is unknown. The consequence of the contradictory condition is the inconsistency of the parts of the problem with each other and, thus, their mutual opposite.

A ***sufficient*** condition is satisfied if the coercive connection is compatible with the proposed goal, and the goal is defined adequately to the requirements of the system. Sufficiency implies accuracy and has everything necessary to fulfill the requirement without any excesses. An example of a sufficient condition for a resource task: a storekeeper of a warehouse for electronic products receives an order for immediate delivery. He checks his stocks, determines that the necessary item is in stock, and delivers it on the same day.

From the very beginning of the study of the problem, it is necessary to give equal weight to the constraint and condition. Problems are rarely studied in an ideal setting; they are usually studied in a situation in which restrictions can only be relatively sufficient and obviously incomplete. Some of the most difficult problems are precisely those regarding which there is no certainty that the restriction is sufficient. In this case, the specialist in systems analysis should proceed from the assumption of sufficiency.

Sometimes it’s important to identify the environment that caused the problem. Information of this content can serve as a basis for researching a problem or determining the structure of its research. Studying the history of the problem can help determine the root of the problem. In contentious situations, only history can be an acceptable common denominator of research. The historical formulation of the problem implies knowledge of the problem and some relevant facts.

2.4. Methods of comparison and measurement of systems.

The most important methodological problem of system analysis is the development of the *theory and methods of comparing and measuring systems*. This problem is extremely relevant for the practice of applied system research, and primarily for economic systems, but still remains poorly developed. Such properties of systems as integrity, hierarchy, non-additivity, infinity, and others, pose numerous difficulties in quantifying the effectiveness of their functioning. In the practice of system research, it is often necessary to compare systems with different structures, assess the evolution of systems structurally and functionally, and compare heterogeneous elements and subsystems.

One such problem is comparing heterogeneous objects. The practical need for such a comparison arises quite often. Although the compared objects have a different nature, most often the sets of their characteristics intersect. And if the goals of comparison are described by characteristics from the region of this intersection, then it becomes possible to directly compare heterogeneous objects. For example, when transporting goods, mass can act as their characteristic, and in this case, all transported objects are measured and compared by mass. Another example of such a comparison can be an economic indicator - the cost of heterogeneous goods and services, which are measured and correlated with each other in any currency.

In the practice of system research, the tasks most often arise of comparing heterogeneous elements and subsystems based on the results of their functioning. In this case, their characteristics usually do not overlap. The need for such a comparison (or measurement in a single measure, scale) often arises when trying to determine the characteristics of the functioning of systems through the characteristics of the functioning of elements. This problem is related to the fundamental and still not satisfactory solution to the problem of operations research and system analysis - reduction of the vector criterion (characterized by a set of numerical values - the coordinates of the vector) to the scalar form.

For convenience, we consider two sides of the quantitative representation of systems:

- measurements of the structure of the object (characteristics of its structural description);
- measuring the parameters of its functioning.

The determination of the numerical values of the parameters of the structural description of the object in most cases is not problematic. Such characteristics of the structure of the system as the number of hierarchy levels, the number of subsystems and elements, and some others, most often lend themselves to direct calculation. For example, in the structural description of any branch of the national economy, the number of levels of its organization, the number of management links at each level, and the corresponding number of production associations by type are given. In turn, each association can be represented by the number and types of enterprises, and enterprises can be characterized by the product range, production capacity, number of employees, equipment characteristics, and so on. The listed parameters are an integral part of the quantitative characteristics of any economic system, in addition, these parameters are the basis for representing the dynamics of the system under study. They capture those elements and subsystems that act and interact in the description of its functioning. Therefore, the choice of the parameters of the structural description of the system is directly determined by the purpose of the study, considered by the structural section of the system and the hypothesis of the mechanism of its functioning.

The structural description of the system indirectly characterizes its functional capabilities, but in no way reflects the essence of the processes occurring in it. To study the functionality of the system, there is its parametric description. That is why it is usually impossible to evaluate the evolution of the structure of a system in time or compare different structures with each other without taking into account the quality of functioning of the compared systems, since there is no objective comparison criterion. With such a comparison, all the principles of systemic research of the system are violated, because the difference in the goals and objectives of the systems, the difference in the structure, and the functioning mechanism of the compared systems are not taken into account.

The failure of this approach is obvious, since a correct comparison involves taking into account the listed system factors. In addition, a correct comparison implies a unity of measure, a unity of a functional task (or goal, if the system as a whole is compared) and a unity of conditions. Based on the properties of complex systems, a fundamental measurement principle is formulated in the theory of systems - a consequence of Godel's theorem, which states that *the quality of functioning of a system can only be judged from the point of view of a higher order system.* In other words, while inside the system, it is impossible to determine the effectiveness of its activities. To do this, one must stand above it, it is imperative to present the system under study as part of a more general system and conduct an assessment in terms of the goals and objectives of the latter.

Obviously, the implementation of the principles of measurement and comparison is possible only with a systematic representation of the object of study, subject to the principles of its description. In this case, the mechanism for generalizing and detailing information during the transition from one level of the system description to another should be fixed in an explicit form.

It is usually assumed that the activity of the system is aimed at achieving a goal that can be expressed by some single criterion. Almost all methods of operations research are based on the assumption of the existence of a single criterion. In this case, the activity of the control system becomes adequate to the procedure for solving a certain optimization problem in which the extremum of a certain functional criterion is found, the variables of which are constrained. The most correct criterion, in this case, is the global criterion - maximizing the life cycle of the system under study. The achievement of the corresponding extremum of the criterion is identified with the achievement of the goal of the system. Optimization is carried out by choosing the values of special variables, which are called controllable in system theory.

In some cases, a similar approach can be applied in the context of system analysis when modeling individual aspects of the functioning of the system. However, in the general case, this approach is not applicable, which is a brake on the further development of operations research methods.

The fact is that for complex systems it is usually impossible to specify any one scalar criterion, the optimization of which would correspond to the achievement of the goals of the system. Each link of the hierarchical control system, as a rule, is forced to solve a whole range of problems, trying to find a solution that optimizes the vector (multi-parameter) criterion. In addition, the criteria for the various control units are different and, in principle, are not strictly consistent with each other. Some of the criteria cannot be unambiguously formalized.

Both in formalization and in heuristic, intuitive-logical analysis of systems, the problem of multicriteria is usually the most difficult. Such questions as how to compare systems in the process of their evolution, how to compare elements of systems, are by no means trivial.

A direct formal (and not only formal) assessment according to many criteria (according to a vector criterion) is possible only if one criterion is clearly dominant. In all other cases, one has to look for a way to reduce many criteria to one. This problem is called ***criteria scalarization***.

Methods for overcoming it are the most vulnerable part of the methodology for the quantitative study of complex systems.

The need for scalarization arises when the improvement of one criterion leads to the deterioration of others, that is, the criteria are contradictory: as, for example, in the well-known two-criterion task “efficiency - cost”. In this case, a rational decision is always a compromise between improving some criteria and worsening others.

Consider the most common principles on which compromise schemes can be based.

The principle of uniformity. In accordance with this principle, the best solution is the one in which the lowest value of the possible values of the criteria is greater than in other solutions. Here, during optimization, the criteria are aligned. This principle applies when criteria are equally important.

Principle of absolute concession. It suggests the best solution option, in which the total level of reduction of some criteria is not higher than the total level of increase of others in comparison with other solutions. This is equivalent to maximizing the sum of the criteria. This principle requires the normalization of criteria and their equal priority. The disadvantage of this approach is the possibility of obtaining a sharp difference in the levels of individual criteria.

Principle of relative concession is related to the previous one. The best solution is considered, in which the total relative level of decrease in some criteria does not exceed the relative level of increase in other criteria. Formally, this is equivalent to searching for a variant with the greatest product of the values of the considered criteria. This is where the criteria are aligned. The criteria are assumed to be equally important.

The most common is the ***principle of highlighting the main criterion***. The main criterion is singled out, the optimization of which is identified with the achievement of the main goal of solving the problem, provided that the level of the remaining criteria is not less than admissible. Normalization of the criteria is not required.

No less common is the ***principle of maximizing the weighted sum of criteria***. Here, each criterion is assigned a special factor - weight. Weights play the role of scale factors, and normalizing factors, and coefficients that determine the importance of criteria. The scalar criterion is formed by summing the criteria taken into account multiplied by the corresponding weights.

The most difficult methodologically part of the scalarization of a vector criterion is ***taking into account the priority of the criteria***. Currently, two accounting schemes are common – rigid and flexible.

In a ***strict priority accounting scheme***, the so-called lexicographic method is used. Criteria are arranged in a priority row, for example, in decreasing order of importance, so that a criterion with a higher number in the row corresponds to less importance. A consistent optimization of the criteria is carried out, in which an increase in the level of less important criteria is not allowed if this reduces the level of a more important criterion. The method is used in the search for solutions that are "close" to the optimal.

In a ***flexible priority accounting scheme***, the ordering of criteria is carried out by setting either a priority vector or a weight vector. The components of the priority vector determine the degree of superiority in importance of one criterion compared to the neighboring one in the priority row. Such estimates should be given for each pair of criteria. The assessment characterizes the magnitude of the largest allowable decrease in the value of a more important criterion in comparison with an increase in the value of a less important criterion. ***The weights of the criteria characterize the share of the contribution of each criterion to the overall quality.*** They are not negative and in total with set unit. The tasks of substantiating criteria weights are inherently more complicated than justifying the components of the priority vector. This is determined by the fact that for the latter it is enough to carry out, for example, a pairwise comparison of the criteria, and to set the weights, analyze the entire set of criteria.

In all of the schemes mentioned, a significant role is assigned to the researcher or the decision maker. It is he who justifies the weights or determines the priority of the criteria.

From a mathematical point of view, the application of the above methods of scalarization of vector criteria in measuring efficiency and comparing the quality of functioning of socio-economic objects is incorrect from the point of view of the basic principles of system research.

Firstly, these methods assume the additivity of estimates, since they are based on the mapping of element ratings to the system estimate through some, most often linear, form, the coefficients of which are determined by the type of compromise chosen.

Secondly, the transitivity of the estimates is assumed, both for the elements and for the system as a whole.

Both of these assumptions roughly distort the true picture of relations in a complex system, since the non-additivity and non-transitivity of the indicators of the functioning of elements, subsystems and the system as a whole are determining system properties that make up an important side of their essence.

The failure of such approaches as a scientific tool for studying systems is obvious. However, using them as an apparatus for the operational assessment of the state of a managed system object for making decisions in a limited time can be quite justified provided that the basic normative indicators used in such methods are determined in the course of special studies on system models and a correct and justified range of their application is found in which the distortion does not exceed the allowable.

TOPIC 3. CONTROL SYSTEMS

As mentioned in the previous section, the solution to the problem that arose in the system implies the development of managerial influences on this system, the implementation of which is carried out by the governing bodies (control system). The task of the ***control system*** is to convert the external impact on the managed system – the control object into a control action so that the ***control of the object*** takes place according to the set (desired) goals, criteria and restrictions. ***Management*** – the process of targeted behavior of a system is carried out through informational actions generated by a subject (a person or a group of people) or a device.

Management Tasks:

• goal-setting – determining the desired state or behavior of the system;

• stabilization – keeping the system in an existing state under conditions of disturbing influences;

• execution of the program – the system is brought into the required state under conditions when the values of the controlled quantities change according to deterministic laws;

• tracking – keeping the system on a given trajectory (ensuring the required behavior) when the laws of change of controlled quantities are unknown or change;

• optimization – keeping or transferring the system to a state with extreme values of characteristics under given conditions and limitations.

A control system containing a control, control and information system can be considered as a single system – a ***control system***, and a control (of a subject or control), managed (control object) and information (providing communication between the first two subsystems of information flows) of the system as its subsystem.

The main groups of functions of the control system are:

• decision-making functions – the functions of transforming the content of information (creating new information);

• routine information processing functions;

• information exchange functions.

The control systems being studied, created and currently being designed (and primarily economic objects) are characterized by exceptional complexity. The complexity of the system is determined by the large number of elements and the functions performed by them, the high degree of interaction of the elements, the complexity of the algorithms for choosing certain control actions, and the large amounts of information processed in this process.

One of the main features of control systems, for example, economic objects are considered hierarchical and complex structural and functional relationships between elements of the system. Therefore, the development of control systems for such objects requires a detailed analysis and synthesis of the designed control system.

3.1. Analysis of control systems.

Under the analysis of control systems (CS) is understood the research process of the control system, based on its decomposition with the subsequent determination of the static and dynamic characteristics of the constituent elements, considered in conjunction with other elements of the system and the environment.

The objectives of the analysis of the control system:

- a detailed study of the control system for more efficient use and decision-making on its further improvement or replacement;
- study of alternative options for the newly created management system in order to choose the best option.

The tasks of the analysis of the control system include:

- definition of the object of analysis;
- system structuring;
- determination of the functional features of the system;
- study of the information characteristics of the system;
- determination of quantitative and qualitative indicators of the system;
- efficiency mark;
- generalization and presentation of analysis results.

Briefly consider the content solutions to the above tasks of the analysis of control systems.

Definition of the object of analysis. To solve this problem, you must perform the following steps:

• highlight the analyzed management system;

• determine the goals and objectives of management;

• to carry out the initial decomposition of the system with the allocation of the control subsystem (governing bodies), control objects and the environment

The researcher can choose one of two areas of analysis: the first is the determination of the state of the control system to identify areas that need improvement and stimulate change; the other is the study of alternative options for a newly created system in order to choose the best option.

If necessary, subsystems and environmental factors are identified that have a positive (providing subsystems) and negative (adversary rival, climatic, territorial and other conditions) impact on the functioning of the system.

The types and forms of influences of the control subsystem and reactions of control objects, as well as environmental influences, are established. The basic requirements for the system are determined, and a general functioning algorithm is formulated.

System structuring. Depending on the research objective, various issues are included in the concept of the structure of the control system. So, in an automated industry management system, a structure is understood as the definition of the set of system nodes and the connections between them, the distribution of tasks assigned to the ACS hardware by the levels and nodes of the system, and the choice of a set of technical tools to ensure their effective solution. The structure of technological process management in ACS is understood as a scheme that defines, firstly, the distribution of technological processes of a complex by subsystems of various levels, with subordination of subsystems of this level to subsystems of a higher level; secondly, the distribution of control functions and their corresponding algorithms by subsystems. The distribution of the first type is the production structure of the complex, distribution of the second kind - the functional structure of the governing body. Both aspects are interconnected and the justification of the structure involves their development taking into account these relationships.

The structure of a production organization is understood as a stable spatio-temporal distribution of economic decisions and the resources ensuring their implementation with corresponding interconnections.

The structure of the organizational system means the form of the distribution of tasks and decision-making powers between individuals or groups of individuals (structural units) that make up the organizational system (organization) aimed at achieving its goals.

The purpose of structuring is a detailed study of the management system, the establishment of relations and relations between its elements.

Various options for the structures of the analyzed system make it possible to determine the characteristics and individual particular shortcomings of the selected elements and the relationships between them and outline ways to eliminate them.

Therefore, the task of analyzing the structure is understood as determining the main characteristics of the system for some selected (fixed) structure.

The main characteristics of the structure of the system can be divided into two groups. The first includes characteristics related to the hierarchy of systems: the number of subsystems of the system in question, the nature of the relationship between levels (subsystems), the degree of centralization and decentralization in management, signs of dividing the system into subsystems. The second one is the efficiency (in the broad sense) of the functioning of a system of one or another structure: efficiency (cost), reliability, survivability, speed and throughput, the ability to rebuild, etc.

Determination of functional features of the system. The task of determining the functional features of the system is strictly related to the task of structuring. Taking into account the structuring, a list of particular tasks and functions of each element of the system, the order of their interaction, and the necessary input and output data are determined.

The study of information characteristics of the system. Information serves as a goal-setting, unifying, coordinating condition, providing informational and intellectual support for decision-making.

In the process of researching information characteristics are determined:

- the nature and quality of information used to generate control actions;
- sufficiency of information to develop control actions;
- total volumes of incoming and outgoing information per unit time in the whole system and separately for the main elements;
- the amount of information permanently stored in the system;
- unit volumes of information transmitted;

- methods for transmitting or delivering information;
- main directions of information flows, etc.

Determination of quantitative and qualitative indicators of the system. After understanding the task, determining the object of analysis and compiling its multi-level description are made:

- preliminary selection of a list of indicators of each level;

- development of models and methods for determining indicators of various levels;

- clarification of the conditions for determining indicators, including the expected effects of the supersystem, the possibility of integration with other control systems and the availability of duplicate systems.

As a result of solving this problem:

- systematized private qualitative and quantitative indicators of structures, functioning processes and information;

- generalized indicators characterizing the external properties of the analyzed system and its individual elements are determined.

The task of documenting the synthesis and presentation of the analysis results includes:

- a brief description of the structure, functioning processes and information flows of the system;
- generalized value of indicators and results of evaluating the effectiveness of the system (values of indicators are given);
- generalized identified deficiencies and preliminary recommendations for the further use of the system, improvement or its replacement.

Efficiency mark. This problem is solved in order to determine the results achieved in the process of functioning of the management system and the material and time resources spent on achieving these results.

It should be noted that the concept of an indicator that evaluates the functioning of the system is used in two senses. Firstly, these are indicators that measure certain results of the real (or imitation) functioning of the system. These are experimental performance indicators. Another option is a theoretical assessment of the possible values of experimentally determined indicators - theoretical performance indicators. The values of theoretical and experimental indicators of functioning may not coincide. The mismatch may be due to the imperfection ("rudeness") of the method of constructing theoretical estimates, insufficient awareness of the person giving the corresponding theoretical estimates, the possibility of several options for the flow of the functioning process, etc. The accuracy of theoretical estimates is

Generalization and presentation of analysis results. The task of documenting the synthesis and presentation of the analysis results includes:

- A brief description of the structure, functioning processes and information flows of the system;
- the generalized value of indicators and results of evaluating the effectiveness of the system (values of indicators are given);
- generalized identified deficiencies and preliminary recommendations for the further use of the system, improvement or its replacement.

3.2. Synthesis of control systems.

In contrast to analysis, the study of a given control system, ***synthesis*** means the process of creating a new system by determining its rational or optimal properties and corresponding indicators. The synthesis of control systems is carried out by coordinating the static and dynamic characteristics of the system, which together provide the maximum degree of compliance of the system with the tasks set.

Synthesis objectives of the control system includes the following initial conditions:

- creating a new management system based on new achievements of science and technology;
- improving the existing management system based on the identified shortcomings, as well as the emergence of new tasks and requirements.

First state takes place in the following cases:

- when introducing new public management systems that ensure the resolution of contradictions between old inefficient principles and management methods and the current political, economic and social conditions of their functioning;

- in the process of a complete modernization of the technical means of ergotic (automated) control systems with the introduction of a new element base, network structures and modern mathematical, software, linguistic and information support, which significantly increase management efficiency;
- when creating automatic control and regulation systems having new construction principles and criteria for achieving goals.

Second state takes place in the following cases:

- improving individual organs and methods of solving problems in public management systems;
- making private changes to the types of support for ergotic systems;
- refinement of automatic control systems.

In general, the tasks of synthesis of control systems are to determine the structure and parameters of the system based on the given requirements for the values of indicators of the effectiveness of its functioning, as well as ways to ensure the goals of the functioning of the system.

Synthesis, or *structural synthesis*, is central to the creation of a control system. It includes the following components.

1. *Synthesis of the structure of a controlled system*, i.e., determining the optimal composition and relationships of system elements, the optimal breakdown of the set of managed objects into separate subsets that have the specified characteristics of the relationships.

2. *Synthesis of the structure of the control system:*

a) the choice of the number of levels and subsystems (system hierarchy);

b) selection of management organization principles, i.e. the establishment between the levels of the right relationships (this is due to the coordination of the goals of the subsystems of different levels and the optimal stimulation of their work, the distribution of rights and responsibilities, the creation of decision-making circuits);

at) optimal distribution of functions between people and computer technology;

d) selection of organizational hierarchy.

3. *Synthesis of the structure of the system for transmitting and processing information*. Including:

and) synthesis of the structure of the information transmission and processing system;

b) synthesis of the structure of the information management complex (including the placement of service points).

The essence of structural synthesis is the development (creation, design, improvement, reorganization and organization) of a system that should have the desired properties. Structural synthesis is carried out with the aim of substantiating many elements of the structure, relations and relationships, which together ensure maximum compliance with the given requirements. The objects of structural synthesis research are various options for the developed (improved) control system structures.

The synthesis is a multi-step iterative process, including the sequential solution of the following main tasks:

- the formation of the intent and purpose of creating a management system;
- Formation of new system options
- Bringing the descriptions of system options into mutual correspondence;
- Evaluation of the effectiveness of options and making decisions about choosing a new system option;
- development of requirements for the management system;
- development of programs for the implementation of requirements for the management system;
- implementation of the developed requirements for the control system.

Consider the content solutions to the above problems of synthesis of control systems.

3.2.1. Formation of the purpose and target of creating a management system.

The idea arises on the basis of the received task, highlighting the shortcomings of the existing management system, the emergence of a practical need or new scientific achievements.

Formation of the plan begins with a historical analysis of the problem, practical possibilities, scientific achievement, needs, analysis of similar systems, the current situation, other people's opinions and all the associated factors. This is a creative stage, poorly structured and poorly formalized.

The results of solving the task of creating the plan and the goal of creating a system should be:

- determination of the purpose of the management system;
- definition of the goal (objective function);
- definition of system tasks;
- formulation of the main idea of creating a system;
- determination of the directions of system development.

3.2.2 Formation of options for a new management system.

Variants of the system are formed on the basis of analysis of the general goal of creating a system, studying social needs, the estimated volume of satisfaction of these needs, studying the status and development prospects of similar domestic and foreign systems.

The process of forming each version of a new system can be described by a conceptual and mathematical model.

Consider the procedure for constructing a conceptual model of a variant of a new control system.

When constructing a conceptual model, several stages can be distinguished.

At the *first stage*, the level of detail of the conceptual model of the system variant is determined.

A system model is a collection of subsystems (elements). This subset includes all subsystems (elements) that ensure the integrity of the system. The exclusion of any elements should not lead to a loss of the basic properties of the system in the performance of its intended functions.

In turn, each subsystem consists of a set of elements, which can also be divided into elements. Thus, the problem of choosing the level of detail can be solved by constructing a hierarchical sequence of models, where the system is represented by a family of models, each of which reflects its behavior at different levels of detail. At each level, of course, there are characteristic features of the system, principles and dependencies that determine its behavior.

The choice of level of detail depends on the objectives of the simulation and the degree of prior knowledge of the properties of the elements. Typically, a model includes elements of one level of detail, but it may be necessary to build a model from elements of different levels.

At the *second stage* of constructing the conceptual model, it is localized (establishing the boundaries of interaction with the super-system) by representing the external environment in the form of generators of external influences, and these generators are included in the system as its elements. The receivers of the impact of the system on the environment and (or) another system are usually not included in the model, assuming that the external environment (another system) receives the results of the system's functioning completely and without delay (Fig. 4).

At the *third stage*, the construction of the model structure is completed, indicating the relationships between its constituent elements. Relations can be divided into material and information.

In control systems, *information communications* are of paramount importance. Moreover, first of all, it is necessary to highlight the functionally necessary internal relationships that determine the integrity of the model and ensure its adequacy to the system.

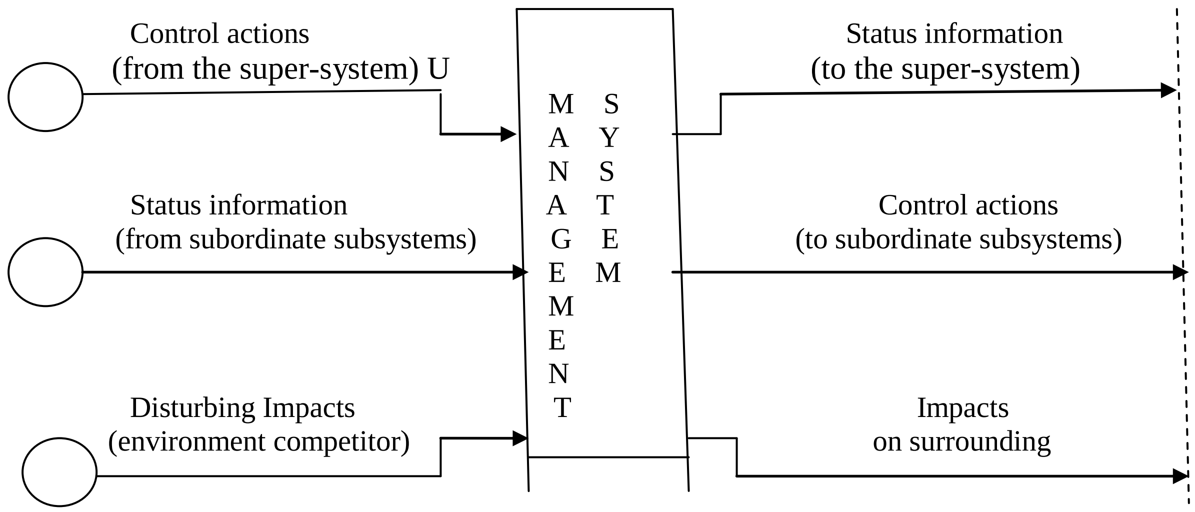


Fig. 4. Localized system

Each generated version of the system includes various types of descriptions: structural (morphological), functional, informational and parametric.

Structural description includes a description of the structure and types of support for the management system, the purpose, composition and placement of its elements.

Functional description includes the tasks solved by the system, the system functioning order.

Informational description includes a description of the input and output information, the flows of information circulating in the system, methods of presentation and transmission.

Parametric description includes a list of quantitative indicators (parameters) characterizing the individual properties of the system that must be provided in the process of its creation.

Requirements for indicators in the form of various restrictions are formed in the process of evaluating the effectiveness of each investigated version of the system and are specified during its development.

At the *fourth stage*, controlled characteristics are determined, i.e. the model should include those parameters (indicators) of the system that allow the variation of their values in the modeling process, which will ensure that the developer of models of characteristics that are of interest for specific external influences are found at a given time interval for the functioning of the system. The remaining parameters should, if possible, be excluded from the model, of course, without prejudice to its adequacy, and if necessary, enter them into limitations. It is desirable that in the conceptual model all decision rules or algorithms for controlling elements and (or) processes of the model that reflect the statics of the system be specified.

The *fifth stage* describes the dynamics of the system. The previously obtained model must be supplemented with a description of the functioning of the system. It should be noted that in complex systems, several processes often occur simultaneously. Each process is a certain sequence of individual elementary operations, some of which can be performed in parallel by different elements (resources) of the system.

3.2.3. Bringing the descriptions of the options of the control system into mutual correspondence.

Bringing the descriptions of a variant of the system into mutual correspondence includes.

- comparison of descriptions (structural, functional, informational, parametric);
- elimination of contradictions;
- combination of the named descriptions.

Matching descriptions.

Compliance with the requirements of the information description is provided morphologically (structurally) and functionally. First, the question of the compatibility of the information description is decided. The functional description may not be sufficient to cover the blocks or processes of the structural description and then it needs to be supplemented (in particular, by conducting new research). All blocks of the structural description should be covered by the functional description, contain methods and formulas for calculating all output and intermediate parameters. Next, you need to find out to what extent the information description is provided functionally and morphologically. Some of the results that can be considered as requirements will turn out to be morphologically unrealizable or will require the development of new elements (subsystems). Based on the morphological and functional description, the closest of the attainable parameters included in the parametric description are calculated (without the compatibility requirement). There can be two cases: 1) the required parameter values are unattainable; 2) the required parameter values are achievable separately, but incompatible. In the first case, the promotion of ideas, the restructuring of morphology or functionality are necessary, in the second - constructive restructuring.

Resolving Contradictions.

The idea or associative search for the effective replacement of the elements of the morphological description is based on the functional properties of the system. To do this, it is necessary to identify the fundamental contradiction that impedes the achievement of a positive result. Functional failure is the initial impetus for the detection of a fundamental contradiction. Identifying the essence of the contradiction requires an analysis of the morphological and informational properties of the system. Elimination of the contradiction by compromise, so that their general combination is satisfactory, is rarely promising. Expanding the range of applications can lead to irreconcilable contradictions. In this case, new ideas are required, i.e. the inclusion in the system of subsystems or elements with fundamentally new properties, a radical restructuring of the structure and relationships, the creation of new processes, etc.

Combining Descriptions.

Compilation of a single description, covering the morphological, functional, informational properties and parameters in full.

Evaluating the effectiveness of options and making decisions about choosing an option for a new system.

The solution to this problem includes:

- determination of the values of selected performance indicators of each investigated variant of the created system;
- a comparative assessment of effectiveness, which is carried out in accordance with a given preference rule and established criteria;
- making a decision on choosing the best system option.

After choosing the final version of the system, the criterion of system efficiency is specified, the initial version of the values of the indicators of the control system is formed, and the system is re-synthesized, which becomes more and more definite every time.

3.2.4. Development of requirements and requirements implementation programs to the control system.

For artificial systems of an organizational or ergotic (human-machine) type, it is very difficult to clearly formulate a goal. The goal is developed in the form of quantitative and qualitative requirements for the essential properties of the system that determine the situation or region of the situation in *n*-dimensional space that must be achieved during the functioning of the system (the value of n is determined by the number of selected essential properties of the object).

Requirements are formed in the form of indicators (quantitative) and characteristics (qualitative). As a rule, requirements are set in the form of a restriction on the permissible limits of the values of indicators.

The development of requirements is carried out in the process of solving all of the above tasks. General requirements for the control system are documented, and then individual requirements for its elements are clarified, including elements highlighted in the morphological (structural), functional, informational and parametric description of the system.

Typically, a program or plan for implementing requirements includes:

- a list of goals and objectives (tasks) to the executors (responsible for creating the management system) deployed in time, interconnected with respect to the general goal of creating a new system and balanced in resources and in relation to the general goal of creating a new system;
- schedule (order) of providing performers with resources (information, material, energy, etc.).

Resource balance means that there are no tasks that are not provided with resources, and that limited resources are rationally distributed among all performers.

3.2.5. Implementation of the developed requirements for the control system.

The goal of the task is to implement the developed requirements for the management system in a timely manner, in accordance with the developed program. The process of directly creating a new management system is very complex.

Consider the conditional stages of implementation of the developed requirements for a man-machine (ergotic) control system:

- modeling (mathematical, physical, scenario) of subsystems and the system as a whole;
- prototyping of the system;
- system design;
- system design;
- manufacturing system;
- system test;
- assessment of ways of modernization;
- a return to the analysis of the idea of creating a system and the prospects for its development in connection with the creation of a new system.

Briefly describe these stages.

Modeling of subsystems and the system as a whole. At this stage, the conceptual description of the system is implemented using a mathematical model.

The purpose of the simulation is to check various aspects of the functioning of the system, its stability with respect to external factors and evaluate the effectiveness (according to the functional and physical criteria) of its functioning in different working conditions. Testing the model involves the creation of the entire evaluation apparatus. Modeling can improve the efficiency of the system (according to the physical criterion) by additionally changing its morphology and functional properties. Based on the simulation results, a conclusion is drawn about the transition to the next development stage or specification of requirements.

Prototyping system. The main task of prototyping is to develop devices based on new ideas.

Distinguish between full and partial layout. Partial prototyping is used when the basic subsystems are clear and individual blocks need to be clarified. Partial prototyping results are used to re-simulate the system and further refine it based on new data. Full prototyping of the main and auxiliary subsystems is used in the development of new systems.

The stage of prototyping is decisive and final for the creative part of development, and then the technological part begins.

System design. The design task is to cover the entire system, as well as the tools and methods necessary for its creation and maintenance.

There should be no doubtful questions in the project: design should be based on full information and solve only engineering (in the broad sense) problems.

System construction. The design determines the spatio-temporal arrangement of the system elements, their conjugation, connection and docking.

The design task is to develop a system manufacturing technology or an indication of the possibility of using ready-made technology.

The design description should be developed to a level that is accessible and understandable to persons who have not participated in the development of the system and are not familiar with the initial ideas.

Manufacturing system. Under the manufacture of a new system refers to the element-wise and block (subsystem) testing, as well as the creation of a process and organization.

The technology and practice of manufacturing the system leave their mark on the elements of the system and its properties as a whole.

For new systems, there may be cases when the production of subsystems with the required parameters (process preparation, personnel selection, working out group cohesion) is an overwhelming task, and then corresponding additional work is inevitable (production improvement, staff training, changing conditions) or returning to one of their initial stages .

System test. The test includes full-scale and model parts with a rigid connection between them. For complex systems, full-scale tests can be (due to their high cost, complexity and duration) up to 10% of all work. Tests are based on physical performance criteria. The design of experiments involves an integrated approach and a consistent analysis of the results so that the results of previous experiments are fully taken into account in subsequent ones.

In tests, the method of using the system and increasing the maximum permissible value of its effectiveness (according to the physical criterion) are being worked out. Tests determine the compliance of the system with its purpose and objective function - by the functional criterion, which is calculated from the test results.

Prospects for further development of the system are evaluated on the basis of a comparison of physical and functional criteria in terms of opportunities and ways to further increase them.

Assessment of modernization paths. Scientific and technological progress has created a new situation in the world of the choice of alternatives for creating new systems, which is due to the following circumstances:

- the life cycle of a system created by a person (equipment, weapons) has become much less than a person’s life;
- shortening the life cycle of a system created by man is accompanied by an increase in the full cycle of creating a system;
- the presence of the problem of investing funds and resources.

The scale of human-created systems has grown. Some of them, for example, energy, transport, information, have become global. With the increasing complexity and scale of creating a new system, the costs of their implementation increased. The risk when choosing the option to create a new system is becoming more noticeable.

The basis for extending the life cycle of a system is its timely and repeated modernization, the ideas of which are laid at the stage of creating the system.

Therefore, to give a system any property, it is necessary to build its subsystem, interconnected with all other subsystems, the general goal, which will be the effective manifestation of this property and, of course, ensuring its manifestation.

The materiality (significance) of any property of the system will depend primarily on the significance of the subsystem that manifests and provides this manifestation.

Establishing relationships between properties and processes is even more difficult. The identification of the totality of these relations, the establishment of relationships between the properties of the system and processes, their indicators is the most important task of the study of control systems.

The identification of the essential properties of processes and systems is mainly a creative process, it is informal and largely depends on the qualification of the researcher, his experience and intuition. Some of the properties are determined by the researcher when developing requirements, since the latter are presented to the values of the indicators of the essential properties of the system or process.

The determination (assessment) of the values of indicators of essential properties is made, as a rule, in two ways: by "direct measurements" on the system and using the model of its functioning.

An important point is the formation of rules for determining the fact and magnitude of the discrepancy between the values of the indicators of the essential properties of the process and the system and their required values.

3.3. The main types and levels of analysis and synthesis of control systems.

The following types of analysis and synthesis of control systems are distinguished: structural analysis and synthesis of control systems; functional analysis and synthesis of control systems; information analysis and synthesis of control systems; parametric analysis and synthesis of control systems.

3.3.1. Structural analysis and synthesis of control systems.

Before revealing the essence of structural analysis and synthesis, it is necessary once again to return to the concept of "structure".

Structure – this is the internal organization of the system, which contributes to the communication of the components of the system. It determines the existence of the system as a whole and its qualitative features. The structure will determine the ordering of the elements of the system. Thus, *structure* is a relatively stable, ordered way of connecting elements, giving their interaction within an internally dissected object an integral character.

The essence of structural analysis is the determination of the static characteristics of a system by its structure.

Structural analysis is carried out in order to study the static characteristics of the system by isolating in it subsystems and elements of various levels and the relationships between them.

The objects of structural analysis are various options for the structures of the control system, which are formed in the process of its decomposition.

As indicators of the studied structures, it is advisable to use:

- many highlighted elements, relationships and relationships;
- characteristics of elements and relationships;
- generalized indicators of structures characterizing their impact on the effectiveness of the management system (the number of management levels, structural stability, economic costs of maintaining the required structural characteristics, etc.).

When selecting and evaluating structure indicators, various methods of description and modeling are used, which depend on the type of structure, the degree of uncertainty of the initial data, and the requirements for the accuracy and reliability of the analysis results. The procedure for determining the structure indicators includes the following steps:

- definition of initial data for structure assessment;
- the calculation of the values of the characteristics of structural elements and the relationships between them;
- calculation of values of characteristics (performance indicators) of the structure.

Model studies and structural evaluations are based on specific numerical values.

Based on the assessment of the structure, a choice of a structure option or a proposal for its improvement is made.

The essence of structural synthesis is the development (creation, design, improvement, reorganization and organization of the system), which should have the desired properties.

Structural synthesis is carried out with the aim of substantiating many elements of the structure, relations and relationships, which together ensure maximum compliance with the given requirements.

The objects of structural synthesis research are various options for the developed (improved) control system structures.

The main generalized indicators of the studied structures include:

- the number of managed objects;
- time and reliability of bringing information to managed objects;
- the likelihood of a complete control cycle using the synthesized structure;
- viability of the structure;
- the total cost of the structure, etc.

In the process of structural synthesis, a lot of structural elements, relationships and relationships between them, characteristics of elements and relationships that provide optimal or rational values of generalized indicators in accordance with the selected performance criteria are determined. The efficiency criterion is selected taking into account the requirements for the control system.

3.3.2. Functional analysis and synthesis of control systems.

Functional analysis of the control system is carried out simultaneously with the study of the structure of the control system.

The essence of functional analysis is the determination of the dynamic characteristics of systems based on accepted algorithms for its functioning.

Functional analysis is carried out in order to determine the dynamic characteristics of the system by studying the processes of changing its states over time based on accepted control algorithms (methods, methods, principles, concepts). We can say that functional analysis is aimed at a detailed study of management processes.

The objects of study of functional analysis are the management methods and algorithms implemented by the system, including the general functioning algorithm containing all the main stages (phases, functions) of management, and private methods and algorithms aimed at the implementation of individual control stages (formation of the management goal, collection and processing of necessary information , decision making, planning, organization, control, implementation of decisions, etc.).

Functional analysis may include the following main steps:

- definition and description of the general management process implemented by the system under study;

- decomposition of the general management process into a number of private functions (tasks, operations) performed by the elements of the control system;

- determination of qualitative and quantitative characteristics of the studied processes and management functions;

- the formation of criteria and evaluation of the effectiveness of the functioning of the management system;

- decision making on the need to improve the functional characteristics of the control system.

Let us dwell briefly on the content of these stages.

Definition and description of the general management process implemented by the system under study includes:

- *formation or refinement of management objectives*. If the management system is not set or formulated, the functional analysis does not make sense;
- *formation of control actions*. The formation of control actions is carried out on the basis of the established goal and includes the following components:

a) obtaining information about the control object and the environment;

b) the accumulation, processing and analysis of information;

c) determination of possible exposure options;

d) the choice of a rational variant of impacts;

e) development of a program (plan, algorithm) for the implementation of the impacts, providing for the sequence of issuing the impacts and the expected (reference) states and reactions of the object to these impacts;

- *implementation of impacts*. Implementation of impacts includes two main stages:

a) the transfer of impacts to the control object by available direct connections (material, energy, information);

b) testing the impacts of the control object, during which it undergoes a transition to a new state and the formation of response actions (reactions) transmitted to the control system via feedback (information);

- *control over the results of the implementation of impacts*. Monitoring the results of the implementation of impacts includes:

a) obtaining information about the state of the object after exposure;

b) processing this information and comparing it with the reference;

c) analysis of the results of comparison and the transition to the formation of new control actions.

Decomposition of the overall management process includes:

- detailing the overall management goal for a number of private interconnected goals and the formation of a tree (hierarchy) of goals;
- definition of elements of the control system that implement the formed goals;
- the exclusion of elements that do not have a functioning purpose;
- identification of management functions (basic and supporting) that are necessary for the effective implementation of all stages of management, in accordance with the general and particular goals of management;
- comparing the correspondence of the allocated functions to the elements (performers, managers, authorities, technical devices) of the analyzed system and evaluating their implementation;
- identification of duplicate, useless, ineffective functions and development of recommendations for improving the management system.

In the course of functional analysis, it is necessary to *determine the qualitative and quantitative characteristics of the studied processes and management functions* in order to make informed decisions about the degree to which the control system meets the requirements and the need for its further improvement.

The combination of quantitative and qualitative characteristics can be divided into the following groups:

- *complex characteristics that allow to evaluate the essential properties of the control system*:

a) Continuity management process – the absence of breaks between sequentially performed stages (phases) or other actions leading to a decrease in the quality of management. The continuity of the process is violated if an unplanned pause occurs between two successive stages, leading to a decrease in the quality of the subsequent stages of the analysis (for example, due to loss of information value), untimely achievement of the set goal or disruption of the entire management process.

b) *Efficiency management* process – completion of the management cycle in the required time frame.

c) *Accuracy* – ensuring maximum correspondence of the real movement (or final state) to the required (reference) movement (or final state) of the control object. The degree of accuracy depends on the difference between the reference and the actual movement or condition of the control object. In the study of enterprise management processes, accuracy can be estimated using the difference between the projected and real profit obtained as a result of management activities of the management of this enterprise.

d) *Sustainability* management process – the ability to maintain and restore their quality in conditions of external and internal disturbances.

e) Secrecy management process – the ability to withhold from the competitors or other opposing systems the planned and carried out actions. This property determines the quality of the management process in competing (warring) systems, which are forced for some reason to hide the transmitted or processed information.

e) *Efficiency* – the degree of conformity of the real (actual or expected) results of the management process with the required or, in other words, the degree of achievement of the management goal;

- *structural characteristics, allowing to evaluate the structure of the control process, formed in the process of its decomposition*.

Structural characteristics of the management process are used to evaluate the set of analyzed elements (functions, works, actions, phases, steps, etc.) of the control process and the relationships between them.

The structural characteristics of the management process of organizational systems (when they are decomposed into levels and functions) include:

a) the number of management functions at each level and the total number of management functions implemented by the investigated management process; subordination (dependence on input and output information) of control functions;

b) the number of control functions, the implementation of which depends on the output information of the control functions of a higher level;

c) the time of implementation of each management function.

When analyzing the structure of the management process, it is advisable to take into account the following characteristics of the network structures of organizational systems: the connectedness of the structure, determined by the number of information links between the allocated process functions; structural redundancy, which determines the excess of the number of connections between the functions of the process over the minimum necessary.

- *particular characteristics that determine the properties of individual stages (phases), functions, activities and other managerial actions considered as separate elements of the management process.*

Particular characteristics of the management process include:

a) the number of information inputs and outputs of each function;

b) the number and list of information and calculation problems to be solved when implementing the corresponding management function;

c) the amount of input, output and processed information;

d) the average duration or other probabilistic characteristics of the deadlines for solving the corresponding particular problems;

e) characteristics of the flow of applications for the performance of the relevant functions;

f) a list and characterization of algorithms, machine programs, or application packages used to implement functions.

Evaluation of the relationships between the functions of the control process can be carried out using the following characteristics: the volume and content of information transmitted using the appropriate communication time of information transfer; the nature of disturbances affecting the quality of the transmitted information.

Functional synthesis, as well as analysis, is carried out simultaneously with the study of the structure of the control system.

The essence of functional synthesis is the rationale for the dynamic characteristics of the control system, which should have the desired properties.

The purpose of functional synthesis is the rationale for the optimal or rational characteristics of the functioning processes of the control system, i.e. processes of changing its states over time in accordance with the goal.

When stating the general task of functional synthesis, it is necessary to take into account the criteria of management efficiency.

To obtain solutions that are close to optimal, it is necessary to study the functioning processes within the framework of all the formed variants of structures and, in turn, to form variants of structures that ensure the effective implementation of the selected algorithms.

3.3.3. Information analysis and synthesis of control systems.

The object of information analysis and synthesis are information processes that occur in the control system. Let us dwell on their essence and content, for which we consider a communication (information) scheme for transmitting information in a control system. This scheme of information transfer in the control system is shown in Fig. 5. In fig. 5, the source of information is a control object that sends information about its status via a feedback channel. The information receiver, it is also a control object, depending on the amount and content of information about the control object, develops a decision on the impact on it. This solution in the form of commands and control signals via a direct communication channel is transmitted to the control object. After executing the commands, the control object sends information on the change in its state to the control object, etc. Thus,

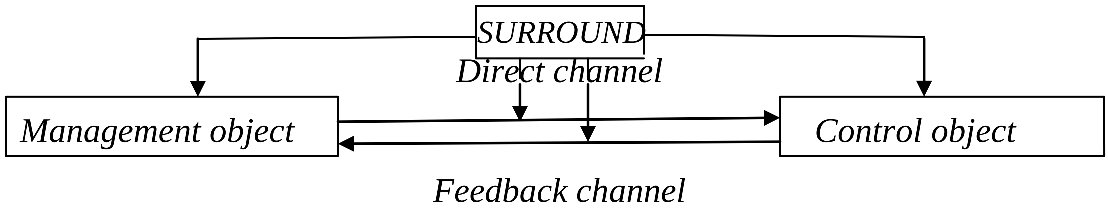


Fig. 5. Communication scheme of information transfer

In really functioning control systems, the information source, the information receiver, and the information transmission line are affected by the environment in which the given system functions, making its own adjustments both to the quantity of information and to the quality.

The management process, as the process of generating control actions, is an ***information process*** (IP).

Information process there is a purposeful set of operations to transform information implemented in a particular environment, starting from the moment it enters the system (occurrence), and ending with the issuance to the user. Moreover, the concept of "user" must be understood in a broad sense. The user can be: a decision maker, receiving information in a convenient form for perception; technical devices, information converters on magnetic tape, disk, in memory, communication channel, etc.; programs that convert the information received.

Any information process in the control system can be structurally represented as a set of processes:

- collection, reception, perception of information (these processes reflect the interaction of the system with the external environment);
- information transfer between separate subsystems of the system;
- processing, analysis, selection of information, the creation of new information;
- use of information;

- storage, memorization of information;
- transfer of information from the system to the external environment.

Management (information) processes can be implemented on a computer if they can be formalized. Formalization refers to the description of the object being studied. in exact terms or statements. Formalization is inextricably linked with the construction of artificial, or formalized, scientific languages. Such languages are created to accurately express thoughts in order to exclude the possibility of ambiguous understanding. Formalization makes it possible to build scientific languages with a precisely established structure and given rules for converting some expressions into others. An indispensable condition for constructing such a language is the use of the axiomatic method, thanks to which it is possible to obtain all the statements of the theory from a small number of statements accepted without proof, or axioms. Formalization of the management process includes the allocation of management functions and tasks, the development of formalization algorithms and the implementation of algorithms. The process is considered completely formalized, if the algorithms for tasks are presented and mathematically translated into machine programs, and when solving problems, their physical content is no longer necessary. The need for knowledge of the physical content appears only when using the results.

The essence of information analysis is the definition of the object and the forms of presentation of information, methods and means of its transmission, processing, storage, input and output for a known structure and algorithm of the control system. Information analysis is carried out in order to study the quantitative and qualitative characteristics of the information used in the control system. The objects of research are information processes that occur in the control system.

The information analysis procedure includes:

- determination of the need for information at each stage of management;
- information needs planning;
- determination of quantitative and qualitative characteristics of

communication processes;

- determining the need for information in assessing the effectiveness of managerial decisions (impacts).

The indicators (characteristics) of information include:

- volume and speed of information transfer;
- the reliability of the transmitted messages;
- direction of information flows;
- characteristics of information processing methods and errors made in doing so;
- high-quality information;
- the number of processed or transmitted documents;
- the total number of processed or transmitted documents, etc.

Based on the results of the information analysis, preliminary recommendations are developed on the development of information support for the management system, including methods for transmitting, processing and presenting information, the composition of the information necessary for the normal functioning of the system, the structure of information exchange, etc.

The essence of information synthesis is the justification of the necessary volume and forms of presentation of information, methods and means of its transmission, processing, storage, input and output for the developed structure and algorithm of functioning of the control system.

Information synthesis supplements the tasks of functional synthesis and is carried out in order to determine the required qualitative and quantitative characteristics of the information used in the process of functioning of the control system.

In the course of information synthesis, the substantiation of the necessary volume and forms of presentation of information, methods and means of its transmission, processing, storage, input and output is carried out.

Optimal or rational characteristics of information are determined, as a rule, using indicators and performance criteria that take into account the structural and functional features of the system. In this case, one of the main problems of information synthesis is the quantitative assessment of the influence of these characteristics on the results of the functioning of the control system.

3.3.4. Parametric analysis and synthesis of control systems.

Parametric analysis and synthesis summarizes the results of the above types of analysis and synthesis and is performed to evaluate the effectiveness of the control system based on the determination of quantitative values of its indicators.

The essence of parametric analysis is the determination of the necessary and sufficient set of quantitative values of indicators characterizing all the studied properties of the system and the formation of dependencies characterizing the total effect of the application of the system or its elements.

The purpose of the parametric analysis is to evaluate the effectiveness of the control system based on the determination of the quantitative values of its indicators.

The objects of study of parametric analysis are particular and generalized indicators of the system that form a hierarchical structure.

Using indicators of the upper level, the external properties of the analyzed system are determined and its influence on the efficiency of solving problems by a higher level system is evaluated.

Lower level indicators are particular indicators (parameters) of a system that characterize its structure, functioning processes, information flows or other properties.

When conducting a parametric analysis of a specific control system, it is necessary to solve two main problems:

- determine the qualitative and quantitative characteristics (indicators) of the system, the degree of detail of which satisfies the researcher;
- to identify the existing shortcomings of the analyzed system and decide on its future use.

Based on the results of parametric analysis, a conclusion is drawn on the appropriateness of using the existing system, and the main directions for its improvement are determined, which ensure the improvement of those particular indicators that have the maximum impact on management efficiency.

The essence of parametric synthesis is the justification of the necessary and sufficient set of quantitative values of indicators, allowing to evaluate the desired properties of the developed system and its total effect.

The goal of parametric synthesis is a comprehensive definition of the required quantitative values of its indicators, consistent and balanced by the levels of research of the system, including general indicators of management effectiveness, as well as particular indicators of the structure and processes of information functioning.

3.3.5. The main levels of analysis and synthesis of control systems.

A systematic approach requires a multi-level study of the control system. The following levels of analysis and synthesis of control systems are distinguished: external, initial, system-wide, systemic.

Externally analyzes a higher-level system (super-system), which includes the investigated control system. In the process of studying the super-system: the goals and objectives of the super-system are determined; stand out (in the super-system) subsystems (functions, tasks), in the interests of which the control system is applied; indicators and criteria of these subsystems are specified; external properties and corresponding indicators of the control system are determined that can affect the effectiveness of super-systems.

At baseline the control system under study stands out as a separate targeted element of the super-system, which includes various, including opposing, interests of the subsystem. The main objectives of the study at the initial level: the allocation of the investigated system in the form of a separate focused element (FE); identification of input goal-setting, providing and interference (destructive) effects coming from various subsystems of the super-system on the central heating system; the establishment of indicators and criteria for the effectiveness of the central economic indicators, which characterize the external properties of the control system and its impact on the super-system.

At the system-wide level FE is being detailed on the control system (CS) and the control object (CO). The main objectives of the study at this level are: decomposition of the central energy center into a control system and a control object; formation of control actions; determination of routes to the goal; determination of indicators revealing the structure of the system and the effectiveness of control actions.

At system levels further decomposition of the FE and the CO by highlighting the individual elements and the relationships between them.

In accordance with the postulate of decomposition and a multi-level model for the study of control systems, the entire set of indicators (characteristics) of the system has a hierarchical structure and includes indicators: of the external level; initial level; system-wide level; system levels.

External indicators include indicators of individual subsystems of the super-system that interact with the control system under study.

Benchmark indicators characterize the external properties of the control system and its impact on the super-system. They include:

- performance indicators with which you can assess the degree of fitness of the system or its individual elements of the appropriate level to fulfill the tasks;

- selection parameters containing the characteristics of individual properties of the control system that affect the performance indicator.

System-wide indicators determine the structure of the control system at the level of CE and CO, as well as the functioning processes of the corresponding elements in the development of control actions and reactions.

System Level Metrics include various structural, functional and informational characteristics of the studied system to the accepted degree of detail.

TOPIC 4. ECONOMIC SYSTEMS

4.1. The concept of the economic system, their classification and models.

Economic system – it is a complex, self-regulatory, open system consisting of subsystems (firms, companies, enterprises, etc.) that characterize the production, distribution, exchange and consumption of material goods and services. Each subsystem is described by a set of parameters, and its own set of parameters has connections between the subsystems.

In modern scientific and educational literature, the classification of economic systems is based on two signs: the form of ownership of economic resources and the method of coordination of economic activity. Based on this, distinguish between *traditional, command (planned), market and mixed* economic systems.

Traditional economic system based on the dominance of traditions and customs in economic activity. Technical, scientific and social development in such countries is very limited, because it conflicts with the economic structure, religious and cultural values. This model of the economy was characteristic of ancient and medieval society, but it also persists in modern underdeveloped states.

Team economic system due to the fact that most enterprises are state-owned. They carry out their activities on the basis of state directives, all decisions on the production, distribution, exchange and consumption of material goods and services in society are made by the state.

Market economic system it is determined by private ownership of resources, using the system of markets and prices to coordinate economic activity and manage it. In the free market economy, the state does not play any role in the allocation of resources; all decisions are made by market entities independently, at their own peril and risk.

In today's real life there are no examples of a purely command or purely market economy that is completely free from the state. Most countries seek to organically and flexibly combine market efficiency with government regulation of the economy. Such a union forms a mixed economy.

Mixed economic system represents an economic system where both the state and the private sector play an important role in the production, distribution, exchange and consumption of all resources and material goods in the country. At the same time, the regulatory role of the market is supplemented by a state regulation mechanism, and private property coexists with public-state one. A mixed economy is by far the most efficient form of management. There are five main tasks that can be solved by a mixed economy:

- employment provision;
- full use of production facilities;
- price stabilization;
- parallel growth of wages and labor productivity;
- balance of payments balance.

The solution of these tasks was carried out by states in different periods in different ways, taking into account mutual experience. Conventionally, three models of a mixed economy can be distinguished.

Neo-etatist (France, England, Italy, Japan) is characterized by a developed nationalized sector. Its main feature is the nationalization of key industries, as well as the impact on the market so that the capabilities of individual players are approximately the same. In some cases, antitrust mechanisms are included in economic policy.

Neoliberal model (Germany, USA). It is characterized by less state intervention in market affairs than under the neo-etatist scenario. The authorities are trying to influence the quality of the functioning of economic institutions, but not the competition process itself. However, the antitrust component may also be involved in order to protect free competition. It is considered as the most effective regulatory system. The state essentially intervenes only to protect competition.

Concerted action model (Sweden. Holland, Austria). The basis of this model is the principle of agreement of representatives of social parties (government, trade unions, employers). Through special taxes on investment, the government prevents the economy from “overheating” and regulates the labor market. Special laws affect the ratio of wage growth to labor productivity, progressive taxation, often calculated on a progressive scale (usually higher than in countries where the neoliberal model is practiced) helps to equalize income. In the countries of this model, a powerful social security system has been created, an active structural policy is being pursued. The ultimate goal of the authorities is to find resources to maintain equal social status of citizens.

Currently, Ukraine has an ***eclectic economic system*** consisting of elements of an administrative command system, a market economy of free competition, and a modern market system. Its peculiarity is that the property relations and organizational forms of the economic system (even eclectic) that exist in our country are constantly moving, changing. Thus, an important feature of the system is missing – its relative stability, and it has a transitional character. This transition seems to stretch for decades, and from this point of view, the transition economy can also be called a system and it occupies a special place in the development of society.

Transitional economic system this is an economy that is in a state of change, a transition from one state to another, both within one type of economy and from one to another type of economy.

The transition period in the development of society should be distinguished from a transition economy, during which one type of economic relationship is replaced by another.

Moreover, in the transitional economy of each country, three fundamental trends intersect. The first of them consists in the gradual dying (both natural and artificial) of “mutant socialism”, which got its name by comparison not with the theoretical ideal, but with the real tendency of socialization existing in world practice. The second trend is related to the genesis of the relations of the post-classical world capitalist economy (modern market economy based on private-corporate property). The third trend is to strengthen the process of socialization – the increasing role of social (group, national and international) values in economic development and the humanization of public life as a prerequisite for any modern transformations. Obviously

To summarize, we note that economic systems are multidimensional. They can be formalized: $ES = F(A_1, A_2, A_3 \ldots A_n)$. In other words, an economic system (ES) is determined by its properties (*A*), where there are n such properties. This means that the economic system cannot be defined in terms of a single characteristic.

4.2. Application of a systems approach in the economy.

In recent years, there have been active discussions on the application of a systems approach in the management of economic systems. The various points of view that exist regarding certain aspects of its use are similar in one thing – in the general opinion of scientists about the undeniable value and significance of this approach, in management, because when speaking about managing economic systems, we must keep in mind the management of a complex, dynamic, open system. This approach makes us think of an extremely difficult task related to the implementation of the analysis of such an object for optimal control of it. The most common difficulties in managing economic systems are related to system analysis technology.

Today, the concept of "analysis" has outgrown its original framework and, in most cases, involves scientific research. The complexity of managing the economic system does not allow the decision maker (DM) to approach decision making from their purely subjective positions. Each of his decisions must be objective, scientifically sounds, therefore he is preceded by a preliminary study, which almost always proceeds according to the traditional algorithm: “analysis – diagnosis – prognosis”. The depth of its implementation depends, first of all, on the importance of the problem being solved. The complexity, systematic analysis is due to the fact that its form should be adequate to the object of study – the system. The effectiveness of the functioning of the entire system will depend on the state of each element taken separately in it,

The integration of many system elements is aimed at achieving certain goals, results and has dynamism, consistency, interdependence and focus. This tells us about the presence of certain processes in the system in which each element is connected by a causal relationship with the others. In our opinion, the decision-maker’s approach to the system analysis of management from the point of view of knowledge of the patterns of intrasystem processes, their interactions, can significantly facilitate the implementation of the system analysis itself.

Knowledge of the essence and logic of processes allows us to identify problems in management before they occur, that is, to adequately predict the management situation. Therefore, it becomes obvious that quite often there are situations when opening and clarification of a process in management or its interaction with other processes in the system is required. There are a number of analytical methods that allow this to be implemented, but one should dwell on the morphological (structural) method of analysis, since it, having a relatively simple procedure, allows one to determine the answers to almost all the most important problems related to intrasystem processes in management.

Morphological analysis method also called the *"method of morphological box."* To understand the essence of this method, consider the procedure for working on its basis.

At the initial stage, the entirety of knowledge about the object is used to systematically review its constituent elements, their properties, phenomena associated with it, etc. This is based on a systematic coverage technique: with it, the entire body of knowledge about the object is divided into levels, which are systematically viewed one by one. Moreover, a necessary requirement is the complete absence of any preliminary judgment. Further, the identified knowledge, objects, phenomena, parameters, etc., for any signs are divided into groups. Each group, in turn, undergoes a thorough study, during which the elements included in it are ordered and occupy a certain place. This approach allows us to accumulate data for further research using the "morphological box" method.

After the necessary data has been accumulated, a sequential pairwise connection is made of any element of one group with each element of another group, making up for each pair a characteristic that reveals the essence of the combination in question. Typically, for this procedure, a table or matrix is used as the organizing element, into the cells of which the mentioned characteristics are entered.

After all the characteristics are compiled, it will be possible to establish the most optimal sequence of phenomena in the overall management process. So, for example, when analyzing the management of the collective, it becomes obvious: the leader must exercise control in the collective in such a way as to exclude the appearance of labor and personal contradictions (technological, psychological and social) in it. Namely: to form motives for purposeful activity, to help increase the capabilities of the team, organize its purposeful activity and obtain real, pre-planned results. It also follows that an advanced warning of problems by the manager is possible only if the analysis and planning functions are multilevel, that is, they will cover the entire upcoming process of working with the team. To summarize, we can say that the interaction of relatively simple intrasystem processes forms a new integrative form, which in itself acts as an integrated management process, not reducible to the sum of its generators.

It is hardly possible to classify all situations of economic management in which there is a need for system analysis. Note the most common types of control situations in which the use of system analysis is possible:

1) Solving new problems. With the help of system analysis, a problem is formulated, it is determined what and what needs to be known, who should know.

2) The solution to the problem involves linking goals with many means of achieving them.

3) The problem has ramified connections that cause long-term consequences in different sectors of the national economy, and the decision on them requires taking into account full efficiency and full costs.

4) Solving problems in which there are various difficult to compare with each other options for solving a problem or achieving an interconnected set of goals.

5) Cases when completely new systems are created in the national economy or the old systems are fundamentally rebuilt.

6) Cases when improvement, improvement, reconstruction of production or economic relations is carried out.

7) Problems associated with the automation of production, and especially management, in the process of creating automated control

systems at any link.

8) Work on improving the methods and forms of economic management, for it is known that not one of the methods of economic management acts on its own, but only in a certain combination, in interconnection.

9) Cases when the improvement of the organization of production or management is carried out at facilities unique, atypical, differing in the great specificity of their activities, where it is impossible to act by analogy.

10) Cases where future decisions, development of a development plan or program should take into account the uncertainty and risk factor.

11) Cases where the planning or development of responsible decisions about development directions is taken for a rather distant future.

12) Development or improvement of the management system, when it comes to creating a system of optimal planning or management, where it is necessary to develop the criteria for optimality themselves, taking into account the goals of the development and functioning of the economic system, its place in the social division of labor and economic relationships.

4.3. System analysis technique economic systems.

Once again, it should be noted that a systematic analysis of economic systems arose in response to the requirements of practice: as a result of the need to study and design complex systems, to manage them in the face of incomplete information, limited resources, and lack of time. Since the methodology of *system analysis contains a set of methods and tools for the study of complex, multi-level and multicomponent systems, based on an integrated approach, taking into account the relationships and interactions between elements of the system.*

For specialists in economic systems management, a modern system analysis technique recommends the following list of procedures:

1. *The definition of the boundaries of the studied economic system.*

2. *Definition of all supersystems, which include the studied economic system as a part.*

Based on the interconnectedness of all spheres of life in modern society, *any economic object, in particular, an enterprise, should be* *studied as an integral part of many systems* – economic, political, state, regional, social, environmental, international.

Each of these suprasystems, for example, economic, in turn, has many components with which the enterprise is connected - suppliers, consumers, competitors, partners, banks, etc. These same components are included simultaneously in other suprasystems – sociocultural, environmental and etc. And if we take into account that each of these systems, as well as each of their components, have their own specific goals that contradict each other, it becomes clear the need for a conscious study of the environment surrounding the enterprise. Otherwise, the totality of the many influences exerted by the supersystems on the enterprise will seem chaotic and unpredictable, excluding the possibility of its reasonable management.

3. *Identification of the main features and directions of development of all supersystems to which this system belongs, in particular, the formulation of their goals and contradictions between them.*

4. *Determining the role of the system under study in each supersystem as a means of achieving the goals of the supersystem.*

Two aspects should be considered:

- *idealized expected role* systems from the point of view of the supersystem, that is, those functions that should be performed in order to realize the goals of the supersystem;
- *real role* systems in achieving the goals of the supersystem.

An example of such a bilateral approach can be an assessment of the needs of customers in a particular type of goods, their quality and quantity, and on the other hand, an assessment of the parameters of goods actually produced by a particular enterprise.

Determination of the expected role of the enterprise in the consumer environment and its real role, as well as their comparison, allow us to understand many of the reasons for the success or failure of the company, the features of its work, to predict the real features of its future development.

5. *Identification of the composition of the system, i.e. identification of the parts of which it consists.*

6. *The definition of the structure of the system, which is a set of relationships between its components.*

The multi-structural nature of any economic system should be emphasized.

Example. At the enterprise there are:

- organizational structure, i.e., the totality of the so-called relations of subordination and coordination, in other words, relations of subordination and coordination;
- information structure, expressed in certain formal and informal flows of information;
- flows of materials, raw materials, parts, finished products that make up their structures;
- a structure representing a combination of property relations;
- moral and psychological structure of purely human relations - likes and dislikes between employees;
- relations between various groups of workers, some of which are political in nature, for example, between members of trade unions, parties, and social movements.

7. *Determination of the functions of the active elements of the system, their "contribution" to the implementation of the role of the system as a whole.*

Of fundamental importance is a harmonious, consistent combination of functions of different elements of the system. This problem is especially relevant for divisions and workshops of large enterprises, whose functions are often largely “inconsistent,” not sufficiently subordinated to the general idea.

8. *Identification of the reasons uniting separate parts in a system, in integrity.*

They are called integrating factors, which primarily include human activity. In the course of activity, a person is aware of his interests, defines goals, carries out practical actions, forming a system of means to achieve goals. The initial, primary integrating factor is the goal.

A goal in any field of activity is a complex combination of various conflicting interests. The intersection of such interests, in a peculiar combination of them, is the true goal. A comprehensive knowledge of it allows us to judge the degree of stability of the system, its consistency, integrity, to predict the nature of its further development.

9. *Definition of all possible connections, communications of the system with the external environment.*

For a really deep, comprehensive study of the system, it is not enough to reveal its connection with all the supersystems to which it belongs. It is still necessary to know such systems in the external environment to which the components of the system under study belong. So, it is necessary to determine all the systems that belong to the employees of the enterprise – trade unions, political parties, families, socio-cultural values and ethical norms, ethnic groups, etc. It is also necessary to know well the connections of the structural units and employees of the enterprise with the systems of interests and goals of consumers, competitors, suppliers, foreign partners, etc. It is also necessary to see the connection between the technologies used in the enterprise and the "space" of the scientific and technical process, etc. Awareness of the organic, although contradictory unity of all the systems surrounding the company,

10. *Consideration of the investigated system in development.*

For a deep understanding of any system, one cannot limit oneself to considering short periods of time of its existence and development. It is advisable, if possible, to investigate its entire history, to identify the reasons that prompted the creation of this system, to identify other systems from which it grew and was built. It is also important to study not only the history of the system or the dynamics of its current state, but also try, using special techniques, to see the development of the system in the future, that is, to predict its future states, problems, opportunities.

Example. The need for a dynamic approach to the study of systems can easily be illustrated by comparing two enterprises for which at some point in time the values of one of the parameters coincided, for example, sales. It does not at all follow from this coincidence that enterprises occupy the same position in the market: one of them can gain strength, move toward prosperity, and the other, on the contrary, can experience recession. Therefore, it is impossible to judge any system, in particular, an enterprise, only by "instant photography", by one value of a parameter, it is necessary to study the ***changes*** in parameters, considering them in dynamics.

The sequence of system analysis procedures described here is not mandatory and logical. The list of procedures itself is obligatory rather than their sequence. The only rule is the advisability of returning repeatedly during the study to each of the procedures described. Only this is the key to a deep and comprehensive study of any system.

In conclusion, the following can be noted. The success of any economic activity is all the more likely the higher the level of consistency, and failures are caused by lack of consistency. The appearance of a problem is a sign of lack of consistency, the solution to a problem is the result of an increase in consistency.

In general, we can say that in the process of system analysis:

- problems that cannot be posed and solved by separate methods are solved;
- not only formal methods are used, but also methods of qualitative analysis, that is, methods aimed at enhancing the use of intuition and the experience of specialists - heuristics;
- different methods are combined using a single technique;
- there is an opportunity to combine the knowledge, judgment and intuition of specialists in various fields of knowledge and obliges them to a certain discipline of thinking;
- focuses on goals and goal setting;
- first, the object (problem) is considered as a whole connected formation, and then a more detailed analysis is made with the establishment of cause-effect relationships between the elements and the environment.

4.4. Enterprise as a single-minded system.

Among the systems created by people, a special category of the so-called *purposeful systems* can be distinguished. These are such systems that *contain people as their components*. From the point of view of goal analysis, such systems are particularly complex objects.

Let us consider as an illustration the evolution of the views of Western society on the economic system – the enterprise.

The processes of a number of recent decades, especially after the Second World War, have led the Western world to the idea of an enterprise as an organization in the broad social sense of the word, i.e., the voluntary association of owners and workers who are carriers of individual goals. Therefore, *the goal of a modern enterprise cannot be reduced, as noted above, to maximize profits; the goal of a modern enterprise is the sum of the goals of all its employees, owners, consumers and, strictly speaking, all other subjects of society, somehow related to it.* To distinguish the goals of human-containing systems from any other, all systems should be divided into two classes – mechanical and organic systems. Mechanical systems can be built to a large extent at the discretion of their creators; they possess once and for all properties set from the outside and do not have their own goals. And organic systems, by analogy with living, biological organisms, have the ability to conscious change, to self-development. Such systems create the organs that they lack, the means to achieve their goals. If the enterprise management creates the conditions for its *development*, then such an enterprise is able to survive in modern economic conditions and achieve some success. This is a consequence of the fact that the enterprise becomes an *open system* by reflecting for the purposes of its employees the world around it, its changing ideas, values and interests. If you try to build an enterprise according to the laws of the functioning of mechanisms, then such an enterprise cannot become anything more than a mechanism doomed to die in the conditions of the modern market,

What is the basis of the goals of an employee of a modern enterprise? It has long been a thing of the past that the main goal of an employee is only to get the maximum salary, that it is a material incentive that is the main motive for his work. Special studies have shown that *the needs of the modern employee, which underlie his goals, are multifaceted, multifaceted.* In civilized societies, not material incentives come to the fore, but motives of a spiritual, psychological plan, moral character. Indeed, *modern man feels the need for self-realization, creativity, freedom, public recognition, a* *reliable future and, of course, good material support.* Only such a company will be fully stable and prosperous, where the most important human and professional needs of its employees will be met. However, the goals of the firm as a whole cannot be reduced only to the goals of its employees or to the goals of its owners. In fact, the goals of the enterprise should be a harmonious combination – a system of four categories of goals: the goals of its employees, the goals of its owners, the goals of consumers of its products and the goals of society as a whole.

Among all the goals of the company, it is necessary to highlight the *core, basic goal*, which will be the leading incentive for the company; it should play not only an organizing and integrating role, but also fulfill an inspiring, propaganda function. This goal is the *mission of the company, its purpose for consumers.* Naturally, it is publicly announced, advertised, and, most importantly, *brought to the awareness of each employee of the enterprise, prompting him to actively serve for the benefit of the consumer.* It is clear that profit maximization cannot serve as the mission of the enterprise, since it is only its internal goal, while the *mission is a goal that goes beyond the scope of the enterprise.* For example, the mission of Mac Donalds is to provide fast, quality customer service using a standard set of products.

All other goals of the enterprise should be a means of realizing its mission. Such tools include a marketing service, production, personnel selection and training, research and development, and much more. Naturally, the company’s mission can be effectively realized only when all the means used for this are connected into a single harmonious system. Moreover, each of the tools, in turn, also represents a system, consists of different components. For example, production consists of interconnected workshops, departments, services. Each workshop is also a system that includes machines, equipment, maintenance personnel and much more. We can conclude that the totality of funds designed to achieve some goal, for example, the mission of a company, or any other goal, is a system that contains many subsystems, as if “nested” in each other, recalling the design of the "nesting dolls". Moreover, *any of these systems has duality, being both a goal and a means:* on the one hand, integral quality, the role of this system is a goal for which the system components are intended as means, and on the other hand, this system itself is a means to achieve a goal of a higher order. For example, the production of motors is a goal for employees of the engine shop, but a means for the enterprise as a whole. This system itself is a means to an achievement of a higher order. For example, the production of motors is a goal for employees of the engine shop, but a means for the enterprise as a whole. This system itself is a means to an achievement of a higher order. For example, the production of motors is a goal for employees of the engine shop, but a means for the enterprise as a whole.

For the successful preparation of solutions, it is especially important that this method allows you to divide a complex, intractable task into a set of relatively simple ones, for the solution of which there are proven techniques and methods. Indeed, unlike many other areas of activity, management is associated with the solution of such problems that are caused by a huge number of various factors and conditions, which are far from always expressed quantitatively. All this makes every task that is solved in the management sphere unique in its own way, without a ready-made solution. The sequential division of the problem into private subproblems is an important stage of system analysis. The dividing should continue until it is divided into the usual, obvious sub-problems solved by well-tried techniques.

Indeed, it is completely insufficient, based on common goals, to correctly determine the *tasks* facing the governing bodies of a particular organization at a certain stage. Significant difficulties always arise in the transition to *practical* forms and methods for solving them. If a *gap is allowed between goals and means*, then the organization will not be able to solve the tasks. Thus, the inability to use the techniques by which goals and means are linked into a single whole, leads to the inability of managers to realize their mission - to achieve goals.

The method of system analysis aimed at ensuring the *unity of the chosen goal and the means to achieve it* is to build a “tree of goals” – it is a *structured, built on a hierarchical principle (distributed by level, ranked) set of goals of the economic system.*

The construction of the “tree of goals” of the economic system begins with the procedure of structuring, dividing the main goal into components called subgoals, each of which is a means, direction or stage of its achievement. Then, each of the subgoals, in turn, is considered as a target and is divided into components. Any of the received elements should also be considered as a goal and decomposed into its component parts. If all these elements are represented graphically, we get the so-called “goal tree”, facing down with a crown. In this case, the main goal is at the top level. The process of dismemberment should be carried out until at the very lowest level of the “tree” there are funds whose implementation does not cause fundamental difficulties and doubts.

This method has apparent simplicity, and this can cause a desire to use it for economic systems, without deeply mastering all its sides and features, without adapting it to the development of precisely managerial decisions taking into account their specificity. In practice, the process of structuring the goals of economic systems is very difficult to carry out, it requires special rigor of thinking, because in real economic systems there are a lot of informal relationships, complex interactions that are difficult to distinguish and take into account.

The essential advantage of this method lies in the organic unity of analysis and synthesis. Experience shows that often organizations use mainly analysis in the narrow sense of the word, the division of tasks, problem situations into components. Much worse is the case with synthesis, for which dialectic thinking, a certain philosophical culture is necessary. At the same time, management requires a synthetic, systematic approach, since management is an activity that is primarily aimed at uniting, at synthesizing the interests of people. The application of the “goal tree” method serves to connect in the process of creating a managerial decision of analytical and synthetic work. The very process of dividing a common goal into subgoals serves as a way of combining them, since not only individual components are identified, but also the relationships between them, connection with the main goal. Thus, structuring is carried out simultaneously with integration.

Although the goal tree does not fully reflect the structure of systems, it cannot replace the entire set of system analysis procedures, but at the same time, it helps to visually express the “target” approach to organizing a modern enterprise, which is especially important in a dynamic environment. affecting the goals of the enterprise.

4.5. “Goal tree” and company performance indicators.

A company (firm, enterprise) is a complex interacting system of owners, managers, employees, resources and technologies, and the relationship between all elements of this system. A systematic analysis of the company’s activities involves obtaining answers to the following questions: is there a universal “goal of goals” that is “desirable” for almost any company; what are the modern approaches to the integrated assessment of the enterprise; what are the generally recognized goals and their hierarchy, forming the “goal tree" of the company?

Until recently, the highest default target (and at the same time an indicator of success) for most Ukrainian companies caught up in a market economy was profit, and only profit. Moreover, for them, the profit of today is important, which all over the world has long been distinguished from long-term, "strategic" success and profit in the future.

Many years of Western and already accumulated domestic experience have proved that companies that focus only on profits for a given year or on ensuring current profitability (understood as saving on everything) suffer from myopia. And the right choice of activity criteria has a big impact on decisions. Its main postulates:

- *maximizing the value of the company is the main goal of strategic management*;
- *value growth is the main criterion for management effectiveness*.

That is, increasing the efficiency of enterprise management is determined not only by liquidity or profit margins, but by an increase in the "price" of the business. Targeted management requires the selection at the top level of one value-oriented objective function. And such a goal is “business value” in the interests of its owners (owners, shareholders).

Do not think that the lack of a developed stock market (stock market) makes this approach inapplicable in Ukraine. For example, even in a small business, a company with regular management set up acquires real value and only such a business can be sold as a "business", and not the amount of tangible assets whose effective management is inseparable from the entrepreneur himself.

The answer to the question, "what factors affect the value of the enterprise", which we must strive to increase, allows us to determine the next level of the "goal tree".

One of the main discoveries of the modern theory of business management, made in the early 90s of the 20th century, was that in the decision-making process, managers and owners are experiencing an increasing need for information not only of a financial nature. In the conditions of rapidly developing markets and fierce competition, non-financial information based on the valuation of intangible assets of an enterprise is becoming increasingly important. Along with (1) *making a profit and increasing capitalization (finance),* the following goals are of paramount importance today: (2) *gaining market shares and gaining competitive advantages, customer loyalty, the ability of an enterprise to ensure their retention,* (3) *the progressiveness of technology and the level of well-functioning business – processes,* (4) *powerful and highly qualified personnel potential* – all these factors are of great importance and affect the value of the company in the present and in the future.

The Balanced Scorecard (BSC) system is a balanced scorecard that allows you to evaluate these factors and opens up new opportunities for management and allows you to control the tactical state and strategic development of the business. It is the presence of such a balanced scorecard that allows us to move from a qualitative description of the goals of the enterprise through the ideal image of the desired future result of entrepreneurial activity to the operational one. In this case, the goal is the future desired and achievable result, quantifiable and / or verified in the experiment.

This system is the basis of the most powerful and most popular enterprise management system in the world by SAP AG – the SAP – SEM module (Strategic Enterprise Management).

Using this approach, it is possible to build "trees" of company goals and automation goals, as a fragment of it.

At the top level of this tree is the Company's Mission, interpreted as the Target state of the Company, which is the basis for developing a development strategy.

The system of balanced indicators translates the mission and corporate strategy into a system of clearly defined goals and objectives and, most importantly, into a system of indicators that determine the degree of achievement of these objectives within the four main projections:

- financial (which company is presented to its shareholders and investors),
- marketing (which company is presented to its customers),
- internal business processes (which business processes need to be improved, which ones to abandon, which ones to focus on),
- training and growth (whether the company can continue its development, increase efficiency and increase value).

Within each such projection, private goals, performance indicators and their evaluating indicators are determined, which largely depend on the specifics of the company's activities, the chosen strategies and the possibilities of their observation using software products used for automation. Key performance indicators for each of these projections are shown in Table 2.

Table 2. The upper levels of the "goal tree" and means of monitoring their achievement with the help of automated control systems (based on a balanced system of performance indicators).

Objectives in the field:	Performance indicators	Evaluating indicators	Software tool
1. Finance	1.1. Return on assets	Profit / Assets	**ERP systems**
	1.2. Asset turnover	Turnover / Assets	
	1.3. Profitability	Profit / turnover	
2.Marketing	***By key market segments***		
	2.1. Key factors for product success	Averaged by a group of experts, ranked and selected by the level of 80% attractiveness, weighted estimates of the attractiveness of key success factors	**Analytical CRM Systems**
	2.2. Customer satisfaction	The sum of weighted assessments of satisfaction averaged over a group of experts on the set of key success factors.	
	2.3 The degree of customer loyalty	The percentage of repeated calls in relation to the total number of sales	
	2.4. Market share	Percentage of the company's sales in relation to the total sales of goods in this segment	
3. Business processes	***Key business processes***		
	3.1. The degree of maturity of individual processes	Maturity scale	**Orgware / Work flow**
	3.2. Process system maturity	The sum of the normalized weighted assessments for the totality of key processes (at the level of 80% importance)	
	3.3. Number of work procedures violations	Cases for the reporting period	
4. Training	***Key Professionals***		

and growth	4.1. Key staff comfort factors	Averaged over a group of experts, ranked and selected at the level of 80%, weighted estimates of key factors for the comfort of staff	**HRM systems**
	4.2. Employee satisfaction	The sum of weighted assessments of satisfaction averaged over a group of experts on the set of key success factors.	
	4.3. The degree of employee loyalty	The percentage of layoffs in relation to the total number of employees	
	4.4. Skills development	Number of retraining for the reporting period	

Each of the indicators can be further detailed by entering indicators of the lower level. For example, the decomposition of the Goals in the field of finance is based on the premise that the main objective of the business at the operational level is to maximize the rate of return on assets, i.e. the ratio of profit before tax and interest payments on loans to assets - an indicator that characterizes the main activity of the enterprise.

$$\mathrm{PA} = \frac{\mathrm{Profit}}{\mathrm{Assets}}$$

The company should choose due to which this indicator will primarily improve – by increasing asset turnover, for example, by more efficient inventory management, or by reducing costs and thereby increasing profitability of turnover. To control these indicators, the RA coefficient is converted by multiplying the numerator and denominator by the same number (sales revenue or, which is the same, turnover) into the product of two indicators:

$$\mathrm{PA} = \frac{\mathrm{Turnover}}{\mathrm{Assets}} + \frac{\mathrm{Profit}}{\mathrm{Turnover}} = \mathrm{K}_{\mathrm{ta}} + \mathrm{K}_{\mathrm{pt}}.$$

Such a transformation makes it possible to control two more targets: K_{ta} – asset turnover and K_{pt} – profitability of turnover (or sales).

Further detailing of these indicators is also possible, which will become the criteria for the success of the achievement of the goals by managers of the company.

When using the goal tree method, the term decision tree is often introduced as a means of decision-making. When applying the "tree" to identify and clarify management functions, they speak of a "tree of goals and functions." When structuring the topics of a research organization, it is more convenient to use the term "problem tree", and when developing forecasts, the term "tree of development directions (or development forecasting)". The “goal tree” method is focused on obtaining a complete and relatively stable structure of goals, problems, directions, i.e. a structure that has changed little over a period of time with the inevitable changes occurring in any developing system.

4.6. Information aspects of the system analysis of economic systems.

On the basis of the structure of production, its specifics, the nature of social, production and economic processes, information is generated that displays all aspects of its functioning.

In a systematic sense, this information is considered in terms of the following aspects:

pragmatic – fulfillment of goals and objectives, criteria for assessing their feasibility, ways to describe information images and flows, strategies and tactics for achieving goals;

semantic – semantic content of information, its unambiguity and concreteness and applicability in fulfilling the goals and objectives;

syntactic – the rules and laws of receiving, processing, storing and transmitting information, and includes the ***structural*** aspect – the rules and laws of classifying information, the formation of information files, databases and knowledge bases.

Stationary modes of information exchange between various structures, services, production units are called ***information flows***. They are focused and subordinate to the global goals of production as an organizational and economic system.

Consider the systematic purpose of the main information flows and their components:

input information flows – external, in relation to the considered system, parameters of input material and energy characteristics, tasks and other components of the information description;

status information – information flows characterizing the dynamic and static state of the system in question;

output information flows – characterizing the functioning of the system in relation to the external environment.

Production management, as a process, is purely informational in nature *and functionally subdivided into information components or information processes* (*levels*):

strategic planning and management – determination of the programmed path of managerial influences to fulfill the global goals of the system (planning procedure);

operational planning and management – a time-detailed procedure for applying managerial influences on the technological, economic and organizational parameters of production in order to fulfill tasks and various schedules (for example, control procedures that minimize the current deviations of controlled parameters from tasks);

operational control and accounting **–** diagnostics of the state of production, identification of deviations, state analysis, causal economic and organizational-technological analysis.

Information flows exactly correspond to control levels or control loops, subdivided: *organizational and economic level; organizational and technological level; level of control of technological processes and units.*

The procedure for obtaining, on the basis of the initial information flows *In* (*s*) about the set of feasible control options that generate the state of the system s of optimal management decisions *U*(*s*) depends on many factors: the principles of optimality used, the class of management problems, and admissible solutions (see special literature). Depending on

In(*s*), there are three types of information support for the process of development and adoption of optimal management decisions *U*(*s*):

- in the conditions of complete information, when the system has In (s) in the amount necessary to accept *U*(*s*);

- in conditions of incomplete or inaccurate information, when, for the adoption of *U*(*s*); additional procedures are required to obtain, increase the reliability or restore information on the basis of available probabilistic, statistical or other methods of processing information;

- in conditions of complete or partial informational uncertainty, when either information on the state of the managed system is completely or partially unknown and the laws for its receipt and processing are unknown.

Management, as a process of targeted impact, is carried out by people and therefore is necessarily present:

- the problem of subjectivity upon receipt and use of information;

- the problem of variability and inconsistency of management goals, (part of the local goals of the system and its subsystems are contradictory and change over time);

- the problem of information activity, consisting in the fact that in the management process, the active elements – people involved in the formation of managerial decisions, can purposefully distort information in accordance with their goals and objectives, not necessarily coinciding with the goals of management;

- the problem of uncertainty, including the uncertainty of states and environmental influences, the dynamic variability of the internal properties of the control system itself.

In direction and semantic content, information flows used for management tasks are characterized as:

- informative moving from control objects to control nodes (levels);

- manager moving in the opposite direction;

- control and conversion and diagnostic, covering all levels of the system and determining the rules of functioning and mutually linking the functioning algorithms of individual elements of the system, aimed at monitoring the state of the system and identifying causes that negatively affect the fulfillment of management objectives.

Information management problems associated with the use of various information technologies include:

- optimization of the hierarchy of goals and information structure by clarifying goals and eliminating contradictions between them, eliminating unnecessary control nodes, eliminating empty information, creating new nodes and new information flows, if necessary;

- optimization of control algorithms and coordination of information processing processes using computers;

- optimization of the internal structure control nodes by reducing the length and levels of coordination when making management decisions;

- optimization of the structure of the control object by increasing manageability, observability, coordination and reachability as properties of a control object;

- organization of information (including the organization of primary information, information flows, on the basis of correct rules, techniques, methods for obtaining, processing and storage of information and other aspects), the concept considered in relation to any basis taken as a standard, and *there is no absolute measure of information organization*.

Substantially, the organization of information is determined by comparing the results of the system at a given time interval and determining production losses from incorrect controls. Moreover, only those decisions are distinguished that, in turn, were due to the lack of reliable information. Note that the tasks are considered to be fully feasible, goals attainable, assessment criteria are correct. Measure – ΔG organization is determined

$$-\Delta G = G(ф) - G(*),$$

where $G(ф)$ is the actual measure, $G(*)$ is the given measure. Otherwise, this measure is called a measure of management disorganization.

For quantitative dimensional assessments, measures of disorganization of information are structured by informational features and loss calculation is performed.

At present, Ukrainian enterprises, following the entire civilized world, have entered a period of not just a market economy, but a “information” economy of a post-industrial society. Basic needs have already been met, and firms must either look for specific needs, or create new ones, or simply improve products currently being created. Despite the fact that in most cases, to the chagrin of enterprises and the joy of consumers, competition supplants weak companies, the only way to survive today is to use the information meaningfully and quickly.

What kind of information do firms need in order to find their place “under the sun?” Only accounting principles define a firm as an independent entity, but in reality it is closely integrated with the market and the environment. The objects of the strongest ties include consumers, competitors, partners and investors. In addition, its activities are influenced by political, economic, social and technological situations. When a company receives information about consumers, it determines the circle of its desires and creates a set of goals that it would like to achieve. Information about competitors, partners, investors makes it possible to choose the most important goals from this set and determine how to implement the selected goals.

However, it is important not only to know external factors, but also the internal capabilities and needs of the company. Knowing these relationships, firstly, helps company managers to realize the organization’s potential necessary to achieve their goals, and secondly, to obtain accurate information about the processes occurring within the enterprise. Other important information is about sources of opportunity, the third is about internal processes. The availability of adequate information is important not only for the development of the company itself, but also for its counterparties. In order to develop effective information channels with customers and partners, the company must understand its own processes. A company that can easily provide others with reliable and necessary information receives a serious advantage, as other market participants are also in constant search for reliable information. Consumers are interested in reliability and speed of order execution, investors are interested in financial information about the company, partners are in knowledge about the direction of the company’s development; especially important is that all this information must be received in a timely manner. Therefore, obtaining information from the outside and providing it to others creates both additional opportunities and causes the emergence of new ways to realize these opportunities.

In addition, it is now safe to say that in the 21st century, accurate knowledge of the internal operations of a company is the basis of business growth and survival. Enterprise modeling and resource planning systems provide a clear understanding of internal processes. In view of the importance of these processes, we consider how answers to the questions posed can be obtained using mathematical modeling of economic systems.

TOPIC 5. MATHEMATICAL MODELING OF ECONOMIC SYSTEMS

As already mentioned, a systematic approach involves the study of complex systems and, first of all, economic systems should be carried out not on a real system-object, but on a model system. In this case, it is possible, without resorting to experiments on real economic systems, to evaluate various working hypotheses regarding the appropriateness of certain actions using the appropriate abstract model system, and to develop the most preferable solution to achieve the goal by the system. Therefore, modeling of economic systems is an important stage in the decision-making procedure, and in recent years, with the development of computer and information technologies, there has been an increasing understanding that mathematical computer modeling plays a key role in the analysis of economic systems,

In modeling, two main role functions are distinguished - the function of the analyst performing the modeling and decision-making, and the function of the “decision maker” - the decision maker, the person who actually makes the decision. Under these conditions, modeling is entrusted with a responsible mission, to serve as a kind of “interface” between the analyst and the decision maker - modeling acts as a kind of “universal language” in which many economic situations can be described in an objective form. Let us consider this situation in more detail.

5.1. Scheme of operational research of the economic system.

The entire range of work on the study and improvement of the economic system to achieve this goal is carried out by the operational group of system analysts or is also called the *operating side* (OS). This set of work is carried out in the interests of the decision maker. A decision maker may reject research results, but may accept. In fig. Figure 6 shows an example diagram of the stages of operational research on the study and improvement of the economic system.

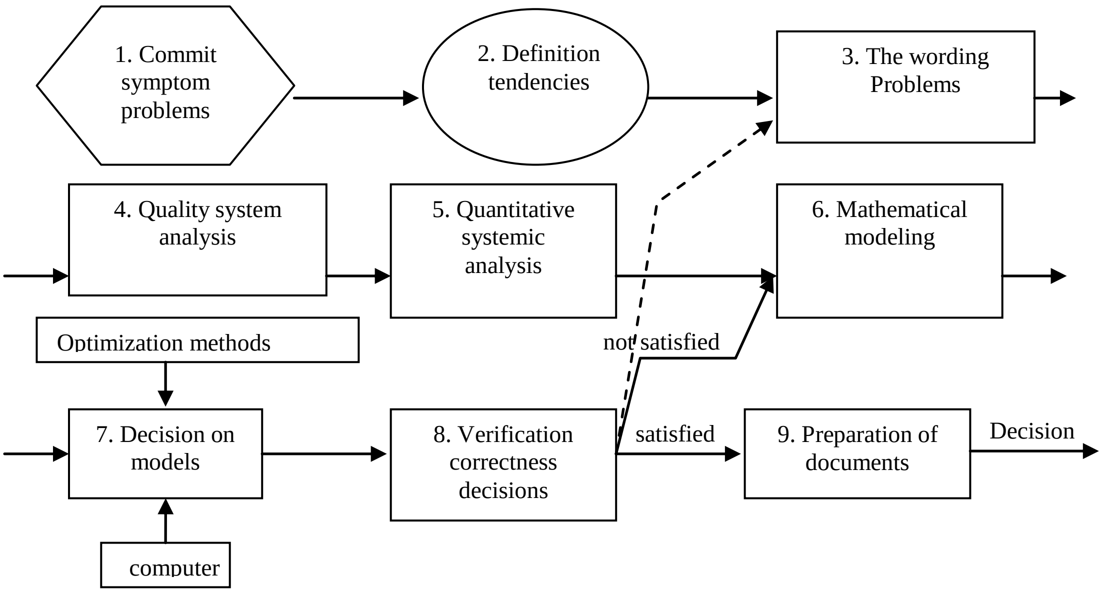


Fig. 6. Scheme of the stages of operational research.

We give a brief description of the stages of operational research.

1. In the most general case, the cause for the study and improvement of the system are fixed symptoms that reveal problematic issues in the system.

2. The identified symptoms of the problem can form a connected chain of facts (tendency) that helps to formulate the problem.

3. The most important stage in the study of the system is a clear statement of the problem, which is present at this level of the life of the system.

4. Qualitative system analysis is the splitting of a holistic system into separate elements (entities). To do this, you need:

- to isolate the system under study from the superior system, i.e., to establish the boundaries of the system to be optimized. Extending the boundaries of the system increases the dimension and complexity of a multicomponent system, thereby complicating its analysis,

- formulate the goal carried out by the system,

- list the factors that affect the achievement of the goal,

- identify possible limitations within which the system can be improved.

5. Quantitative system analysis involves describing all of the factors that are involved in the operation at a quantitative level, that is, based on measurable parameters. For this:

- establishes a *criterion (performance indicator)* (K) – a quantity that quantitatively measures the degree of achievement of a system's goal and allows comparison of different decisions on efficiency. In case there is a single-purpose decision-making, then K is a scalar; if multi-purpose decision-making, then K is a vector;

- quantitative internal parameters of the system are introduced that measure the factors involved in the description of the system. The whole set of these factors must be divided into two parts:

a) *uncontrollable (uncontrolled) factors* that the OS does not control and cannot change in this particular system (operation). The parameters $a_1, a_2, \dots, a_k$of these factors we will consider as the coordinates of the vector, and denote $a = (a_1, a_2, \dots, a_k)$.

Uncontrolled factors $a_1, a_2, \dots, a_k$, based on their knowledge of them, can be divided into three groups: fixed, random, indefinite.

Fixed uncontrollable factors – these are factors whose values are precisely known by the OS. *Random uncontrolled factors* are random variables whose distribution laws (functions) are precisely known by the OS. *Uncertain uncontrolled factors* are deterministic or random variables, with respect to which the OS knows only the range of possible values or the class of possible distribution laws,

b) *controlled parameters (variables*) $x_1, x_2, \dots, x_n$ – quantities that the OS can control and change them at its discretion. We will consider $x_1, x_2, \dots, x_n$ as the coordinates of the vector – a single element of the mathematical model, call it strategy and denote $x = (x_1, x_2, \dots, x_n)$.

6. The essence of mathematical modeling is the establishment of quantitative relationships between the entered values of K, a, and x in the form of the so-called *operational (mathematical) model*. Elements of the

model contain all the information used in the calculation of the system. The process of constructing a model is very time-consuming and requires a clear understanding of the specific features of the system under consideration. There are many different classifications of mathematical models. In particular, there are models multi-criteria dynamic, in which in addition to the parameters and x there is clearly a time variable, and static, in which this variable is not. In reality, all processes occur in time, so dynamic models, generally speaking, more accurately describe reality.aHowever, it should be borne in mind that all these models are based on the foundation of single-criterion optimization methods and limited to simpler static models without a clear understanding of which it is impossible to work with a more complex mathematical apparatus. Moreover, the performance criterion is presented as a numerical function of only strategies and uncontrollable factors, i.e., $K = f(x, a)$, where f is the model of the objective function, it establishes the functional dependence of the criterion K on uncontrolled parameters a and controlled values of x.

For the objective function, the direction of improvement of the criterion is indicated.

$$K = f\,(x, a) \rightarrow \min\ (\max). \qquad (5.1)$$

This expression determines the meaning of system optimization, that is, it is the mathematical equivalent of the purpose of the operation. Setting the objective function is the first part of the construction of the operating model.

The second part of the operating model is a mathematical description of the restrictions on the choice of variables x. All restrictions in general form can be written in the form of inequalities and equalities:

$$\varphi_i\,(x, a)\ (\leq,, =, \geq)\ 0,\ i = \overline{1, m}. \qquad (5.2)$$

Each function φ_i (x, a) is called a restriction function. In some problems, there are requirements for the form of the variables x or K.

$$\left.\begin{array}{l} x \in D \\ K \in M \end{array}\right\}. \qquad (5.3)$$

For example, the requirement often arises that x or K must be integers. In some cases, they must belong to some standard set of values.

A model in the form of (5.1), (5.2), (5.3) is a *model of an operational type* or an optimization model (not an optimization one – without an objective function).

The optimization model (5.1), (5.2), (5.3) allows us to pose the problem of *optimizing* the system (operation) as a mathematical problem: find controlled variables x^* that satisfy the constraint system (5.2), (5.3) and provide the best value for the criterion K the objective function.

7. The solution of the mathematical problem posed requires the use of optimization methods, including, in addition to classical mathematical methods, also special methods of operations research associated, for example, with multicriteria optimization methods or when the model contains random uncontrolled parameters. It should also be noted that for the most part, real optimization problems lead to a large amount of computation (up to tens of thousands). Therefore, modern methods of finding optimal solutions are focused on the use of computer tools.

8. Comparing the obtained solution with a meaningful (verbal) statement of the problem, one can detect contradictions or some incorrect elements of the solution. Errors in the mathematical model or failure to take into account some significant limitations may be the cause of the incorrectness. At this stage, the decision maker may participate. If the obtained solution is acceptable – it is accepted, if not – you need to return to the stage of mathematical modeling or even to the earlier stages of the study.

9. The found optimal solution x^* allows you to prepare a control solution in the form of a document for the decision maker.

Thus, operational research is an iterative process that converges to a certain optimal solution. The considered scheme is approximate. It allows you to better understand the meaning of system analysis as a science – the quantitative justification of optimal solutions based on the construction and use of a mathematical model. Unfortunately, the process of translating into a quantitative description of complex systems is not a technology. The mathematical model may turn out to be successful or unsuccessful for practical solutions. In addition, far from always the whole complex of goals and objectives facing the simulated object can be expressed in the form of some objective function.

To illustrate the main stages of the operational project and the constituent elements of mathematical models, we consider examples of building models for some meaningful tasks.

5.2. Models and their mathematical description.

As we already know, the studied economic object, considered as a system, is an integral part of a number of different hierarchical systems. In economic systems, the main actor is a person. Therefore, when studying a specific economic problem, we are forced to “break off” the hierarchy of systems “going down” at some stage. Whether we do it on a person, or on a certain set of people – this already depends on the problem being investigated.

Of course, a person does not necessarily act as the “smallest” element that can be considered as “indivisible”. It may well turn out that as such an “indivisible” element one can consider, for example, individual firms (for the tasks of optimizing the management of the regional economy), social groups (for the tasks of allocating state budget funds), or sectors of the economy (when considering the balance of resources within the framework of gross product).

In other words: at some stage of the investigation, the elements that make up our system are no longer assumed by us as systems, but as “finite” and “indivisible” objects. Thus, the hierarchy of systems unfolds upward, proceeding from such objects, which, thereby, become objects of the lowest level of the hierarchy.

Such an object – by virtue of our assumptions (that is, from our situational point of view) – will no longer have an “internal structure”. Therefore, it should be considered as an object that can be characterized - in the framework of the problem we are considering - only by two classes of characteristics. The need for this arises due to the reason that such objects must form a system – that is, they must be able to form connections with each other.

But this is only possible if two conditions are met.

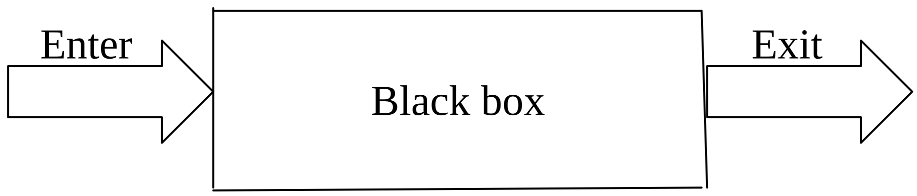
First, the object must have the ability to perceive the impact of other similar objects (this can be information, information, data, signals, etc.). Secondly, he himself must have the ability to “generate” such influences that will affect other objects similar to him.

5.2.1. The black box model and its description.

Thus, we come to the definition: a fragment of a system that is considered as a whole and is characterized only by its “input” (possessing, therefore, the ability to perceive influences from other fragments of the system) and “output” (by which it interacts with other objects of the system), called the *black box.*

The black box is perhaps the most powerful abstract concept that exists within the framework of modeling. It is due to its introduction that it becomes possible to build closed systems that simulate the object or process under study. The black box is a “measure of our ignorance” about the system under study.

As a rule, it is indicated as follows in the form of a rectangle into which the input arrows (in) the characteristics of the black box – the parameters that they *convert* to the output (out) characteristics of the black box.



So, to set the black box, it is necessary to set the correspondence “input parameters” to “output parameters”. It should be remembered that the internal structure of such a box remains unknown to us: we do not know how it is arranged, do not know how it functions, do not know what states it can have and how the transition between its states is carried out (even if they have it is). The only thing that can be said is to build a model for describing the input characteristics of such an object (a set of classes of variables to which it “answers”), and correlate it (with certain relations) with a model of output characteristics of a black box (that is, with a set of classes of variables in within the framework of which his “answers” can be expressed).

In the general case, it is thus assumed that such an object - a black box - is integrated as an “active element” into a certain system. This is especially evident in the case of a graphical (for example, in the form of a block diagram) description of the system.

The data (characteristics, parameters, information, etc.) that characterizes the input is often referred to as black box *input signals*. The data (characteristics, parameters, information, etc.) that characterizes the output is often called the black box *output signals*. Such terminology came from technical systems, to which the concept of a black box was first applied.

When moving to mathematical models, at the mathematical level of description, such a converter of variables from one set (input characteristics) to another (output characteristics) is modeled by an operator (function).

The mathematical definition of the operator is known: Let V and W be some sets (for example, vector or linear spaces).

Operator A acting from V to W is a map of the form A: $V \to W$, which assigns to each element x of the set V a certain element of the set W. As a rule, the notation $y = A(x)$ or $y = Ax$ is used for the operator.

Thus, a black box acts as an operator when:

1) The parameters that characterize the input of the black box can be grouped into a certain set V.

2) The parameters that characterize the output of the black box can be grouped into a certain set W.

3) A certain rule is specified (algorithm, method of conversion, calculation, etc.), which allows to calculate the value of y from the set W of the output signals of the black box from a known input signal - the value x from the set V.

In view of the foregoing, the black box acts as a model of the system under study. And in the operator with which it is modeled, and, in fact, lies the mathematical model of the element that makes up our system. For this reason, the mathematical description of the black box is usually moved to the last stages of the simulation.

An important class of operators are the so-called *linear operators*. Although today the field of activity in modeling real systems using linear operators is extremely limited, they nevertheless still act as a powerful tool for mathematical analysis of systems. As we already wrote, system models also constitute a hierarchical system of logically related terms and concepts. Therefore, it often turns out that a system that is described *nonlinearly* at a certain level of logical depth of understanding, at a *higher level*, can well be described within the framework of an already *linear* apparatus and *linear* operators. Examples of such descriptions will be given in subsequent chapters.

However, let us return to linear operators and give their definition.

Operator A acting from *V* to *W* is called linear if, for any elements x_1 and x_2 from the set *V* and any complex number μ, the relations

1) $A(x_1 + x_2) = A(x_1) + A(x_2)$ (the additivity property of the operator), and

2) $A(\mu\, x) = \mu\, A(x)$ (the property of homogeneity of the operator).

Examples of linear operators.

Here are some examples of mathematical objects that are linear operators.

Matrix as a linear operator.

An ordinary matrix is a linear operator, if we consider it as a transformation of one column vector *x* into another column vector, *y*.

$$y = Ax, x = \begin{vmatrix} x_1 \\ x_2 \\ \cdots \\ x_n \end{vmatrix}, y = \begin{vmatrix} y_1 \\ y_2 \\ \cdots \\ y_m \end{vmatrix}, A = \begin{bmatrix} a_1 & \cdots & a_n \\ \vdots & \ddots & \vdots \\ a_m & \cdots & a_{mn} \end{bmatrix}.$$

This relation is written for the case of a rectangular matrix of operator *A* of dimension $m \times n$, which corresponds to the fact that the set *V* is a collection of column vectors *x* of dimension $n\times1$ and *W* is a collection of column vectors of dimension $m\times1$.

Thus, the matrix, known from the course of higher mathematics, within the framework of economic cybernetics can be considered as a linear operator that models a number of properties of the black box. In particular, in this way, control models can be described – then the column vector x represents the information necessary for the solution, and the column vector y describes the solution itself. Matrix A in this case is an abbreviated record of the decision-making algorithm that corresponds to our model.

Differentiation operation as a linear operator.

The operation of differentiation – taking the derivative of a certain function – is also a linear operator.

In this case, *V* is the set of all (differentiable the required number of times!) Functions, and *W* is also the set of functions (but differentiable the number of times, is one less than the functions of the set *V*!).

Denoting the element of the set *V* by *f*(*t*), and the operator *A* denote as $\frac{d}{dt}$, we easily verify the validity of conditions 1) and 2) from the definition of a linear operator.

$$\frac{d\big(f_1(t)+f_2(t)\big)}{dt}=\frac{df_1(t)}{dt}+\frac{df_2(t)}{dt},$$

$$\frac{d\mu f(t)}{dt}=\mu\frac{df(t)}{dt}.$$

Note that, as is easily proved in the same way, the operator

$$A=Q(t)\frac{d}{dt},$$

where $Q(t)$ is an arbitrary function, is also linear. We emphasize that in the latter case, differentiation is always the first to act on the function *f*(*t*), and only then is the *multiplication* of the result of *differentiation* by the function $Q(t)$. The execution of just such a sequence of actions is extremely important, which is easy to verify by comparing the results of two different action algorithms: the first – “differentiate first, and then multiply”, and the second – “multiply first, and then differentiate”!

Integration operation.

With the integration operation, after all of the above, no questions arise: of course, it – taking an indefinite integral – is also a *linear* operator. Actually, this was mentioned even in the framework of the course of higher mathematics – but then you did not even suspect that this, in fact, is a story about mathematical models!

The property of a certain object to be "differentiating" (sometimes - "difference") or "integrating" (sometimes – "summing up") is often set as the functions of certain black boxes that perform certain *control functions* in the system. This is especially evident for radio circuits – however, economic systems also show us many similar examples. What is a bank? – this is an “integrating” object. What are ratings – economic or social? It’s a differentiation procedure.

In fact, many more important mathematical details from the described example were left unanswered. But let us ask ourselves the question: do we really need these mathematical details are they really important for us in the process of solving practical problems?! Having received a solution, we can always check whether it satisfies our equation and our boundary conditions! And mathematical rigor is not always necessary in solving practical problems. Therefore – boldly introduce new mathematical operations, terms and concepts, being guided by only one, but the main criterion: *they should help solve the investigated problem!* Actually, that is exactly what scientists did throughout the development of science. Oliver Heaviside himself used his calculus (which for a long time it was called - “Heaviside calculus”), - mathematical rigor was imposed only 10-15 years after his death. Paul Dirac - introduced a function that was very different from everything that was known to mathematicians before: they explained this only after 20 years. Richard Feynman introduced the mathematical operations that mathematicians still suffer from! Werner Heisenberg introduced operations that helped him explain quantum effects — and only then did mathematicians realize that these were well-known matrices!

5.2.2. The concept of "feedback".

So, we can consider the management of the system as the implementation of *transitions* between its states. But what is the *condition*? This, by definition, is something *stable*, that is, it means that the parameters that characterize it take on some stationary, time-invariant values. However, each system is exposed to random (or deliberate) environmental influences. In this case, we expect that the system, being deduced from a *certain* (for example, *equilibrium or stationary*) state, has the ability to "spontaneously" return to *stationary* characteristics, that is, to the state in question.

But what if the system does not have this property? To answer this question, we ask a counter: how then can we talk about the "state"? Thus, we conclude that talking about the state for the system makes sense only if this state is *stable.* In other words, we expect that the state of the system should have some *stability boundaries*, that is, with a small change in its parameters (still remaining *inside* the stability boundary), the system will *remain* in the same state.

But there may be situations when such stability limits for the system are "too narrow" and we would very much like to *expand* them. Is it possible to do this, and if so, how?

In order to answer this question, you need to introduce the concept of "control action". In order to describe it, we will split the entire set of parameters characterizing the system into two classes. First class: parameters that we cannot influence. The second class is the parameters that we can – within certain limits – change. These are the parameters that we can change, and are called *control.*

Control parameters are the characteristics of the system that have two properties: firstly, they can be changed in the direction we need (for example, in magnitude and sign) by external influences relative to the system under study, and secondly, they determine the boundaries of stability system (in particular, the rate at which *other* characteristics of the system tend toward its stationary value, which characterizes a given *state of the system*). In general, the control parameters will be different for each state.

Note that we do not associate control parameters solely with the process of *returning* the system to this state. The definition is given in such a way that it also allows controlling the *transition* of the system to a new state. For example, this is possible when the boundaries of the stability of the system (in a given state!) Under the influence of external control are *narrowed* to a value when external random influences (factors) already lead the system beyond these boundaries.

As follows from the above note, we can, in the general case, divide all methods of controlling the system into two alternative classes.

- Management designed to ensure the *stability of the system in this state*. This is ensured by the so-called *negative feedback.*
- Management designed to ensure the *transfer of the system from one state to another*. This is achieved through *positive feedback.*

How is *feedback* generally organized?

Imagine a system. Let her *deviate* from her current state. We can judge this by changing the values of a number of parameters that characterize it. Now we are forced to make a decision – that is, to determine the goal of our management: whether to facilitate the *return* of the system to its original state (negative feedback – the adjective "negative" has not only literal meaning (we will see below!), But also emphasizes that we strive *reduce* the changes made by the environment), or vice versa, *increase* this deviation so that the system moves to a *new* state (positive feedback: again, the adjective “positive” has not only literal meaning, but also symbolic, emphasizing our desire to increase the deviations that occur in the system).

In fact, the *positive* and *negative* feedbacks thus form a *control loop*, which has a closed form due to the appearance of the possibility of dosing control actions and analysis of their results.

There are only two known – and complementary! – a way to manage people in social and economic structures: these are the methods of “carrot” and “stick”. In fact, they are often transformed into methods of *encouragement* and *punishment.* This is the implementation of the same positive or negative feedback. Encouragement corresponds to negative feedback that *captures* certain actions of the employee, that is, *encouraging* him to *continue* his current activities. Now we can say – encouragement *stimulates* his being in this state. Punishment is the opposite: encourages him to change his current state to another. By the way: now it’s also become clear to us that the reasons for the existence of *precisely these two* systems for controlling an individual are an optimal set that allows for the effective management of their activities and behavior. Using *only one* of these methods, therefore, means *inefficiency* in management. In an efficiently operating company, both methods of reward and methods of punishing employees must be clearly fixed. Of course, at the same time, rewards and punishments should relate *exclusively to that area*, the results of which depend on the personal activity of the employee, that is, they are determined by the *state in which the employee is located*. Misunderstanding of this circumstance – when an employee is punished or rewarded not for his *personal actions*, leads to inefficiency in managing economic systems.

We now turn to the mathematical form of the description of the above.

The linear case is the Malthus model.

Consider a system that is characterized by only one parameter x – such systems were called *single-component*. Let the state of the system be characterized by its value x_0. Due to external influences, the system changed and became characterized by the value of the parameter x_1. The simplest case of control is when we realized such conditions that the rate of change of the parameter is proportional to its deviation from its equilibrium (stationary) value x_0.

Mathematically, this can be written as follows:

$$\frac{dx}{dt} = \gamma(x - x_0) \text{ либо } \frac{d\Delta x}{dt} = \gamma\Delta x, \text{ где } \Delta x = x - x_0.$$

It is more convenient to write this equation immediately with respect to a change in a characteristic – that is, a change in a system parameter Δx.

In the equation γ this is the so-called control parameter, which also characterizes the system, and which we can change both in magnitude and sign – for example, make it either positive or negative – with the help of external (control) influences.

The solution to the equation is written as

$$\Delta x = (x_1 - x_0)e^{\gamma t} \text{ or } x = x_0 + (x_1 - x_0)exp(\gamma t).$$

Here x_1 is the value of the characteristic x (deviation from equilibrium) at $t = 0$, that is at the initial moment of time.

It can be seen from the solution that when $\gamma > 0$ the system will increasingly *move away* from its *equilibrium* state, characterized by value x_0. On the contrary, when $\gamma < 0$ the system will return to its *equilibrium* state. Thus, in the first case – when $\gamma > 0$ – there is a positive feedback, and when $\gamma > 0$ – a negative feedback.

The speed with which this removal/approximation will be carried out depends on the absolute value of the control parameter - from. The larger this value, the faster the system moves away / returns to an equilibrium state.$|\gamma|$

So, within the framework of this mathematical model, we get the opportunity to regulate – that is, control the system through:

1. Creating positive / negative feedback.
2. Changes in the *strength* of this feedback (modulus of the control parameter) $|\gamma|$.

An example of the considered equation describing the *real* socio-economic situation is the so-called *Malthus model* for the population. It is based on the “simple and natural” assumption: the increase in the number of people is proportional to their available number. In this case, the equation describing the *deviation* of the system from a certain *initial* number of people N_0 can be written as follows: $dN/dt = \gamma N$. Of course, here, in order to take place is an *increase* rather than a decrease in the population. The solution to this equation has the $N(t)=N_0\exp(\gamma t)$ – it is believed that at $t = 0$ the population became N_0. As can be seen from the solution, the population in this model is growing rapidly, – the period of *doubling* the population can be calculated by the formula $T = \ln 2/\gamma$: according to demographic statistics, this period of time today is 40 years. In the Malthus model, we obtained a population growth *exponentially*. At the same time, it is known that the resources that a country has (and the planet as a whole!) Increase in *arithmetic* progression. But then we come to the conclusion that, as time passes, population growth occurs *faster* than the growth of resources! In other words, the *relative* amount of resources – the amount of resources per person – will *decrease* over time. This, in fact, is the conclusion of the Malthusian theory. He made this conclusion at the beginning of the 19th century, and at the end of the 20th century, scientists who formed an informal organization called the Club of Rome came to the same conclusion. Of course, they came to him, using much more sophisticated theoretical and mathematical models. Actually, it is in such a simple model, which turned out to be surprisingly *little sensitive* to subsequent refinements, that are the reasons for the ever-increasing calls for birth control (that is, to reduce the control parameter γ). Of course, this will not solve the problem – but at least it will give time for decision-making. Perhaps to achieve that $\gamma = 0$ – at least on a global scale? However, as it is easy to see, this value is *unstable*: as soon as it becomes positive, the population begins to grow again, and as soon as it becomes negative, the population begins to decrease. Of course, this will not happen right away – but such a management organization already affects the *entire population of the Earth*, and therefore requires *completely new ways of managing and coordinating the entire planet*. It is *impossible* to do this today. So what to do ?! First of all, to *study* this problem, build new models, consider new possible scenarios.

Nonlinear Feedback – Verhulst Model.

The case was described above when the system *deviated* from its original position and rapidly moved away from it, within the framework of this model, arbitrarily far. However, we expect – in any case, models of systems are built precisely on the basis of this – that, sooner or later, our system will enter a *new* state. In other words, now we are faced with the problem of a mathematical description of the *transition* of a system from one state to another.

To build such a model, we ask ourselves: why is it even possible to “slow down” changes in the characteristics of the system? For example, this can be done as follows: as soon as the value of the characteristic of the system x begins to approach the *desired new* value of x_2, the value of the control parameter should decrease and reach zero at $x = x_2$.

In other words, to describe the control of *transferring* the system to a new state, we must consider the case when there are dependencies of the control parameter on the current characteristics of the system. As a rule, we obtain nonlinear differential equations.

For example, for our equation, its modification looks like this:

$$\frac{dx}{dt} = \gamma(x)x.$$

The simplest case is when $\gamma(x) = 1 - x$, and we get an equation called the Verhulst equation or the *logistic* equation (any linear dependence of the control parameter on the characteristics of the system can be reduced to this form by coordinate transformation)

$$\frac{dx}{dt} = (1 - x)x.$$

It is easy to see that this equation describes the *transition* of the system from the "unstable" state $x = 0$ to the *stable* state $x = 1$ – only positive x values are considered.

In the most general case, *deviations* from equilibrium – that is, from a *steady* state – are most often described within the framework of a *linear* approach. Even if *nonlinear* additives are considered, they are assumed, in a certain sense, to be "small" in comparison with linear terms. Therefore, we can conclude: for control by *negative* feedback, as a rule, a *linear* description is sufficient. Since linear methods in mathematics are well developed, it is therefore not surprising that the main successes in cybernetics (especially technical cybernetics) have been achieved precisely in the field of systems control in order to *maintain* their current state. At the same time, in the field of *economic* cybernetics, a huge set of tasks is completely opposite: it is necessary to control the *process of transferring* the system under study to the state that we need. Therefore, *nonlinear* mathematical models are the main object of study in economic cybernetics. The mathematical apparatus for their study is very complicated, for this reason there are not many results achieved. However, in the framework of technical cybernetics for nonlinear problems, results are also achieved, very few.

The solution of the Verhulst equation can be written as

$$x(t) = \frac{x_0 e^t}{1 + x_0 e^t}.$$

Here, we denote x_0 by the value of the system characteristic at the initial instant of time, at $t = 0$. It follows from the solution that when $t \to \infty,\ x(t) \to 1$.

The question arises: can we talk in this case about the presence of *feedback* in general? Maybe it would be more correct to talk about a system *model*? Much depends on what problem we solve, that is, on the *purpose* of our research. As a rule, the question of building a system model is nothing more than a *stage* in the preparation and selection of a management system for a given social or economic object. This idea will become more understandable when the Verhulst equation is written in *dimensional* form, that is, as it usually turns out in modeling:

$$\frac{dx}{dt} = ax - bx^2 = ax\left(1 - \frac{b}{a}x\right).$$

In this form of writing, the *control parameters* a and b are explicitly introduced, by changing which we can control both the final state of the system and the process of achieving it.

Interpretation and generalization of the Verhulst model: “catch quota” *as a model for optimal management*.

The Verhulst model appeared as the simplest generalization of the Malthus model to the presence of "natural restrictions" on fertility, leading to the death of individuals. This model often describes the reproduction of biological objects of various kinds – from bacteria to higher organisms – such as fish.

In connection with the latter, let us consider the *organization of a control system* for their abundance, taking into account catch, using the example of fish. Such a task reflects our natural desire to use a resource – in this case, fish – for our needs. At the same time, however, we want to *control the number of fish* in such a way as to achieve the maximum possible catch without the fish disappearing. Thus, we will consider the problem of the optimal use of the natural resource. In this case, the term *optimality* means that 1) fish should be caught as much as possible, but 2) the resource should not be depleted.

Since our intervention is external to the system, the Verhlust equation $\frac{dx}{dt} = (1 - x)x$ needs to be modified.

Consider the two simplest options for modification.

First of all, we can catch fish at a *constant speed* indicated β (the number of fish caught per unit time, for example, annually). In this case, the Verhlust equation takes the form

$$\frac{dx}{dt} = (1-x)x - \beta = -\left(x - \frac{1}{2}\right)^2 - \left(\frac{1}{4} - \beta\right).$$

From this equation it follows that when .$\beta > \frac{1}{4}$ the number of fish can only decrease, because in this case the derivative will always be negative. In other words, if we catch *annually* (as a natural time interval it is convenient to choose 1 year - the time of the reproductive cycle of fish) more than 25% of the *stationary* number of fish (that is, those that would be without a catch, in our notation their number is 1), then the fish resource will be depleted, that is, the number of fish will go to zero. When $0 > \beta < \frac{1}{4}$ – the fish resource is established at a certain level, which makes up some *part* of the maximum possible *x* = 1. At the same time, however, the *maximum catch quota* β= 1/4 is unstable (any arbitrarily small excess will lead to the disappearance of the system – fish), and therefore must be declared *inadmissible*.

Maybe try to organize fishing in a different way? For example, we will set the catch quota as a value proportional to the number of fish already available? Then we get the equation

$$\frac{dx}{dt} = (1-x)x - px = (1-p)x - x^2.$$

Here the *px* value sets the speed of fishing β. From the obtained equation, it is obvious that the inequalities 0 <*p* <1 hold. Under these conditions, the stationary number of fish is set at *x* = *B*, where *B* is found as a solution to the equation $(1-x)x = px$. The catch rate can then be calculated using the formula β = *pB*. We ask ourselves a question: when can this speed be *maximum*? The answer to this question is easiest to find from geometric considerations. Point *B* is located at the *intersection* of the quadratic parabola $(1-x)x$ graph and the straight line *px*. The highest catch rate β = *px* is equal to the largest ordinate of the function graph $(1-x)x$ and this is achieved at *x* = 1/2. In this case, the value of *p* = 1/2 (it is necessary that the value of *px* be equal to 1/4 – the maximum value of the function $(1 - x)x$, which is achieved at $x = 1/2$. And this is achieved, in turn, at $p = 1/2$.

Thus, for our task, the maximum fishing speed is set at $\beta = 1/4$, but now, as is easy to see from the last equation, a stable amount of fish is established.

So we gave an example of a situation where consideration of different scenarios of system management – in our case, these were different scenarios of fishing – allows us to achieve a *stable* transfer of the system to a new state. Of course, problems that are important for practice will most likely not have such a simple form – however, the *general methodology* for solving them will be the same: first, we select the appropriate *model of the system* and formulate a *basic* mathematical model for it. And then – we will explore different *control methods* that can be implemented within the framework of this model. Often, for this we have to clearly highlight the assumptions that were the basis of the basic model, and examine whether we can abandon them – and how the mathematical model of both the system and the management of this system will change.

We now turn to the consideration of more general models and problems.

5.2.3. The simplest task of production planning.

Let there be some economic object (enterprise, workshop, artel, etc.) that can produce some products of n types. In the production process, it is permissible to use m types of resources (raw materials). The technologies used are characterized by the norms of the costs of a unit of raw material per unit of a manufactured product. Denote by a_{ij} the amount of the i-th resource ($i = 1, ..., m$), which is spent on the production of a unit of the j-th product ($j = 1, ..., n$). Then all resource costs of the enterprise (object) under consideration for the manufacture of products can be represented in the form of a rectangular matrix A of dimension m by n:

$$A = \begin{bmatrix} a_{11}...a_{1j}...a_{1n} \\ a_{21}...a_{2j}...a_{2n} \\ a_{31}...a_{3j}...a_{3n} \\ .... \\ a_{m1}...a_{mj}...a_{mn} \end{bmatrix}.$$

Here is the column vector

$$a^j = \begin{bmatrix} a_{1j} \\ a_{2j} \\ a_{3j} \\ ... \\ a_{mj} \end{bmatrix}$$

matrix *A* represents all the resource costs in the production of the *j*-th product, and the row vector $a_i = (a_{i1}, a_{i2}, \dots, a_{in})$ of the matrix *A* represents the costs of the *i*-th resource for all manufactured products.

If the *j*-th product is produced in quantity x_j, then within the framework of the technologies described above, we must spend $a_{1j}x_j$ the first resource, $a_{2j}x_j$– the second, and so on, $a_{mj}x_j$-th. A *master production plan* for all products can be represented as an *n*-dimensional row vector $x = (x_1,\ x_2, \dots,\ x_n)$ (or column vector). Then the total costs of the *i*-th resource for the production of all products can be expressed as the sum $\sum_{j=1}^{n} a_{ij}x_j$ representing a scalar product *i*-th row vectors a_i matrix A and column vectors *x*. Obviously, every real production system has limitations on the resources that it spends in the production process. Within the framework of the presented model, these restrictions are generated by the *m*-dimensional row vector $b = (b_1,\ b_2,...,b_m)$ (or the column vector) where b_i is the maximum amount of the *i*-th resource that can be spent in the production process. In mathematical form, these constraints are represented as a system of *m* inequalities:

$$a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n \le b_1,$$
$$a_{21}x_1 + a_{22}x_2 + ... + a_n x_n \le b_2,$$
$$.. \quad (5.1)$$
$$a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n \le b_m.$$

Using the rules of matrix algebra, system (5.1) can be written in short form, representing the left side as the product of matrix A and column vector *x*, and the right side as column vector *b*:

$$A \cdot x = \begin{bmatrix} a_{11}...a_{1j}...a_{1n} \\ a_{21}...a_{2j}...a_{2n} \\ a_{31}...a_{3j}...a_{3n} \\ .... \\ a_{m1}...a_{mj}...a_{mn} \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ ... \\ x_n \end{bmatrix} \le \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ ... \\ b_m \end{bmatrix} = b . \quad (5.2)$$

Natural restrictions on the non-negativity of the components of the production plan should also be added to system (5.2): $x_1 \ge 0,\ x_2 \ge 0, ... ,\ x_n \ge 0$ or, which is the same,

$$x \ge 0. \quad (5.3)$$

Denoting by c_j the unit price of the *j*-th product, we obtain the expression of the total income from fulfilling the production plan specified by the vector *x*:

$$\sum_{j=1}^{n} c_j x_j = c \cdot x . \quad (5.4)$$

Here $c = (c_1,\ c_2, ... , c_n)$ is a vector, each coordinate of which is the unit cost of the corresponding manufactured product, and $c \cdot x$ is the scalar product of the vectors *c* and *x*.

Formulas (5.2) – (5.4) are nothing more than the simplest mathematical model that describes individual aspects of the functioning of an economic object whose behavior we want to control. In the framework of this model, generally speaking, it is possible to set various goals (tasks), but, most likely, the most “natural” goal will be to find a production plan $x \in R^n$ that gives the highest value of total income, that is, function (5.4), which is considered as an objective function and at the same time satisfies the constraint system (5.2) – (5.3). Briefly, such a task (optimization of the objective function) can be written in the following form:

$$f(x) = c \cdot x \to max, where\ x \in D = \{x \in R^n | A \cdot x \leq b, x \geq 0\}. \quad (5.5)$$

Despite the obvious convention of the situation under consideration and the apparent simplicity of the problem (5.5), its solution is far from trivial and in many ways became practically possible only after the development of a special mathematical apparatus. An essential advantage of the solution methods used here is their versatility, since very many economic and non-economic problems can be reduced to model (5.5).

5.2.4. Transport task.

Consider the problem of organizing the transportation of a product between its production points, the number of which is m, and n consumption points. Each *i*-th production point (i = 1,2,…,m) is characterized by a product stock $a_i \geq 0$ and each *j*-th point of consumption (j = 1,2, ..., p) – the need for a product $b_j \geq 0$. The road network connecting the system of the points under consideration is modeled using a matrix *C* of dimension *m* by *n*, the elements of which c_{ij} are the norms of the cost of transporting a unit of cargo from production point i to consumption point *j*. The cargo transportation plan in this transport network is presented in the form of an array of dimensional elements:$m \times n$

$$x = (x_{11}, \dots, x_{1n}, x_{21}, \dots, x_{2n}, \dots, x_{i1}, \dots, x_{in}, \dots, x_{m1}, \dots, x_{mn}). \quad (5.6)$$

In (5.6), the transportation plan x can be considered as a vector splitting into m groups, with n elements in each, and the *i*-th group corresponds to the volumes of cargo exported from the *i*-th production point to all possible consumption points. If there is no real carriage between points *i* and *j*, then it is assumed $x_{ij} = 0$.

Limitations on Possible Values $x \in R^{mn}$ have the form:

1. Restriction on the satisfaction of needs at all points of consumption:

$$\textstyle\sum_{i=1}^{m} x_{ij} \geq b_j, (j = 1,2, \dots, n). \quad (5.7)$$

2. Restrictions on the possibility of exporting stocks from all points of production:

$$\sum_{j=1}^{n} x_{ij} \leq a_i, (i = 1,2, \dots, m). \quad (5.8)$$

3. Conditions for the non-negativity of the components of the plan vector x:

$$x_{ij} \geq 0, (i = 1,2, \dots, m)(j = 1,2, \dots, n).$$

An essential characteristic of the described model is the ratio of parameters a_i and b_j. If the total volume of production is equal to the total volume of consumption, namely,

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j,$$

then the system is called *balanced*. Under the condition of balance, it is reasonable to impose such restrictions on the total import and export of goods, in which the whole cargo is completely exported and there are no unmet needs, i.e. conditions (5.7) and (5.8) take the form of equalities.

By analogy with the task of production planning, we assume that the cost of transportation is directly proportional to the amount of cargo carried. Then the total cost of transportation in the system will take the form:

$$f(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} \cdot x_{ij}. \quad (5.9)$$

The objective function (5.9) and the restrictions described above, written in the form

$$D = \left\{ x \in R^{m \cdot n} \middle| \sum_{i=1}^{m} x_{ij} = b_j, j = 1,2, \dots, n; \sum_{j=1}^{n} x_{ij} = a_i, i = 1,2, \dots, m; x_{ij} \geq 0 \right\}$$

set up a *balanced transport model*. On its basis, an optimization problem can be formulated to minimize the total cost of transportation:

$$f(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} \cdot x_{ij} \to min, x \in D, \quad (5.10)$$

which in the literature was called the *balanced transport problem in a matrix formulation.*

As we have already said, practically every mathematical modeling task is an optimization one, that is, it consists in choosing among a set of acceptable strategies those that can be qualified in one way or another as optimal for the value of the objective function that reflects the goal of controlling the system. All optimal decision making tasks can be classified. in accordance with the type of objective functions, the dimension and content of vectors and x, which display uncontrolled and controllable parameters, respectively. a

The simplest group of operations research tasks consists of those tasks in which there are no uncontrolled factors or there are only fixed uncontrolled factors, and the efficiency criterion (usually single criterion) is defined by a numerical function.

The section of applied mathematics devoted to the study of such problems is called *mathematical programming*, and the tasks themselves are called *mathematical programming problems*. In this case, the concept of programming is used in the sense of planning (as opposed to computer programming).

5.2.5. Modeling banking operations.

Any financial and credit transaction, investment project or commercial agreement presupposes the existence of a number of conditions for their implementation, with which the parties involved agree. Such conditions include the following quantitative data: monetary amounts, time parameters, interest rates and some other additional values. Each of these characteristics can be represented in a variety of ways. For example, payments can be one-time (one-time) or by installments, constant or time-varying. There are more than a dozen types of interest rates and interest calculation methods. The time is set in the form of fixed terms of payments, intervals of revenue, moments of debt repayment, etc. In the framework of one financial transaction, the listed indicators form some interconnected system (financial problem), subordinate to the corresponding logic. Due to the multiplicity of parameters of such a system, the final concrete results (except for elementary situations) are often not obvious. Moreover, a change in the value of even one quantity in the system to a greater or lesser extent, but will necessarily affect the results of the corresponding operation. It follows with obviousness that such systems can and should be the object of application of quantitative financial analysis - the object of mathematical modeling. Proven practice methods of such mathematical modeling and solving financial problems are the subject of financial mathematics. Due to the multiplicity of parameters of such a system, the final concrete results (except for elementary situations) are often not obvious. Moreover, a change in the value of even one quantity in the system to a greater or lesser extent, but will necessarily affect the results of the corresponding operation. It follows with obviousness that such systems can and should be the object of application of quantitative financial analysis - the object of mathematical modeling. Proven practice methods of such mathematical modeling and solving financial problems are the subject of financial mathematics. Due to the multiplicity of parameters of such a system, the final concrete results (except for elementary situations) are often not obvious. Moreover, a change in the value of even one quantity in the system to a greater or lesser extent, but will necessarily affect the results of the corresponding operation. It follows with obviousness that such systems can and should be the object of application of quantitative financial analysis - the object of mathematical modeling. Proven practice methods of such mathematical modeling and solving financial problems are the subject of financial mathematics. It follows with obviousness that such systems can and should be the object of application of quantitative financial analysis - the object of mathematical modeling. Proven practice methods of such mathematical modeling and solving financial problems are the subject of financial mathematics. It follows with obviousness that such systems can and should be the object of application of quantitative financial analysis - the object of mathematical modeling. Proven practice methods of such mathematical modeling and solving financial problems are the subject of financial mathematics.

Quantitative financial analysis is used both in conditions of certainty and uncertainty. In the first case, it is assumed that the data for constructing a mathematical model of a financial transaction are known and fixed in advance, for example, when issuing ordinary bonds, all parameters are clearly specified - term, coupon yield, and redemption order. The construction of a mathematical model of a financial transaction is noticeably more complicated when it is necessary to take into account uncertainty – the dynamics of the money market (interest rate level, exchange rate fluctuations, etc.), the behavior of the counterparty.

The main tasks of financial mathematics in constructing mathematical models of financial operations include:

- measurement of the final financial results of the operation (transaction, contract) for each of the parties involved;
- development of financial transaction plans, including debt repayment plans;
- measuring the dependence of the final results of an operation on its main parameters;
- determination of permissible critical values of these parameters and calculation of parameters of equivalent (break-even) changes in the initial conditions of the operation.

Of great importance in financial calculations, and, consequently, in mathematical models of banking operations is the time factor. In practical financial transactions, the amount of money, regardless of its purpose or origin, one way or another, but always, is associated with specific points in time or time periods. To do this, the contracts record the appropriate dates, dates, frequency of payments. The time factor, especially in long-term operations, plays no less, and sometimes even more, role than the amount of money. The need to take into account the time factor in mathematical modeling follows from the essence of financing, lending, and investing and is expressed in the principle of the *unequal value of money at different points in time*, or in another formulation – the *principle of changing the value of money over time*. So, you have all been convinced in your life experience that 1000 UAH received after 5 years are not equivalent to the same amount received today, even if inflation and the risk of not receiving them are not taken into account. In the presence of inflation, the influence of the time factor is greatly enhanced.

Methods for the quantitative analysis of financial transactions depend significantly on scientific and technological progress. Recently, many innovations are directly or indirectly related to the computerization of financial and banking activities. The possibilities of computerization and achievements in a number of areas of knowledge (system analysis, computer science, expert systems, linear and nonlinear programming, etc.) made it possible to significantly modernize both the technology of financial banking and the financial and mathematical apparatus used in quantitative financial analysis.

Knowledge of the methods used in financial mathematics is necessary when working directly in any field of finance and credit, including at the stage of developing contract terms. You can not do without them in financial design, as well as in the comparison and selection of long-term investment projects. Financial calculations (mathematical models) are a necessary component of calculations in long-term personal insurance, for example, designing and analyzing the state of pension funds (calculating tariffs, assessing the ability of funds to fulfill their obligations to pensioners, etc.), and long-term medical insurance.

As an example of mathematical modeling of banking operations, consider *honoring* – this is the reduction of the value of the monetary amount attributed to a future point in time to the value at the current moment in time. This is done, for example, when economic evaluation of investment performance accounting bills or at income approach to business valuation.

Discounting reflects the economic fact that the amount of money that we have at the moment has a greater real value than the equal amount that appears in the future. This is due to several reasons, for example:

- The amount available can make a profit, for example, being put on a deposit in a bank.
- The purchasing power of the available amount will decrease due to inflation.
- There is always the risk of not receiving the estimated amount.

The term “discounting” is also used in a broader sense - as a means of determining any value that relates to the future at an earlier point in time.

Depending on the type of interest rate, two methods of discounting are used – mathematical discounting and bank (commercial) accounting. In the first case, the accrual rate is applied, i.e., the effective interest rate, in the second – the discount rate.

Mathematical discounting.

Suppose that in the future at time $t > 0$ we will have to pay some amount $C(t)$. Let us determine what amount $C(0)$ should be located at present $t_0 = 0$ in order to pay the amount $C(t)$ if the effective interest rate for calculating interest per unit time is i and does not change over time.

The *effective interest rate i* refers to the relative amount of income for the considered period of time $(t, t+\Delta t)$ – the ratio of income (interest money) to the amount of debt: $i = \Delta C(t)/C(t)$. Based on the agreed effective interest rate i, the amount of income over the time interval Δt will be $\Delta C(t) = C(t) \cdot i$. In practice, it is customary to express the effective interest rate as a percentage: $i\% = i \cdot 100\%$. For example, $i\% = 22\%$, therefore, the effective interest rate $i = 0.22$. Effective interest rate is one of the most important elements of commercial, credit or investment contracts. It does not depend on the amount of the invested amount, but is determined by the efficiency with which invested money, bring profit (income) per invested monetary unit.

There are two schemes for calculating the income $\Delta C(t)$ on the combined interval $\Delta t = \Delta t_1 + \Delta t_2$ the simple and compound interest method:

1. The principle of *simple interest* assumes that the interest on the first Δt_1 and second Δt_2 time intervals are accrued only on the fixed capital $C(t)$, i.e. $\Delta C_1(t) = C(t) \cdot i_1$, $\Delta C_2(t) = C(t) \cdot i_2$. Therefore $\Delta C(t) = \Delta C_1(t) + \Delta C_2(t) = C(t) \cdot (i_1 + i_2)$. Accordingly, the final interest rate j for the time interval $\Delta t = \Delta t_1 + \Delta t_2$ will be $j = \Delta C(t)/C(t) = i_1 + i_2$.

If the sum $C(t)$ is invested not in two, but in n consecutive time intervals $\Delta t_1, \Delta t_2, \ldots, \Delta t_n$, with effective interest rates $i_1, i_2, \ldots, i_n$ respectively, then the capital $C(t)$ for the period of time $\Delta t = \Delta t_1 + \Delta t_2 + \ldots + \Delta t_n$ turns into the sum

$$C(t + \Delta t) = C(t) \cdot (1 + i_1 + i_2 + \ldots + i_n), \qquad (5.11)$$

and income (interest) on the time interval $\Delta t = \Delta t_1 + \Delta t_2 + \ldots + \Delta t_n$ will be

$$\Delta C(t) = C(t + \Delta t) - C(t) = C(t) \cdot (i_1 + i_2 + \ldots + i_n),$$

and the final interest rate $j = i_1 + i_2 + \ldots + i_n$.

Given equal interest rates $i_1 = i_2 =\ldots= i_n = i$ at all time intervals $\Delta t_1 = \Delta t_2 =\ldots= \Delta t_n = \Delta t_0$ of interest, the percentage $\Delta C(t)$ for the time interval $\Delta t = n\cdot\Delta t_0$ will be $\Delta C(t) = C(t)\cdot n\cdot i$, and the final interest rate is $j = n \cdot i$, where $n = t/\Delta t_0$ – is the number of interest accrued in time t at the rate of i intervals Δt_0.

2. The principle of *compound interest* assumes that interest on the second time interval Δt_2 is calculated not only on fixed capital $\Delta C(t)$ but also on already earned interest $\Delta C_1(t)$ on the first time interval Δt_1. Therefore, at the end of the second time interval Δt2, the fixed capital C (t) will increase to

$$C(t + \Delta t) = C(t) + C(t)\cdot i_1 + (C(t) + C(t)\cdot i_1)\cdot i_2 = C(t)\cdot(1 + i_1)\cdot(1 + i_2).$$

Accordingly, the final interest rate j for the time period $\Delta t = \Delta t_1 + \Delta t_2$ is determined from the condition

$$1 + j = (1 + i_1)\cdot(1 + i_2) \text{ i.e. } j = i_1 + i_2 + i_1 \cdot i_2 .$$

If the sum $C(t)$ is invested not in two, but in n consecutive time intervals $\Delta t_1, \Delta t_2,\ldots, \Delta t_n$, with effective interest rates $i_1, i_2,\ldots, i_n$ respectively, then the capital $C(t)$ for the period of time $\Delta t = \Delta t_1 + \Delta t_2 +\ldots+ \Delta t_n$ turns into the sum

$$C(t + \Delta t) = C(t)\cdot(1 + i_1)\cdot(1 + i_2)\cdot\ldots\cdot(1 + i_n), \qquad (5.12)$$

and interest money in the time interval $\Delta t = \Delta t_1 + \Delta t_2 +\ldots+ \Delta t_n$

$$\Delta C(t) = C(t +\Delta t) - C(t) = C(t)\cdot((1 + i_1)\cdot(1 + i_2)\cdot\ldots\cdot(1 + i_n) - 1),$$

and the final interest rate $j = (1 + i_1)\cdot(1 + i_2)\cdot\ldots\cdot(1 + i_n) - 1$.

Given equal interest rates $i_1= i_2=\ldots= i_n = i$ at all time intervals $\Delta t_1 = \Delta t_2 =\ldots= \Delta t_n = \Delta t_0$ of interest, the percentage $\Delta C(t)$ for the time interval $\Delta t = n\cdot\Delta t_0$ will be $\Delta C(t) = C(t)\cdot((1 + i)^n - 1)$, and the final interest rate $j = (1 + i)^n - 1$.

We will begin our consideration with discounting at a simple rate. Then from the accumulation formula for simple percentages $C(t) = C(0)\cdot(1 + t\cdot i)$ it follows that in order for t to be able to pay the sum $C(t)$ at the initial time $t_0 = 0$ it is necessary to have the sum $C(0) = C(t)\cdot(1 + t\cdot i)^{-1}$. The value of $r_n(t,i) = (1 + t\cdot i)^{-1}$ is called the *discount* or *discount factor* at the rate of increase of simple interest.

Now we turn to the consideration when interest accrual during mathematical discounting occurs at a complex interest rate i, which does not change over time. In this case, in order to have exactly the sum $C(t)$ at the moment t at the moment $t_0 = 0$ you need to have the sum $C(0) = C(t)\cdot(1 + i)^{-t}$, since after investing at time t the sum $C(0)$ will turn into the sum $C(0)\cdot(1+ i)^t = C(t)$. The quantity $r_c(t,i) = (1 + i)^{-t} = \upsilon^t$ is called the *discount* or *discount factor* at the compound interest rate. The value $\upsilon = (1 + i)^{-1}$ is called the *discount coefficient* (*accounting*) for compound interest. With its help, the formula for the reduced (modern) value of $C(0)$ for compound interest can be written in the form $C(0) = C(t)\cdot\upsilon^t$. The value of υ can also be expressed in terms of the percentage intensity: $\delta = \ln(1+i)$: $\upsilon = (1 + i)^{-1} = \exp(-\delta)$. Discount factor $r_c(t,i) = (1 + i)^{-t}$ at the effective interest rate shows how much the initial amount $C(0)$ of the sum $C(0)$ is in the final amount $C(0)$.

As already mentioned, the difference $\Delta C(t) = C(t) - C(0)$ can be considered not only as interest accrued on $C(0)$ for time t, but also as a discount from the sum $C(t)$. Using the discount factor $r(t,i)$ the discount $\Delta C(t) = C(t) - C(0) = C(t)\cdot(1 - r(t,i))$. Accordingly, for simple percentages, $\Delta C(t) = C(t)\cdot(1 - (1 + t\cdot i)^{-1}) = \frac{C(t)\cdot t\cdot i}{(1+t\cdot i)}$, for complex percentages – $\Delta C(t) = C(t)\cdot(1 -(1 + i)^{-t}) = C(t)\cdot(1 - \upsilon^t)$.

The sums of money $C(t)$ at time t and C $C(0)$ at time $t_0 = 0$ are called *equivalent at the comparison rate i*, and the formula for comparing money amounts $C(t_0) = C(t)\cdot r(t,i)$ (or $C(t) = C(t_0)\cdot M(t,i)$) at any time t and t_0 is called *mathematical discounting at a discrete interest rate*.

In the case when the interest rate i continuously changes over time and to increase at compound interest it is necessary to apply a continuous interest rate $\delta = \delta(t)$ then the discount factor $r(t,\delta) = exp\left(-\int_{t_0}^{t}\delta(z)dz\right)$. This operation is the inverse of continuous accumulation is called *continuous mathematical discounting at intensive interest*, and $r(t,\delta)$ is called *the discount factor at a continuous interest rate.*

Bank discounting at the discount rate.

We formulate one of the tasks of bank discounting at an effective discount rate. Suppose that at time $t_0 = 0$ we take a loan (credit) from the bank in the amount of $C(0)$. Then at the moment $t = 1$ (for example, in a year) we must return to the bank the amount, $C(1) = C(0)\cdot(1 + i)$, which consists of two parts: return of the fixed capital $C(0)$ and interest on capital $\Delta C(1) = C(0)\cdot i$ with the effective interest rate i for this period.

In principle, the bank may require us to pay the interest $P(1) = \Delta C(1) = C(1) – C(0) = C(0)\cdot i$ at time $t = 1$, we paid in advance at the time $t_0 = 0$ receiving a loan. This financial transaction is called *interest retention*. In this case, the percentage amount $P(1) = C(0)\cdot I$ which should be paid to the bank at time $t = 1$, must be brought to the moment $t_0 = 0$ and the sum will be $P(0) = C(0)\cdot i\cdot(1 + i)^{-1}$. Therefore, if interest on capital must be paid in advance, at the time $t_0 = 0$ of the loan, then these interest paid in advance, make up the share $d = i/(1 + i)$ of the loan amount $C(0)$, i.e. $P(0) = C(0)\cdot d$. The value of d is called the *effective discount rate* per unit of time. It shows how much of the withheld interest is the percentage of the loan amount issued per unit of time and is usually set as a percentage: : $d\% = P(0)/C(0)\cdot 100\%$. Now, after we paid in advance to the bank the interest due to it in the amount of $P(0) = C(0)\cdot d$ at the time of receiving the loan, then after the loan expires one year, we will return to the bank only the amount of the loan $C(0)$.

The effective discount rate d also allows you to calculate the interest $P(1) = \Delta C(1) = C(1) – C(0)$ at the time $t = 1$ i.e., the discount from the sum $C(1)$ at the time $t_0 = 0$: $\Delta C(1) = C(1)\cdot d = C(0)\cdot i$, as well as the loan amount $C(0) = C(1) – \Delta C(1) = C(1)\cdot(1 – d)$ according to the known amount $C(1)$ of repayment of the loan at time $t = 1$.

The effective discount rate d can also be expressed in terms of the discount coefficient $\upsilon = (1 + i)^{-1} = \exp(-\delta)$:

$$d = 1 - (1 + i)^{-1} = 1 - e^{-\delta}.$$

Suppose now that the amount $C(0)$ is given by the bank for a period of $1/p$ with advance payment of interest. In this case, the effective interest rate per unit of time is j, and the effective interest rate for the period $i^{(p)} = j_p^*/p$, where j_p^* – is the nominal interest rate per unit of time. As was previously established for the calculation of simple interest, the effective and nominal interest rates coincide, i.e., $j_p^* = j$ and $i_{п}^{(p)} = j/p$. Therefore, the sum $P(1/p) = \Delta C(1/p) = C(1/p) – C(0)$ which must be paid at the moment

$t = 1/p$ as a percentage, is calculated by the formula $P(1/p) = C(0)\cdot j/p$. If we bring it to the moment $t_0 = 0$ then it will turn into the sum $P(0) = C(0)\cdot(j/p)\cdot(1 + j/p)^{-1} = C(0)\cdot j/(p + j)$. Hence, the effective discount rate for $1/p$ when calculating simple interest is $j/(p + j)$: $d_{\text{п}}^{(p)} = j/(p + j)$.

$$d_{\text{п}}^{(p)} = \frac{j}{p+j} = \frac{\frac{d}{1-d}}{p+\frac{d}{1-d}} = \frac{d}{p(1-d)+d} = \frac{d}{p-(p-1)d}. \qquad (5.13)$$

In the case of accrual of compound interest and if the effective interest rate per unit of time is j and the nominal interest rate per unit of time is equal j_p^*, then the effective interest rate for the period $1/p$ is $i_{\text{c}}^{(p)} = j_p^*/p = (1 + j)^{1/p} - 1$. Therefore, in the case of compound interest, the amount of P $P(1/p)$ which must be paid at time $t = 1/p$ in the form of interest, is calculated by the formula $P(1/p) = C(0)\cdot[(1 + j)^{1/p} - 1]$. If we bring it to the moment $t_0 = 0$ then it will turn into the sum $P(0) = C(0)\cdot i_{\text{c}}^{(p)}\cdot(1 + j)^{-1|p} = C(0)\cdot(1 - (1 + j)^{-1/p})$. Hence, the effective discount rate $d_{\text{c}}^{(p)}$ for the time $1/p$ when calculating compound interest is $1 - (1 + j)^{-1/p}$: $d_{\text{c}}^{(p)} = 1 - (1 + j)^{-1|p}$. Now, taking into account the fact that $j = d/(1 - d)$, then for the effective discount rate $d_{\text{c}}^{(p)}$ for the time $1/p$ we get the formula

$$d_{\text{c}}^{(p)} = 1 - (1 + j)^{-1/p} = 1 - (1 + d/(1 - d))^{-1/p} = 1 - (1 - d)^{1/p}. \qquad (5.14).$$

However, in financial mathematics, it is customary to work not with effective (i.e., real) *discount rates* $d^{(p)}$ for $1/p$ time, but with so-called *nominal* (i.e., conditional, not really existing) discount rates, which are assigned, like d, to one time. Then, taking into account formulas (5.13) and (5.14) for simple and compound interest, respectively, we have

$$d_n^{*(p)} = p \cdot d_p = p \cdot \frac{d}{p-(p-1)d}; \qquad (5.15)$$

$$d_{\text{c}}^{*(p)} = p \cdot d_p = p \cdot \left(1 - (1-d)^{\frac{1}{\text{p}}}\right). \qquad (5.16)$$

The discount rate $d^{*(p)}$ per unit of time is called the *nominal discount rate accrued with frequency* p.

The nominal discount rate $d^{*(p)}$ per unit of time for both simple (5.15) and complex (5.16) percent is always greater than the real effective discount rate d per unit of time. Consider this with a specific example. Let the annual effective interest rate $j = 0{,}25$ ($j\% = 25\%$) and interest accrue on a quarterly basis, that is, $p = 4$. Moreover, the annual effective interest rate $d = j/(1 + j) = 0{,}2$ and effective discount rates for a period of $1/p$ for simple interest according to (5.13) $d_{\text{п}}^{(p)} = \frac{d}{p-(p-1)d} = \frac{0{,}2}{4-(4-1)0{,}2} \approx 0{,}0588$, for compound interest according to (5.14) $d_{\text{c}}^{(p)} = 1 - (1 - d)^{1|p} \approx 0{,}05426$. In this case, the annual nominal discount rate obtained from (5.15) $d_{\text{п}}^{*(p)} = 4 \cdot 0{,}0588 = 0{,}2352$ and from (5.16) $d_{\text{c}}^{*(p)} = 4 \cdot 0{,}05426 = 0{,}217$.

Now consider a situation where bank discounting does not occur per unit of time either at the effective discount rate d or at nominal discount rates $d_{\text{п}}^{*(p)}$ and $d_{\text{c}}^{*(p)}$ given per unit of time, but at n unit time intervals. In this case, in addition to the effective discount rate d, nominal discount rates $d_{\text{п}}^{*(p)}$ and $d_{\text{c}}^{*(p)}$for discounting, simple and complex discount rates are also applied. If simple interest is accrued, discounting is made at a *simple discount rate* $d_{\text{п}}$. If compound interest is accrued, then – at a *complex discount rate* d_{c}. In addition, when using these discount rates, you must also consider how many times per unit time discounting is performed. Consider the use of simple and complex discount rates in the following example. Suppose the holder of the bill, according to which, upon expiration of the period t, the bills must be paid the amount $C(t)$ sells it at the time $t_0 = 0$, for example, to the bank, n units of time earlier than the maturity of the bill, i.e. $t - t_0 = t = n$. Naturally, the bank will purchase it from the owner at a price $C(0)$ which is less than the amount $C(t) = C(n)$, indicated on the bill, that is, buys (takes into account) it at a discount. The discount size $\Delta C(0) = C(n) - C(0)$, or the accounting amount, is calculated on the amount $C(n)$ payable at the end of the term n bills of exchange at the time the bill is taken into account at the bank $t_0 = 0$.

1. Discounting is carried out at a simple discount rate $d_{\text{п}}$ charged once per unit time for n unit time intervals. In this case, discounting n times at a simple discount rate $d_{\text{п}}$, is made all the time from the sum of $C(n)$ and, therefore, the discount size $\Delta C(n)$, or the accounting amount, is $C(n) \cdot n \cdot d_{\text{п}}$: $\Delta C(n) = C(n) \cdot n \cdot d_{\text{п}}$ where

n is the period from the moment of accounting to the maturity date of the bill. In this way,

$$C(0) = C(n) – \Delta C(n) = C(n) – C(n) \cdot n \cdot d_п = C(n) \cdot(1 – n \cdot d_п). \quad (5.17)$$

Here $(1 – n \cdot d_п)$ is the discount factor $r(n,d_п)$ at a simple discount rate: $d_п$: $r(n,d_п) = (1 – n \cdot d_п)$. It follows from formula (5.17) that for $n > 1/d_п$ the value of the discount factor at a simple discount rate $r(n,d_п)$ and, therefore, the sum $C(0)$ will become negative. In other words, with a relatively long term of the bill, accounting for it can lead to zero or even negative amount $C(0)$ which makes no sense. For example, at $d_п\% = 20\%$ a five-year period is already sufficient for the holder of the bill to receive nothing when it is taken into account. This situation does not occur when discounting n times at the effective discount rate d, calculated once per unit time. Indeed, the discount size $\Delta C(n) = C(n) – C(0)$ in this calculation option is determined by the formula $\Delta C(n) = C(n)\frac{ni}{1+ni} = C(n)\frac{nd}{1+(n-1)d}$ and when $n \to \infty$ we get that $\Delta C(n) \to C(n)$. Here $i = \frac{d}{1-d}$ – is the effective interest rate per unit of time, and a simple discount rate $d_п = \frac{i}{1+ni} = \frac{d}{1+(n-1)d}$.

A simple discount rate $d_п$ is sometimes applied when calculating the accumulated amount $C(n)$. In particular, this necessitates the determination of the amount $C(n)$ which must be affixed to the bill if the current debt amount $C(0)$ is specified, or otherwise the present value of the bill $C(0)$. The accumulated sum $C(n)$ in this case is determined from formula (5.17): $C(n) = C(0) \cdot (1 - n \cdot d_п)^{-1}$. The accumulation factor $M_n(n, d_п)$ at a simple discount rate is equal here $(1 - n \cdot d_п)^{-1}$.

Note that at $n \to 1/d_п$ the accumulated sum becomes an infinitely large number, and for $n > 1/d_п$ the calculation is meaningless, since the accumulated sum becomes a negative number. This situation does not occur when discounting n times at the effective discount rate d, calculated once per unit time: for any term n, the accumulated sum $C(n)$ is greater than zero. Indeed, the accumulation factor $M_n(n, d)$ in this calculation option is determined by the formula $M_n(n, d) = 1 + n \cdot i = \frac{1+(n-1)d}{1-d}$ and for d

< 1 for any n >1, $M_n(n, d) > 0$ and, therefore, the accumulated sum $C(n)$ is always greater than zero. Here $i = \frac{d}{1-d}$ – is the effective interest rate per unit of time.

2. Discounting takes place at a complex discount rate d_c, which is charged once per unit of time. In this case, discounting at n unit time intervals is as follows. Each time, the discount rate d_c is applied not to the initial amount $C(n)$ which is discounted (as at a simple discount rate), but to the amount discounted at the previous time step. Therefore, discounting at a complex discount rate d_c is carried out according to the formula

$$C(0) = C(n)\cdot(1 - d_c)^n. \quad (5.18)$$

It follows from formula (5.18) that the discount factor $r(n,d_c)$ at a complex discount rate d_c is $(1 - d_c)^n$. The size of the discount is ΔC (n) = $\Delta C(n) = C(n) - C(0) = C(n)\cdot(1 - (1 - d_c)^n)$. The buildup factor $M_c(n, d_c) = (1 - d_c)^{-n}$.

Here is an example of using complex and simple discount rates. A debt in the amount of UAH 5 million, which is due in 5 years, is sold at a discount at a complex discount rate of 15% per annum. What is the amount received for the debt of the amount $C(0)$ and the value of the discount $\Delta C(n)$ (in thousand UAH)?

When using a complex discount rate, we have: $C(0) = C(n)\cdot(1 - d_c)^n = 5000\cdot(1 - 0,15)^5 = 2218,5$ thousand UAH; $\Delta C(n) = C(n) - C(0) = 5000 - 2218,5 = 2781,5$ thousand UAH.

If you apply a simple discount rate of the same size, then: $C(0) = 5000\cdot(1 - 5\cdot0,15) = 1250$ thousand UAH .; $\Delta C(n) = 5000 - 1250 = 3750$ thousand UAH.

As follows from the above example, discounting at a complex discount rate is more beneficial for the debtor than at a simple discount rate. The above becomes clear when comparing the formulas for discount factors: $r(n,d_п) = (1 - n\cdot d_п)$ и $r(n,d_c) = (1 - d_c)^n$. According to the first of the above formulas, the value of the discount factor $r(n,d_п)$ uniformly decreases as n grows and reaches zero at $n \to \infty$. The values of the discount factors $r(n,d_п)$ and $r(n,d_c)$ when applying simple $d_п$ and complex d_c discount rates, respectively, are shown in Fig. 7.

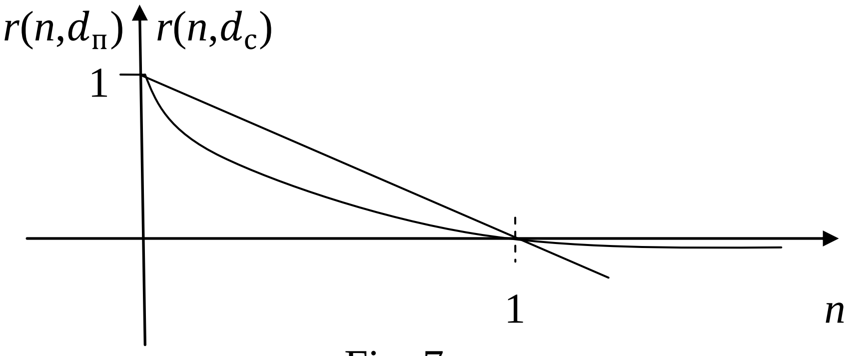


Fig. 7

2. Discounting is made not once, but m times per unit time for n unit time intervals, i.e. each time at a time interval of $1/m$ accounting is done at the discount rate $d^{(m)} = \frac{d^{*(m)}}{m}$, where $d^{*(m)}$ – is the nominal discount rate per unit of time, charged at a frequency m. In this case, for a simple discount rate $d_{п}^{(m)}$ charged at a frequency m when calculating it once, we obtain

$$C(0) = C(n) \cdot \left(1 - n \cdot m \cdot \frac{d_{п}^{*(m)}}{m}\right) = C(n) \cdot \left(1 - n \cdot d_{п}^{*(m)}\right).$$

Here $d_{п}^{*(m)}$ is the nominal discount rate per unit of time, calculated at a frequency m at a simple discount rate $d_{п}^{(m)}$ for a time period of $1/m$.

Hence, for the discount factor at a simple discount rate, we get $r_{п}(n, d_{п}^{*(m)}) = \left(1 - n \cdot d_{п}^{*(m)}\right)$, and for the accumulation multiplier, $M_{n}(n, d_{п}^{*(m)}) = \left(1 - n \cdot d_{п}^{*(m)}\right)^{-1}$.

For a complex discount rate $d_{с}^{(m)}$ when calculating it $n \cdot m$ times we get

$$C(0) = C(n) \cdot \left(1 - \frac{d_{с}^{*(m)}}{m}\right)^{mn}.$$

Hence, for the discount factor at a complex discount rate, we get $r_c(n, d_c^{*(m)}) = \left(1 - \frac{d_c^{*(m)}}{m}\right)^{mn}$ and for the accumulation factor, $M_c(n, d_c^{*(m)}) = \left(1 - \frac{d_c^{*(m)}}{m}\right)^{-mn}$.

If an effective discount rate d is given per unit of time, then nominal discount rates $d_П^{*(m)}$ and $d_c^{*(m)}$ per unit of time can be determined from formulas (5.15) and (5.16) provided that $p = m$. From these formulas it follows that for a simple discount rate

$$d_П^{*(m)} = m \cdot \frac{d}{m-(m-1)d},$$

and for a complex discount rate

$$d_c^{*(m)} = m \cdot \left(1 - \sqrt[m]{1-d}\right).$$

CHECK-UP QUESTIONS TO TOPICS

TOPIC 1. BASES OF THEORY OF SYSTEMS

1. What is the discipline of "theory of systems" and what is its object of study?
2. Explain the content of the scientific concept in the term “system” and describe its properties.
3. What are the main functions of the system, what is meant by the purpose of the system and the criterion of purpose, and what conditions should the purpose of the system satisfy?
4. What is meant by the external environment and resources in the theory of systems, and what is their role in the functioning of the system?
5. Explain the scientific concept of “system structure” from the point of view of systems theory.
6. Explain the concept of “system status” and describe the main types of system behavior.
7. What is meant by the relationship and interconnection between the elements of the system?
8. Structural representations of systems as a means of their research.
9. What are recursive, synergistic, and cyclic relationships?
10. What is feedback and its purpose?
11. What is the basic principle of functioning of complex self-regulating, self-organizing systems?
12. On what grounds, and on what types of systems are classified in system theory?
13. Formulate the three main conceptual questions of system theory.
14. List the control questions on which you can determine whether the system meets all the requirements from the point of view of system theory.
15. What are the basic principles for describing systems?
16. What key points should be reflected in the description of the system?
17. What is the problem when moving from a verbal description of a system to a formal description?
18. What does formalization of the system mean, and what are its main stages?

19. Purpose and synthesis of the formal scheme of the structure of the system.
20. What should be guided by when choosing the parameters for describing the system and its elements?

TOPIC 2. BASES OF SYSTEM ANALYSIS

21. Explain the content of the scientific concept in the term "system analysis" and reveal the meaning of the main tasks of system analysis.
22. What is a "systematic approach" in the acquisition of knowledge, and what are the main points in the system analysis?
23. List the basic principles of a systems approach.
24. What actions does the implementation of a systematic approach include?
25. What is the main significance of system analysis and where can and should it be applied?
26. Expand the content of the main approaches used in system analysis.
27. What is the specificity of the mathematical and logical approaches in system analysis?
28. What criteria should correspond to the model in system analysis and the principles of their classification?
29. What is the purpose of modeling in system analysis, and what points should you pay attention to when modeling?
30. What is a mathematical model and its purpose?
31. Explain the content of the scientific concept in the term "target function of the system" and its purpose.
32. What is the difference between analytical and simulation mathematical models?
33. What is the difference between a deterministic and a stochastic mathematical model?
34. What is the methodology of logical system analysis and its scope?
35. What is a systematic understanding of the goal, and what rules should be followed when building the "goal tree"?
36. What is understood by a problem and what is the method of formulating and formulating a problem in system analysis?
37. List the types of problems for the solution that apply system analysis, and give a description of its effectiveness for each problem.
38. What is a solution of a problem in system analysis?
39. What is the problem of comparing systems?

40. What are the two sides of the quantitative representation of systems that are most used in comparing them, and give them a characteristic.
41. How is the performance of a system evaluated to achieve a goal that can be expressed by a single criterion?
42. What is the problem of scalarization of criteria and describe the basic principles for its solution?

TOPIC 3. CONTROL SYSTEMS

43. What is meant by a control system and what are its main tasks?
44. What is meant by a control system, and what are its main functions?
45. What is meant by the analysis of control systems, and what are its goals?
46. List the main tasks of the analysis of the control system.
47. What is the content of solutions to the following tasks of the analysis of control systems: determination of the object of analysis; system structuring?
48. What is the content of the solutions to the following problems of analysis of control systems: determination of the functional features of the system; study of the information characteristics of the system
49. What is the content of the solution to the following problem of analysis of control systems: determination of quantitative and qualitative indicators of the system?
50. What is the content of the solutions to the following tasks of the analysis of control systems: performance evaluation; generalization and presentation of analysis results?
51. What is meant by the synthesis of control systems, what are its goals and for what cases are they implemented?
52. What is the essence of structural synthesis and what are its main components?
53. List the main tasks of synthesis of a control system.
54. What is the content of solutions to the following problems of synthesis of control systems: the formation of the purpose and purpose of creating a control system; forming options for a new system?
55. What is the procedure for constructing a conceptual model of a variant of a new management system?

56. What is the content of the solutions to the following problems of synthesis of control systems: bringing the descriptions of system variants into mutual correspondence; assessing the effectiveness of options and deciding on the choice of a new system option?
57. What is the content of the solutions to the following problem of synthesis of control systems: development of requirements and programs for their implementation to the management system?
58. What is the essence and purpose of the structural analysis and synthesis of the control system, what are their stages and content?
59. What is the essence and purpose of functional analysis and synthesis of the control system, what are their stages and content?
60. What is the essence and purpose of information analysis and synthesis of a control system, what are their stages and content?
61. What is the essence and purpose of parametric analysis and synthesis of the control system, what are their stages and content?

TOPIC 4. ECONOMIC SYSTEMS

62. Define the economic system and describe its basic properties.
63. What are the characteristics of the classification of economic systems, and what types of economic systems are divided according to these characteristics?
64. What principles are based on traditional, command and market economies?
65. What is a mixed economic system, what are its main tasks and models?
66. What economic system is called transitional and what are its features?
67. Describe the following mixed economy models: neo-statist, neoliberal.
68. Describe the following mixed economy models: concerted action model eclectic.
69. Give the rationale for applying a systems approach in the economy.
70. List the most common types of situations for managing economic entities in which system analysis is possible.
71. What procedures does the system analysis of economic systems provide?
72. What are the specifics of analysis and synthesis of an economic object as a goal-oriented system?

73. How is the morphological description of the economic system carried out?
74. What studies suggest the following levels of analysis and synthesis of economic systems: external, initial, system-wide, systemic?
75. What is the specificity of building a “goal tree” for the economic system?
76. What are the informational aspects of a systems analysis of economic systems?
77. What goals for economic systems are of paramount importance at the present stage of economic relations?
78. Give an example of a balanced scorecard that allows you to control the tactical state and strategic development of the business.
79. What is the structure and systemic purpose of the main information flows in economic systems?
80. What are the levels of production management and what are the names of information flows corresponding to these levels?
81. On what grounds, depending on the type of information support, distinguish the process of development and adoption of optimal management decisions by production?
82. Formulate the main problems arising in the management of production related to information support.
83. Formulate the main information problems of production management related to the use of various information technologies?
84. Imagine the economic object - the enterprise as a system and give it a characteristic.
85. An economic object is a system, its characteristics, and what is the concept of managing it.
86. List and explain the main tasks of managing economic systems.
87. Describe the structure of the management system of economic systems and explain its elements.
88. Describe the structure of the economic object management system - the enterprise.
89. List and explain the main tasks of managing economic systems.
90. What is understood by the problem and its solution for the economic system?
91. What is the concept of feedback in economic systems.
92. How is enterprise feedback organized?

93. What is a systematic approach for analyzing an economic object?

TOPIC 5. MATHEMATICAL MODELING OF ECONOMIC SYSTEMS

94. Describe the role of modeling for economic systems.
95. What is the essence of mathematical modeling of economic systems?
96. Describe the scheme of operational research of economic systems.
97. What is the objective function of the mathematical model of the economic system?
98. Describe the structure of the static mathematical model of the economic system for the optimization problem.
99. Define a black box. Give examples of economic systems that use this modeling method.
100. Describe examples of the use of the concept of "input-output" in the modeling of economic systems. In particular, is this concept used in microeconomics? Argument the answer.
101. Give a definition of the operator and the conditions under which a black box can perform the functions of an operator. Is a black box always an operator? Argument the answer and give examples.
102. What is a “linear operator”? Under what conditions can a black box be considered as a linear operator? Give examples.
103. What is a random process? Give your own definition for this concept.
104. Give examples of economic systems where random processes appear or are used.
105. Formulate your own definition of control parameters. Give examples of control parameters for economic systems.
106. What is the positive and negative feedback? Formulate your own definition of these concepts. Give examples of these relationships for economic systems.
107. Give examples of economic problems where it is necessary with the help of management to ensure the stability of the economic system. Describe how you would achieve your goal.
108. Give examples of economic problems where it is necessary with the help of management to ensure the transfer of the economic system to a new state. Describe how you would achieve your goal.

109. Give examples of economic systems (objects, processes, etc.) for which the linear feedback model is valid (Malthus model). How do you propose, within the framework of the examples given by you, to control the parameter?γ
110. Give examples of economic systems (objects, processes, etc.) for which non-linear feedback will be valid (Verhulst model). Describe how you propose a change in control parameters.
111. Describe the mathematical model of the production planning problem.
112. Describe the mathematical model of the transportation problem.
113. What is the essence of mathematical modeling of financial operations?
114. What financial transactions are known to you for which mathematical modeling is a necessary component of calculations.
115. Formulate one of the problems of mathematical discounting and write down the mathematical model of this problem.
116. Formulate one of the problems of bank discounting at the discount rate and write down the mathematical model of this problem.
117. Write down the mathematical model of bank accounting for a bill of exchange at any time in the interval from its acquisition and repayment.

LITERATURE

1. Spitsnadel V. N. Fundamentals of system analysis: Textbook. allowance.// SPb .: “Publishing house. Business Press House, 2000 - 326 p.
2. Butorin V.K. Introduction to systems analysis. Lecture course. // 2nd edition, revised and supplemented / Novokuznetsk: NFI KemSU. - 2005. - 72 p.
3. Krichevsky A.I. Basics of system analysis: Lecture course. // Novosibirsk State University of Economics and Management, 2009 - 136 p.
4. *Plunkett L., Hale G.* Development and adoption of managerial decisions // M .: Economics. - 2002.- 300 p.
5. Kachala V.V. Fundamentals of systems theory and systems analysis. Textbook for universities.// M .: Hot line - Telecom, 2007.216 s.
6. Chernyak Yu.I. Analysis and synthesis of systems in the economy.// M .: Economics, 1970 .-- 151 p.
7. V.N. Volkova, A.A. Denisov. Fundamentals of systems theory and systems analysis: Textbook.// Ed. 3rd revised and supplemented. SPb: Publishing house of SPbSTU, 2003. - 512s.
8. Bertalanfi L. General theory of systems - a critical review // Research on the general theory of systems. - M .: Progress, 1969.S. 23-82.
9. Peregudov F.I., Tarasenko F.P. Introduction to systems analysis. // M .: Higher school, 1989 .-- 367s.
10. A.R. Diyazitdinova, I.B. Cordon. General theory of systems and systems analysis. Textbook // Samara: PSUTI, 2017. – 125s.
11. Chernyshov, V.N.,A.V. Chernyshov. Theory of systems and systems analysis: a training manual // Tambov: Publishing house of Tamb. state tech. University, 2008 .-- 96 s.
12. Chernyak Yu.I. System analysis in economic management.// M .: Economics, 1975 .-- 191 p.
13. Mukhin V.I., Malinin V.S. Management Systems Research: A Textbook for High Schools. // M: Publishing house "Exam", 2003. - 384 p.
14. *Milner B.Z., Evenko L.I., Rapoport V.S.*A systematic approach to the organization of management // M .: Economics. - 1983.-355 p.
15. *Buslenko N.P.* Modeling of complex systems // M .: Nauka, 1978.-400s.