ISSN 0554-6397
UDK 331.101.5:629.5
159.944:629.5
613.68
STRUČNI RAD (*Professional paper*)
Primljeno (*Received*): 12/2003.

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Influence of Ship Technology and Work Organization on Fatigue

Summary

The process of automation of ship systems has been increasingly taking over even some human functions of active control and work. Such a process affects the change of to date habits of ship's crew. The change of habits is marked through the repetition of routine actions of serving automation and passive or compensatory control of automated processes within which the operator has no possibility of controlling the process dynamics. This leads to inhibition of the operator's creativity due to the dominating role of technology whose work characteristics impose to the operator the function of a passive controller of the process of navigation. This finally gives rise to one the causal elements in the occurrence of fatigue. It follows that it is disputable whether there is much point in the automation of those processes that negate human element in the domain of identification and selection of essential data in the stohastic conditions of navigation which is then reflected on priority and timely decision-making. Not only has progressive introduction of automation decreased the need for human work in the domain of creativity but has also affected the reduction in the number of crewmembers on board. This has also lead to a changed work organisation as passive control and the reduced number of crewmembers at the same time meant increased work burden for the crew due to ever faster exploitation of ships. The factors mentioned above have resulted in additional occurrence of fatigue due to the lack of necessary rest period making fatigue an essential element of human error that again is a factor of 75 – 95% of marine accidents. By the reorganisation of work on board ships based on the ILO and STCW Conventions, introduction of ergonomic standards in the design of technological systems of ships management as well as appropriate education and training of seamen, it is possible to reduce fatigue.

Key words: ship technology, work organization, automation, ship system, process of navigation, fatigue

Introduction

Nowadays we are all part of a fast changing society based on an increasing rate of technology development. Fast over-development of technological innovations is present especially in the shipping industry. For shipowners and the shipping industry these new developments have resulted in rationalization of the existing ship systems and drastic lowering of the number of crew members. The main product of new technology on board ship is automation supported by computerised programmes which often exclude man from the active system of process control. The task of oversight comprises the detection, diagnosis and correction of malfunctions in the system of automation as well as within machinery itself. The primary purpose of such arrangements is to reduce the number of crewmembers required to operate the vessel. The second reason is a more precise operation of sophisticated machinery. It means that control functions of automation systems are increasingly being performed by computer. For a ship's crew these conditions mean a larger number tasks than before leading them to either physical or mental fatigue, or both. Today mariners perform a much larger number of tasks than before because of the reduction in number of crewmembers and faster ships which almost always sail, with minimum time spent in ports and minimum rest periods for the crew. Shortly, the impact of actual technology in shipping industry has caused many more tasks and a larger amount of stress to mariners than older, less profitable technology. Increasing numbers of working hours is a burden because of fast ship cargo operations and «on time» schedules, fatigued mariners. This has also lead to creation of an «organisational climate» in which mariners tend to be isolated from each other. Loneliness and boredom are in many instances the result. Insufficient challenge in their jobs caused by over–automation leads to a mismatch between what they can and what they are allowed to do. All these conditions make the basis for the development of mental fatigue as well. An attempt to shed light on relationships among mariners, ship organisation and actual ship managing technology from the aspect of fatigue will be the aim of this paper.

1. Cause and definition of fatigue

According to the National Transportation Safety Board (NTSB) – USA, «fatigue was viewed as a simple condition related to the amount of time spent working on a given task».[1] Scientific research, however, has shown that fatigue is related to much more than just the time on task. From this point of view «When we say that we are fatigued, we generally mean that we are feeling tired, either physically, mentally, or both. We may have some of the common physical symptoms of fatigue, such as sore muscles, heavy

1 David J. Wels and Jay Wels (2001) The Call For One Level of Safety Flight Time And Duty Time Issues in Air Cargo Operations, Air Line Pilots Association, International (ALPA), p.5.

eyelids, or feeling like we want to sit or lie down. Or, we may have some of the mental symptoms of fatigue such as having difficulty concentrating, becoming forgetful, or having difficulty doing mental arithmetic. Because of the variety of symptoms people experience when fatigued, and because it has not been possible to pinpoint specific physiological changes that characterize fatigue, a scientifically rigorous definition of fatigue continues to elude us».[2] In one way or another, fatigue can impair information processing and reaction time, increasing the probability of errors and ultimately leading to ship accidents. The main scientific problem with fatigue is that fatigue can not be measured. In other words «Unlike alcohol and drugs, which can be measured by, for example, blood tests, there is no unequivocal physical or chemical test that can tell us that a person is impaired to a certain extent by fatigue».[3] Parabolicly, we can say that «machismo» world of mariners recognised and at the same time denied the problem of fatigue. This can be proved by an old set phrase «Wooden ships and iron men» which supposes that the strength of the mariners must be great enough to cope with the hazardous nature of their job. Unfortunately, the percentage of casualties to which fatigue made its contribution show that modern technology and automation are stronger than the «macho» seafarer or the modern «iron man». Two studies on fatigue among seafarers are of particular relevance and prove the above mentioned. The US Coastguard study estimates that fatigue is a factor in 16% of critical vessel casualties.[4] The study also found that the fatigue contribution for groundings was 36% and 25% for collisions.[5] The other one is a Japanese study which showed higher values: 53% for groundings and 38% for collisions.[6] Actually, the problem is how to express fatigue in an objective way. In these matters science is focused on alertness which can be measured as level of mental and physical preparedness for responding to circumstances. Alertness is a derivative of fatigue and if fatigue generally is an unproductive, immeasurable part of physical and mental state, alertness is another, active, productive and measurable part of the same state. For this purpose Circadian Rhythm or biological clock is a scientific tool for measuring fluctuations in alertness during day and night. The method which is usually used is sleep on set time, or the Multiple Sleep Latency Test (MSLT) which reliably demonstrates how our level of alertness varies over the day. Boring and monotonous environment during bridge watch at night in conditions of passive control of navigational instruments could drop alertness to «drowsy» level (fig. 1).

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2 Anita M. Rothblum and Antonio B. Carvalhais (2000) Maritime Work-Rest Schedules, Fatigue, and Casualties, U.S. Coast Guard; Maritime Human Factor Conference , MITAGS in Linthicum, MD.,p. 1

3 A. Winbow (2000) Control of The Human Element, International Maritime Organization (IMO), IFAC, p. 28

4 Det Norske Veritas (1999) Great Barrier Reef Pilotage Fatigue Risk Assesment for AMSA, p. 10

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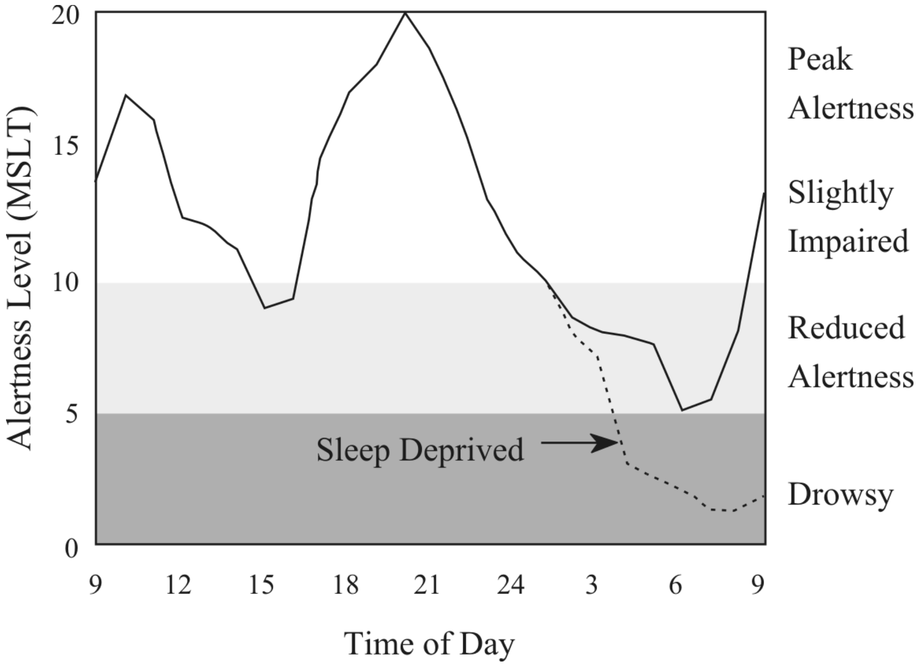
Fig. 1. Circadian rhythm



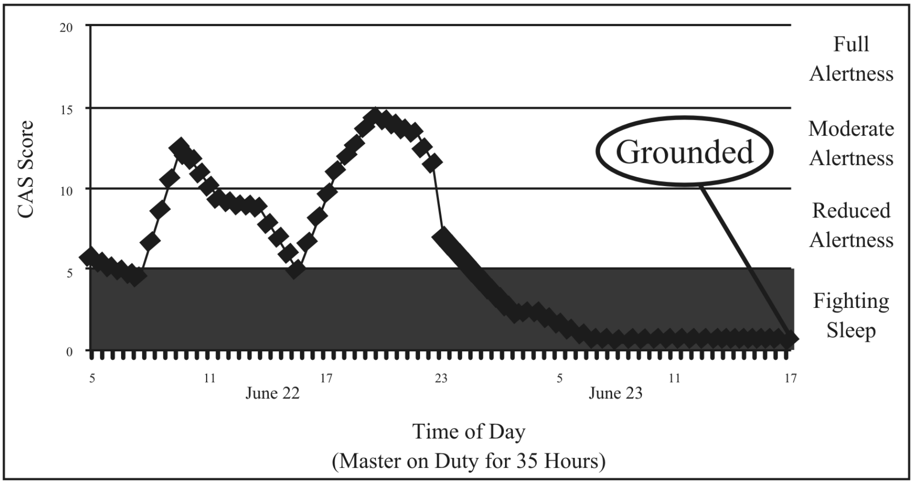
Source: Maritime Human Factors Conference, 2000, Linthicum, MD

The solid line in fig.1 shows fluctuations in alertness of well-rested people on a normal 9 – 5 work schedule. The dotted line shows how alertness dropped during 24 hours when a person stayed awake. People in this state are able to fall asleep within a couple minutes and their level of alertness falls hastily.

Circadian Technologies Inc. (CTI), active in Cambridge, Massachusetts, has developed a computer programme simulating human daily cycle of sleep and wakefulness. This programme (CAS) was used to simulate the conditions of the Master of the tanker World Prodigy before grounding. Before the grounding of the tanker her Master was awake for 35 hours and the accident happened in conditions of good visibility and calm sea (fig. 2).

CAS simulation shows that the Master coped with tiredness for almost 18 hours. In such conditions the rate of reaction is slow; person's ability to understand what happens in his own environment is drastically reduced while the so-called micro-sleep (sudden falling asleep for several seconds) is inevitable. As the simulation graph indicates, the Master was at an extraordinarily low level of wakefulness when he took over the command of the ship. In the observed period there were occasions when he managed to raise the level of wakefulness but he never managed to reach the state of complete attention. In such conditions reaction to emergencies cannot be realized efficiently.

Fig. 2. Cas simulation of tiredness of World Prodigy Master



Source: Circadian Technologies Inc., Cambridge, Mass. 2000.

Consequently, background of crew's tiredness and fatigue should be sought in factors such as Company Management with its requirements expressed by Company Standing Orders (Company policy which makes the basis of generally accepted behaviour in carrying out duties, including working hours). To the above mentioned we should also add the influence of actual technology through continuous need for adaptation as well as an increasingly long time necessary to master different novelties on coming aboard - «familiarisation – getting to know about the devices on board».

In other words, polarity occurs between requirements imposed by time, profit and technology during ship exploitation on one hand and crew's possibilities through knowledge, experience adaptation ability, on the other hand. In this relationship knowledge, experience and crew's adaptation ability are often put into relations of highly demanding conditions that win over essential human needs for rest and relax.

2. Influence of work environment and technological solutions to fatigue

Basically, the dominant share of human error in maritime accidents (75-96%)[7] is not the result of operator's error only. Many errors that occurred and brought to accidents came out of bad technological solutions and inadequate work environment.

7 Thomas F. Sanquist, John D. Lee, Marvin C. McCallum, Anita M. Rothblum (1996) Evaluating Shipboard Automation: Application to Mariner Training, Certification, and Equipment Design, National Transportation Safety Board Forum on Integrated Bridge Systems, p. 2

The effort of mastering the functioning of ergonomically inadequate equipment leads to additional, especially mental fatigue.

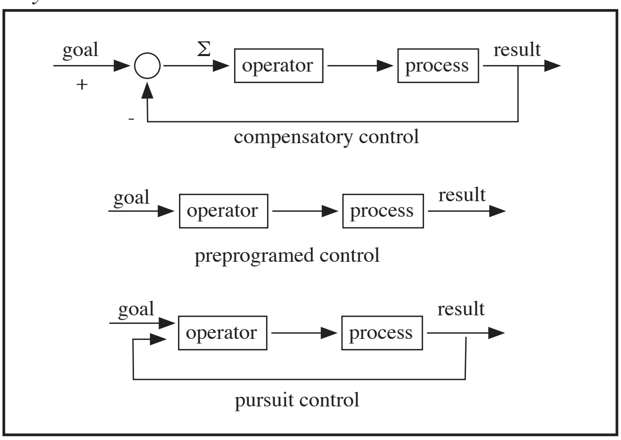
Poorly designed equipment is cited as cause in 1/3 of major maritime accidents[8]. Electronic and mechanical control systems have special influence in this way.

Normally there are three control levels: compensatory level, preprogramed level and pursuit level (fig.3). On compensatory level the difference between the real and wanted state of the controlled magnitude is limited. Control effect on this level does not contain information from which the operator could make comparison of the real and wanted state. Preprogramed control is oriented towards recognition of wanted control actions and their programming. Control of the pursuit connection allows the operator to predict output data on the basis of the input data.

Possibility to spot or in advance suppose information on the goal differs from the possibility of process dynamics control. In other words, this means that on the compensatory control level the only useful information available as real process result is a deviation that can be minimized in relation to the goal. With open control information is used to start pre-programme control level after which the process sequences take place regardless of the result, i.e. the wanted goal.

Pursuit control can be observed at the level of combination of the two formerly mentioned ones. Taking into consideration the input information in relation to the wanted result the operator can predict when the result will become visible and can also make conclusions about the proceeding of the process itself on the basis of derived parameters such as speed or previously memorized information on movement. Process output values are in the function of process input values. The ability to predict process output values is in function of human knowledge and is at the same time an active manner of process real parameter control.

Fig. 3. Control systems



Source: H. Schuffel, Some Aspects of the Future Role of Ergonomics in Ship Control, 1981, p. 9.

The term «automation» as used in marine engineering refers to arrangements which remove man from the control loop and permit unattended operation of the system. With such systems the task of the human operator shifts from participation in the control loop to one of oversight and the adjustment of set conditions.

Automation based on the compensatory level (open loop), when introduced, changes the mariner's task, which in turn may require the mariner to learn new skills in order to perform automation–assisted tasks. This means alienation of traditional mariner's knowledge and skills caused by passive control of ship systems, which leads to suppressed creativity and often denies the need for active navigational knowledge. At the same time pressure arose from a new aspect of communication among mariners and automation whose logics are usually different. In case of malfunction when prompt diagnosis is required to avoid or limit damage, a typical operator is usually not well-prepared for this task. These stressful situations quickly lead mariners to the stage of mental fatigue. The main reason is that after a certain period of time mariners perform their duties with the feeling that technology with its sophisticated computerised programmes will tell them what to do to solve the problems or indicate how to act in emergencies. In the meantime, they lose their active knowledge as well. This leads them to the phenomenon of *technology complacency* which is second reason of mental fatigue. The third reason of mental fatigue is poor automated equipment design and poor manuals which can induce the mariner to make errors. Too often equipment designers are not sufficiently familiar with maritime operations to be able to understand how maritime tasks are performed, including the types of information required by the mariner in order to make timely operational decisions. It is hardly practical in case of emergency and under fault conditions to consult the operating manual which may run to several large volumes. Important controls and information are sometimes buried under layers of menus, and data may be presented in an obscure fashion. Unfortunately ships are designed and built more or less at the whim of the shipyard or the owner in lots of one, two or possibly three with little consistency from one shipyard to another or from one client to another. The absence of clear ergonomic standards is widely present in the design of ship's equipment and navigational aids. Besides, mariners are usually not trained for responding to failure of poorly designed equipment and poor manuals, and at the same time they are usually faced with equipment with which they are not familiar because of widely variegated manufacturers without common manual standards. It means that mariners are usually focused on the problem of effective use of ship's equipment and at the same time they must be alert for any changes during navigation. That is the point where mental fatigue starts.

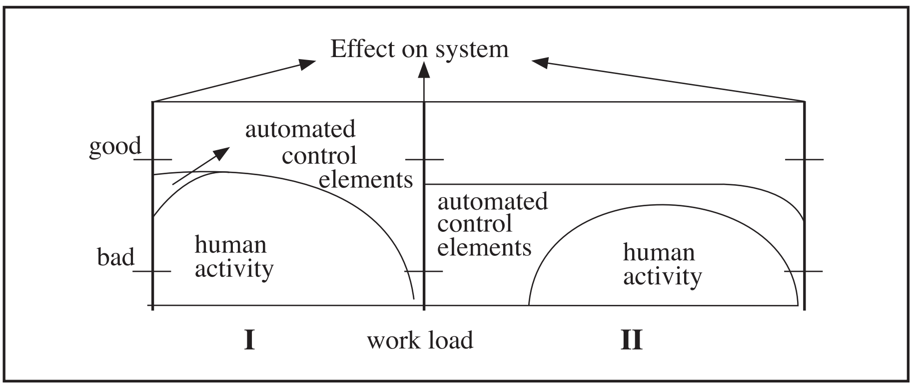
In other words, it is not questionable which processes can technologically be automated but what is questionable is the sense of automation of those processes that negate man in the domain in which he is objectively superior, and this is selective and priority decision-making in changeable circumstances. Consequently, there has to be made a clear distinction between automation of those processes that by their nature can be assistance and support to man and those processes that by their action passivize and reduce man's concentration, thus being a direct cause of fatigue.

Up to date experiences with automated ship control systems indicate to the occurrence of real problems contributing to fatigue during long-term repetition of routine control actions. This happens exactly due to an excessive range of control element automation on compensatory level both on the bridge and in the engine-room that passivizes and sometimes confuses the operator with its extensive and unclear instructions – integrated navigation systems, ARPA radar, electronic chart, GMDSS equipment as well as automatic processes of engine operation control in the engine-room.

Figure 4 shows qualitative comparison of automated systems (**II**) and systems that are mainly manually controlled (**I**). Although in system II there is space for greater human work loads, its efficiency is not higher than that of system I exactly because of fatigue and bad concentration manifested when man is in the role of passive process controller.

Technological possibilities of process automation are used as a way of reducing need for human work and the number of crewmembers. On the other hand, technology has allowed faster ship exploitation with regard to the reduction of time needed for loading and discharge of cargo. At the same time ship transporting capacities are increasing as well as average speed of navigation. Consequently, with the reduction in number of crewmembers work emphasis moves onto the domain of passive automation control and creation of prerequisites for mental fatigue while workload is increasing due to faster ship exploitation and the reduction in number of crewmembers whose duties and tasks are multiplied leading to physical fatigue. Dynamic ship exploitation uses space for greater human workloads - system II. This results in mental fatigue in the area of applied automation and tiredness in the area of workload required for guidance of ship in navigation. Alternative automation switching to manual control is a possibility that is rarely used and also leads to man's passivization expressed exactly in the instants in which urgent and priority action is needed.

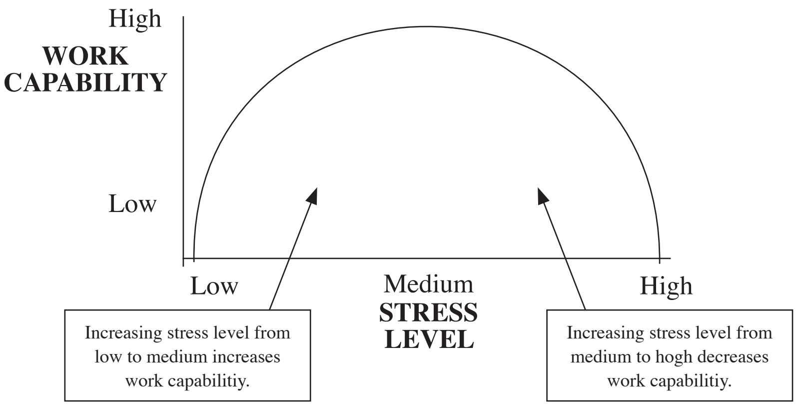
Fig. 4. Effect of human activity and automated control elements on system



Source: H. Schuffel, Some Aspects of the Future Role of Ergonomics in Ship Control, 1981.

On such bases appears the phenomenon of *technology complacency* or influence of technology on moving active knowledge and skills into the domain of passive and finally inaccessible ones in instants of emergency. This hypothesis is supported by H. Schuffel in the following conclusion: *«Long-term carrying out passive control actions reduces the need for traditional knowledge and skills resulting in a possible loss of such knowledge and skills»*[9]. Furthermore, with long-term passivization comes a reduction in general work capability since the level of stress reached is low leading to a reduced level of body energy– fig. 5.

Fig. 5. Relation of stress level to work capability



Source: STAR centre, Simulation Training & Assessment Research, Florida

During navigation there is always the possibility of sudden change of circumstances that requires urgent action. From the operator previously exposed to passive work and boredom such circumstances require prompt and efficient reaction. In such instants there is a great possibility of the operator's confusion due to physical and mental non-preparedness for circumstances requiring maximum concentration and physical readiness. These are exactly the instants of sudden increase of stress conditions – from low to high. If stress level does not remain at a medium value but increases to the high, decrease of work capability and mental fatigue occur.

Sociological research carried out in the Netherlands (STANSS 1980, 1981) indicates the fact that people become seafarers because they expect to do an interesting, challenging and changing job. Such natural positive attitudes should also be supported by the technological systems on board through ergonomic solutions that would ensure satisfaction in performing duties related to ship guidance in navigation. Increased

[9] Schuffel, H. (1981) Some Aspects of the Future Rolle of Ergonomics in Ship Control, Second Conference on Human Factors in the Designand Operation of Ships, Amsterdam, p. 11

satisfaction in carrying out seafarer's duties would reduce the influence of both monotony and passivization, and consequently of mental fatigue.

With regard to ergonomic aspect, only the control elements at pursuit level (closed loop), for those processes that are of help and support to the operator justify the application of automation and reduce the possibility of occurrence of fatigue during long-term use. In that sense Anita M. Rothblum proposes: *«Human error can be significantly reduced by adequate design of devices (equipment), work environment and adequate organisation within which the equipment and work environment will be designed with the basic prerequisite to support the operator and to adjust to his possibilities and limitations – human-centred design»*[10]. At the same time, marked passivization of man on board requires from him permanent training on simulation devices of the same kind on shore where he should exercise all predictable circumstances in which he can possibly find himself on board. The urge for creating common standards of use for individual parts of equipment and devices should also be observed from the ergonomic aspect that will help to avoid operator's frustration due to passivization and monotony.

3. Application of International Labour Organisation measures and standards aiming at reduction of tiredness and fatigue

Activities of the International Labour Organization (ILO) are based on the fundamental principles of the right to work without discrimination as well as the right of protection from employer's exploitation and from work in inadequate conditions.

The application of ILO principles in maritime affairs was proposed after many years of cooperation by IMO and ILO at the Maritime session in 1996 at which ILO was presented with a proposal on creating guidelines and standards to be applied to work on board. Namely, 1978 STCW Convention with amendments made in 1995 also contains regulations on required hours of rest in relation to hours of work spent on watch-keeping – Part A-VIII/1 and Part B-VIII/1 of STCW Code.

By joining IMO/ILO work groups at the meeting held in 1996 a relation of consent was established between the IMO Secretary General and ILO General Manager. The result of their mutual effort and work was Seafarer's Hours of Work and the Manning of Ships Convention, No.180, brought in 1996.

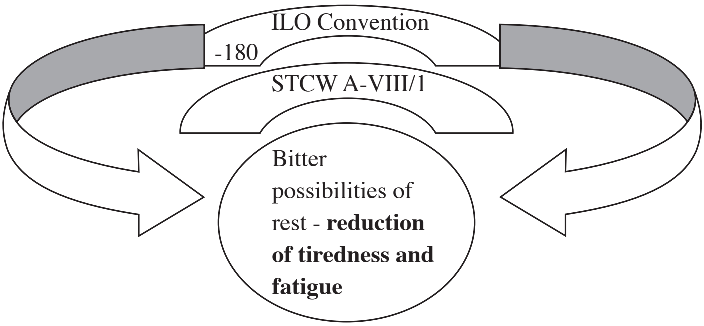
Later IMO/ILO work group activity based on the Convention brought in 1966 resulted in 1999 in a document called IMO/ILO Guidelines for the Development of Tables of Seafarer's Shipboard Working Arrangements and Formats of Records of Seafarer's Hours of Work or Hours of Rest. It is the application of the above mentioned

[10] Rothblum A.(2000), *Human Error and Marine Safety*, Maritime Human Factor Conference, Linthicum, MD. p. 8

document that makes significant contribution in the prevention of tiredness and fatigue as aggravating factors of reaction in emergency conditions.

Regarding STCW Convention we can conclude that International Labour Organisation measures and standards are more favourable from the aspect of the total crew readiness for work. This readiness is manifested by better possibilities of rest and, consequently, by smaller possibility of occurrence of the ship's crew tiredness and fatigue as significant cause of maritime accident occurrence and wrong reacting in emergencies.

Fig.6. Application of ILO standards



Functionality of organisational components in ordinary work conditions can be increased by the application of ILO Convention No. 180. Figure 6 indicates the possibilities of ILO Convention application implementing STCW Convention or directly. Therefore, the application of ILO Convention No. 180 is essential as precaution since its application helps to reduce fatigue and increase work capability of the crew in ordinary work conditions.

Conclusion

Application of automation on board ships has diminished the importance of skill-based performance and increased the role of rule-based and particularly cognitive performance facing fault conditions. Reliability of control systems which are not designed on the basis of "human-centred design" with man in the control loop, are severely limited. Redundancy can be provided for the mechanical components but not for the human component. The result is mental fatigue and after a period of time, physical as well. Working hours on board ships should be limited in accordance with ILO Convention 180. The minimum rest hours should be determined on the same basis. Ergonomic prerogatives and standards of equipment and instruments should be based on system ergonomics which will be capable to provide reliable prognosis for skill-based actions.

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Toni Bielić

Utjecaj brodske tehnologije i organizacije rada na umor

Sažetak

Proces automatizacije brodskih sustava sve više preuzima čak i neke funkcije čovjekova aktivnog upravljanja i rada. Tim se procesom mijenjaju dosadašnji uobičajeni poslovi brodske posade. Te su promjene naglašene u ponavljanju rutinskih postupaka pri posluživanju automatike i pasivnoj ili kompenzacijskoj kontroli automatiziranih procesa u kojoj operater nije u mogućnosti upravljati dinamikom procesa. To dovodi do inhibicije operaterove kreativnosti uslijed dominantne uloge tehnologije koja svojim značajkama operateru nameće ulogu pasivnog kontrolora navigacijskog procesa. To konačno dovodi do pojave jednog od elemenata koji uzrokuju pojavu umora. Slijedi pitanje koliko ima smisla u automatizaciji tih procesa kojom se negira ljudski element u domeni prepoznavanja i odabira bitnih podataka u stohastičkim uvjetima navigacije, što se potom odražava na prioritetno i pravovremeno donošenje odluka. Ne samo da progresivno uvođenje automatizacije smanjuje potrebu za ljudskim radom u domeni kreativnosti, već dovodi i do smanjenja brojnosti brodskih posada. Potom slijede promjene u organizaciji rada uvjetovane pasivnom kontrolom i smanjenom brojnošću posada, čime je ujedno prouzročena i veća opterećenost posade u uvjetima sve brže eksploatacije brodova. Spomenuti su činitelji doveli do dodatne pojave umora zbog izostanka nužnog odmora, čime je umor postao bitnim elementom propusta izazvanih ljudskim faktorom, a koji su opet uzrokom 75-95% pomorskih nezgoda. Reorganizacijom rada na brodovima temeljem Konvencija MOR i STCW, uvođenjem ergonomskih standarda u osmišljavanje tehnoloških sustava upravljanja brodovima te odgovarajućim obrazovanjem i osposobljavanjem pomoraca moguće je smanjiti pojavu umora.

Ključne riječi: brodska tehnologija, organizacija rada, automatizacija, brodski sustav, navigacijski proces, umor

Effetti della tecnologia di bordo e dell'organizzazione di lavoro sulla stanchezza

Sommario

Il processo di automazione dei sistemi di bordo, in continua crescita, ha ormai sostituito molte funzioni dell'uomo nel controllo attivo ed in molte operazioni. Tale processo ha indotto a un cambiamento di comportamento dell'equipaggio della nave. Il mutamento è avvenuto sia per la ripetitività delle operazioni di routine a sostegno dell'automazione che per il controllo passivo e di compensazione dei processi automatici per cui non vi è possibilità per l'operatore di prendere parte attiva nel controllo dei processi. Ciò rappresenta un severo impedimento alla creatività dell'operatore che a causa del ruolo dominante della tecnologia e delle operazioni che la caratterizzano riducono le funzioni dell'uomo a passivo controllore del processo di navigazione. Questo rappresenta uno dei fattori alla base del fenomeno di stanchezza. Ci si può chiedere, quindi, quale sia l'utilità dell'automazione nei processi in cui si annulla il fattore umano, in un campo dove l'identificazione e la selezione dei dati diventa essenziale come nel caso di situazioni stocastiche della navigazione per cui la priorità e tempestività del processo decisionale è di fondametale importanza.

La progressiva introduzione dell'automazione non ha ha solo diminuito l'apporto dell'uomo e della sua creatività, ma ha prodotto una drastica riduzione del personale di bordo provocando un mutamento dell'organizzazione di lavoro e riducendo l'operatore a una passiva attività di vigilanza. Inoltre la riduzione del personale ha segnato un aumento del carico di lavoro per l'equipaggio dovuto alla maggiore e più rapida utilizzazione delle navi. Tutti questi fattori concorrono a creare le condizioni del fenomeno di stanchezza e se a ciò si aggiunge la carenza di un adeguato periodo di riposo, si può concludere come la stanchezza costituisca l'elemento determinante dell'errore umano che a sua volta si dimostra essere fattore decisivo per il 75-95% dei casi di sinistri marittimi.

Una riorganizzazione del lavoro a bordo basata sull'applicazione delle Convenzioni ILO e STCW, l'introduzione di standard ergonomici nella progettazione dei sistemi tecnologici di conduzione delle navi e una adeguata istruzione ed addestramento dei marittimi potrebbero contribuire alla riduzione della stanchezza.

Parole chiave: tecnologia di bordo, automazione, stanchezza, errore umano