ON INTERACTION OF ELEMENTS IN THE SYSTEM "MAN – NAVIGATING BRIDGE"

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Abstract It is a generally accepted fact that the principal trend in the process of the improvement of means and methods of navigation nowadays is the transition from the automation of separate devices and operations to the complex bridge automation i.e. the creation of the integrated bridge monitoring and control systems (integrated navigation systems INS).
These systems are aimed to decrease the working load on the watch officer, to provide him with the necessary information for the fulfillment of the timely and effective actions in the quickly changing conditions of navigation. They facilitate the change of the human functions on the bridge: the watchkeeper turns into an operator who has to interact not with the objects of steering and control, but with their information models helping him to form his situational awareness. If formerly a watch officer had to effect all the measurements and calculations, necessary for the safe navigation and was able to a certain degree to form a judgment concerning the reliability of the results, nowadays he has to rely on the automated devices and often has no chance to verify their readings in an alternative method.
However, the navigation system may function erroneously, the watch officer becomes aware of that somewhat later. Apparently furnishing the ships with costly modern navigation facilities has to give certain advantages i.e. to improve the safety of navigation.
However, the practical experience shows that the improvement of the navigational aids does not result in the reduction of the accident statistics in shipping. Moreover, we may even see a growing tendency of their increase.
The investigation of some accident cases and the latest research results of the prominent maritime scientists prove that the causes of the incidents and accidents are often different failures of the interaction in the system 'watch officer – INS". It appears that as a result of a high level of bridge automation, a new factor, negatively influencing the safety of a ship arose, which should be properly investigated and taken into consideration both by the manufactures, the users of the navigation equipment.
Some aspects of the above problem and measures to be undertaken to lower the probability of failures are discussed in this paper.

Keyword :

The general direction and the principal trend in the navigation art development nowadays is the creation of the integrated systems for the information provision of the watchkeeping personnel with the most important data concerning the operation of the key devices and processes.

The bridges of modern seagoing ships are overfilled with numerous instruments, indicators and controls of the ship movement parameters and they actually resemble cockpits of modern airliners.

Such electronic complex is aimed at the solution of the problems of navigation, radio communication, control of the technical devices and its interaction with the human navigator forms the human-machine system of ship moment control. The principal purpose of this system is to render the information support to the watch officer by providing him or her with sufficient in

number and properly presented data, necessary for decision-making. Furnishing the ships with modern navigation systems is also purposed to lower the working load on the watch officer, to set him free from some routine operations, to enable him to devote more time to the observation of the surroundings and to take timely measures for the prevention of the dangerous situations. Nevertheless, according to various data 70-80 percent of all accidents are referred to the human faults, and the considerable part of those is the consequence of the faulty decisions and not enough grounded actions of navigators.

The latest experience of navigation proves that the improvement of navigational means as such did not result in the reduction of the number of accidents; moreover lately there is even a tendency to its growth.

The accidents at sea became much more serious and dangerous than those that had happened two decades before. The investigation results of the accidents at sea give clear evidence that only very few of them were caused only by technical failures, the causes are mostly combined ones: machines + people. In other words drawbacks and weaknesses, inherent in the personnel and the technical devices of ships which become especially apparent in the process of their interaction, in the complicated condition of ship operation are considered to be the main causes of the disasters at sea. But still the priority role belongs to people, who not always adequately and purposely use the resources, means and methods of the effective actions aimed at the prevention of dangerous situations and accidents, which are in their disposal. A new actual problem arose: the provision of the effective interaction of the elements of the (man-machine) complex, the successful solution of which should facilitate the safety of navigation. This article is devoted to the discussion of some aspects of this problem.

First of all it is necessary to note that the sixties of the last century marked the beginning of the essentially new stage in the ship control arrangement – the transition from the automation of separate devices, processes, operations and technical components to the complex automation of a ship as a whole. This approach considerably influenced the human functions in the process of ship control, the character of the human interaction with the ship and the technical means and an individual position as a member of the crew. The principal cause of the above is the separation of a man from the technical means, as the objects of control. Now he interacts not with these objects directly, but with their information models.

Due to the automation in the ship navigation process a more adequate information model is presented as a result of the synthesis of the information presented by the sensors, characterizing the current position and the movement parameters of the ship as well as the navigation conditions. Correlating the above data with the ship control problems at the current moment, the navigator makes a decision aimed at the safety of navigation. In other words the navigator on the bridge of a modern ship has turned into an operator, the essence of whose activity consists in the interaction with the integrated navigation system (INS), the ship and the surroundings by means of the information models and the controls.

A human operator is regarded as a component of the control system providing the processing of the information and decision-making. The reliability and the efficiency of the man-machine system is to a considerable degree attributed to the professionalism and the psychological qualities of the navigator. The more complicated the ISN becomes, the higher are the requirements to the operator's qualification: his knowledge, experience and his skill in manipulating the data of the system with the purpose of the safety of navigation provision.

The investigation effected in aviation and nuclear power engineering shows that not a single man is able impeccably perform his duties all the time. Any man apprehends and acts with a certain quantity of information. If the quantity of the signals he has to receive exceeds a certain limit, the process of selective reception of information starts. As a result a man performing a certain task makes one of the following four of mistakes:

- Action omission mistakes – the man does not perform certain actions absolutely indispensable under the circumstances;
- Action mistakes – the actions performed erroneously;

- Sequence mistakes – the actions are performed in a wrong succession;
- Time mistakes – the actions are not timely performed.

All the above is often characteristic of watch officers performing multiple functions on the bridge necessary for the ship control.

The practical experience shows that a certain data array related to the internal and external information is absolutely necessary for making effective decisions in the ship control process in different situations. There is a conception "informational necessity" i.e. a certain information amount necessary for the solution of a specific problem. Both the surplus and the deficit of information negatively influences on human abilities of the man making an important decision. The first extremity causes tension, difficulties with the choice of the necessary data in the abundance of information, loss of time and, as a consequence, delayed or improper actions.

The deficit of information may cause the erroneous estimation of the situation and consequently mistakes in the choice of actions. In the ideal case it is desirable to have the quantity of information exactly necessary and sufficient for the achievement of the specific purpose. In practice a watch officer is doing his best to approach this condition addressing the information sources he regards (on the basis of his knowledge and experience) as necessary to satisfy his information needs under the circumstances. It is not an easy task to make a proper decision in the complicated conditions of navigation having deficit of time for decision making when drawbacks and errors may cause serious consequences. According to the Polish researcher T. Olchovy about 40 per cent of ship disasters in the second part of the 20^{th} century were caused by the lack or unreliability of the information available to the persons making decisions. It is also worthy to mention that the remarkable role was played by the design and poor disposition of the information sources of the bridge i.e. the disregard of the ergonomic requirements to designing and furnishing ships. For instance as it has become known the disaster of the tanker "Torry Canyon" near Scilly Isles was to a certain degree caused by the improper disposition of the autopilot switch of operation modes, a number of high-speed ship disasters are attributed to the poor ahead view from the bridge.

In 2004 the American Bureau of Shipping (ABS) concluded a large project aimed at the assessment of the "human" element role in maritime accidents. (Maritime Accidents and Human Performance: the Statistical Trail). In this project the statistic data concerning ship accident rate of British, US, Canadian and Australian safety agencies were used. The analysis of the disaster causes showed that 84 per cent of them occurred through the human fault or with the human contribution. Approximately one third of them are connected with the loss of the situation awareness, inconvenient arrangement of the instruments on the bridge, inadequate operation procedures.

That is the causes of many accident cases at sea are the drawbacks in the design and furnishing of the navigating bridges of ships.

The investigation results of a number of late ship disasters give evidence that they were caused by the loss or poor interaction of the elements in the "operator – INS" complex i.e. the conditions necessary of its successful functioning. It appears to us that one of the possible ways of determining the character of the above disorders may be the system approach. T.H. Hawkins, a British researcher suggested that in data collecting in the aircraft disaster investigation process model Shell should be used which facilitates the avoidance of the important information loss and the questions "What?", "Who?", "When?" answered with the succeeding movement to the more complicated questions: "How?", "Why?". There four components in SHEL: Liveware (L) – people, personnel; Hardware (H) – technical devices, mechanisms; Software (S) – plans, programmes, manuals; Environment (E) – working surroundings. The most important and flexible component is Liveware connected with all the other ones, which affects in conjunction with them any occurring event. (Fig.1)

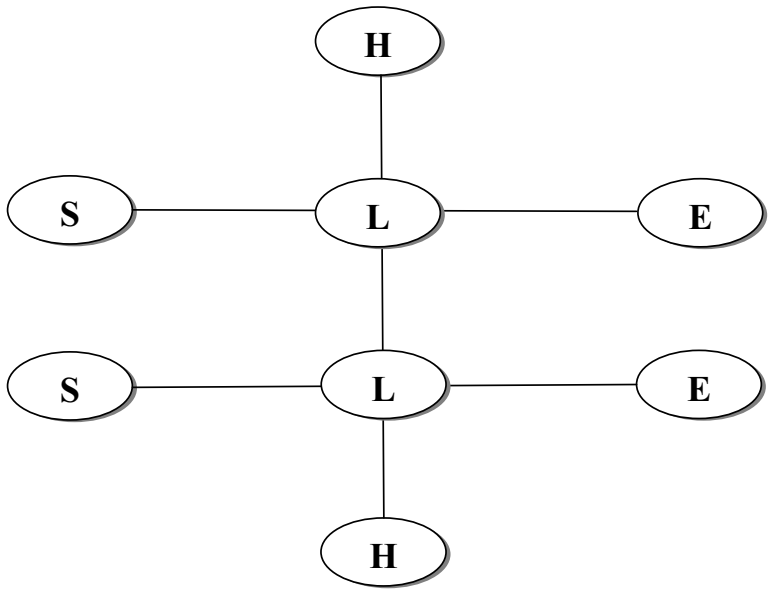

Fig.1 "SHEL" model according to Hokings

Proceeding from the above the seagoing vessel may be regarded as a compound dynamic system, comprising four interacting subsystems one of which is always a man (Fig.2)

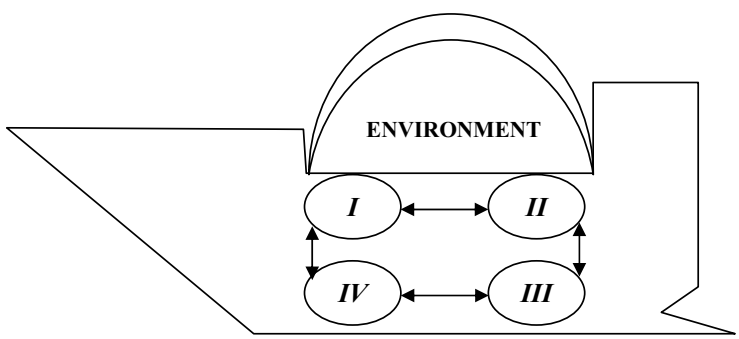

Fig. 2 Ship as a system

The following symbols are accepted for the designation of the subsystems:
I Liveware – Hardware (L – H)
II Liveware – Liveware (L – L)
III Liveware – Environment (L – E)
IV Liveware – Software (L – S)

Besides, the system as a whole undergoes the influence of the outer surroundings of the ship operation which include: sea, atmosphere, political events, terrorism, navigation equipment, instructions of the owners and charterers.

A ship as a transport facility is designed, built, equipped and manned with the regard of its destination, in order to assure the normal functioning and interaction of all the above subsystems both in the normal operational situation and in emergency. This necessitates the presence of a certain structure, elements and a proper interaction among them which requires high level of the

system organization, necessary for the safe and efficient fulfillment by the ship of its working functions.

It is obvious that in practice it is hardly possible to provide continuously in full a sufficiently high level of the ship system organization. There are too many causes of deviations in the operation of certain elements and consequently the loss of the coordinated interaction of some subsystems. Usually such undesirable events are timely noted and the measures for their elimination taken, as a result the normal operation conditions are preserved and the incidents and accidents are avoided. Otherwise the development of dangerous situations with serious negative consequences for the ship, the crew and the environment is quite possible.

Thus, in the proposed conception of a ship as a complex system, a highly organized object, the accidents and incidents on board are the consequences of the loss of the element coordination within any of the working subsystem or among subsystems or both at the same time. For instance, in the subsystem "L – H" either technical devices may fail or the people operating them may err or mistake. Malfunction of "L – S" subsystem may be the result of the crew member's unfamiliarity with or wrong understanding of the standing instructions, rules or manuals aboard; also the above documents may be not adequately prepared and badly understood. In any of these cases the consequences will be the wrong assessment, decisions and actions. The above officer/operator – INS complex is an element of the "L – H" subsystem, its functional reliability affects a great deal the safety of the ship's navigation. In its turn the reliability of this complex (faultless, unfailing operation during all the cruise) preconditions a well coordinated interaction watch officer – integrated navigation system. A well known British professional in the problem under consideration, professor J Reason demonstrates in one of his works devoted to the issues of safety the evolution of the safety precautions at sea comprising three stages: first stage, the "technical age" the principal attention is devoted to the operational and engineering methods of reduction and elimination of the dangers.

The next stage to come was "human error age" (1930-1980), when it has become evident that the people are able to disarrange the operation of the most perfect technical safety systems.

Nowadays we have the sociotechnical age, the time of understating that the accidents occur not exclusively due to the technical shortcomings or human mistakes but they are often the results of the poor interaction between the technical and socials aspects of the system. In this connection J. Reason considers that it is very important to answer the question "Where and how within the system are bad decisions translated into unsafe acts capable of breaching the system defenses? By what means may we thwart potential accident pathways by neutralizing the effects of delayed action failures?"

As if an answer to these questions lately in a number of publications appeared in the maritime press devoted to the problems of the interaction of the elements in the "watch officer – INS system". Thus Madam M. Lützhof [1], a researcher of the Linküping University (Sweden) proves, that the new navigational aids, purposed to prevent accidents often cause the contrary effect and become a factor contributing to collisions and groundings. The author of the article, a former navigation officer, licensed master with 13 years of sea experience devoted a lot of time to the research of the watch arrangement on the bridge of different ship types and conditions of navigation. Her research results show that the new technology is a barrier to that essence which the great majority of the officers consider to be their principal functions. "They feel that there is an electronic filter between them and the reality". Mrs M. Lützhof explains. Today the navigating bridges of ships are overfilled with technical devices and are very much similar to the cockpits of modern airliners and there is a growing tendency to their further integration. But the result is not always advantageous for the users. The existing trends in the bridge design and furnishing it with the navigational aids result in surplus of information, and it is not always presented in a comfortable way. (Thus some data may be presented in incompatible formats, which complicates the comparison of the information in the preparation process of the plan of actions, performed by the officers.) Sometimes the problems arise because the technology producers badly realize the seamen's working conditions. The endeavour of the designers and the producers to integrate all the functions into one system of navigation not

always meets the needs of those keeping watch on the bridge. In this connection the officers often do not use all the capabilities of the integrated system of the bridge although they are very well aware of them, but turn to the means and devices, they are familiar with: radar, compass, paper charts. The author makes a conclusion that it is a very difficult task to achieve a proper coordination and agreement between the people and machines, as the machines are not social, their actions are rigidly programmed and are not connected with the actual situation of the ship navigation (high seas, narrow, off shore). That is why sharing the work load between the watch officer and the INS in different conditions of navigation is determined on the ground of the awareness and experience of the officer and his confidence in the system. Nevertheless, the confidence is never a constant value, a systematic monitoring of the machinery and the situation are essential for the safety of navigation; the INS should not be the replacement of the common sense and at any time some methods of the ship's position determination should be used and not only the automation means. Similar considerations are expressed in the article of Captain N. Jayakody and Professor Lin. Zhengiang [2]. Their investigations demonstrate some cases, when the crew was not competent enough for the provision of safe navigation because of the inability to operate the newest equipment, installed on board the ship. The modern technology should be "friendly" to the user; it should not be too complicated with the purpose of the minimization of mistakes and the performance of the necessary correction and repair actions. Although the new technology renders a great aid in the ship control, sometimes it may act erroneously. In this situation it is very important to be provided with other alternatives for overcoming the barriers and limitations of the technology.

Mr. H. Mehrkens in his article [3] states that the ships equipped with modern navigation facilities are a great challenge to the pilots. A bridge team very often is not enough prepared to their usage, in very many cases modern equipment does not solve those problems, the solution of which has been advertized. Modern bridge designs are fitted for one man's operation with all the information displays and controls, mounted around his seat. This design type is incompatible with the accepted principles of bridge resources control such as the common awareness of the situation, mistake detection and prevention. The conclusion is that there is a growing unconformity between the modern ship equipment and the human functions in ship navigation provision. The publication of Mr. Hadnett the head of the pilots' operations in the port of London, "A bridge too far?" [4] is devoted to the issues of the improvement of the watchkeeping standards of on modern ships. In particular it is stated that all the efforts of furnishing merchant ships with electronic navigation instruments has the purpose of enhancement of the safety of navigation, the improvement of the situational awareness. Nevertheless the experience shows that the general standard of watchkeeping on the bridge markedly deteriorated. The new equipment makes the officers to be supersure of their situational awareness and it results in much greater risk than before, when the mandatory conditions of watchkeeping were the observation and safe speed of the ship. The author believes that the presence on the bridge of the diverse complicated equipment contributed to many maritime accidents. Wishing to cut the crew expense, ship-owners pass on the fundamental knowledge concerning watchkeeping to the third party, the electronic navigation instruments. The latter reached such a degree of complexity, that only a well trained and experienced operator is able to use them successfully for the purpose of safety provision. The article makes conclusion of the necessity "to return to the essence"; meaning a profound knowledge of Collision Regulations, basic navigational habits, usage of visual bearings, radar for the determination of the ship position.

Mr. S. Ahnverjarvi [5] describes in his article the cases when drawbacks of the officer and the navigational equipment may result in a casualty. The author notes that lately quite often the cause of grounding is a failure of the navigation system and control, which is revealed too late by the watch officer. As a result he has not enough time for taking the necessary actions to avoid the accident. Five navigational accidents analyzed were caused by the malfunction of the INS elements. In all the 5 cases the starting event was the malfunction of the equipment and the delayed reaction of the watch officer to the dangerous divergences in the navigation process, which could not prevent the grounding. Many of the casualties at sea are connected with the psychological factor. The newest navigational systems used on shipboard, set the watchkeeping personnel free from some operational

functions and at the same time dull the watch officers vigilance, the sense of his psychological defense and lowers the level of the subjective sense of risk.

Repeated and effective usage of these systems in various situations results in great reliance on the instruments and a sense of pseudosafety, in lowering alertness so necessary for the adequate watchkeeping, readiness to the situation changes and the immediate reaction to these changes. Consequently the probability of the erroneous actions rises. All the above proves that the failures of the proper functioning of the complex "watch officer – INS" may happen on modern ships with the navigating bridges equipped with the newest integrated systems with the consequential casualties and incidents. The main preconditions to those are:

1) Insufficient preparation of the ship officers to operating INS in different conditions of navigation;
2) Defects and faults in the systems of ship navigation and control of which the watch officer is not always informed by the selfdiagnostic appliances;
3) Improper navigating bridge design and arrangement of instruments and controls on the working place of the operator.

In this connection it is worthy to note that there are considerable changes in the watch officer interrelation with the navigation equipment formerly used by the officer: the navigation instruments and devices (sextant, chronometer, direction finder) for the purpose of navigation safety i.e. he effected the necessary measurements, calculations and could to a certain degree have his own judgment concerning the reliability of the results. Nowadays he has to rely completely on the readings of the automated devices, if there is no chance to verify them by means of traditional methods "manually". Besides, the reliability of the automation is not 100 per. cent, these instruments are influenced by outer factors such as vibration, pitch and roll, wave strokes, temperature change. They may cause failures of the INS elements, and such incidents are not very rare.

In order to minimize the probability of man-machine interaction failure, it is necessary:

1) To enhance the awareness of the navigators (knowledge and skills) concerning the usage, maintenance, potentialities and limitations inherent in the integrated systems of navigation and control by means of proper training, simulator usage, practice examples, check-up of the knowledge and skills etc. The insufficient general technical knowledge of the personnel, limiting the effective usage of modern navigational means is the cause of 35% accidents: ship officers not infrequently don't understand the principle of operation of certain devices, their operational limitations, conditions of their usage. As a result there are mistakes of the "instrument" character, erroneous calculations (measurements of parameters), and full reliance on the readings without verifying them in an alternative way, false interpretation of the obtained information. Insufficient competence of ship officers in the operation of modern INS is often the fault of those who mount the systems on board because they only superficially explain the necessary information and leave heaps of manuals and instructions (for the seamen to read). Another tendency is also marked: many navigators having no sufficient professional knowledge and experience do not realize all the advantages of the INS, i.e. do not use it to its full effectively. As the consequence of the above the costs of furnishing the ship with the newest navigation system do not bring the due effect i.e. the enhance of the navigation safety. For the purpose of the improvement of the awareness of navigators and their adaption to the new conditions of professional activity on modern ships systematic seminars are being conducted in Great Britain – SASMEX (Safety at Sea and Marine Equipment Exhibition) where such issues as "Man's role on the navigating bridge", "Interaction watch officer – INS", "Influence of the modern system on lowering casualty risks" etc. are considered. In particular it is noted that the new technology does not replace the navigation essentials that is why watch officers, especially young ones, should not fall into the trap of full confidence in the information they see on the display. Important issue is the upbringing of psychological stability allowing the officers to preserve the necessary professional qualities and skills during all the period of shipboard service. A psychologically stable operator is the one able successfully perform his professional duties in the conditions of extreme mental loads without any remarkable loss of efficiency. Man is quite a special

link in the system of ship control, he is a personality. Critical working conditions may arouse such personality qualities which have never appeared during the training process. Such a quality is of utmost importance for the ship officer, whose mental load with different level of degree of intensity and periodicity may last during the whole voyage.

2) Provide high reliability of INS elements functioning and the system as a whole, which is the duty of the system manufactures in the process of design and production taking into account the INS disposition on board (the influence of pitch and roll, vibration, changing magnetic fields, surrounding temperature etc.). It is worthy to note, that the navigation system manufacturers often do not have sufficient information concerning the conditions of their production usage ("feedback") and proceed from their own conception of what is necessary and important for the officers on the bridge. The practical value of INS would considerably grow if experienced maritime professionals were drawn in the elaboration of the ideas and design of the systems. Besides it would be possible to change the configuration (the structure and characteristics of the elements) of the INS depending on its application and the conditions of ship operation – taking into consideration the opinions and the proposals of those, who are going to use these systems in their everyday activity. The necessity of navigation systems standardization is obvious which will allow the seamen to use the bridge equipment with better confidence on board any vessel.

3) Provision of INS with full selfdiagnostic devices for timely forewarning the watch officer of any failure or malfunction of the system elements. In view of the costs of production rise this way seems hardly practicable. In this connection the special programme including the issues of diagnostics and reaction to the deviations in the automatic systems should be a part of the bridge resource management training course for watch officers. An obvious proof of the above conclusion may be the dangerous situation which occurred on cruise liner "Crown Princess", under the Bermuda flag. The ship sailed from the port of Canaveral (USA) having the destination for New York. There were 4545 passengers and crew members aboard. INS equipment was mounted on the ship just before leaving the port, which a badly experienced watch officer used for turning to the new course. However the speed of the circulation happened to be unexpectedly too high and resulted in the list 45º to starboard. The chief mate having come to the bridge straightened the liner but the consequence was the injuries of more than 300 passengers and crew members. The cause of the incident is bad knowledge of the INS characteristics by the ship officers.

Of course not every failure of the INS system brings to a casualty: the final result depends on many factors (narrows, high seas), speed of the ship, professional competence of the watch officer and the quality of the instructions on the actions in emergency situations. Nevertheless according to the "golden" rule of seafarers – "think that you are nearer to the danger", it is absolutely necessary have a chance of timely detection of any abnormality in the INS functioning. That is why the principal method of prevention of emergence situations on board ships, equipped with INS, is the systematic monitoring of the state of the navigation equipment by the watch officer, not relying on the failure alarm which due to the design peculiarities, may not inform about all possible failures in the system.

4) Improvement of the navigating bridge and layout of INS elements. In December 2000 IMO MSC accepted Guidelines on Ergonomic Criteria for Bridge Equipment and Layout), and all the concerned were informed by the Circular MSC/Circ 982. These Guidelines served as an amendment and further development of the SOLAS-74 in July 2002. The purpose of these guidelines which concern only new built ships is to provide ergonomic requirements to the bridge equipment, to the layout of the instruments and controls for the reliable and effective fulfillment of all the necessary operations on the bridge. The guidelines comprise five parts which contain the recommendations concerning the position of the officer's working place, the layout of the instruments, the provision of comfortable conditions (working surrounding), the placement of commutation means various sources of information, alarm devices, provision of conditions for visual observation etc. They also contain the list of other requirements and recommendations concerning certain systems and facilities on the bridge. Undoubtedly, observing the criteria and provisions of the above guidelines

in the processes of designing, equipping and operation of ships is to play a remarkable positive role in the enhancement of the safety of navigation. A convenient layout of the instruments and control devices of ship movement parameters, comfortable conditions for the watch officer taking into consideration all the potential requirements to visual and instrument information, unified design of different devices, provide a in great degree the adaptation of the technical means to the human inherent potentialities, i.e. facilitate the reduction a number of human mistakes and drawbacks referred to the ergonomic causes.

5) Provision of sufficient rest, physical and psychological readiness of officers taking over the watch. Elimination of all the working loads not connected with watchkeeping.

6) Working out habits of an old "cross-check" method of mistake avoidance, somewhat forgotten in our "age of automation". It is not the redundancy of officer checks up of the data acquired by means of one system using another one if the first one is suspected to err. On the contrary it is the usual navigational practice to verify the data acquired by one system by means of another one. It is very important that such data as the ship position, course, covered distance etc should be determined by two different methods.

7) Improvement of the working surroundings of the watch officer as far as it is possible by diminishing the action of the factors unfavorable for a man: noise, high/low temperature, air humidity.

8) Thematic seminars with the officers after exercises and training with the analysis of the committed errors and taking the measures for their elimination, making the necessary, amendments to the ships SMS included.

9) Improvement of the watch arrangement on the bridge, in particular by means of creation of an atmosphere of confidence, mutual understanding and support within the crew. As a result of all the above the people on the bridge should follow the principle "people to check people" which would help timely avoid or correct a mistake of any crew member, especially when sailing in complicated conditions.

In conclusion it is worthy to note the conception of electronic navigation (e-Navigation) being now under elaboration by IMO in cooperation with AICM envisages that this system among other objectives will provide an efficient interaction of watch personnel with technical facilities in the process of navigation.

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