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PSYCHOPHYSIOLOGICAL PREDICTORS OF HUMAN AND SYSTEM INTEGRATION ON MODERN NAVAL SHIPS OF THE RUSSIAN NAVY

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The paper demonstrates that modern ergonomics in a man-machine combination specifies scientific-based "machine" requirements as well as man-requirements since they limit reliability of a whole system. A private company conducted a comparative study of training network operators suffering from astheno-neurotic syndrome. It has been discovered that besides usual procedure of job specification and recruiting, it is necessary to assess dominating type of behavior, perception and information processing. Compatibility of the type with work requirements affects effectiveness of mastering of profession as well as burnout and occupational health. This theory was tested in a private company when developing quality management system using Expert System For Complex Personality Analysis. Observation was held within six years. The result is that quantity of days because of illness reduced in 2.9 times. It can be said that this parameter is the objective index of human integration and properly developed quality management system in a company. The quality management system worked out in the base of Expert System For Complex Personality Analysis allows to reduce burnout of personnel and keep up their occupational health. Basing on survey results, the main profiles of operator performance were analyzed taking into account dominating type of behavior, perception and information processing. Thus, psychophysiological predictors for potential naval operators were identified. This objective is relevant in naval construction of Russia.

Key words: marine medicine, naval operators, ergonomic requirements, psychophysiological predictors, human and system integration, Expert System For Complex Personality Analysis, occupational burnout, occupational health, operating capability, effectiveness of occupation.

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> We are increasingly major not in sciences but in problems. On the one hand, it allows to delve into the phenomenon under study, on the other hand – to expand the scope of the studied phenomenon from all points of view.
>
> V.I. Vernadsky

Introduction. The rapid development of ergonomics, engineering psychology, hygiene, physiology and labor psychology testifies to the increasing role of social, physiological and psychological problem of the human factor. Problem approach to the most significant tasks of our time is the most effective. In this regard, it is appropriate to recall the words of V.I. Vernadsky in the epigraph of the article.

In accordance with the concept of the human factor in the maritime affair that has emerged in recent years, **the crew is the main component of the crew – ship – environment system**. Negative qualities and personality characteristics of a sailor are a manifestation of his individual characteristics (personal factor), as well as a product of the imperfections of the components of the ship's system. The reasons for the wrong action may be due to both the negative qualities of the sailor, and the discrepancy between the components of the ship system and the characteristics of the crew (human factor).

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[1]Predictor is a prognostic index, the mean of forecasting. The term is used in different fields:
– extrapolation function (mathematics);
– finite-difference scheme predictor-corrector for solving differential equations;
– index, factor (med.);
– independent value; predictor; extrapolator; predicted parameter (techn.);

– structural system, which function is forecasting, i.e. independent value (econ.).

The problem of the human factor is due to the fact that the technical capabilities for increasing the combat power of military equipment are now endless; they are limited only by the capabilities of the person himself. It is not by chance that the rationing theory is based on the priority of medical requirements over the technical attainability of norms. The three basic parameters of this theory are: preserving the health of personnel of habitable military equipment facilities, ensuring given level of crew performance and combat crews, and providing technical attainability of the standards determined by the socio-economic level of the state. That is why the human factor problem must be taken into account at all stages of the creation of modern and, especially, perspective ships. In recent years, issues of ergonomics gained great importance and to some extent became decisive in technology development, especially in the designing, manufacturing and operating machinery and complex control systems. This is due to the fact that in the conditions of rapid development of scientific and technological progress and the emergence of new technology, human labor activity is becoming more and more complex and tense. The description of these processes does not keep pace with real life [1, pp. 19–31]. According to statistics, the reliability of the performance of increasingly complicated functions by man-operator is reduced, therefore, increasing the reliability of the technical part of the system loses its meaning, since, the reliability of the man-machine system is also limited by the reliability of the person. Biological reorganization of the human body does not keep pace with the changes in working conditions that is the cause of a number of negative phenomena. Sometimes working in overextending conditions and in unfavorable environment, a person makes mistakes, which «price» in the modern world has shot up. In most cases, the actions of the operators are wrong not because of low qualifications, but **because of the discrepancy between the design features of the equipment and the capabilities of the person**.

High mental and general health workloads of operators of complex systems are evidenced by the following data: the human factor now accounts for 40 to 70% of all failures of complex systems engineering. In accordance with world statistics, 64% of disasters in the navy occur because of errors, called logical and moral.

No matter how perfect the technique is, ultimately its effective and safe application depends on how fully the design parameters are coordinated with the optimal working conditions of the person, **with his psycho-physiological capabilities and features**. For this reason, it becomes necessary to study the operation of machines (systems) and the activities of operators in a single “man-equipment-environment” complex.

Despite the fact that we live in the 21st century, some still perceive ergonomic requirements in a very simplified way: such as “not to assign two-meter height to the post on submarines and in tanks!”

Ergonomics is both a scientific and **design discipline** that has arisen at the intersection of various disciplines that study a person in labor activity. System scientific ergonomic research combines knowledge and methods accumulated in anthropology, psychophysiology, occupational health and safety, labor physiology and biomechanics, sociology and labor economics, technology and labor organization, engineering psychology and labor psychology [5, pp. 27–35].

Besides the information interaction, there are other types of interaction between the operator and the machine that are characterized by the operator’s working posture when servicing the machine, by efforts, speed, number of movements during the working process. Is it possible to achieve the most effective interaction between the operator, the machine and the environment? It turns out, it is possible! The use of this approach is already typical abroad.

Over the past decade, active work has been carried out on the integration of man and the system in the shipbuilding of the US Navy and several other NATO countries. A representative article in the Journal of the US Naval Engineers, 2011, No. 3, is called “It's not just hardware and software! This is the integration of man and the system on the submarine of the US Navy” [6, pp. 1–10].

The authors of the article, Patricia Hemburger, David Miskimens and Scott Truver, wrote: “Until recently, the Fleet's approach to the design, construction and acquisition of sophisticated weapons systems did not fully or partly include the human warrior as an integral part of the combat system. Fleet preferred to treat systems as a combination of hardware and software. The results often turned out to be less than optimal opportunities and led to a high life-cycle cost, and sometimes to the non-fulfillment of combat tasks.

There was no awareness of the fact that the “system” includes not only the hardware and software (s/w), but also the people who often operate them working in overextending conditions, maintain the hardware

and software in the warfare area and ashore, and most importantly, who sometimes have to make a decision in a split second with fatal consequences reaching the international level.
The main problem is that, until recently, systems were rarely developed specifically for military personnel who would manage these systems and keep them in good condition. This led to increased costs for the service life, reduced combat capabilities, and sometimes to the non-fulfillment of combat tasks.
For this reason, the US Navy included in their projects, although at first and not quite consistently, **human-systems integration (HSI)**, i.e. specialized, formalized applied discipline, essentially representing **the unity of system designing and the science of human behavior**. The primary tasks of the US Navy HSI engineers are the following: the safety, interconnection and operational efficiency for people who live among these systems and instrumental complexes and manage and maintain them in good condition.
The primary goal of HSI is to influence the design and construction of the system during the research, development and procurement process as early as possible, taking into account human capabilities and limitations of human capabilities, in order to ensure high overall efficiency at a minimum total cost of ownership. HSI ensures that these goals are achieved by developing systems taking into account human operators to improve overall efficiency by maximizing the psychological, physiological, sensory factors of a person's quality of work. Thus, HSI allows to increase focus on the fact that **"man is the main element of all operating systems"**.
Implementation of HSI required to involve new companies with unusual counterparties, such as manufacturers of acoustic equipment BOSE, developers of computer games, creators of monitors, as well as physiologists and psychologists. This approach was the most productive when creating the Virginia nuclear submarine (SSN-774) - in the course of implementing the program of creation a class of next generation nuclear-powered submarines.
This approach is also fragmentarily used in the Russian Navy. GOST RV 04/29/004-2004[2] requires to specify ergonomic requirements for the types (subspecies) of operator activity at the stage of technical design of the sample when creating a system of forming and maintaining the required operator performance. Ergonomic requirements for types (subspecies) of operator activity are specified in the list of professionally important qualities (PIQ) containing the psychophysiological and psychological characteristics of a human operator, including the socio-psychological characteristics, necessary to perform functional duties. The list of psycho-physiological characteristics of the type (subspecies) of operator activity should determine characteristics reflecting the following basic human abilities: sensory (sensations); perceptual (perception); attention (attention); psychomotor; mnemic (memory); thinking; imaginative [visuality (imagination)]; verbal. At the same time, it is necessary to emphasize that at all stages of creation of ships, simplification and ignoring the requirements of GOST standards still prevail.
Analysis of the results of numerous ergonomic examinations in the process of creating (designing and building) of Navy ships in recent decades has shown that a preliminary assessment of operator workload and possible values of time, accuracy and reliability quality indicators of perfomance of tasks assigned to a personnel **is unusable in such a complicated ESS as a ship, if applied to a human operator.**
According to GOST RV 29.04.004-2004 and GOST RV 29.04.005-2005, at the stage of implementation of a technical project, the head executor does not conduct job studies and does not reveal:
- leading operations and actions in the activity with an assessment of permissible time limits for their implementation;
- volume and preferential methods of information processing and taking a decision;
- load of analyzers;
- involved psychological and physiological functions and processes;

[1]GOST RV 29.04.004-2004 SSETO "Operator activities in pieces of armament. Classification, general ergonomic requirements and evaluation methods", approved and came into force by decision of State Committee for the Russian Federation for Standardization and Metrology of 9 March 2004 No.118-st. Introduction date July 7, 2005.
[1]GOST RV 29.04.005-2005 SSETO "Professiograms of operator specialties. The order of development and content requirements", approved by decision of Federal Technical Regulation and Metrology Agency, February 28, 2005, No.30-st. Introduction date January 1, 2006.

- the feasibility of the functions and tasks of the operator at the required level of time and their compliance with the capabilities of the person;
- physical and psycho-physiological intensity of activity.

Despite the requirements of the above-mentioned GOSTs, bureau-designers do not want to be engaged in such activities as:
- analysis of the list of designation and the schedule of manning the command stations (CS) and battle stations (BS) of the crew;
- classification of the crew with the definition of groups of operator occupations according to the classification adopted in the Navy;
- search and creation of groups of qualified experts for each group of operator occupations in the crew;
- conducting of the job research, working with experts;
- development of a set of professional study characteristics, identification of professionally important qualities (PIQ) for each group of operator occupations;
- determination of the requirements for the PIQ of the seaman specialists of operator occupation;
- if necessary, correcting of the list of designation and the schedule of manning the CS and BS of the crew;
- Development of Recommendations on the occupational selection and designation of the crew.

In 2018, the first feeble attempts of the industry to carry out an ergonomic evaluation at the technical design stage with the conducting of job research and identification of the PIQ of the operators of the Olimp subsystems were taken by the Concern Morinformsystem-Agat JSC and revealed their complete helplessness in the above-mentioned issues.

It is essential to correct this situation, otherwise we may fall behind in the military shipbuilding from our competitors on the global stage forever. Taking into account the lack of personnel qualified in matters of professiography, it is advisable to use the latest well-proven domestic development - Expert System For Complex Personality Analysis (ESCPA, patents: 2473308[4] and 149593[5]).

Materials and methods of the study. We carried out a study of operators under training in the course of KNIR "Professional" that was assigned by the General Staff of the Armed Forces of the Russian Federation. An assessment of predominant type of behavior, perception and information processing of operators (n=85) and assessment of group of occupations (specialities) – telegraphist, radio telegraphist, telephonist were conducted. The assessment was held using Expert System For Complex Personality Analysis. During the study the training operators were assessed upon an external criterion of training success and mastering the occupation. Then, profiles of personality and profession were built. Thereafter, a distance (per unit) between points of personality and position, as well as angle distance (in degree) between them, was evaluated.

From the point of view of compliance of personal traits and qualities of operator with the requirements of occupation (PIQ for occupation), the procedure is clear and well developed [4, pp. 115-122] although the current constantly accelerating development of science and technology introduces significant changes in the activity and the formation of new automatic workstations (AWS) and, as a result, specifies new requirements for operators. Another problem is a professional burnout of specialists that affects their professional health maintenance. It is often the case that an operator was chosen by corresponding PIQ but after a while, his professional burnout happened. Whereas, time and material resources were spent on his selection, training and coaching in the course of the professional activity.

The assessment of impact of person internal stress that occurs while on duty and is recognized using Expert System For Complex Personality Analysis was carried out during the study in the Clinic of Diseases of Nervous System of S.M.Kirov Military Medical Academy [3, pp. 41–46].

Patients in the age from 25 to 50 years diagnosed with "asthenoneurotism" (F48.0 according to ICD-10) were examined in the study. 31 patients were enrolled. A length of employment of enrolled was from 8 to 37 years, main professional groups: document controller, record keeper, teachers, accounting expert. Patients were divided into two groups.

[1] Patent 2473308. RF, IPC A61B5/16. Method of assessing the prevailing type of personality (variants) [Patent] / Bilyi A.M., Sysoev V.N.; publ. January 27, 2013. Bulletin no.3.

[1] Utility model patent No.149593. RF, IPC G06N 5/00(2006.01) G06Q 50/22 (2012.01) " Expert System For Complex Personality Analysis (ESCPA)" [Patent] / Bilyi A.M., Sysoev V.N.; publ. January 10, 2015. Bulletin no.1.

The first group included patients with asthenoneurotism caused mainly by factors of professional activity namely discrepancy between personality and professionally important qualities for an occupation that was identified in the course of discussion and analysis of personal data.
The second group included patients with asthenoneurotism caused other factors such as wrong motivational attitudes, severe course of main disease ("the control group").
5182 patients were enrolled in the study (Table 1).

Table 1

Description of selection

Description of selection	Number of enrolled
Auditors of training course that took operator training course	146
Clinic of Diseases of Nervous System	36
Private institution	5000
Total	5182

The age of examined was from 18 to 73 years, just over 50% — male. 6809 observations was conducted (Table 2).

Table 2

Observational technique and number of observations

Name of observational technique	Number of observations
S-test	146
Technique «Sense of rhythm»	146
Technique «Power of nervous system»	146
Technique «Regularities»	146
Alphanumeric technique	146
Cattell personality questionnaire (16 FLO, Form C)	146
Multi-level personality questionnaire "Adaptibility"	146
Questionnaire of formal-dynamic qualities of personality (QFDQP, Rusalov V.M.)	146
Eysenck Personality Questionnaire	95
Personality assessment according to Expert System For Complex Personality Analysis	5182
Assessment of activity profile (job specification) using ESCPA	7
Classic job specification	7
Questionnaire for assessment of astenoneurotizm	36
Sickness certificate	314
Total	6809

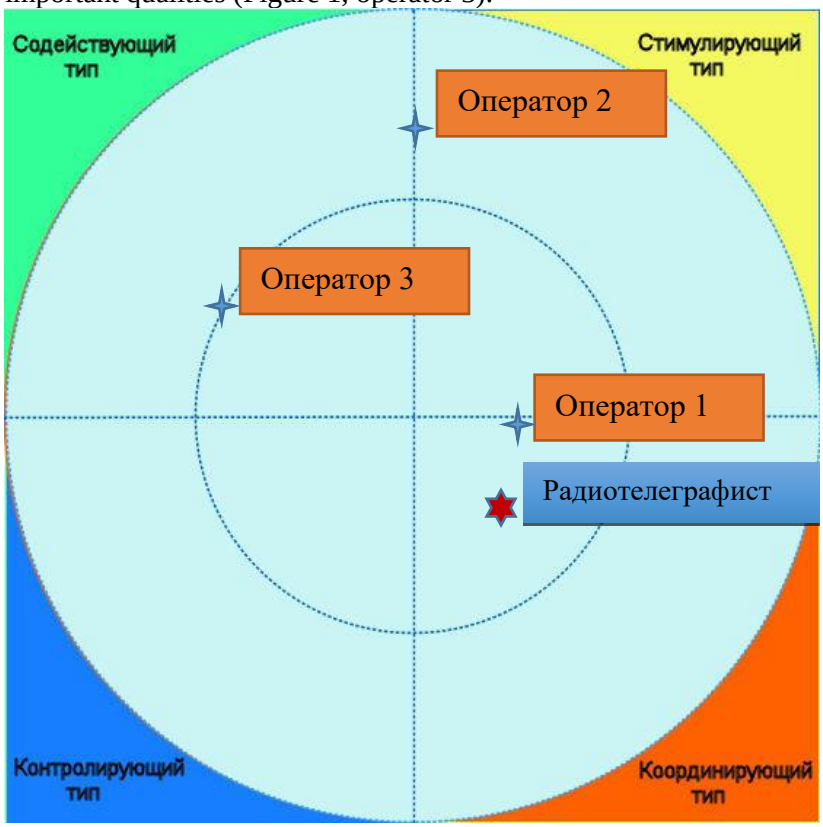
The assessment of observation results was conducted using MS Excel, Statistica, 1C Total Enterprise Management, MySQL software.
Results and discussion. The following regulatities were revealed: points that represent personality in "successful" operators are arranged closer to the point that represents occupation (specialty) per unit as well as in degree (Table 3).

Table 3

Distances between points representing assessment of a personality and a position (specialty) in "successful" and "unsuccessful" operators

Parameter	Successful (M)	Unsuccessful (M)	P
Distance per unit	2.25	6.83	<0.000001
Angle distance in degree	19.4	154.6	<0.000001

It is essential to note that it is necessary to assess an angle distance either as a distance per unit may be short but points may arrange in the contrary types. In this case, a person possesses contrary qualities to master a profession (specialty), in other words, the person doesn't have necessary professionally important qualities (Figure 1, operator 3).



Содействующий тип	Promoting type
Стимулирующий тип	Stimulating type
Контролирующий тип	Controlling type
Координирующий тип	Coordinating type
Оператор 1	Operator 1
Оператор 2	Operator 2
Оператор 3	Operator 3
Радиотелеграфист	Radio telegraphist

Figure 1. An example of graphic comparison of assessment of prevailing behavior, perception and information processing (operators 1–3) with assessment of position (the radio telegraphist specialty) according to Expert System For Complex Personality Analysis.

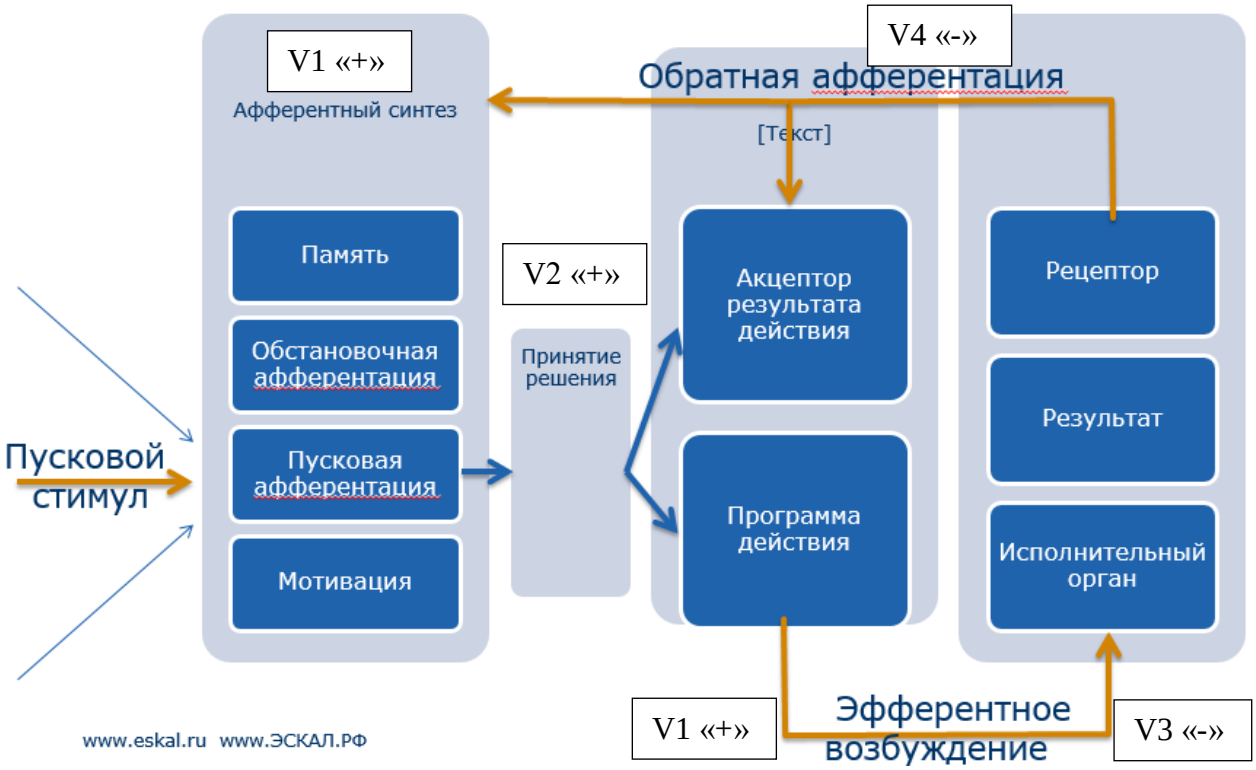
Given this, it follows that the more inclined the person is to the held position (specialty), the more effective is his activities and the less internal efforts is required to master a profession and to be succeed in further work on this position.

According to the results of observations in the clinic of nervous diseases, it was revealed that the 1st patient group had a higher level of internal stress (0.25±0.33 points) in comparison with the 2nd group (–0.72±0.13 points). The differences are statistically significant at $p<0.001$.

Thus, the internal stress, as assessed according to Expert System For Complex Personality Analysis, that is induced in a person in the course of realization the required type of behavior, reflects the degree of compliance of personality and qualities of a person with professionally important qualities for a position. The less personality and qualities of a person compliance with professionally important qualities for a position, the higher internal stress intended to the realization the required type of behavior is revealed in a person. In course of time, this stress may lead to a reduction in person efficiency, quicker forming of professional burnout (PB) in specialists. With further preservation of such a situation, against the

background of reducing in functional stores of the body, psychogenic-induced disorders may occur and career longevity may reduce.

It has been established that each of prevailing types of behavior, perception and information processing according to Expert System For Complex Personality Analysis has its own functioning features when solving managing tasks in correspondence with the theory of functional systems of Anokhin A.P. Thus, there is positive correlation relationship with “Afferent synthesis” and “Efferent excitations” for the "coordinating" prevailing type of behavior, in other words, it may be said that this type perceives “triggering” and carries out “an action” as quick as possible. The "coordinating" type of behavior is defined by positive correlation relationship with “program of action”, in other words, it may be said that they find different decision options. The "promoting" type of behavior is defined by negative correlation relationship with “Efferent excitations”, in other words it may be said that the person with this type of behavior prefers preservation of a good relationship with network to problem solving. The "controlling" type of behavior is defined by negative correlation relationship with “backward afferentation” that testifies that the person with this type of behavior complies fully with the requirements of instruction (rules) in spite of that the task may be already solved and doesn’t require additional actions (Figure 2).



Афферентный синтез	Afferent synthesis
Память	Memory
Обстановочная афферентация	Starting afferentation
Пусковая афферентация	Triggering afferentation
Мотивация	Motivation
Пусковой стимул	Startup stimulus
Обратная афферентация	Backward afferentation
Акцептор результата действия	Acceptor of the action result
Программа действия	Program of action
Рецептор	Receptor
Результат	The action result
Исполнительный орган	Executive organ
Принятие решения	Decision making
Эфферентное возбуждение	Efferent excitations

Figure 2. Communication of prevailing types of behavior, perception and information processing at the solution of tasks of management with elements of the theory of functional systems of A.P.Anokhin. V1 — the "coordinating" type, V2 — "stimulating", V3 — "promoting", V4 — "controlling".

Deming cycle — «PDCA» (plan-do-study-act) is known in quality management system (QMS). It is a cyclic-repeated decision process used in quality management system. PDCA represents a simple plan of action for a chief for process management and goals achieving. The cycle starts from the planning and ends with plan correction to archieve the goal.
Comparing ESCPA structure with functional system of Anokhin A.P. and Deming cycle (plan-do-study-act), we prove that they are practically identical. That's grounds to estimate QMS procedures according to ESCPA assessments, group them by the most effective type of behavior, as well as, sort out candidates and form a personnel reserve. Such approach significantly increase personnel efficiency index.
The hypothesis was tested in a private company with total staff upward of 5.000 people in the period from 2008 to 2013 in the course of implementation of QMS using Expert System For Complex Personality Analysis. System efficiency was assessed by the number of sick leave days per 1000 people by year and by month in the period from 2008 to 2013. It was found that an average number of sick leave days after the system introduction reduced in 2.9 times. Number of sick leave days till (2008-2010) and after the system introduction (2011-2013) by year and by month are given in Table 4 [2, pp. 191–196].

Table 4

The number of labor losses in days by year and month till (2008–2010) and after (2011-–2013) introduction of system, per mille

Parameter	Till system introduction	After system introduction	p
Number of labor losses in days by year	14,090.94	4,802.67	$p<0.05$
Number of labor losses in days by month	1,174.25	411.66	$p<0.001$

Thus, in order to preserve professional health and prevent professional burnout of operators, it is necessary to assess the requirements of the activity, the prevailing type of behavior, perception and information processing of the operator in order to identify the level of internal stress in the operator in the process.
According to the main function performed by the human operator to achieve the goals set for the human-machine system (HMS), the human-operator activity is divided[6] into:

- regulating (manipulating);
- controlling (correcting);
- technologic (operational);
- research (creative);
- managing (organizational);
- combined.

The predictors of performance in an activity and reducing the risks of professional burnout can be defined taking into account the prevailing type of behavior, perception and data processing according to ESCPA.
Thus, predictors for regulating (manipulating) activity of operator of man-machine system will be located mainly in the "coordinating" type sector, for controlling (correcting) activity – in the "controlling" type sector; for technologic (operational) activity – in the "assisting" type sector; for research (creative) activity: under searching for decision – in the "stimulating" type sector; under organization of research work - in the "coordinating" and "controlling" type" sectors; under an in-depth analysis of observation results – in the "assisting" type sector, for managing (organizational) activity – will be located mainly in the "coordinating" type sector, as well as, with passing into the "controlling" type" sector (see Figure).

Conclusion. Expanding the capabilities of ship equipment with uncompensated increasing the effect of unfavorable factors on seaman body will not allow to achieve a required performance of navy specialists, new samples of weapons and equipment at all and reduce navigational safety. Implementation of ergonomic requirements will provide the adequacy of workload to functional capabilities of the person,

reduce the level of extremeness of factors that influence him, maintain the human performance at a given level, preserve acceptable functional state and therefore, prevents the development of mental stress state.
During the past decade, the work on integration of man and a system is in progress in the U.S. Navy and many others NATO countries. Different specialists such as naval engineers, psychophysiologists, engineer psychologists, ergonomists, specialists in occupational physiology and biomechanics contribute to a process. There is no such thing in the native shipbuilding. In order to solve that long overdue problem it is necessary to see the problem at first. Intention of military authorities as well as regulatory support, proper institutional, strong staff, methodological, logistics support are also essential to address the issue.
The present day a human factor serves as economic reality: the state experiences 30-40% losses of ship equipment losses due to professional and psychophysiological unreliability of personnel. Therefore, we may surely predict the increasing of state and social significance of accounting the human factor at all stages of engineering and forming as well as in the process of operating of ship equipment.
The main directions for improving reliability of human factor in the Navy are the following:

1. Aptitude screening;
2. System of medical treatment measures intended for health maintenance and performance of marine specialists;
3. Grounds for medical technical decisions aimed at complete account of human capabilities and limitations during the development of new ship equipment.

Inference.

1. Basing on experimental research and work activity experience it was revealed that in the definite field (profession) the ergonomic requirements are developed for newly designed types of work equipment, contents of working process, conditions and organization of its introduction as well as for measures for professional selection and specialists training. Modern ergonomics in the "human-machine" system means not only scientifically-based machine requirements but also requirements to a person as that particular requirements limit the reliability of the whole system. It is of great importance for military shipbuilding in Russia.
2. Job research isn't conducted and preliminary professiograms and psychograms of specialties (positions) necessary for professional selection and crew designation are not developed at the stage of technical design basis (especially, at the stage of ergonomic evaluation of AWP of operator and group of tested ergonomic indices).
3. The more in-depth assessment of the personality and abilities of an operator as well as assessment of activity requirements corresponding to the preliminary type of perception and processing of data are essential for preventing the professional burnout and career longevity maintenance.
4. The main factor causing the professional burnout development and resulting in reducing of professional health is the level of internal stress of an operator that came up in the working process while attempting to meet the activity requirements.
5. The more fully and successfully approach to assessment of internal stress in operator in working process taking into account his personality and abilities and activity requirements taking into account managing systems of Anochin A.P. and activity description by Deming is presented in Expert System For Complex Personality Analysis.
6. It is essential to conduct the optimization of job research given the uprising of newly factors such as:

- quick uprising of new professions (positions);
- lack of qualified experts for assessment in new fields of activity;
- difficulty in understanding by activity experts specific terms in psychology and psychophysiology [1, pp. 19–31].

7. At modern stage of national military shipbuilding it is necessary to proceed to full scale engineering development of professional activity of naval specialists in complex integrated ship managing systems at AWP of operators.

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