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CHAPTER 2

MANAGEMENT OF TRANSPORT SYSTEMS AND PROCESSES BASED ON A UNIFIED THEORY OF SELF-ORGANIZING SYSTEMS

ABSTRACT

A comprehensive analysis of processes and control systems in railway transport is presented with an emphasis on their synthesis, modeling and optimization.

Modern approaches to the synthesis, modeling and optimization of processes and control systems in railway transport are revealed. The central place is occupied by the Unified Theory of Self-Organizing Systems, which is used as a methodological basis for the study of complex technical and organizational objects in interaction with the environment. Based on this concept, the Method for Detecting Hidden Statistical Patterns (MDHSP) is proposed, aimed at finding "bottlenecks" in the functioning of transport systems and processes.

The key categories of management are considered – norm, tolerance, system approach, cause-and-effect relationships, which determine new principles for assessing and predicting the state of transport systems. Special attention is paid to the practical application of MDHSP in the field of train safety management, technical condition of infrastructure and organization of the transportation process. It is shown that the use of negative statistics (accidents, failures, failures) as a basis for analysis allows to identify the underlying prerequisites of problems and to form preventive and strategic management solutions.

KEYWORDS

Processes and control systems, modeling systems, railway transport, transport technologies, transport process management, tolerance, statistical regularity, norm of behavior of the system "bottleneck".

CHAPTER 2

The concept of a unified theory of self-organizing systems (UTSS) was to generalize the achievements of the problem of self-organization in various fields of knowledge and to solve gaps, that is, "unresolved issues". The concept of self-organization has been known for quite some time. The peculiarities of studying this concept are that self-organization has become the subject of consideration of many sciences: biology, physiology, physics, systems theory, cybernetics, etc. This led to terminological confusion: the same concepts were defined differently, and vice versa – different concepts were sometimes defined the same way. And language and terminological barriers do not allow the use of achievements in related fields of knowledge.

A systematic "rediscovery" of the same laws, or general principles, has been observed.

The phenomenon of self-organization has remained one of the most mysterious mysteries of nature for many centuries. The diversity of functioning and development of highly organized systems gives reason to believe in the existence of a certain universal mechanism of self-organization. The problem of self-organization is multidisciplinary, that is, it is studied by a number of sciences about living nature, natural and technical sciences. The achievements of biology, physiology, physics, cybernetics, systems theories, synergetics, psychology and other sciences made it possible to highlight the main principles of the process of self-organization within each of them.

By the middle of the twentieth century, generalizing theories of the process of self-organization had developed independently of each other. Despite different approaches to the integration of scientific knowledge at the crossroads of sciences, they successfully complemented each other, practically preparing the basis for building a single theory of self-organization of developing systems. Of particular importance in the integration of scientific knowledge were the works of A. Poincaré, L. von Bertalanffy, P. Anokhin, K. Shannon, L. Zadeh, G. Hacken, I. Prigozhin, J. von Neumann, E. Bauer, E. Schrödinger and others.

Fundamentally new was L. Zadeh's justification of the general theory of self-organization as fuzzy spaces and the introduction of the corresponding measure of uncertainty [1]. In the last quarter of the 20th century, the works of V. Druz and V. Samsonkin comprehensively considered the representation of the norm of self-organization processes, developed the theory of tolerant spaces, and established the connection between the level of tolerance and the possible complexity of developing self-organized systems [2]. At the beginning of the 21st century, they also established the nature of the construction of characteristic semantic spaces with the introduction of a single measure of partial interdependence of functional activity and the viability of the integral complex "functional system – environment". All this in general opened a fundamentally new approach to solving many practical problems that were inaccessible when using classical research methods.

2.1 TERMINOLOGY AND INTERPRETATION IN THE FIELD OF TRANSPORT TECHNOLOGIES, PROCESSES AND SYSTEMS

Railway transport is one of the key elements of the transport system, ensuring the efficient transportation of passengers and cargo over long distances. Its reliability, safety and environmental friendliness make it indispensable in modern conditions of integration of transport networks. Important aspects of the functioning of railway transport are technologies, processes and systems that affect the quality and efficiency of transportation.

The chapter examines the main concepts and terminology related to transport technologies, processes and systems, as well as their interconnections. In particular, such key categories as management, control, monitoring, modeling, simulation and others that play an important role in the development of the railway industry are analyzed.

Management is a generalized concept that encompasses the processes of decision-making, organization, coordination and control to achieve certain goals in transport systems.

Management is an action in the meaning of "to manage"; an administrative institution or department in charge of a certain field of activity [3].

Management is an action in the meaning of "to manage"; administrative institution or department in charge of a certain field of activity; control [4].

Control is a component of management and involves the practical implementation of management decisions by regulating the operation of objects and processes. Control is an action with the meaning of "to control"; leadership; a system or set of devices with the help of which machines, mechanisms, etc. are controlled [5].

Management reflects the strategic aspect of management, which includes analysis, planning, organization, motivation and control of resources in order to increase the efficiency of the transport system. Management is a set of principles, methods, means and forms of production management in order to increase its efficiency and increase profits [6].

Management is a concept used mainly to characterize the processes of management of economic organizations (enterprises). Management — in part 1, a set of principles, methods, means and forms of production management in order to increase its efficiency and increase profits. Management in socio-economic systems; distinguish between general and special management functions; General functions include forecasting and planning, organization, coordination, motivation (stimulation), accounting and analysis, control; special management functions are in principle the same as general ones, but only in a certain (special) field of activity: in the field of circulation, supply, sales, production preparation, production maintenance, etc. [7].

Control is the process of checking the compliance of performed actions with established norms, standards or plans with the possibility of adjustment.

Monitoring is the set of methods used to obtain information on the effectiveness of implementing various activities and the level of achievement of planned results [8].

Bottleneck is a basic concept of the unified theory of self-organizing systems and, accordingly, the Method of detecting hidden statistical patterns. The concept of "bottleneck" in this study is a synonym for a problematic place in the functioning of a management object, or more precisely, the dialectical unity of "object-environment", because the management object (technical means, process, organization) should definitely be considered in unity and interdependence with the surrounding environment.

Reliability theory states that in order to increase the reliability of the functioning of a management object, attention should be paid to the least reliable chain, that is, the bottleneck.

The bottleneck of an organizational structure is the place of maximum resource consumption (material and technical, financial, intellectual) to maintain a stable equilibrium of the functioning of this structure. Recognition of the unity of the laws of development management requires the establishment of the most general system-forming principles regardless of the specific system and specific environment. The principle of bottleneck is one of the system-forming principles.

The principle of bottleneck is considered in conjunction with the principle of least action, which contribute to the selection of the most rational way to achieve the final result of the activity of the management object.

The principle of least action reveals a general law for nature — the desire to ensure functioning in a specific environment with minimal resource expenditure. Dialectically, the principle of least action is related to the principle of bottleneck, which indicates the need to maximize the expenditure of resources on a problematic (narrow) city in order to maintain the equilibrium stability of the system.

Gaps are information that has not been disclosed in other studies and is disclosed in this one.

Identifying research gaps is an important step in developing knowledge and solving real-world problems. Typically, gaps are identified by examining and analyzing information sources. To do this effectively, several strategies can be used:

1) *thematic analysis* involves organizing existing research findings into topics, allowing for a comprehensive assessment of the literature. By analyzing the extent to which each topic is covered, researchers can identify areas that have received minimal attention or limited research. This approach illuminates "blind spots" in the field, paving the way for new inquiries;

2) *methodological critique* focuses on assessing whether the methodologies used in the current study are sufficiently robust to address key questions or address important problems. This strategy often reveals weaknesses in experimental designs, sampling methods, or analytical tools, offering opportunities for innovation and improvement;

3) *trends* are fertile ground for identifying research gaps. Rapid changes in technology, regulations and environmental conditions create new challenges and opportunities. For example, areas such as the application of artificial intelligence in railway systems or the development of sustainable materials for construction may not yet have been widely explored, leaving a rich field for research;

4) *practical implications* to check whether existing research effectively addresses real-world problems, especially those faced by industries. This includes checking whether research meets the practical needs of industries such as transport or construction, in terms of safety, efficiency and compliance with standards such as CENELEC (European Committee for Electrotechnical Standardization) and TSI (Technical Specifications for Interoperability). Research that bridges the gap between theory and practice is invaluable in promoting innovation and ensuring compliance with regulatory requirements.

A *system* is an order resulting from the correct, planned arrangement and interconnection of parts of something [9].

System – a set of any elements, units, parts, united by a common feature or purpose [10].

A *systems approach* – a methodological approach to the study of objects as systems, which takes into account the relationships between the constituent elements, their hierarchy and integrity [11].

A *systems approach* – a method of studying complex objects by analyzing them as systems, which involves studying the structure, functions, relationships and integrity [12].

System analysis – a set of methodological tools used to prepare and justify solutions to complex economic problems [13].

System analysis – one of the most important means of finding solutions and understanding the problems of social life. It implements the systems approach – the principle of comprehensive study and research of reality – common to any systems of objects: "input", "process", "output", "goal", "feedback", "growth", "interaction", etc. [14].

Model – a reproduction, image, description or imitation of a certain phenomenon, process or object [15].

Modelling is a method of studying objects, processes or phenomena by creating and analyzing their models. This approach allows studying the characteristics and behavior of complex systems using their simplified representations [16].

Model – a simplified representation of a real system or process in the form of mathematical, graphical or physical structures [16].

Modelling is the process of creating and analyzing models to study the characteristics of a system [16].

Simulation is a research method that involves experimentally reproducing the behavior of a system based on its model [16].

Imitation is the reproduction of the functioning of a system in artificial conditions to assess its parameters and optimize solutions [16].

Transport technologies are a set of methods, tools and instruments used to ensure the effective functioning of railway transportation [17].

Transport processes are a sequence of actions aimed at performing transportation, maintaining infrastructure, and managing logistics flows [18].

Thus, the above concepts are basic for the analysis of transport technologies, processes, and systems, as well as for further research into methods for improving the efficiency of rail transport.

2.2 A METHOD FOR DETECTING HIDDEN STATISTICAL PATTERNS IN TRAFFIC MANAGEMENT

Basic terms of the Method for Detecting Hidden Statistical Patterns (MDHSP):

– *system* – any control object (technological process, function, workplace, organizational structure), which is considered in interaction and unity with the environment;

– *final result* – the goal and system-forming factor of the system. In practice, it is one of the parameters of the system's activity, an indicator of the system's state. Its dynamics is a criterion for the similarity of different system states;

– *bottleneck* – the most problematic place in the system's activity, as well as the area of maximum resource consumption to maintain the system's equilibrium stability;

– *norm* in the sense of functional optimum – stereotypical (most probable) behavior of the system;

– *control parameter* – a fixed statistical indicator of the system's activity;

– *statistical pattern* – a trend or a clear tendency in the gradual dynamics of statistical indicators that describe the activity of the railway system;

– *classifier*. Classification – the division of objects (phenomena and concepts) into classes or categories depending on their general characteristics. A classifier is a systematic list in which it is convenient to find a description of each object or phenomenon.

The MDHSP is a multidisciplinary theory that logically follows from the Unified Theory of Self-Organizing Systems.

Fig. 2.1 shows the scientific directions that became the MDHSP basis.

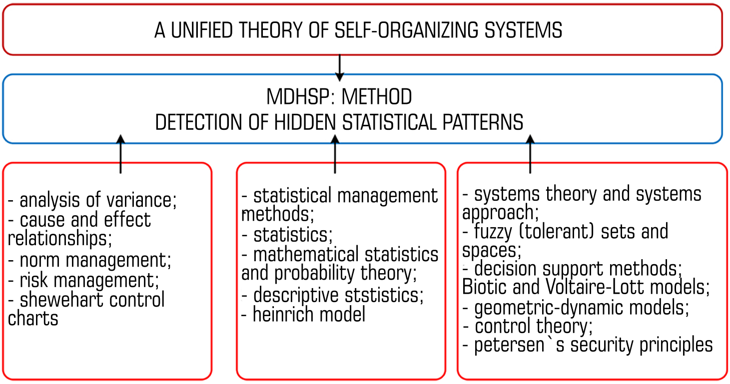


Fig. 2.1 The set of scientific directions that form the theoretical basis of the MDHSP
Source: [2]

2.3 THE CONCEPT AND KEY PRINCIPLES OF THE MDHSP

The MDHSP conducts a search for hidden patterns in the activities of a management object, whether it is an organization as a whole, a structural unit of an organization or even an individual person, a technological process or function.

Regardless of the scale, all these objects (organization, unit, person, process, function, etc.) are considered as a holistic system in *interaction and interconnection with the environment*. The environment can be classified as internal or working (the closest environment) and the general environment (natural and social).

In this chapter, terms with the root "statistics" are often used. Therefore, let's provide its definition. Statistics is a multifaceted concept that includes:

– a branch of social sciences that aims to collect, organize, analyze and compare facts related to a wide variety of mass phenomena;

– a system of indicators;

– a tool for establishing specific patterns;

– numerical/digital data.

– statistical methods used in the collection, presentation, analysis and interpretation of data.

Statistical regularity – the most important category of statistics, which is considered as a quantitative regularity of changes in space and time of mass phenomena and processes of life, consisting of many elements (units or parameters of the set). It is inherent not to individual units of the set, but to the entire set as a whole. For this reason, the regularity is revealed with a sufficiently large number of observations and only on average. Thus, this is an average regularity of mass phenomena and processes. These regularities arise as a result of the influence of a large number of constantly acting and random causes. Statistical regularities provide researchers with invaluable typical values, which are most often devoid of specificity. But it is known that any general concept is abstract and therefore devoid of specificity: it contains essential features of a class of objects, and the insignificant, which characterizes the single, individual, is not included in it [14].

Thus, a statistical regularity is an objective quantitative regularity of a mass process. It arises as a result of the action of objective laws, expressing causal relationships.

The regularities of the system's behavior allow to establish its state, shortcomings in its functioning, or to confirm its relevance. Therefore, establishing the regularities of behavior is a key stage in system management. These things are obvious, but regularities do not lie on the surface; it is necessary to detect them and prove their reality.

Let's evaluate the behavior of the system by a control parameter. The control parameter is a parameter of the final result, and the final result is considered in the sense of the theory of a functional system [19].

There may be several such control parameters. But let's choose that:

a) depend on the activity of most of the system elements that determine its functionality;

b) change in different periods of supervision, that is, they are not constant, and have a fairly wide range of quantitative manifestation;

c) have methods and means of objective measurement and recording of values over time in the form of statistics, which should preferably be approved by relevant documents in order to be mandatory for the system personnel.

Any control parameter that corresponds to points (a)–(c) can reveal patterns, provided that there is an appropriate amount of statistics. Therefore, in practice, the number of control parameters should be minimal, preferably one. This simplifies the management process and eliminates contradictions in the dynamics of control parameters if there are more than one.

It should be emphasized that the Method belongs to a widespread group of *statistical management methods*. Accordingly, it should be said about the need for the reliability of control parameter statistics. But this fact is not a limitation on the application of the Method, because in most organizations there is a fairly strict responsibility for providing false statistics at both the corporate and state levels.

MDHSP is a theoretical justification for making effective decisions to control functions, processes and structures of systems.

And one more characteristic: MDHSP is a *systems approach*. The concept of a systems approach has been used more and more often in recent years when they want to emphasize the complexity of the task or the complexity of its solution. Analytical methods for managing complex systems that have existed for a long time are ineffective. This is especially true for the tasks of managing production and social systems, given its high responsibility.

The application of a systems approach today is mainly reduced to terminology, the presentation of system elements and their relationships, the declaration of the concept of "dimensionality", mathematical models with simplified implementation conditions. What is missing here? Specifics!

The proposed MDHSP is based on formalized procedures and measurable concepts. It began to be created almost 25 years ago to solve the task of managing traffic safety on the railway transport of Ukraine. The first version of the method was published 20 years ago [20]. Later it became obvious that the established principles, procedures, models and concepts can be used to manage almost any system or function.

The system approach is the opposite of system analysis. The analytical approach studies a separate component of the system, determines its characteristics and management parameters that are effective specifically for this structural subsystem. But this may not correspond to the effective management of the system as a whole. The key principles of MDHSP are given below:

1. Signs of the definition of "bottlenecks".

Having considered the principles of self-organization, one of them can be distinguished – the principle of the bottleneck, which was considered with the principle of least action. Bottlenecks are the most problematic places or places of maximum resource consumption to maintain the stability and safety of its transportation process.

This concept seems to be clear, but how to determine the bottleneck in the statistics of the final outcome parameter. Three signs of a bottleneck are proposed.

Sign 1 – "outlier" (**Fig. 2.2**) of the control parameters for the observation period.

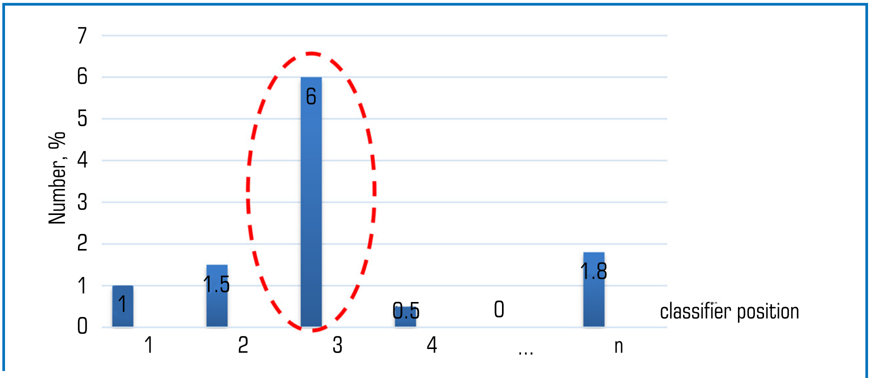


Fig. 2.2 The first sign of a bottleneck – "outlier"

The red line in **Fig. 2.2** indicates the "bottleneck" of the first sign, *n* – the number of elements of the statistical parameter.

Sign 2 – "negative trend" of the dynamics (or time series) of changes in the control parameter being analyzed in adjacent time periods. This sign is shown graphically in **Fig. 2.3**.

Sign 3. If, based on the graphical representation of the statistics of control parameters, a uniform manifestation is observed (i.e., there is no pronounced bottleneck according to Signs 1 and 2) – **Fig. 2.4**, then the sources of improvement of the situation should be sought in the plane of organization of the technological process as a whole.

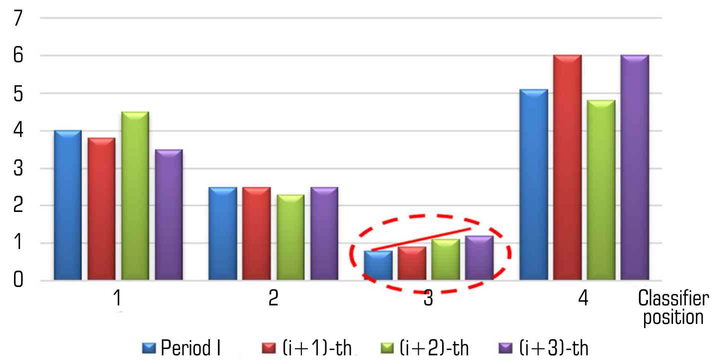


Fig. 2.3 The second sign of a bottleneck — "negative trend" — is marked with a red line for four observation time periods

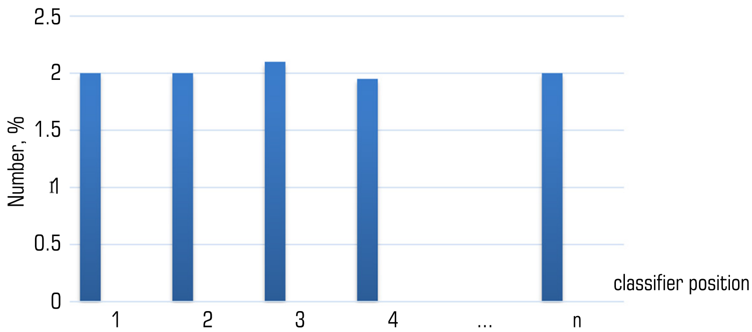


Fig. 2.4 Uniform manifestation of components of the control parameter classifier

There may be several "bottlenecks".

2. Systematization of control parameter statistics.

The problem of using statistical methods is the verbal way of presenting statistics as in the relevant sources of information. Therefore, to use statistical management methods, verbal information must be systematized or formalized.

Statistical data that characterize the final result of the company's activities are quite diverse and their volume is large. For example, the activities of railway transport in Ukraine are characterized by 53 parameters, and taking into account subparameters (components of the parameter) — 114 [21]. These are: volumetric, qualitative, technical, technological indicators that characterize types of transportation, rolling stock indicators, personnel, wages, train delays, etc. All these statistics are approved by regulatory data.

As mentioned above, the MDHSP was initially developed for railway traffic safety management, based on a specific problem that was formulated by the management of the railway company of Ukraine [20]. Therefore, the initial information of the Method used indicators of traffic safety violations (transport incidents/technical failures/delays, etc.), which are found in various sources of information in paper/electronic form in different divisions of the company. That is, negative information about the state of train traffic safety, which related to violations of transportation regulations, was selected as statistics. The reason for the negative information is explained by several thoughts:

– when everything is going well, personnel rarely think about shortcomings and bottlenecks;

– when investigating transport incidents, the circumstances, causes, compliance with service technology, personnel actions, etc. are usually comprehensively studied. And here it is possible to identify hidden shortcomings and shortcomings;

– transport incident statistics are the basis for analyzing the state of traffic safety in railway companies of Ukraine, the EU and many others.

– the statistics that exist in the organization under study are used.

Thus, statistics were used that characterize the negative side of the train traffic safety function, that is, negative statistics. And why negative? Was it possible to use positive statistics? The authors believe that no. Firstly, because companies do not keep statistics of positive actions, because there are a lot of them; secondly, positive statistics are the implementation of technical and technological regulations. That is, it should be so, and such information is of no interest for process management. Thirdly, there is no point in wasting personnel time if everything is going correctly. Thus, it is worth concluding that the initial information for the MDHSP should be statistics of various kinds of failures and violations.

It is proposed to systematize each failure or violation recorded in the statistics of the control parameter in the form of answers to nine questions or in the space of nine parameters (**Fig. 2.5**).

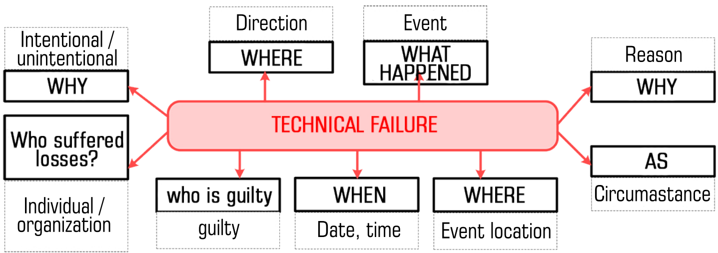


Fig. 2.5 Systematization of failure statistics cases

The parameter "*WHAT happened*" characterizes the event according to the existing classifier and consequences. The geographical location of the event (station, section, section) is assessed by the parameter "*WHERE*". The parameter "*WHEN*" reveals the time of the event. Circumstances ("*HOW*") contain a qualitative characteristic of the event: information about the train (train number, number of cars, tonnage, number of axles), locomotive, cars, weather conditions, rolling stock condition, infrastructure condition, compliance with load requirements, personnel health, etc. Depending on the technological management process, the characteristics of the circumstances that are necessary can be selected. The parameter "*WHY*" is a possible cause or causes of the event. "*WHO*" is the culprit or violator. The answer to the question "*WHY*" should explain the intentionality or accidental nature of the event. The parameter "*WHO*" should contain information about the targeted nature of the damage. "*WHERE*" is the direction of movement.

3. Identification of patterns.

It is carried out by graphically constructing and further analyzing the following dependencies:

a) dynamics of individual systematization parameters WHAT, WHERE, WHEN, ... in time;

b) variations of the components of nine parameters in time;

c) in the space of two and three systematization parameters (for example, WHAT — WHERE, WHY — WHEN, WHAT — WHO — WHERE, ...).

Different patterns are possible, but in most cases, let's mean patterns that reveal bottlenecks of the type **Fig. 2.2–2.4**. Because it is the bottleneck principle that is the criterion for choosing effective management decisions.

4. Expansion of the formula of causal relationships to four points.

Usually, in the analysis of causal relationships of technological process violations, three points are distinguished: consequences, events, causes. Therefore, identifying the *causes* of violations and, accordingly, the culprit is often the main task of investigating violations of the technological process regulations or management functions. In this case, the *event* is defined clearly: it is classified by *consequences*, that is, the degree of losses from the violation. The cause is revealed as a result of the investigation [22].

The determination of the specific formulation of consequences, events and causes is carried out according to existing classifiers:

— consequences classifier, which determines losses for people (company personnel, users, third parties), the material and technical base of the enterprise, the environment;

— event classifier, which consists of points according to losses, for example: catastrophe, accident, incident for the safety of railway transport. For other types of transport, the event classifier is similar;

— the classifier of causes is either officially approved, as in the EU, or actually exists for individual farms, owners, and those involved.

But in fact, the causes are defined as the last previous event and belong to the space of technological parameters. And therefore, they are random in nature. In order to effectively prevent process violations, it is proposed to introduce a fourth point into the cause-effect relationships: the *prerequisite* of the cause, or the basic cause. The prerequisite lies in the space of organizational support of technological processes. Organizational support is such concepts as personnel selection and training, repair facilities, supply, working and leisure conditions, production culture, management, etc. Organizational support is accumulated for more than one year, it is a function of the company's management system, and it is quite conservative. Causes arise due to shortcomings in the organizational support of technological processes. To prevent negative events, changes should be made to the organizational support, that is, the prerequisites. Accordingly, a classifier of prerequisites is being developed.

Thus, there are *four classifiers*: *losses or consequences, events, causes and preconditions*, the mechanism of interaction of which is shown in **Fig. 2.6**. Each classifier consists of the corresponding elements: *n* preconditions, *m* causes, *i* events and five consequences. As is known, it is by consequences that transport events on modes of transport are classified. The elements of the classifier of consequences are generalized from the classifiers of modes of transport and do not belong to any official document.

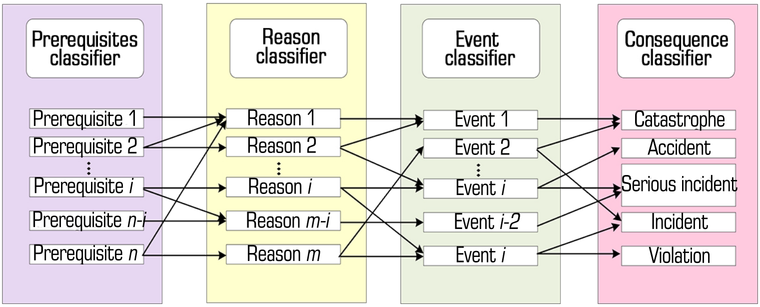


Fig. 2.6 Interaction of cause-and-effect classifiers for transport events

The presence of an arrow in **Fig. 2.6** indicates the corresponding connection. It is known that there is no mutual unambiguous connection between, for example, causes and events. Therefore, for example, event 1 can have two causes: 1 and 2. The *n*-th element of the prerequisite classifier can precede causes *m* and 1.

By the way, the prerequisite or basic cause as a guess is present in various theoretical approaches to process safety management, including D. Petersen's theory, EU railway safety regulations.

5. Tolerance.

Tolerance is understood in the sense of "indistinctness, inaccuracy, blurriness". Large (or high) tolerance is a wide range of manifestation of the control parameter in the normal zone, or low accuracy. Low tolerance is equivalent to high accuracy and dissimilarity.

The source of tolerance of human-machine systems (HMS) is:

a) human activity, which is characterized by untimeliness, insufficient knowledge of the situation, incompetence, shortcomings in the organization of work, errors, etc.;

b) technical means exhibit insufficient reliability, inaccuracy, failures, etc.;

c) the environment, which is characterized by instability, unfriendliness towards humans, negative impact on humans and technology, the need to adapt the boundaries of the equilibrium state, etc.

In general, any HMS, processing the flow of information by comparing input signals with the formed images, allows for a certain inaccuracy. In practice, this inaccuracy should increase as the information becomes more complicated. An intuitively obvious assumption: the more vague the information about the controlled process, the less certain the HMS actions should be.

From the point of view of mathematics, the transition from the indefinite concept of "sameness" to a precisely defined type of relationship is accompanied by the introduction of the term "equivalence" [20]. Similarly, the mathematical point of view that corresponds to our intuitive idea of similarity or indistinguishability is called tolerance.

Equivalence on a finite set $A = \{a_1, a_2, \ldots, a_K\}$ will be called a binary relation. The equivalence relation is generally defined on the set A×A and has the following properties:

1) *reflexivity* $: a_i \approx a_i \left(\forall a_i \in A\right)$;
2) *symmetry* $: a_i \approx a_j \Rightarrow a_j = a_i \left(\forall a_i, a_j \in A, i \neq j\right)$;
3) *transitivity* $: a_i \approx a_j, a_j \approx a_k \Rightarrow a_i = a_k \left(\forall a_i, a_j, a_k \in A, i \neq j \neq k\right)$.

"Tolerance" is a binary relation on the set A×A, which has the following properties:

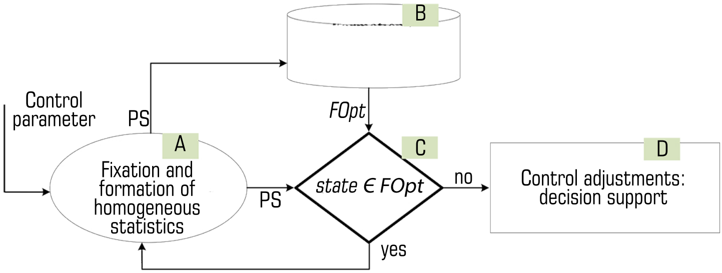
1) *reflexivity* $: a_i \approx a_i \left(\forall a_i \in A\right)$;
2) *symmetry* $: a_i \approx a_j \Rightarrow a_j = a_i \left(\forall a_i, a_j \in A, i \neq j\right)$; (2.1)
3) *NOT transitivity* $: a_i \approx a_j, a_j \approx a_k \overline{\Rightarrow} a_i = a_k$ *at least for one triad* $\left(i, j, k\right)$.

2.4 THE ESSENCE OF THE IDEA AND USE OF THE MDHSP

Three directions of using the MDHSP for system control (processes/functions/structures) can be identified:
1. Identification of the current state of the system.
2. Justification/support of an effective management decision.
3. System control based on the norm of behavior and bottlenecks.
Let's consider both directions.

2.4.1 IDENTIFICATION OF THE CURRENT STATE OF THE SYSTEM BASED ON THE NORM OF ITS FUNCTIONING

The general scheme of this direction is presented in **Fig. 2.7**. Outwardly, it does not differ from the classical formulation of the control and management task. But in order to understand the features of this direction, it is possible to describe the essence of the presented blocks further: *control parameter* – a fixed indicator of the system's activity, officially approved, on which statistics are kept; *state* – system state; *FOpt* – functional optimum of the system's activity (analog of the norm); *PS* – periodic statistics, or current statistics of the control parameter – the number of values for a certain period of time (week/month/year), which is sufficient to identify the system's state.



control parameter – a fixed indicator of the system's activity, officially approved, on which statistics are kept; state – system state; FOpt – functional optimum of the system's activity (analog of the norm); PS – periodic statistics, or current statistics of the control parameter – the number of values for a certain period of time (week/month/year), which is sufficient to identify the system's state

Fig. 2.7 System control based on the norm as a functional optimum

First of all, let's define the terminology. According to [23], the state of a controlled object is understood as the level of activity of its elements in obtaining the final result. It is known that all living systems strive for an equilibrium state, adapting to constant changes in the environment. Equilibrium states are asymptotically stable to weak disturbances (fluctuations). If these fluctuations do not depend on time, then it is possible to speak of a stationary equilibrium state, which characterizes the norm of system behavior. Quantitatively, the state of the system is determined by the numerical value of one or more parameters of the final result of its activity, which it is defined as control parameters.

A few words about the number of control parameters. It is believed that their increase makes the assessment of the state more accurate. However, this is not so. When the environment changes, the range of manifestation increases in some parameters, and decreases in others. The desire to take into account all parameters leads to the expansion of the norm and the inclusion in the list of normal more and more states, which in fact are not such.

If it is about assessing the state of a specific person or the interaction of a specific "human-machine" association, then the ranges of the manifestation of control parameters are individual in nature. Taking into account the adaptive capabilities of the environment leads to a different-vector expansion of the norm in different individuals. The desire to create a general norm for all leads to the need to include in it the manifestation of the control parameters of all individuals. However, this generalized norm for one corresponds to its norm indicators, and for another – not. This is the contradiction of the average statistical norms common in medicine, psychology, technology.

Therefore, the expansion of the norm leads to errors in assessing the state of the system, that is, to its inefficiency. The way out of this problem is often sought in the introduction of an integral indicator in the form of an algebraic sum that combines various parameters with certain weighting factors.

Researchers I. Prigozhin, G. Hacken, A. Dyuldin, V. Druz, and V. Samsonkin have shown that it is possible to consider a minimal number of parameters to describe the final result, and in some cases even a single parameter. This approach is consistent with the general principles of the π-theorem, as discussed [24]. On the other hand, V. Druz proved that the equipotential value of the final result can be achieved by different participation of the component parameters. Therefore, it is important to have statistics of the behavior of any parameter. By processing this statistic properly, *it is possible to determine the norm of the system behavior using one parameter* in its dynamics.

In fact, the number of control parameters is more than one. It takes a lot of time for people to be convinced of the effectiveness and convenience of just one control parameter.

However, it should be noted that the correct choice of a control parameter is sometimes a non-trivial task. It is necessary to well represent the process or management object. The control parameter must, firstly, be measured, and secondly, vary within fairly wide limits.

And now let's describe the blocks presented in **Fig. 2.7**.

Block A: Fixation and formation of homogeneous statistics.

Each value of the control parameter/parameters is fixed. The sources of fixation are diverse: special journals, databases, computer memory. When using statistical information, there is a need to have a *homogeneous* statistical population. The principle of homogeneity is very important in system control: it is about the homogeneity of information, structure, regulatory and documentary support. The homogeneity of the initial information when controlling the system determines the workability, efficiency, adequacy of management decisions and algorithms. Therefore, it becomes understandable that the management of, for example, railway companies strive for homogeneity (often the sameness) of the structure and regulatory framework of the company's components. Homogeneity is understood at a certain level of tolerance or compliance.

Let's define the concept of *homogeneity of a statistical population*. It is relative and does not mean complete compliance of all units of the population at all, but only implies the proximity of the main property, quality, typicality. The same set of units, for example, can be homogeneous in one characteristic and heterogeneous in another. The homogeneity of units of a statistical set is formed under the influence of certain internal factors and conditions [25].

Let's give an example of the principle of homogeneity of a statistical set, which characterizes the activities of a railway company. When characterizing the activities of a company, much attention is paid to locomotives. But their total number means little. Therefore, locomotives are divided or classified into main and shunting, electric and diesel locomotives, freight and passenger, direct and alternating current. And thus, the categories of freight diesel locomotives, passenger electric AC locomotives, etc. are determined. The purpose of such a classification is to determine homogeneous subsets of locomotives for studying issues of wear, repair base, turnover, load, ..., which will be common to individual subsets of the company's locomotive fleet.

Therefore, at the first stage of system research, attempts are made to make statistical sets homogeneous.

However, it is not always possible to make homogeneous subsets of statistical data by classification. Often, information about violations of the technological process is taken as a control parameter: traffic safety, transportation of dangerous goods, failures and breakdowns of various responsible technical means.

There are classifications of such violations. Taking into account the different consequences of violations, the statistics of the control parameter will not be homogeneous or their classification will lead to small subsets, which will make them unrepresentative.

In this case, various models are used to convert or transform a heterogeneous statistical population into a homogeneous one. This can be done, for example, using the Heinrich model.

Further, depending on the difference in *PS* values in two measurements adjacent in time – the current and previous

$$\delta(t) = PS(t) - PS(t - \Delta t), \tag{2.2}$$

as well as the level of tolerance

$$\Delta = \frac{\max(PS(t)) - \min(PS(t))}{6}, \tag{2.3}$$

the current PS value is added to one of the six sets $M_{-3}, M_{-2}, M_{-1}, M_{+1}, M_{+2}, M_{+3}$. The number six in (2.3) is explained by the "3σ rule" for the Gaussian distribution, meaning 3σ in the positive direction from the center of the distribution of μ and 3σ in the negative direction from μ. Without proof, let's accept the obvious fact that a consecutive series of random *PS* values obeys the Gaussian law. The center of the distribution μ is analogous to the arithmetic mean/mode/median of the Gaussian distribution of the random variable *PS*. Accordingly, the designation of the sets means:

M_{+1} – *the set of PS(t) values within* $\mu \le \delta(t) \le \mu + \sigma$;

M_{+2} – " ... ... " $\mu + \sigma \langle \delta(t) \le \mu + 2\sigma$;

M_{+3} – " ... ... " $\mu + 2\sigma \langle \delta(t) \le \mu + 3\sigma$;

M_{-1} – " ... ... " $\mu \langle \delta(t) \le \mu - \sigma$;

M_{-2} – " ... ... " $\mu - \sigma \langle \delta(t) \le \mu - 2\sigma$;

M_{-3} – " ... ... " $\mu - 2\sigma \langle \delta(t) \le \mu - 3\sigma$.

The pair $(\delta(t), M_j)$ *characterizes the current state of the system, i.e.*

$$\delta(t), M_j \equiv state, \tag{2.4}$$

where is defined from (2.2), and j = –1, –2, –3, +1, +2, +3.

Block B: Formation/actualization of the norm.

The term "*norm*" is key in the MDHSP. This concept will be considered in detail below in **Section 2.5**. In the MDHSP, the norm is perceived as a process that determines the optimal mode of functioning of the system, that is, its *functional optimum*. In this concept, the norm is perceived as an interval of optimal functioning of the system with *moving boundaries*. Within these boundaries, optimal communication with the environment and coordinated performance of all system functions are maintained.

The name of the block indicates that the norm is first formed and then constantly updated, theoretically with the appearance at the input of each fixed control parameter or PS. But in fact, the update can be carried out permanently depending on the frequency of receipt of control statistics.

The norm is characterized as the maximum margin of stability of the system. As a deviation from the norm occurs, the system enters a state of tension. At the same time, the variety of compensatory capabilities of the system decreases, and the time of preservation of this particular state is shortened. The reason for this is as follows: an increase in the intensity of the state requires an adequate increase in energy to relieve the tension and transition to the norm. The intensity of the state in which all energy reserves are used to relieve the tension can be taken as the boundary of the functional optimum. After this, irreversible destabilizing processes are observed, which increase with distance from the norm.

By analyzing the location of the norm, it is possible to predict the state of the system and determine its adaptive capabilities. The dependence of the variance of the variation of the control parameter on the functional state allows to consider ***the variance as a criterion for assessing the individual norm and the degree of tension of the system***. This makes the algorithm for controlling the state of the system in the process of continuous activity obvious.

With fatigue, the stability of the system decreases exponentially, the variation of the final result parameter tends to zero. This minimizes the viability of the system.

The norm of the system depends on the environment and therefore changes throughout the life cycle. Since the management object itself and the environment are constantly changing, the norm of the object's behavior should be constantly updated.

Block C: state ∈ FOpt.

The assessment of the equilibrium stability of the system is carried out by comparing the periodic statistics of the control parameter $PS(t)$ with the norm of the system behavior.

In this case, the norm is considered as a functional optimum (*FOpt*), and the state of the system state is determined from the formula (2.4) described above in block B.

In this case:

— if the state of the system corresponds to the norm (the value of state is inside the surface *FOpt*), then nothing needs to be changed in the system. This is shown by the output "yes" of block C;

— if the state of the system does not correspond to the norm of the behavior of the management object, then changes are necessary in the control of the system (output "no" of block C), and for this purpose a methodology for supporting the management decision has been developed, which will be considered in **Section 2.4.2**.

It should be noted that the discrepancy between the state of the system and the functional optimum *FOpt* may be random: a person was suddenly distracted, equipment failure, etc. Therefore, it is necessary to make sure that the state of the system has really changed. For additional verification of the reliability of the state deviation from the norm, the authors used the "Shewhart control charts" method [26]. This is possible only if there is no emergency situation (!).

Block D: Control correction: decision-making support.

The essence of this block will be disclosed below in **Section 2.4.2**.

2.4.2 SUBSTANTIATION/SUPPORT OF THE MANAGEMENT DECISION ≡BLOCK D

This direction is devoted to the substantiation or support of the management decision based on the identification of bottlenecks in the operation of the control system. The general scheme of this direction and, accordingly, the previous block D in the form of a separate methodology or sequence of actions is presented in **Fig. 2.8**.

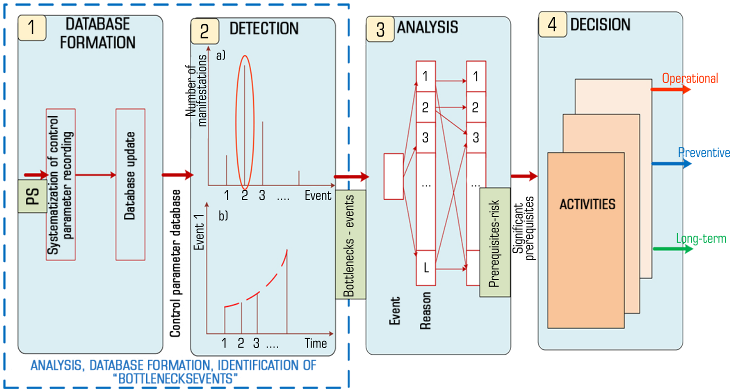


Fig. 2.8 Methodology for substantiating a management decision based on the bottleneck principle

Let's describe the blocks of the methodology in **Fig. 2.8** sequentially.

The input signal of the entire methodology and block 1 is the statistics of the control parameter *PS*(*t*).

Block 1. Formation of the DB.

Systematization of the control parameter record.

As noted above, the control parameter is usually verbal in nature. Even if it can be determined by a number, then in this case it should be specified, for example, date, time, place, classifier item, i.e.

Therefore, for computer analysis of statistics of system performance indicators, each statistical record must be systematized. The key principle "Systematization of statistics of the control parameter" clause 2 of this section suggests systematizing each value of the control parameter in the form of an answer to nine questions:

– WHAT happened – an event that consists in obtaining such a value of the control parameter;

– WHY it happened – the cause of the event;

– HOW it happened – the circumstances of the event;

– WHERE the event took place;

– WHEN the event occurred;

– WHO is responsible for such a value of the control parameter;

– WHO suffered losses or, conversely, income;

– WHY such an event occurred, or a characteristic of the motivation of the responsible person or the structure of the system;

– WHERE – the direction of movement of the process in which the event occurred.

All records of the control parameter are entered into the control parameter database, which consists of nine dimensions and is constantly updated.

By the way, why are there nine questions and, accordingly, nine systematization dimensions? First, nine directions fully describe any event in transport. Second, the sacred Mayan calendar (Tzolk'in) calls the number nine a symbol of periodicity and completeness [27]. Third, in the decimal system, the number 9 is the last among the basic numbers.

Database update.

The structure of the control parameter systematization database (DB) is presented in **Table 2.1**.

Table 2.1 Structure of the control parameter systematization database (DB)

What	Why	How	Where	When	Who	Whom	Why	Whence
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Three-car collision	Narrowing of track	Heavy rain	3rd km of section N	June 25, 2017 7:15	Railway track service	1-BIS mine	Inadver-tent	From sta-tion A to station B
...	...	...	...	...	...	...	...	...

Table 2.1 provides an example that is virtual in nature in order to present the essence of the database elements. In reality, these elements are coded according to classifiers, as will be discussed below. The task of systematization is to determine the number of manifestations and dynamics of measurements of the control parameter for a specific time.

The nine directions of systematization provided in **Table 2.1** are an enlarged systematization. Each direction can be specified. That is, there are first-level parameters (nine directions in **Table 2.1**), and there can be subparameters (second-level parameters), as clarifications or components of the nine first-level parameters. That is, the database should be expanded or specified for the completeness of further analysis and coding of database elements thanks to existing classifiers and enterprise standards. **Table 2.2** provides classifiers that are used in JSC "UZ" and any organization to specify the database of systematization.

Table 2.2 Filling in the refined database

What	Why	How	Where	When	Who	Whom	Why	Whence
1	2	3	4	5	6	7	8	9
Event classifier item	Cause classifier item	List of circum-stances	Railway, station, km	Year, date, time	Unit, staff or private person	Railway, users, environ-ment	Intention-al/uninten-tional	Connection scheme

Thus, for example, the 5th column can be divided into three: year, date, time of the event.

Each value of the control parameter must be systematized and recorded in the database.

The output of block 1 is the current control parameter database taking into account the last *PS(t)*.

Block 2. Detection of bottlenecks-events.

The input of the block is the control parameter systematization database.

The task of this block is to detect bottlenecks by features 1 or 2 according to clause 3. The systematization dimension of the WHAT (1st column of **Table 2.2**) of the database is analyzed. The bottleneck is determined for a certain period, depending on the frequency of fixing the control parameter. Bottlenecks are detected for all components of the event (WHAT dimension) according to the event classifier that exists at the enterprise. At the same time, all (!) WHAT components are analyzed both according to option (a) – by *feature 1*, and (b) – by *feature 2*. One or more bottlenecks are selected according to objective mathematical criteria.

The choice according to *feature 1* depends on the experience, skills of the responsible personnel or manager, according to *feature 2* – bottlenecks will be all WHAT components that have "negative" dynamics.

The output of block 2 is one or more identified bottlenecks-events.

Block 3. Analysis of cause-and-effect relationships.

The final result of this block is the determination of the prerequisites (*so-called fundamental/basic/deep and therefore hidden reasons*) that lead to the emergence of bottlenecks-events.

This occurs in two stages:

1) possible causes of bottlenecks-events are determined. These are usually technological reasons – unexpected failure of technical means or infrastructure, driver or dispatcher error, unforeseen environmental disasters;

2) the prerequisites of technological reasons are determined. The prerequisites are related to the organization of the transportation process and do not affect the transportation process itself. These are: the level of personnel training and technical training, the state of technical means, shortcomings in the management system of the structural unit or the system as a whole, outdated material, technical and intellectual base, shortcomings in repair or maintenance, etc.

Identification of negative prerequisites is determined by analogy with block 2 for events. Due to the war, significant causes of "bottlenecks" are formed. This is the risk of an emergency.

As a result of the analysis of the prerequisites, significant prerequisites of bottlenecks are formed. These are real risks that can be eliminated, because prerequisites, unlike causes, are not random in nature.

The organization of the transportation process is formed over the years and it is it that determines errors and failures in technological processes. Changing the organizational principles of the transportation process requires time and significant expenditure of material and nervous resources, because it is associated with the habits of a large number of people.

But controlling prerequisites is the most rational way to increase efficiency and production culture.

The output of block 3 is the most significant prerequisites, which can also be several. Their selection is also a matter of human skill, as well as the use of expert assessments, for example, the Delphi method. The reason for using experts is that there is neither a culture of working with prerequisites nor appropriate prerequisite classifiers at enterprises.

Block 4. Development of management decisions.

This is the formation of management decisions that can reduce or eliminate the impact of significant prerequisites. In practice, three types of management decisions can be identified:

— operational — introduced quickly as a reflex to a bottleneck in order to get rid of negative events-bottlenecks as quickly as possible in the future. As a rule, these are prohibitive decisions;

— preventive, this is the implementation of organizational and technological measures for verification, training, testing, experiments to reduce the impact of bottlenecks in the medium term;

— strategic — this is the development of programs for a fairly long term and their subsequent implementation.

The specific content of this block largely depends on the specific company.

The implementation of the methods of **Fig. 2.7** and **2.8** of operational management in full will become possible with the introduction of digital technologies 4.0 and 5.0: Big Data Analytics, Blockchain, cloud computing, etc. This is a matter of the near future.

2.5 SYSTEM BEHAVIOR NORM

The term "norm" is of key importance in the MDHSP. This term is widely used in natural, social, technical sciences, medicine, mathematics, chemistry (abnormal crystals), in physics (normal oscillations), in mathematics (normalization of vectors and quantities), in biology (adaptive norm, reaction norm), in aesthetics (aesthetic norms), in linguistics (language norms), jurisprudence (norms of law), etc. It is practically impossible to find a science or field of activity in which the term "norm" is not used in one form or another.

Today there is no generally accepted concept of norm. Examples of the use of the concept: ideal, ordinary, average, optimal, rational, etc. The use of this concept in different fields of knowledge and activity is not a terminological coincidence. In all cases of application of this concept, it is possible to speak of a general substantive nature. The following are often used as equivalents to the term norm: "ordinary", "typical", "average", "mass", "correct", "standard", "ideal", "established measure", "recognized order", etc.

Many scientists from different branches of knowledge were engaged in substantiating the norm: G. Hegel, I. Kant, G. Leibniz, C. Lombroso, L. Quetelet.

The main stages of the evolution of the concept of norm:

– visual empirical – in antiquity;

– classification by essential features – typical of the metaphysical stage of the development of science until the 19th century;

– dialectical – typical of the science of the late 19th–21st centuries.

In technology and natural science, the concept of the *average statistical* or *population* norm has become most widespread. Let's dwell in more detail on this interpretation of the norm.

The achievements of the 19th century in the study of the norm have determined its widespread application. The law of large numbers allows to consider each individual event as random in the general process, and the entire set of events that has the stability of reproduction as a necessity. Already at the beginning of the 20th century, a significant number of works appeared that proved the high efficiency of using average statistical estimates of the norm. Statistical commonality increasingly serves as the basis of empirical laws.

The requirements that must be observed in order to form a correct representation of the norm of the phenomenon under study are determined. One of such requirements is the qualitative homogeneity of the set of manifestations of the parameter that characterizes the phenomenon under study. This requirement is closely related to the problem of the boundaries of the set. Mathematical statistics states: the larger the set of manifestations of the parameter being estimated, the more reliable the estimate in the form of the arithmetic mean should be. However, the expansion of this set leads to a wide variation in relation to its average value and an extremely high conditionality of the average statistical estimate.

Therefore, the average statistical norm includes not only the *arithmetic mean*, but also the *variation*, which is most often characterized by *dispersion or standard deviation*.

Actually, a clear idea of the average statistical norm has been formed. It expresses something "limitingly general", "tendency" or "average". In this case, the concept of the norm is not associated with any specific event or property of a specific element of the population, although each of the elements varies within its minimum and maximum, and the average is formed most often. Processes are recognized as normal for the corresponding environment if they occur in most cases.

Naturally, the average statistical norm for a set of phenomena, objects or people cannot correspond to the individual norm of a separate object or person. The more heterogeneous the set of individuals, the more contradictions arise in the understanding and content of the individual and average statistical norm. In a number of cases, such contradictions led to the complete denial of the norm as a category. This is explained by the fact that the formation of the average statistical understanding of the norm took place during the period when the structural representation of the system was absolutized.

The most profound and well-founded interpretation of the *norm as a functional optimum* is considered. Approaches to the quantitative definition of such an understanding of the norm were laid down at the beginning of the 20th century by Academician P. Anokhin in the theory of functional systems [19, 28]. Later, these ideas were developed in the works of K. Sudakov, A. Korolkov, V. Petlenko, N. Amosov, Yu. Antomonov, V. Druz, Japanese scientists Hirata, Kaku, etc. [29]. It is worth noting the works of M. Breitman, who in the 20s of the 20th century, empirically reached the same conclusions, scientifically generalizing them [20].

The functional expediency of the system in achieving the final result is a forming factor in determining standard patterns, orders, and organization of forms of relations, which constitute the norm of the system while maintaining the stability of these relations. In this view, the norm appears not only as an ordered *structure of relations*, but also as a *process* aimed at maintaining a state of stable equilibrium during changes in the environment.

Structural changes in the ordered relations of the system under the influence of the environment lead to the evolution of the system. Such transformations are natural if the system maintains stable relations with the environment, and the process of evolution itself proceeds in accordance with the order inherent in the system. The norm plays the role of a mechanism for managing the relations of the system with the environment. In the event of loss of stability, the system is transformed or destroyed, its orderliness in this environment disappears. This is also the norm of such relations.

The norm changes during the life cycle depending on the environment and its "aging".

Achieving the final result is a factor in shaping the behavior of the system and forms of relations, which constitute the norm of the system with stable relations with the environment. In this view, the norm appears as an ordered structure of relations and as a process aimed at maintaining a state of stable equilibrium with environmental changes.

In this work, *the norm is understood not as a fixed criterion, but as a process that determines the optimal mode of functioning of the system*, that is, its *functional optimum*. In this concept, *the norm is perceived as an interval of optimal functioning of the system with moving boundaries.* Within these boundaries, the optimal connection with the environment and the coordinated performance of all system functions are preserved.

It was previously emphasized that the authors consider the system as a unity of "management object — environment". The question arises of finding statistical patterns that ensure the stability of the continuous process of system adaptation to environmental changes. The optimum of such a process is the norm, and its most stable state (analogy of the mode in Gauss's law) is a reflection of the norm, which can be determined for certainty by the *maximum of the norm*. In this case, the norm characterizes both the qualitative and potential capabilities of the system. The direction of the norm movement determines the qualitative evolution of the system.

The norm characterizes the maximum margin of stability of the system. This is explained by the maximum range of deviations, which nevertheless ensures the return of the system to the previous (normal) state.

When deviating from the norm, the system goes into a state of tension. At the same time, the variety of compensatory capabilities of the system decreases, and the time of preservation of states is shortened. The reason for this is as follows: an increase in the intensity of the state requires an adequate increase in energy to remove the tension and transition to the norm. The tension at which all energy reserves are used to remove it can be taken as the limit of the functional optimum. After this, irreversible destabilizing processes are observed, which increase with distance from the modal state of the system (norm).

System management requires knowledge of the state and level of reliability of the system and each component. **Fig. 2.9** shows the scale of system states from the point of view of stability and reliability of functioning.

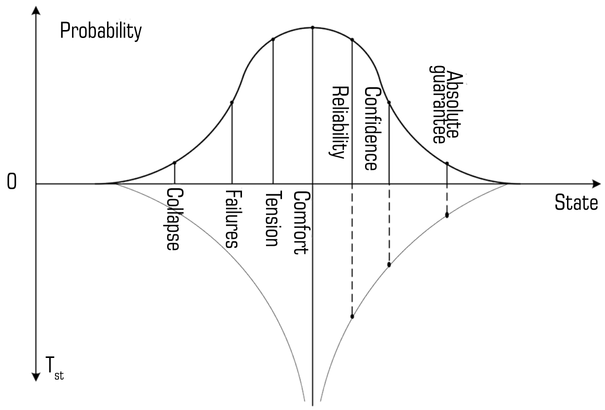


Fig. 2.9 Determination of the probability of the system's activity states and the residence time

Among the set of states, there are two points ("Tension" and "Reliability"), beyond which work becomes unprofitable. They correspond to the inflection points of the normal curve, i.e. $\mu \pm \sigma$. The distance between these points determines the zone of functional optimum, when it is still possible to maintain the equality of income and losses. Approaching these points from the comfort point should cause alarm and take measures to stabilize the activity. This fact allows to establish such a state in which it is necessary to apply measures of increased concern. Outside the zone of functional optimum, there is a mismatch between the capabilities and needs of the system, its individual link or section.

The pattern of change in the probability density of the current statistics of the control parameter *PS* depending on the state of the system is shown in **Fig. 2.10**. Let's explain the graphic construction in **Fig. 2.10**.

1) **Fig. 2.10, *a***.

The density of the PS parameter distribution in the three-dimensional space {*PS*, *state*, *f*} is described by Gauss's law

$$f(PS) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(PS-\mu)^2}{2\sigma^2}}. \qquad (2.5)$$

On the *PS* axis, the point means the current arithmetic mean of the *PS* parameter. This value is constantly being refined, so it is possible to say that *not only the boundaries of the functional optimum, as mentioned earlier, but also the arithmetic mean* of the control parameter are "*floating*".

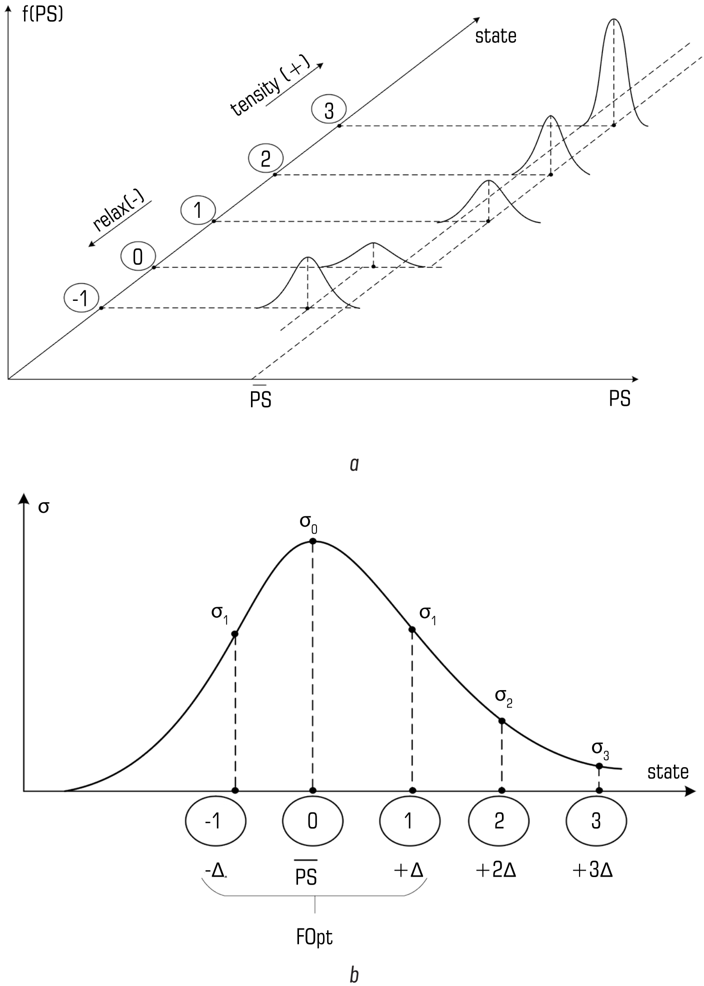


Fig. 2.10 Change in the parameters of the normal distribution of the control parameter depending on the state of the system: *a* – regularity of change in the probability density of the current statistics of the control parameter (PR); *b* – dependence of the PR variation on the state

The "*state*" axis has two directions: tension ("tensity +" and relaxation ("relax –"). Five states are highlighted on the "*state*" axis, which are marked "-1", "0", "1", "2", "3". State "0" corresponds to the "comfort" state in **Fig. 2.9**. This is the optimal state of the system with a large number of options for obtaining the final result.

Therefore, the variance in the distribution (3.3) will be maximum. In the states of tension "1", "2", "3" (in **Fig. 2.9** these are the states "tension", "failures" and "collapse"), the variance gradually decreases in accordance with the state "0". The same considerations can be repeated for the direction of relaxation or "relax". Therefore, all graphical models in the "relax" direction will be symmetrical to the "tensity" direction and are given only for one state "–1", which is symmetrical to the state "1".

Within each removed state, deviations are permissible, which should not exceed inflection points of the curve (3,3), respectively $\mu_{-1}\pm\sigma_{-1}, \mu_0\pm\sigma_0, \mu_1\pm\sigma_1, \mu_2\pm\sigma_2, \mu_3\pm\sigma_3$. If these deviations go beyond the inflection points, the system passes into a new state with different characteristics of its preservation.

In real operating systems, it is customary to talk about a state of tension, and almost never about relaxation. But from the point of view of the quality and efficiency of activity, these two processes are similar;

2) **Fig. 2.10, *b***.

This figure plots the dependence of the PS variation on the state in the form of the mean square deviation, which corresponds to **Fig. 2.10, *a***). The envelope of the mean square deviations σ of the *PS* parameter also corresponds to the Gaussian law (without proof). This allows to determine the functional optimum as the interval between the points of its inflection of the curve $\sigma(PS)$, which it is possible to define as follows:

$$FOpt = \left[\overline{PS}-\Delta, \overline{PS}+\Delta\right], FP, \tag{2.6}$$

and the value of Δ is determined according to the "3σ rule", by the formula

$$\Delta = \frac{\max PS(t) - \min PS(t)}{6}. \tag{2.7}$$

Thus, formulas (2.6) and (2.7) can statistically characterize the functional optimum of the system. Taking into account the constant refinement of $\overline{PS}$ and Δ, this approach to determining the functional optimum can be called a "floating norm".

The dependence of the dispersion of the distribution law of the control parameter (2.5) on the state of the system (**Fig. 2.9**) allows to consider the dispersion (or the mean square deviation) as a criterion for assessing the norm of the system and the degree of tension or relaxation.

The norm is a living being. It is subject to the influence of the internal and external environment, changes in technology, equipment and personnel, and therefore it changes during the life cycle of the system.

The options for change are as follows:

1) changing the center of the probability density distribution of the control parameter around the axis *state*.

The upper part of **Fig. 2.11** shows the features of changing the location of the distribution of the control parameter PS, which are taken from **Fig. 2.10, *a***, but between the inflection points of the Gaussian curves. From this figure it is obvious that the center of the distribution shifts, and for states of tension in one direction, and for states of relaxation in the other direction. The lower part of **Fig. 2.11** shows the dependence of the center of the probability density distribution μ on the state of the system state.

2) shifting the location and width of the functional optimum interval.

This option is shown in **Fig. 2.12**. The black color shows the option of the functional optimum zone, as shown in **Fig. 2.10, *b***. Further, it is possible to move left or right along the *state* axis without changing the width of the interval (this is shown in blue), or to decrease/increase the width of the functional optimum interval (red).

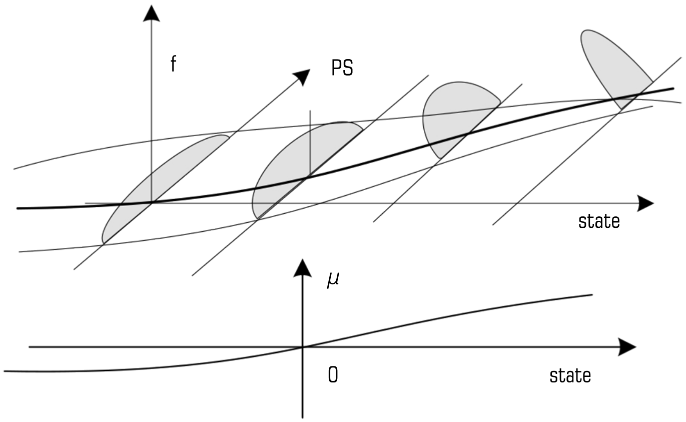


Fig. 2.11 Change of the distribution center according to the increase in tension in the system activity

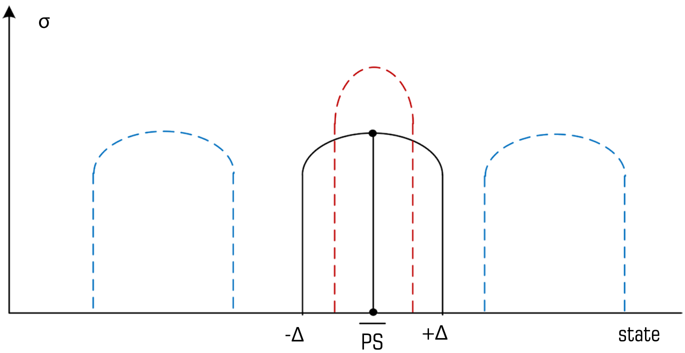


Fig. 2.12 Shift of the location and width of the functional optimum zone

By analyzing the location of *FOpt*, the dynamics and rate of change of the width of the *FOpt* zone, it is possible to predict the state of the system and determine its adaptive capabilities. The dependence of the dispersion on the functional state allows *to consider the dispersion as a criterion for assessing the individual norm of the system and the degree of tension*. This can be a criterion for controlling the state of the system in the process of continuous activity.

With fatigue, the dispersion in all states decreases, the stability of the system decreases exponentially, the variation of the final result parameter tends to zero. This minimizes the viability of the system.

2.6 INTEGRATED SYSTEM CONTROL MODEL BASED ON NORMS AND BOTTLENECKS

Fig. 2.13 presents an integrated system control model based on the system behavior norm and the bottleneck principle. It is developed by combining (integrating) the directions presented in **Section 2.4.1** (**Fig. 2.7**) and **2.4.2** (**Fig. 2.8**). The numbering of the blocks in **Fig. 2.13** is similar to the numbering of the blocks in **Fig. 2.7** and **2.8**. There are two new blocks: five and six.

The control model in **Fig. 2.13** is not only the result of integration, but also of the synergy of the two directions. Similarly to the style of describing the directions that was used above, let's describe the functions of the blocks in **Fig. 2.13**.

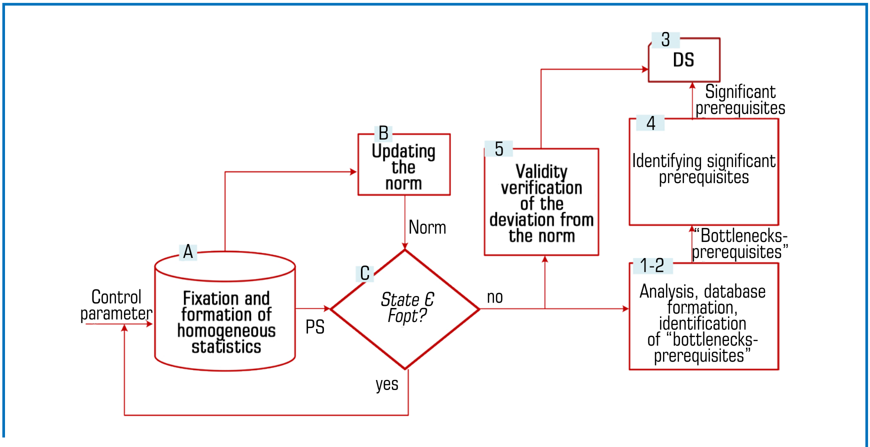


Fig. 2.13 Integrated system control model based on the system behavior norm and the bottleneck principle

Block A: Fixing control parameters and forming homogeneous statistics.

The input signal of block A – control parameter *par*□ – can appear randomly (violation of the regulation, emergency situation, end of technological operation, ...) or periodically (once per hour/day/week/month). The output signal of block A – *PS* consists of a series of adjacent values *par* and is formed periodically, after a certain time Δt according to the existing regulation and the conditions for assessing the state of the system, and is equal to either the number of values *par* in the series, or the *par* statistics are transformed into homogeneous statistics, respectively, for example, (3.2). For example, the value *par*□ is fixed once a day, and the state assessment is controlled once a month, i.e. $\Delta t = 30$ days. Then $PS(\Delta t) = \sum_{i=1}^{30} par_i$ for the case when the statistics are homogeneous.

Let's describe the sequence of actions of block A in the form of a step-by-step algorithm *PROC FSt*.

PROC FSt.

Step 0: suppose it is necessary to estimate the state of the system at the moment t_k. In this case $t_k - t_{k-1} = \Delta t$.

Step 1: from the moment of the last estimate t_{k-1} to t_k the values $par_1, par_2, ..., par_N$ are fixed and accumulated.

Step 2: at the moment of time t_k, a statistical series of the control parameter $PS(t_k)$ is formed according to the rule:

– if the statistics of the control parameter are homogeneous, then $PS(t_k) = \sum_{i=1}^{N} par_i$;

– if the statistics of the control parameter are not homogeneous, then $PS(t_k)$ is formed into homogeneous statistics, for example, according to formula (2.1) and **Fig. 2.13**.

Step 3: the $PS(t_k)$ value is stored in a one-dimensional array or vector

$$\|PS\| = \langle PS(t_1), PS(t_2), PS(t_3), ..., PS(t_{k-1}), ... \rangle. \quad (2.8)$$

Step 4: PROC FSt.

End.

Formation of the current statistics of the control parameter $PS(t)$ is shown in **Fig. 2.14**. It is important to emphasize that the $PS(t)$ values are remembered and stored (step 3 of *PROC FSt*), because they are used in other blocks, for example block 5:

where t – the time of formation of the statistical series $t_2 - t_1 = t_3 - t_2 = ... = t_k - t_{k-1} = t_{k+1} - t_k = \Delta t$; Δt – the periodicity of the system state assessment.

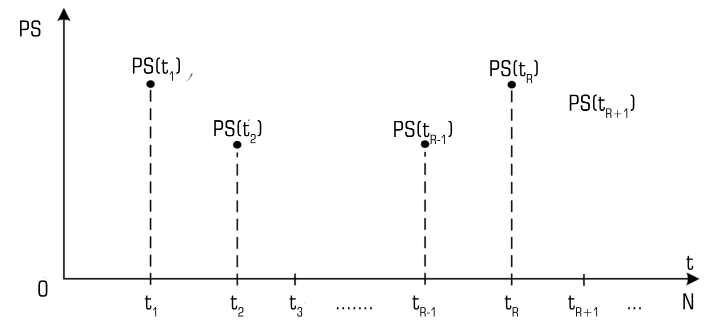


Fig. 2.14 Formation of current statistics of the system status control parameter over time

Block B "Formation/actualization of the norm".

It was noted above that the norm in the MDHSP is perceived as a process that determines the optimal mode of functioning of the system, that is, its *functional optimum*. In this concept, the norm is perceived as an interval of optimal functioning of the system with *moving boundaries*. Within these boundaries, the optimal connection with the environment and the coordinated performance of all system functions are maintained.

The input of this block is $PS(t_k)$. Then the following actions are performed:

Action 1 – the difference between the *PS* values in two measurements adjacent in time – the current and previous ones – is calculated

$$\delta(t) = PS(t_k) - PS(t_{k-1}), \tag{2.9}$$

as well as the tolerance level

$$tol = \frac{\max\|PS\| - \min\|PS\|}{6}. \tag{2.10}$$

The number six in (2.10) is explained by the "3σ rule" for the Gaussian distribution, meaning: "3σ" in the positive direction from the center of the distribution and "3σ" in the negative direction.

Action 2 – Six sets $M_{-3}, M_{-2}, M_{-1}, M_{+1}, M_{+2}, M_{+3}$ are considered. The elements of these sets are formed according to the rules (2.11):

$$\begin{aligned}
&\text{if } \delta(t) \in [0, tol], \text{ then } PS(t_k) \to M_1;\\
&\text{if } \delta(t) \in [tol, 2tol], \text{ then } PS(t_k) \to M_2;\\
&\text{if } \delta(t) \in [2tol, 3tol], \text{ then } PS(t_k) \to M_3;\\
&\text{if } \delta(t) \in [-tol, 0], \text{ then } PS(t_k) \to M_4;\\
&\text{if } \delta(t) \in [-2tol, -tol], \text{ then } PS(t_k) \to M_5;\\
&\text{if } \delta(t) \in [-3tol, -2tol], \text{ then } PS(t_k) \to M_6.
\end{aligned} \tag{2.11}$$

The sign «$\to$» means: becomes an element of the set.

Let's explain the essence of these sets using **Fig. 2.10, *a***. A set M_{-1} is a set of *PS(t)* values in the range between points "-1" and "0" of the *state* axis, M_1 is a set of *PS(t)* values in the range between points "0" and "1" of the *state* axis, M_2 is a set is a set of *PS(t)* values in the range between points "1" and "2" and so on for discrete points of the *state* axis.

Without proof, let's accept the obvious fact that a consecutive series of random PS values in each of the sets $M_{-3}, M_{-2}, M_{-1}, M_{+1}, M_{+2}, M_{+3}$ corresponds to Gauss's law.

In fact, the *pair* $(\delta(t), M_j)$ *characterizes the current state of the system*, i.e.

$$\delta(t), M_j \equiv state, \tag{2.12}$$

where $\delta(t)$ is determined from (4.1), and the index in the sets M_j= -1, -2, -3, +1, +2, +3.

Action 3 – the arithmetic mean and the standard deviation (SD) are determined in each set $M_{-3}, M_{-2}, M_{-1}, M_{+1}, M_{+2}, M_{+3}$, respectively, $\mu_{-3}, \mu_{-2}, \mu_{-1}, \mu_1, \mu_2, \mu_3$ and $\sigma_{-3}, \sigma_{-2}, \sigma_{-1}, \sigma_1, \sigma_2, \sigma_3$.

The arithmetic mean and SD are calculated using the traditional formulas for sampling $x_1, x_2, \ldots, x_N$ of a random variable x:

$$\mu = \frac{\sum_{i=1}^{N} x_i}{N}; \sigma = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \mu)^2}{N-1}}. \tag{2.13}$$

Action 4 – the sample $\sigma_{-3}, \sigma_{-2}, \sigma_{-1}, \sigma_1, \sigma_2, \sigma_3$ is approximated by a Gaussian probability density distribution of the form

$$f(PS) = \frac{1}{\Delta\sqrt{2\pi}} e^{-\frac{(PS-\overline{PS})^2}{2\Delta^2}}, \tag{2.14}$$

the reliability of which is determined either by kurtosis and skewness, or by the Pearson/Yastremski criterion γ^2. The value Δ from (2.14) characterizes the range of the functional optimum, and the relation

$$\left[\overline{PS} - \Delta, \overline{PS} + \Delta\right] = FOpt \tag{2.15}$$

characterizes the norm of the system as a functional optimum.

Block C "Is the system normal?".

Two input parameters: $PS(t_k)$ and *FOpt* respectively (2.15). This is a classic logic block in algorithm theory, which means checking the condition:

$$IF(PS(t_k) \in FOpt\ GO\ TO\ block\ A; \tag{2.16}$$

$$IF(PS(t_k) \notin FOpt\ GO\ TO\ block\ 5. \tag{2.17}$$

That is, if condition (2.16) is met (the system is normal), then management is transferred to block A in **Fig. 2.13**, and if condition (2.17) is met, then management is transferred to block 5 in **Fig. 2.13**. In (2.16), (2.17) and further in the text "GO TO" means "transition to".

Block 5 "Verifying the validity of the deviation from the norm".

From **Fig. 2.13** it is obvious that in the case when the current state of the system does not correspond to the norm *FOpt* (the output "no" of block C), then block 5 is activated.

But a single exit of the current state of the system beyond the limits of *FOpt* can be random. For example, inaccurate information, or an erroneously recorded failure, or a calculation error. Therefore, it is necessary to make sure of the validity of such an effect, because this happens quite rarely and has a rather negative impact on personnel and generally on the operation of the system. It is for this reason that block 5 "Verifying the validity of the deviation from the norm" is provided.

A procedure for verifying the validity of the state with a multi-level solution is proposed. This procedure is associated with the use of Shewhart control cards [26] in the part called "Verifying structures for special reasons".

The choice of Shewhart control charts is explained by several components of the similarity of this method to the object of the monograph in terms of: process – control of the state of products by control parameters (taken as a random variable), the law of the probability density distribution of the control parameter – the normal law or the Gaussian law.

To interpret the course of control, Shewhart used eight additional criteria, of which three are used in this work. The choice of these three criteria is associated with the operational nature of solving transport system management issues.

In the developed model, the conditions of Shewhart cards are used if the state of the system or process does not correspond to *FOpt*. Let's describe the rules in accordance with the selected three Shewhart criteria.

It should be explained that in the following the letter Δ denotes the mean square deviation of the statistics of the control parameter, respectively (2.14) and (2.15).

Rule 1: One $PS(t_k)$ *value outside the interval* $[-3\Delta,+3\Delta]$. This is a very rare event. It is known that its probability is 0.0027 (0.27% of the general population). This may be an unacceptable (catastrophic) change in the state of the system or process, an unusual environmental phenomenon, military action, destruction of infrastructure, in general force majeure circumstances. In any case, this fact requires immediate intervention depending on the result of the control.

Rule 2: Two of the three consecutive values $PS(t_k)$, $PS(t_{k-1})$, $PS(t_{k-2})$ *are in the interval* $[+2\Delta,+3\Delta]$ *or* $[-2\Delta,-3\Delta]$. The probability of such an event is 0.0428 (or 4.28%). Possible reasons: inadequate personnel behavior, cyberattacks, random emissions.

Rule 3: Four out of five consecutive values of $PS(t_k)$, $PS(t_{k-1})$, $PS(t_{k-2})$, $PS(t_{k-3})$, $PS(t_{k-4})$ *are in the interval* $[+\Delta,+3\Delta]$ *or* $[-\Delta,-3\Delta]$.

This state of affairs can be interpreted as the beginning of an exit from the FOpt state and this should concern the system management.

The criterion for checking according to the three Shewhart rules: if at least one rule works, then the deviation from the FOpt is reliable.

The sequence of checking the reliability of the system deviation from the norm based on the three Shewhart rules is presented below in the form of the PROC Shewhart procedure.

PROC Shewhart.

Step 0: the current $PS(t_k)$ value does not belong to *FOpt*.

The $\|PS\|$ elements from (3.6) are considered:

Step1: IF $[PS(t_k)\langle(\overline{PS}-3\Delta)]$ *OR* $[PS(t_k)\rangle(\overline{PS}+3\Delta]$ *GO TO step* 5.

Step 2: IF $\{(PS(t_k), PS(t_{k-1})) \in [\overline{PS}+2\Delta, \overline{PS}+3\Delta]$ *OR*

$(PS(t_k), PS(t_{k-1})) \in [\overline{PS}-3\Delta, \overline{PS}-2\Delta]\}$ *OR*

$\{(PS(t_k), PS(t_{k-2})) \in [\overline{PS}+2\Delta, \overline{PS}+3\Delta]$ *OR*

$(PS(t_k), PS(t_{k-2})) \in [\overline{PS}-3\Delta, \overline{PS}-2\Delta]\}$ *OR*

$\{(PS(t_{k-1}), PS(t_{k-2})) \in [\overline{PS}+2\Delta, \overline{PS}+3\Delta]$ *OR*

$(PS(t_{k-1}), PS(t_{k-2})) \in [\overline{PS}-3\Delta, \overline{PS}-2\Delta]\}$.

GO TO step 5.

Step 3: IF $\Big\{PS(t_k), PS(t_{k-1}), PS(t_{k-2}), PS(t_{k-3}) \in [\overline{PS}+\Delta, \overline{PS}+3\Delta]$ *OR*

$PS(t_k), PS(t_{k-1}), PS(t_{k-2}), PS(t_{k-3}) \in [\overline{PS}-3\Delta, \overline{PS}-\Delta]\}$ *OR*

$\Big\{PS(t_k), PS(t_{k-2}), PS(t_{k-3}), PS(t_{k-4}) \in [\overline{PS}+\Delta, \overline{PS}+3\Delta]$ *OR*

$PS(t_k), PS(t_{k-2}), PS(t_{k-3}), PS(t_{k-4}) \in [\overline{PS}-3\Delta, \overline{PS}-\Delta]\}$ *OR*

$\Big\{PS(t_{k-1}), PS(t_{k-2}), PS(t_{k-3}), PS(t_{k-4}) \in [\overline{PS}+\Delta, \overline{PS}+3\Delta]$ *OR*

$PS(t_{k-1}), PS(t_{k-2}), PS(t_{k-3}), PS(t_{k-4}) \in [\overline{PS}-3\Delta, \overline{PS}-\Delta]\Big\}$ *OR*

$\Big\{PS(t_k), PS(t_{k-2}), PS(t_{k-3}), PS(t_{k-4}) \in [\overline{PS}+\Delta, \overline{PS}+3\Delta]$ *OR*

$PS(t_k), PS(t_{k-2}), PS(t_{k-3}), PS(t_{k-4}) \in [\overline{PS}-3\Delta, \overline{PS}-\Delta]\}$

GO TO step 5.

Step 4: GO TO block "1-2" "deviation from the norm is reliably confirmed".

Step 5: GO TO block "5" "deviation from the norm is random".

Step 6: End of PROC Shewhart.

Block 1–2 "Analysis, database formation, identification of bottlenecks-events" is a combination of blocks 1 and 2 in **Fig. 2.13**, which is shown by a dotted line with a similar name.

Block 3 "Decision support (DS)" is an analogue of block 4 in **Fig. 2.13**.

Block 4 "Identification of significant prerequisites".

The functional structure of this block is shown in **Fig. 2.15**.

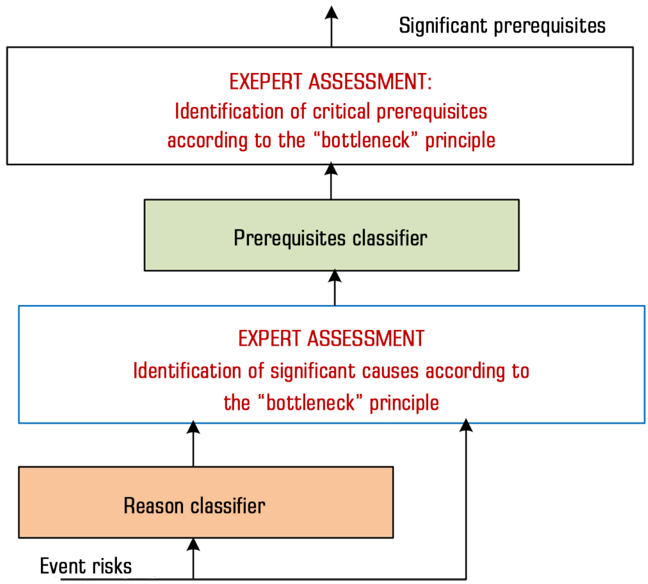


Fig. 2.15 Functional diagram of block 4 "Determination of significant prerequisites"

The input of block 4 is the bottlenecks – events from block 2 in **Fig. 2.8**. Block 4 implements the task of determining the critical or most significant prerequisites in the cause-effect relationships of the control parameter. This is implemented in two stages.

Stage 1: using the cause classifier, the reasons for each position of the bottlenecks – events are identified. And then, using expert assessment, the most significant reasons are identified. The authors have experience using the Delphi methodology to obtain expert assessment [30]. The questionnaire procedure itself takes up to one hour, that is, it is not burdensome.

Stage 2: the interaction of the cause classifiers and prerequisites is analyzed (**Fig. 2.7**). The prerequisites for each of the most significant reasons are identified. And then, using expert assessment, the most significant (significant) prerequisites are identified.

The use of expert methods is due to the absence of (as a rule) classifiers of causes and prerequisites at enterprises, a defined quantitative relationship between their elements, as well as the culture and experience of using such classifiers in analytical work. When this is resolved at the enterprise, then it is possible to do without expert assessments, that is, to detect automatically, or to conduct surveys of experts from time to time.

CONCLUSIONS

The section discusses modern approaches to the synthesis, modeling and optimization of processes and control systems in railway transport.

The application of a unified theory of self-organizing systems as a methodological basis for the study of processes and control systems in railway transport is substantiated. This approach allows to consider the management object in interaction with the environment and ensures the integrity of the analysis.

The essence of the Method for Detecting Hidden Statistical Patterns (MDHSP) is revealed, which is based on the systematization of statistics of management parameters and the identification of "bottlenecks" in the activities of transport organizations. It is proven that the use of this method ensures increased efficiency of management decisions due to the identification of hidden causes of failures and violations.

The practical value of MDHSP for managing traffic safety, the technical condition of the infrastructure and the optimization of the transportation process is shown. Its application allows to move from the statement of negative consequences to the preventive elimination of the prerequisites for violations, which contributes to increasing the level of reliability and stability of the railway system.

The concept of extended causal relationships has been developed, which takes into account not only consequences, events and direct causes, but also deep prerequisites. This opens up the opportunity to form preventive and strategic management decisions aimed at improving the organizational support of the transportation process.

The introduction of the principles of norm, tolerance and a systemic approach to the management of transport systems creates the basis for the use of intelligent information technologies (Big Data Analytics, artificial intelligence, digital management platforms). This allows to increase the adaptability of the transport system to changes in the external environment and ensure its sustainable development.

The results of the study prove that the integration of synthesis, modeling and optimization into a single methodology for managing transport systems creates new opportunities for increasing the efficiency, safety and innovative development of the railway industry.

The obtained provisions can be used in the development of new management methods, as well as in the improvement of regulatory and technical documents in the field of railway transport.

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