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DECISION MAKING CONCEPT TO CREATE COMPLEX TECHNICAL SYSTEMS

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1. The relevance of the application of decision making methods in the development of complex technical systems

Everyone constantly makes decisions in carrying out any actions from the moment of consciousness and look formation at the surrounding world. We are often faced with a choice between different ways of behavior to give a comparative evaluation. A decision making theory gives a recipe of behavior in different situations. The environment in which the person lives becomes more complex with the development of society and information technologies.

The rational decision making theory is designed to provide answers to the questions:

1) What kind of information is essential for this choice?

2) How one should compare data to draw the right conclusion?

The main feature of the rational decision is the optimality, i.e., the selected option should have the highest rating, ceteris paribus.

This simple principle to maximize profits and minimize losses is the most reasonable one in simple situations. The importance of the correct choice determines human life and destiny [1].

In case, when we deal with technical objects (technical systems), our wrong actions can lead to non-compliance with their primary purpose, the financial and temporary losses. The choice of the right science-based solutions becomes of paramount importance in the era of scientific and technological progress, the establishment of a new technological order, based on information technologies.

A whole system of measures to control and ensure quality production has been developed in our country and abroad. A new science of measuring the quality of various objects, named qualimetry, has appeared [2, 3]. This science is based on the modern methods and models of quality and technology level (TL) assessment of the products. It is developing successfully, as evidenced by a lot of articles in periodicals, and the issue of textbooks and monographs [4–8].

With regard to the special-purpose products, in the 1990s a method for the TL assessment of weapons and military equipment (WME) using the mathematical methods of decision making theory and expertise was proposed [9], which then received the application and testing in evaluating the specific WME samples [10–12]. This method, implemented in the computer technology, has caused a wide discussion among scientists and specialists of the military-industrial complex due to its simplicity, availability, reliability and efficiency of the results [13].

This article describes the features and refines the basic concepts of decision making procedures, as well as one of the approaches to the evaluation of technology level of complex technical systems (CTS) and the selection of alternatives for their creation.

2. Definition of «a complex technical system» and the basic stages of its life cycle in decision making process

Currently, technical systems tend to be complex, so we should talk about CTS, the definition of which can be given as follows: «A system is internally organized integrity on the basis of some principle, in which all elements are so closely connected with each other, that they act in relation to the environmental conditions, and other systems as being a single one» [14]. There is no formal and rigorous definition of the concept of a complex or large system[1]. Here are the main features of the system, which must be met by CTS [15, 16]. These are: the integrity and modularity of objects; the existence of more or less stable relationships between the elements of the system, but only the essential connections define the integrative properties of the systems; availability of integrative properties (qualities), inherent to the system in general, but not to its separate elements; and the organization of the developing systems, which manifests itself in the structural features of the system, complexity, and ability to maintain the system development.

The systems analysis recommends starting the process of decision making with identifying and formulating the ultimate goals, considering the problem as a single system and identifying all the effects and interactions of each particular solution, aligning the subsystems goals with a common purpose of the system, identifying and analyzing possible ways of achieving the objectives and choosing the most effective one.

One has to make decisions at all stages of the life cycle of CTS. We distinguish six life cycle stages according to «Information Technology. Systems Engineering. Life Cycle Processes of ISO/IEC 15288:2002 Systems» State Standard [17]:

– design stage;
– development stage;
– production stage;
– operation stage;
– control stage in support of the operation;
– cancellation stage of the usage and eventual mortality.

The stages may be used to build structures by which the life cycle processes are used directly for the lifecycle modeling. The scope and the precise application of the processes in the framework of the described stages and with regard to their duration depend on the changing CTS technical and business (project) requirements, defining and using the life cycle.

Table 1 shows the stages of the CTS life cycle.

Table 1

Stages of the CTS life cycle, the aim and options of decisions at the stages
in accordance with ISO/IEC 15288:2002 State Standard

Life Cycle Stages	Aim	Decision Options
1	2	3
1. Design	– Definition of customer needs – The concept research – Development of proposals for sustainable decisions	– Implementation of the next stage. – Continuation of the stage. – Transition to the previous step. – Delay in the execution of the project. – The project stoppage
2. Development	– Specification of the system requirements – Creation of the draft decision – Formation of the system – Implementation of verification and validation[2] of the system	

[1] Currently, we are constantly faced with multi-level hierarchical systems. There are three types of hierarchical systems and the associated concept of levels for the mathematical description: the level of description or abstraction; the level of complexity of a decision; the organizational level. The following terms are accepted to differ between them: «strata», «train». The system is defined by a family of models, each describing its behavior in terms of the different levels of abstraction. The levels of abstraction, including a description, are called «strata». The complex problem of decision making is divided into a family of successive simple subproblems, so that their solution will allow solving the original problem. This hierarchy is called the hierarchy of decision making layers, but the whole decision making system is called a multi-level system (of decision making). Some of the subsystems are the decision making (critical) elements. The level, which is under the influence of the other one in a hierarchical system, is called «train» (Nikiforov A. D., Kovshov A. N., Smirtladze A. G. Theory of forecasting in engineering and technology. – Moscow : Higher school, 2010. – P. 186–196).

[2] *Verification* is the confirmation that specified requirements have been fulfilled on the basis of objective evidence. Verification is a set of actions to compare the result of the system life cycle with the desired characteristics for this result in the context of the life cycle. The results of the life cycle may be (but are not limited to) the established requirements, the project description and the system itself. *Validation* is the confirmation that the requirements for a specific intended use or application have been fulfilled on the basis of objective evidence. Validation is a set of actions in the context of the life cycle of the system to ensure and provide assurance that the system is able to perform the specified functions in accordance with the objectives and in purpose-specific operating conditions.

End table 1

1	2	3
3. Production	– Manufacturing of the system – Inspecting and testing	
4. Operation	– Using the system to meet the customer needs	
5. Support	– Providing the supported system capabilities	
6. Mortality	– Storage, archiving or cancellation of the system	
7. Utilization		

Fig. 1 shows an information support (IP) of CTS concerning the WME samples, where the utilization stage is allocated [18]. The graph describes the CTS life cycle. The graph sample in relation to the shipbuilding industry is represented in Fig. 2 [19].

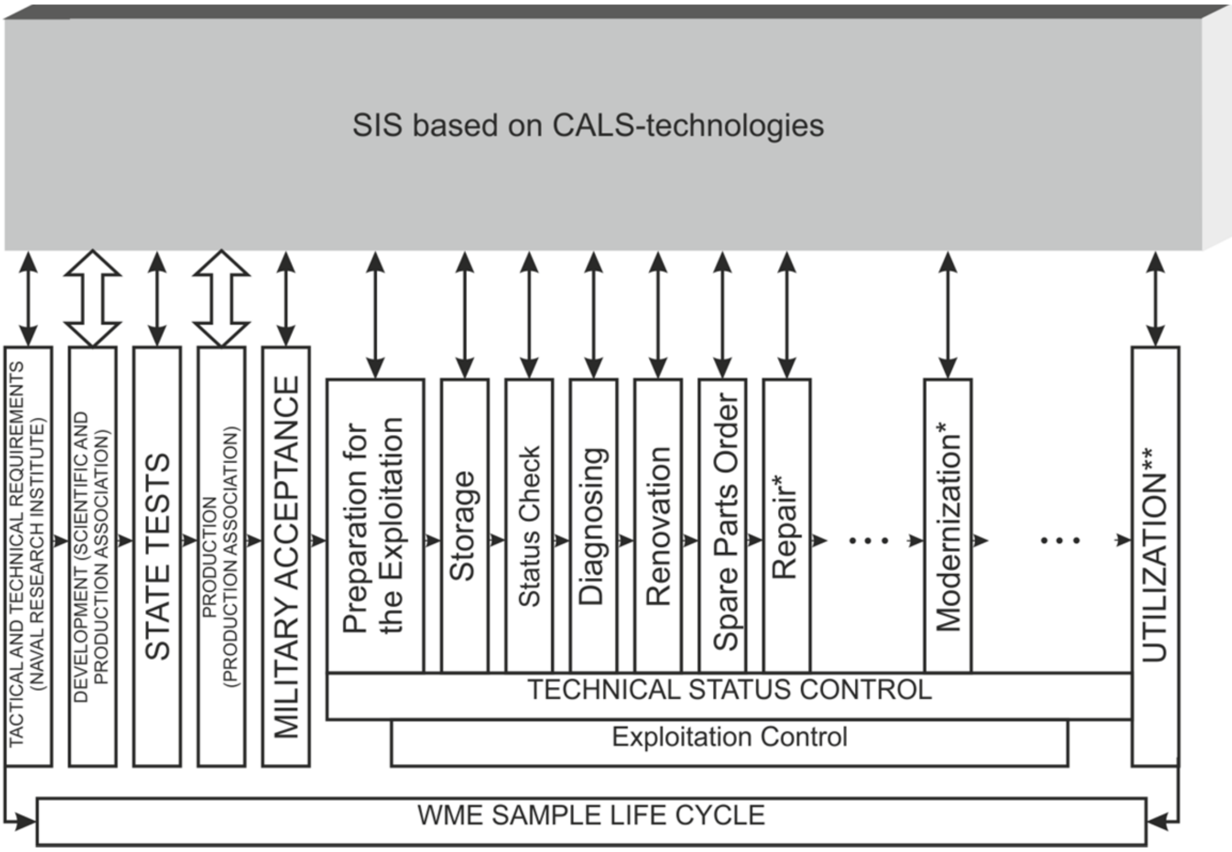


Fig. 1. The implementation of CALS-based technologies at the stages of the CTS life cycle: SIS is Single Information Space; CALS is Continuous Acquisition and Life Cycle Support; ME is Military Equipment

3. The procedure for decision making in the development of complex technical systems

Let's consider the decision making process in the formation of a technical solution. In accordance with ISO/IEC 15288:2002 State Standard, a «project processes» notion has been previously introduced, which include:

– project planning process;
– project evaluation process;
– project control process;
– decision making process;
– risk management process;
– configuration management process;
– information management process.

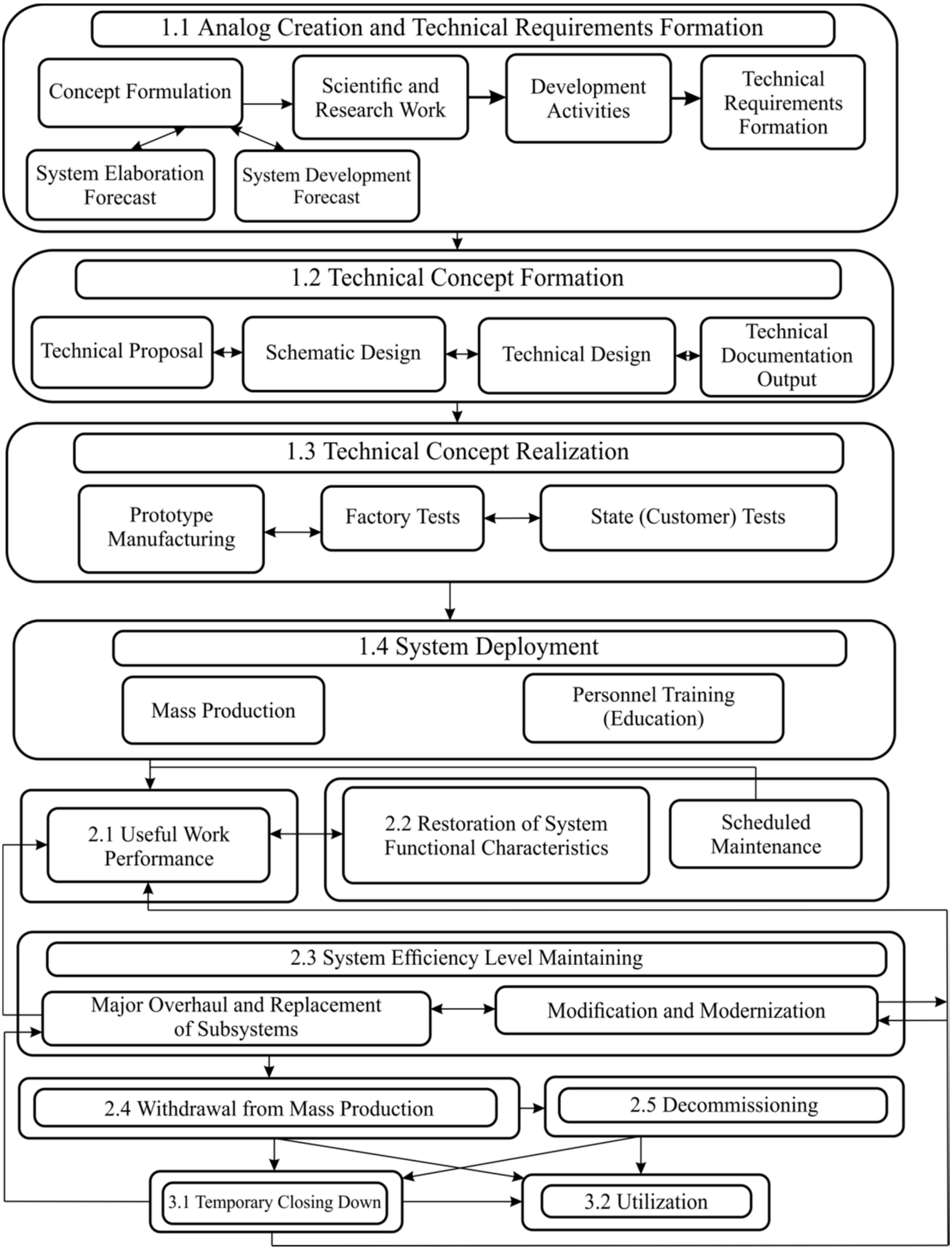


Fig. 2. Graph of the CTS life cycle

The project processes are used for the establishment and implementation of plans, evaluation of actual achievements and advancements of the project in accordance with the plans, and to monitor implementation of the project until its completion. Individual project processes can be carried out at any time of the life cycle and at any level of the design hierarchy, both in accordance with the project plans, and taking into account the unforeseen circumstances. The precision and formalization level at which the project processes are carried out, depends on the complexity of the project and project risks.

The operation research planning, evaluation and monitoring are the key processes for all kinds of control.

The purpose of the project process assessment management is to determine the status of the project. In the process, the project achievements are assessed with respect to requirements, plans and business objectives. In case of significant deviation, information on the evaluation is reported to the concerned parties for the implementation of appropriate control actions.

As a result of the successful implementation of the project evaluation process:

– indicators or results of the evaluation of working characteristics of the project become available;

– the adequacy of the roles, responsibilities and authority of the project participants is evaluated;

– the adequacy of the resources and services necessary for project implementation is evaluated;

– deviations from the planned values of the indicators of operating characteristics of the project are analyzed;

– the concerned parties are informed about the status of the project.

The systems analysis considers that the choice is decision making. However, the presented elements of the project process include «project control process» between «project evaluation» and «decision-making».

The purpose of the project monitoring process is to organize the execution of the project plan and to guarantee the implementation of the project in accordance with the plans and schedules within the project budget and guarantees to meet the technical goals.

As a result of the successful implementation of the project monitoring process:

– corrective actions are identified and performed, if the project results do not meet the planned tasks;

– rescheduling of the project is initiated, if the project's objectives or constraints have changed, or the assumptions made in the planning, were incorrect;

– transition actions from one stage or the scheduled event to the next one (subject to the successful implementation of the previous stage or event) are sanctioned;

– project objectives are achieved.

In accordance with ISO/IEC 15288:2002 State Standard, the purpose of decision making is to choose the preferred direction of the project activities among the available options. This process is a reaction of the system requests for the adoption of decisions aimed at achieving the specified, desired, or optimum results regardless of the nature or source of such requests. The alternative actions are analyzed and the course of actions is chosen. The decisions and their arguments are documented to support decision making in the future.

As a result of the management decision making process:

– decision-making strategy is determined;

– alternative actions directions are specified;

– the most preferred direction is selected;

– the accepted decision, its arguments, and assumptions are documented and reported to the concerned parties.

The decision making process is a process in which the stated problem finds its solution. A lot of publications are devoted to the decision theory. In general, the decision making process from a technological point of view, is stated in the methodological approach of Novosibirsk State Technical University, which can be represented as stages of the solution life cycle [20]:

Stage 1. Targeting.

Stage 2. Setting goals.

Stage 3. Development of decisions.

Stage 4. Making a choice.

Stage 5. Estimation of decisions.

Stage 6. Decision making.

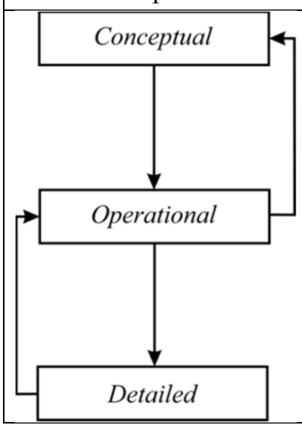
Stage 7. Implementation of decisions.

The first stage is important and decisive, as it gives answers to the questions: what problem is to be solved; what are the conditions for solving the problem; what time is it necessary to solve; what forces and means for the solving are to be used. The system goals are formulated at the second stage. The more accurate the system goals are formulated, the easier it is to choose the means of achieving them. The methodological basis of this stage is systems analysis using expert methods. In the third stage alternative options are produced, searching of various forms to achieve the goals is realized. There are different forms to generate alternatives: brainstorming, a scenario development, and business games. Choosing from a variety of alternative solutions is realized by the decision makers (DM) at the fourth stage on the basis of the formed criterion, by which one can judge the degree of achievement of the planned objectives. The criterion of the usefulness of the alternative solution can be one or a variety of features, measured qualitatively or quantitatively. To describe the goals, several criteria are often introduced, so that they better characterize the target. The criteria for the decisions selection are determined by the methods of expert analysis and mathematical statistics. In the fifth stage, the decisions are assessed on the basis of alternative solutions evaluation model, which takes into account the current situation, goals, a number of limitations, decision options by the decision maker preferences system to select the best solutions. This problem can be solved under conditions of uncertainty, generated by the external environment impact on the assessment of alternative solutions, which can be accounted with the known techniques of the probability theory. In the absence of uncertainty (in the case of certainty), the DM solve many tasks by the known methods of optimization. In our opinion, the sixth stage is the most important, where one must select a solution for the subsequent realization according to a particular algorithm, choosing the only best solution to some criterion or the principle of optimality. When making decisions according to the particular criteria (vector optimization problems), there are additional difficulties of the desired definition in terms of the DM from a variety of compromise solutions acceptable by the local criteria. If it is necessary to determine the only best solution, the set of feasible solutions is reduced to the Pareto set, and there is a search of the solution on the basis of a scheme. The seventh stage implements the actual reached decision. The implementation plan of the chosen solution should provide answers to the questions about who should something do, when and by what means. The specification of decisions can be made by executing the task problem on the work performers, the terms and the objects by the methods of network planning and management.

Decision making can take place at different hierarchical levels. There are conceptual, operational, and detailed decision making levels [21]. Table 2 shows the characteristics of each level of the hierarchy of making management decisions and their relationship with the CTS research.

Table 2

The hierarchy of decision making levels

Decision making levels	Research object	Research aim	Model	Effectiveness indicators and criteria
1	2	3	4	5
	System	Analysis of operational concepts[1]. Definition of a list of sub-objectives, tasks, subsystems, and conditions of their functioning. The system image formation	Analytical	Degree of the operation goal achievement. Suitability criterion. Adaptability criterion

[1] To achieve this goal, a purposeful activity – an operation, is necessary. The operation is a system of task-oriented actions, united by a common idea and a common goal. The concept of «operation» comprises three defining moments [21]: 1) management of human activities (DM), which organizes the operation on the basis of a rational use choice of active agents to achieve the goal of the operation; 2) active agents (technical systems and resources) that are available and used in the operation in accordance with the selected method (control strategy), and 3) other agents (systems), directly interacting with the active agents.

End table 2

1	2	3	4	5
	Subsystem	Analysis of the task implementation by the subsystems. Determination of the general image of the subsystems and means, the general requirements for the quality of their elements	Simulation	Degree of the subsystems' operation. Suitability criterion. Optimality criterion
	Element	Detailed analysis of the elements' quality	Statistical	Detailed analysis of the elements' quality

Thus, studying the basic concepts of operation, determining a list of pre-operation sub-goals and objectives of the subsystems of a complex technical system, forming of its «conceptual» image, it is necessary to solve the problem of the synthesis repeatedly and quickly through the analysis to reject the «worst» alternatives. The conceptual models are used here.

The operational level of the investigation, where objectives of the problem, the conditions of operation of the subsystem, and rational logic of transactions are identified, allows taking into account additional factors, and building a more complex model for the evaluation of the fulfillment effectiveness of tasks by the subsystems of a complex technical system. This level results in a generalized image of the subsystems and the agents to achieve the goal, the formulation of the general quality requirements of their elements. The used at the operational level models are usually realized in the form of complex simulation systems.

The level of detailed research involves the creation of detailed mathematical, physical, and natural models of elements of subsystems for analysis of their quality. Since one operates usually with actual material, using experimental design and mathematical statistics methods at this level, the models here are mainly statistical.

This three-level decomposition of the general decision making task allows establishing the viability of the given concept of operation and generates a single (system) approach to the operation and decision making process, both in terms of its objectives, and with the possibility of other subsystems and equipment. It makes it possible to assess the making decisions at the underlying levels using the known methods of operations research (conditions and objectives are clearly defined).

Scientific and technical progress gives the abundant material on the existing approaches to the creation of CTS (if one refers to the scientific and technical literature). In this case, there is an example of the organization structure of design and research, based on the experience of the creation of aircraft systems [22]. The main features of the design and research system are:

– the presence of a common goal for all kinds of work, which is to ensure the conformity between the structure of the CTS and the values of its basic parameters, on the one hand, and the tasks assigned to the projected CTS, on the other hand;

– a hierarchical system of work and the corresponding goals and work tasks;

– a hierarchical system of methods and logical and mathematical models used for the study and design of the CTS;

– a hierarchical system of performance criteria for technical or organizational solutions;

– a hierarchical system of ways to present the results, in which the results of the previous stage are the initial data for the next step.

The division of design and research work (projects) into three stages of the CTS life cycle (planning, engineering, design of the CTS elements) is, from a different point of view, the division of design and research work into three hierarchical levels that are different in design research goals, formulation of the problem, the proposed methods and models, the research results.

Diagramming of a systematic approach to performance of design and research work, as well as the scheme of rational distribution of the tasks between the experts, are given in Table 3.

Table 3

General description of the CTS design stages

CTS Design Stages	CTS Structure	CTS Level		Design and Research Methods	Performers	
		Highest	Lowest		Organization	Basic Experts
Planning	Operational and Organizational	A higher level system	The projected CTS	Methods for systems analysis and business games	Research Institute of the customer	Economists system executive engineers
Engineering	Working	The projected CTS	The CTS subsystems	Methods for CTS synthesis and operations study	Research Institute of the customer and the performer, Experimental Design Bureau of the performer	System engineers
Design of Elements	Technical	The projected CTS	The CTS elements	Methods for technical objects design, involving operational research	Research Institute and Experimental Design Bureau of the performer	Design engineers of the CTS elements, familiar with operational research

4. The concept of the problem formulation for decision-making and the alternative selection

The alternative selection strategy, which can be based on the proposed complexes of methods, created models and algorithms in problems of management decision making, is one of the common ones in any subject area. When one creates the CTS objects, a decision maker is faced with the decision making tasks at the stages of strategic forecasting, planning, resource allocation, and the formation (synthesis) of alternative solutions. The solution of such problems is reduced to the choice of one or more variants from a given set of alternatives [22]. In order to make such a choice, it is necessary clearly to define the purpose, objectives and criteria (a set of quality indicators), which will be used to estimate a certain set of alternatives.

There are many different approaches to the formulation of the problem for decision making when selecting the CTS objects [23, 24]. Here it is one of the alternatives in relation to the criterion-extremizing choice.

Let x be some decision, possible options of which are defined on the acceptable set X. Quality of the DM decision is assessed by n scalar criteria R_j, $j = 1, 2, ..., n$, the assessment of which forms the effectiveness vector $r = r_1, \ldots, r_n$. The vector is associated with the alternative x of functional mapping $F: X \to R$, which may be given either analytically or statistically or heuristically. It is necessary to find a set of options for Y, satisfying the following requirements:

$$Y_x = \{\forall\, y \in \mid \exists\, X \in X : r(x) \succ r(y)\}.$$

It is assumed that the criterion $r(x)$ for variant x depends only on this option and does not depend on other options included in the acceptable set X.

The technology of management objectives setting in decision making in the CTS creation consists of three stages: analysis of the problem and theoretical research of the formulation of the problem, development of the concept and the creation of the complex of methods and mathematical models, as well as the organization of the testing process and the possibility of their implementation. These stages are presented in Table 4.

Table 4

Technology of setting management objectives and decision making in the CTS creation

Stages	Contents
Stage 1. Theoretical studies	System description and CTS models creation Analysis of the CTS models CTS control synthesis problem (optimization) Solution stability study
Stage 2. Creation of models	Model identification Simulation experiments
Stage 3. Implementation	Analysis of the effectiveness and implementation of the project

The choice of a method (or a set of methods) to solve the problem depends on the quantity and quality of the available information. These data are necessary for the implementation of the concept of the scientifically-based selection, which can be divided into four categories: information on the alternatives, information on the selection criteria, preference information, and information on the set tasks. It should be noted, that the efficiency indicator assesses the quantitative performance of the objective achievement, and the efficiency criterion serves as the indicator by which the most preferred alternative of the CTS is selected.

Conclusions

1. The procedure for making management decisions is quite complex and is one of the main processes in the creation of various CTS objects at all stages of the life cycle. The decision in this case, is the result of observation of the whole cycle of actions: targeting – creation of new and alternative ideas – development of reasonable decisions – estimation of possible decisions – actual decision making – implementation of decisions.

2. Creation of effective CTS objects is the selection of one or more alternatives. In order to make such a choice, it is necessary clearly to define the purpose, objectives and criteria (a set of quality indicators), which will be used to estimate a certain set of alternatives.

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Аннотация. Показано, что теория принятия решений позволяет сделать выбор линии поведения в различных ситуациях. Основное свойство рационального решения – это оптимальность, т.е. при прочих равных условиях выбранный вариант должен иметь самую высокую оценку. Этот простой принцип стремления к максимизации выигрыша и минимизации потерь представляется наиболее разумным в простых ситуациях. Однако при работе с техническими объектами (техническими системами) человеческий фактор (неправильные решения) могут привести к невыполнению их основного назначения, потерям финансового и временного характера. В условиях научно-технического прогресса, становления нового технологического уклада, основанного на новых и, прежде всего, информационных технологиях, выбор правильного и научно-обоснованного решения приобретает первостепенное значение. В рамках созданной системы мер по управлению и обеспечению выпуска качественной продукции сформировалась новая наука – квалиметрия, под которой специалисты понимают науку об измерении качества различных объектов. Данная наука основана на современных методах и моделях оценки качества и технического уровня создаваемой продукции и успешно развивается. Применительно к продукции специального назначения был предложен метод оценки ТУ образцов вооружения и военной техники с привлечением математических методов теории принятия решений и экспертных оценок, который затем получил применение и апробацию при оценке конкретных образцов ВВТ. Данный метод, получил широкое распространение среди ученых и специалистов оборонно-промышленного комплекса в силу простоты, доступности, надежности и оперативности получения результатов. Рассмотрены особенности и уточнены основные понятия процедуры принятия решений, а также один из подходов к постановке задачи при оценке технического уровня сложных технических систем и выбора альтернатив при их создании.

Ключевые слова: сложная техническая система, многоуровневые сложные технические системы, системный анализ, жизненный цикл, стадия жизненного цикла, процесс принятия решений, лицо, принимающее решение, альтернативный вариант (альтернатива), показатели и критерии эффективности.

Abstract. It is shown that the theory of making decision allows to do the choice of line of behavior in different situations. Basic property of rational decision is an optimality, i.e. the variant chosen other things being equal must have the highest estimation. This simple principle of aspiring to maximization of winning and minimization of losses appears most reasonable in simple situations. However, during work with technical objects (by the technical systems) a human factor (wrong decisions) over can bring to non-fulfillment of their basic setting, losses of financial and temporal character. In the conditions of scientific and technical progress, becoming of the new technological mode based on new and, foremost, informative technologies, the choice of correct and scientifically-reasonable decision acquires a primary value. Within the created system of measures for management and ensuring release of qualitative production the new science – a kvalimetriya as which experts understand science about measurement of quality of various objects was created. This science is based on modern methods and models of an assessment of quality and a technological level of the created production and successfully develops. In relation to production of a special purpose the method of an assessment TU of samples of arms and military equipment with attraction of mathematical methods of the theory of decision-making and expert estimates which then has received application and approbation at an assessment of concrete samples of VVT has been offered. This method, was widely adopted among scientists and specialists of defense industry complex owing to simplicity, availability, reliability and efficiency of receiving results. Features are considered and the basic concepts of procedure of decision-making, and also one of approaches to a problem definition at an assessment of a technological level of difficult technical systems and the choice of alternatives during their creation are specified.

Key words: complex technical system, multi-level complex technical systems, systems analysis, life cycle, life cycle stage, the process of decision-making, decision maker, the alternative (Alternative), indicators and performance criteria.

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