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ANALYSIS OF WORKLOAD AND ATTENTION FACTORS ON HUMAN PERFORMANCES OF THE BRIDGE TEAM

The traditional approach to the study of human factors in the maritime work domain is the analysis of accidents. These analyses could provide valuable information, but they are not sufficient in the attempt to capture the causal relationship between performance shaping factors and human performance in the everyday routine work. Important parameters are safety, efficiency and comfort. Another and more suitable approach to the study of human factors everyday routine work in the maritime domain is the quasi-experimental field study where variations in performance (for example attention) can be observed as a function of natural variations in performance shaping factors (for example workload).

The empirical study described in this paper is a study of two relevant human performances concept: workload and attention. We have demonstrated how these natural variations of workload can be very easily observed as a function of the different stages or phases of a voyage. We have also suggested a very easy method for the measurement of the crew attention through the measurement of communications at the bridge of the ship. Full mission Ship Handling Simulator was used for analyzing the human error, as part of the human error stage of the OPTIMPORT project.

Key words: *human error, workload, attention, bridge team, simulation, grounding*

1. INTRODUCTION

The traditional way of studying human performance in the maritime work domain is through the analysis of accident reports or even better through the analysis of accidents. This approach is quite reasonable since it seems to be the common knowledge that a majority (often the figure 80% is mentioned) of accidents are actually caused by human factors or human error.

The advantage of accident reports is that they are easy to get. It is possible to download reports for free from several databases on the Internet (for example databases in Canada, USA and Australia). The further advantage is that the accident report is usually written by a domain expert, who has the ability to evaluate the human performance in the particular case against the performance standard you could expect from the crew in the given situation. This traditional approach has also some disadvantages, since it does not reveal human factors that do not induce reported accidents or near misses. Sometimes the human factor can be seen as a significant ingredient in an incident that is never reported at all. Another problem is that the human performances can induce as well as prevent accidents and near misses (UK AIB, 2007). The human factor is therefore not only the cause behind a problem. It can also be the solution. It could, therefore, be useful to find, discuss and develop new empirical approaches to the collection of knowledge about the human performances contributing to and impacting on the overall safety on board a vessel. This paper suggests a new empirical approach for the collection of data regarding human performances in the everyday routine work in the maritime domain. The approach is based upon a theoretical framework of well-known models, and it is demonstrated to be suitable for the studies of mental workload and attention.

2. HUMAN PERFORMANCES IN MARITIME INDUSTRY

Human performances can be defined as a discipline regarding human abilities and limitations in relation to the design of systems, organizations, tools etc. Important parameters are safety, efficiency and comfort. However, the definition we are going to use through out this paper is human performances as a concept rather than a discipline. This means, that human factors are a number of human related factors, which can also be denominated as the human element, in the safe and efficient operation of – in this case – a ship. Factors other than human factors could be the technical or environmental factors.

The empirical study described in this paper is a study of two relevant human performances concepts: workload and attention. These are just a selection of two among a large number of concepts, but they are nevertheless important due to their regularity in the causal explanations of maritime accidents, near misses and incidents.

The concept of the maritime work domain was introduced in the beginning of the paper, but it is necessary to define it properly. We will start by defining the maritime work domain in broad terms as any kind of work task performed on board any type of a vessel. According to the report on the BERTRANC project (BERTRANC, 2000) it is possible to define five maritime work tasks:

- Navigation (route planning, track keeping and collision avoidance)
- Propulsion (the responsibility for the integrity of the ships propulsion system and associated auxiliaries)
- Cargo handling (loading, keeping the cargo (including passengers) in good condition and unloading)
- Platform maintenance (keeping the ship, her equipment (e.g. the auxiliary equipment) and the crew (the hotel function) in operational condition)

- Ship management (the allocation of tasks and responsibilities, control and supervision and communications).

Although the maritime work domain covers all the above-mentioned aspects, we will narrow our scope in this paper to the work performed in a certain part of the ship: the Bridge from where the ship is navigated. However, this does not indicate that the work performed on the bridge is more important than the work performed at other places on board the ship. The work performed for example in the engine room can be considered to be just as important.

Attention on a task can only be sustained for a fairly short period of time, depending on the specifications of the task. The usual figure cited is around 20 minutes, after which, fatigue sets in and errors are more likely to occur. This is why air traffic controllers are obliged to take breaks from their attention-intensive work at regular intervals. However, there are a number of other reasons why the attention system is responsible for errors (TSB of Canada, 2001).

Information bottleneck – it is only possible to pay attention to a small number of tasks at once. For example, if an air traffic controller is focused on handling a particular plane, then it is likely that they will be less attentive to other aspects of safety, or other warning signals (although this depends on the nature of the signal).

If a task is repeated often enough, we become able to do it without conscious supervision (habit forming), although this routine and repetitive behavior can force us into mistakes. In 1979, an operator at Oyster Creek Nuclear Power Plant intended to close off two pump discharge valves. Through an attention slip, he accidentally closed off two other valves as well, and in doing so, closed off all circulation to the reactor core.

The Automatic Warning System installed on all passenger trains in the UK is an example of a system that was not designed with limitations of human attention in mind. It is a device fitted in the train cab, based on the now obsolete mechanical system of signaling that used to signal either STOP or PROCEED. It sounds a bell when a clear (green) signal is passed and a buzzer when caution or danger is signaled. If the buzzer is not acknowledged by the press of a button, then the train begins to stop automatically.

In commuter traffic, most signals will be at the ‘caution’ aspect, and given the frequency of signals (spaced 1km apart), most drivers will face two signals per minute. Given the tendency for the attention system to automate highly repetitive behavior, many drivers lose focus on the reasons for carrying out this repetitive task, and act in reflex whenever the buzzer sounds. The end result is that drivers often hear the buzzer and press the button reflexively without actively thinking about the train speed and location.

Interpreting the senses - one of the biggest obstacles we face in perceiving the world is that we are forced to interpret information we sense, rather than access it directly. The more visual information available to the perceiver, the less likely it is that errors will be made. Bearing this in mind, systems that include redundant information in their design may cause fewer accidents. An example of this was the change in electrical earth wire colors coding in the 1970’s to include not only colors, but also a striped pattern.

3. LOGICAL REASONING

Humans are not very good at thinking logically, but in technological situations, logical procedures are often necessary (for example, troubleshooting a complex system which has broken down). Illogical behavior is a common source of error in industry. During the Three Mile Island incident in 1979, two valves which should have been open were blocked shut. The operators incorrectly deduced that they were in fact open (Jones, M., 2002), by making an illogical assumption about the instrument display panel. The display for the valves in question merely showed that they had been instructed to be opened, whereas the operators took this feedback as an indication that they were actually open. Following this, all other signs of impending disaster were misinterpreted with reference to the incorrect assumption, and many of the attempts to reduce the danger were counterproductive, resulting in further core damage.

Levels of processing - another way in which information can be more reliably remembered is to learn it at a greater depth. For instance, if it is necessary to remember lists of medical symptoms, then it helps to understand more about the conceptual framework behind the list. If only the "surface" features (such as the words on the list) are remembered, then there is a higher chance of information being forgotten.

- Capacity - short-term memory has an extremely limited capacity. In general, people can remember no more than around seven individual items at a time. This has safety implications in areas such as giving new workers a set of instructions to follow from memory or attempting to remember the correct sequence of procedures within a new task (ATSB, 2006). However, trained individuals are able to retain larger chunks of information in memory. For example, chess grandmasters can remember the location of more pieces on a chessboard than can a novice because they see the pieces not as single units, but as parts of larger conceptual units which form coherent wholes.
- Accessibility - even when items are stored in memory, it is sometimes difficult to access them. There has been much research into the ways in which recall of information can be improved. For example, research has shown that people are much more likely to remember information if they are in similar conditions to when they encoded the information (USCG R&D Center, 2001). This was illustrated in a study involving divers who were given lists of words to learn on dry land and underwater. Words learned on the surface were best recalled on the surface, and those learned underwater best recalled underwater. This has implications for training programmers, where albeit under less extremely contrasting situations, staff trained in an office environment may not be able to remember relevant details on the shop floor.

4. METHOD FOR MEASURING WORKLOAD AND ATTENTION FACTORS ON THE BRIDGE

While workload can be measured as a combination of several objective and quantitative parameters in the environment and on the workplace, it is more difficult to measure attention as an internal psychological phenomenon in one single person or in a group of persons - for example the crew on the bridge of a ship. One common used method for the study of attention is the eye-movement detection. This method – which requires expensive equipment for the measurements - takes advantage of the assumption that we are paying attention to what we look at in any given moment (Iarossi, F. J., 2003). That is true to some extend, but we are nevertheless able to pay attention to something we do not look at - for example a verbal message - and we are also able to look at something without paying attention to it. We would like to demonstrate how it, by very simple - and much cheaper – means, is possible to measure attention by measuring communication on the basis of an assumption similar to the one regarding the eye-movement detection: Communication about a given subject indicates, that attention is paid to it, but it is evidently not possible to conclude the other way around. We would like to introduce two measures of communication: the number of communication sequences per 10 minutes and the distribution of these communication sequences between subjects close in time and relation to the given situation and subjects far from the given situation. Communication about the actual voyage, navigation and navigational aids, traffic and the weather is - due to their relevance - considered to be near to the situation while communication about colleagues, division of work, organizational aspects and private matters are considered to be remote. Communication sequences about the vessel and her equipment are considered to be both near and remote with the weight of 0.5 in each category. The communication can be observed, counted and recorded in the two categories for each ten minutes period of a voyage using for example a simple spreadsheet on a portable PC or simply a scheme on paper. We assumed that there would be a relationship between workload and attention in the way that very low workload would induce a very low level of attention. We have claimed that it is possible to use communication as an indicator of the level of attention. It should therefore be possible to observe an increase in communication as a result on an increase in workload. To exemplify that, we made a study of a voyage on route D, which is the route with the greatest variation in workload among the four selected routes. We systematically recorded the communication on the bridge of the ship from 60 minutes before arrival (in transit where the workload was evaluated to be low) to arrival in the port of destination (where the workload was evaluated to be high). We would expect the amount of communication to increase gradually from transit to arrival. And that was in fact - not surprisingly - what it did to some extend.

In order to find some patterns that could define the human behavior (Hensen H., 1999) we create a scenario that was run on our full mission Ships Handling Simulator (SHS), type Transas NT Pro-4000.

Deliberately, we have designed, on this scenario, a planned route that passes very close to some navigational dangers, represented by shallow waters (Irish Sea – Kish Bank and India Bank). On these two areas the depth of the water is bellow 10 meters, decreasing to 3 meters MHL. The ship conned by the students has a maximum draught of 8 meters, and is sailing

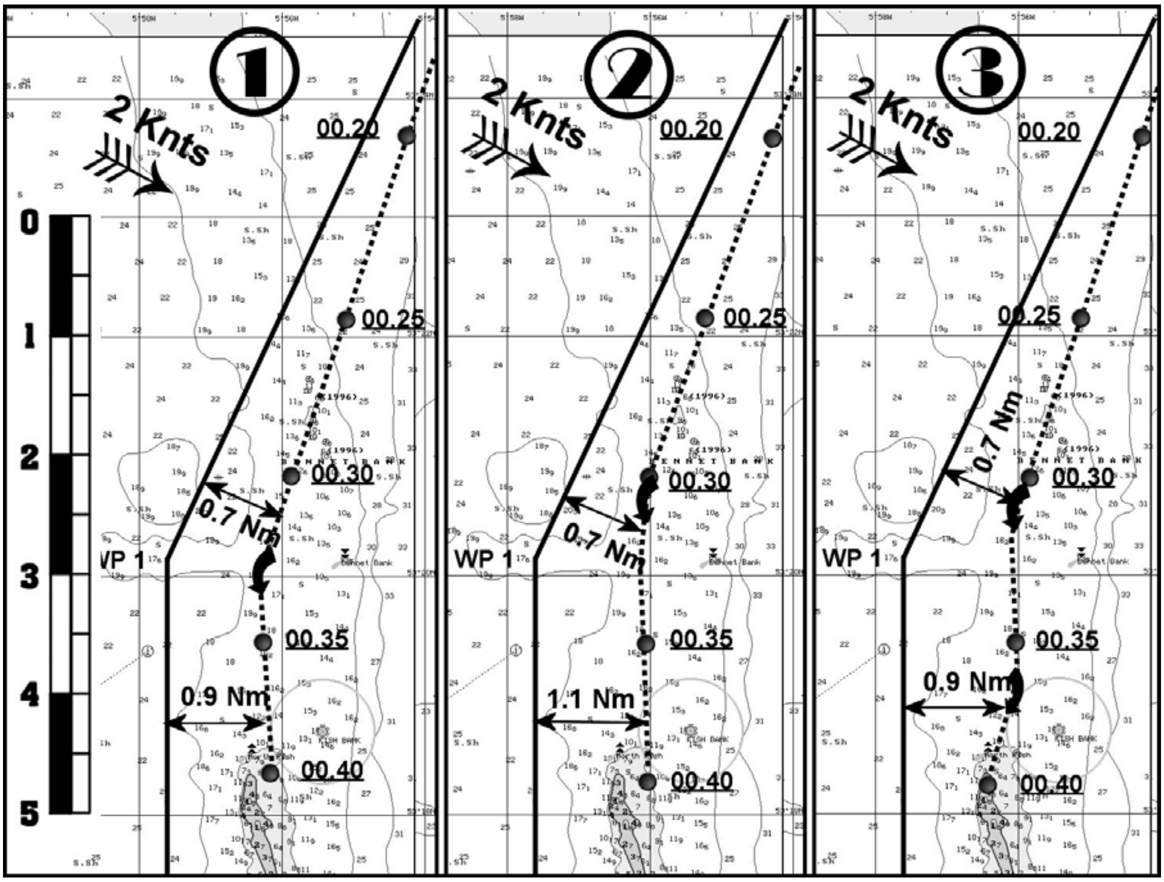

Figure 1 – First set of 3 groundings at the beginning of the scenario (Kish Bank)

with almost 20 knots. Other characteristics for the own ship (full loaded) were: LOA 173.5 m, breadth 23.1 m, fore draught 7.8 m, aft draught 8.2 m, turning diameter (at full speed) 9 cables, deadweight = 17565 tons). Due to shallow water and squat effects, the draught of the cargo ship increases with another 1.1 meter, so the real draught becomes 9.1 meters. Consequently, any accidental intersection of the 10 meters bathymetric line could conduct to the grounding of the ship.

The bridge teams were composed by three students in the 3rd year of study, well familiarized with the simulator and the use of visual and radar position lines for determining the ship's fix. The standard organization of the team was: one student acting as radar observer, one student in charge of conning display, one student in charge of chart work, and, deliberately, we let the team leader to emerge spontaneously (Barsan E., 2006).

In order to increase pressure, the ship encountered fog banks where visibility was under 2 Nm, and it was the first time when they have to navigate in such conditions. They were briefed about the existence of the drifting elements and about the risk of grounding if their

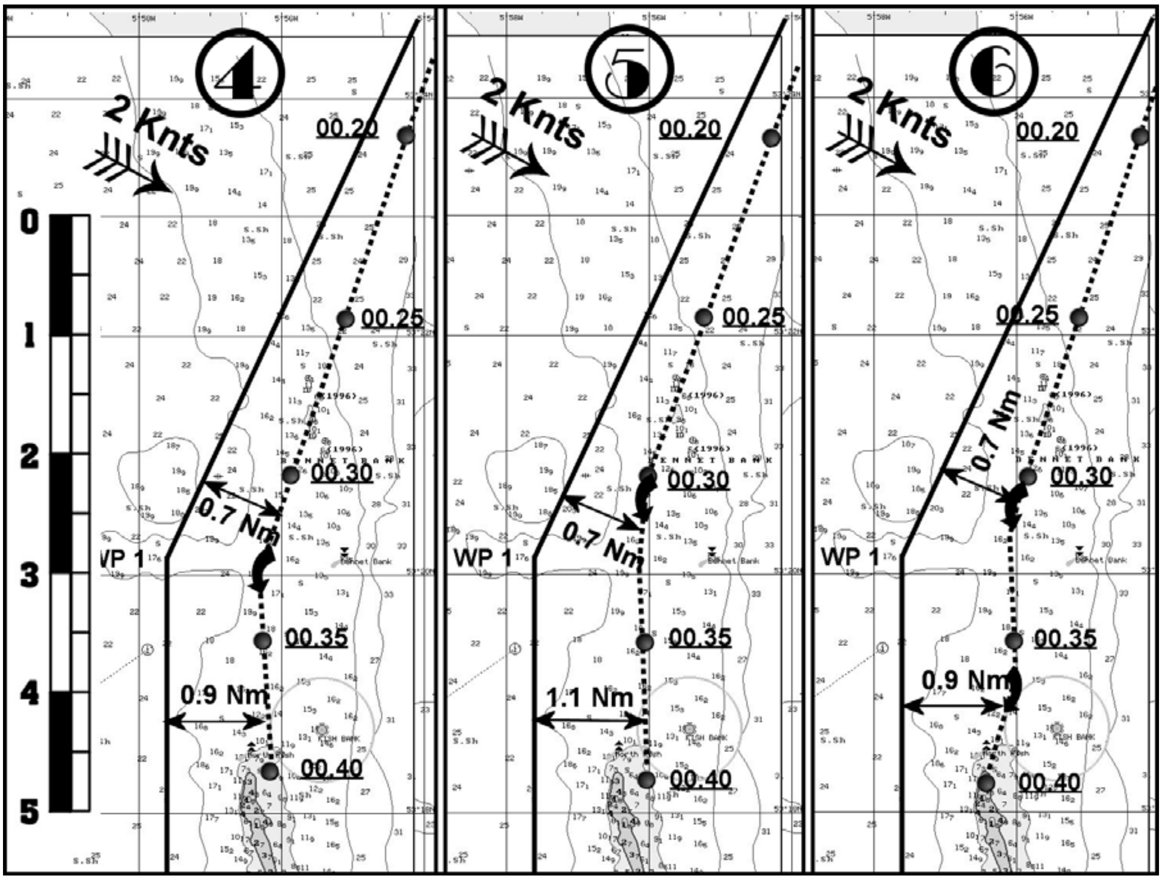

Figure 2 – Second set of 3 groundings at the beginning of the scenario (Kish Bank)

cross track error (XTE) will exceed 0.5 Nm. In the previous two training sessions, the same students were trained to navigate in maritime area with tide currents and how to make course alterations in order to maintain the intended track.

The navigation equipments in operation were: radar and GPS. It was also for the first time that they had the opportunity to use GPS/DGPS for navigation, after they had learned theoretically about this equipment. During the briefing session, students were instructed how to use the navigation information displayed by the virtual GPS equipment. The waypoints of the navigation route were loaded on the GPS, so the voyage could be monitored using the highway navigation window of the GPS.

The risk of grounding exists in the first part of the scenario, 40-45 minutes after the exercise begins (figure 1 and 2), and in the ending part of the scenario, 1 hour 30 minutes after the beginning of the exercise (figure 4).

In order to increase the work load, at the beginning of the watch, students had to fill in some paper work (voyage planning sheet table).

A fault tree analysis is based on the model presented by dr. Brown A., at the Ship Structure Committee (SSC) Symposium (Brown A., 2000) valid for a power driven grounding (figure 3). The fault tree is represented only with the main nodes, and indications regarding the path that is suitable for our findings in connection with the students' behavior (Sirkar H, et all, 1997).

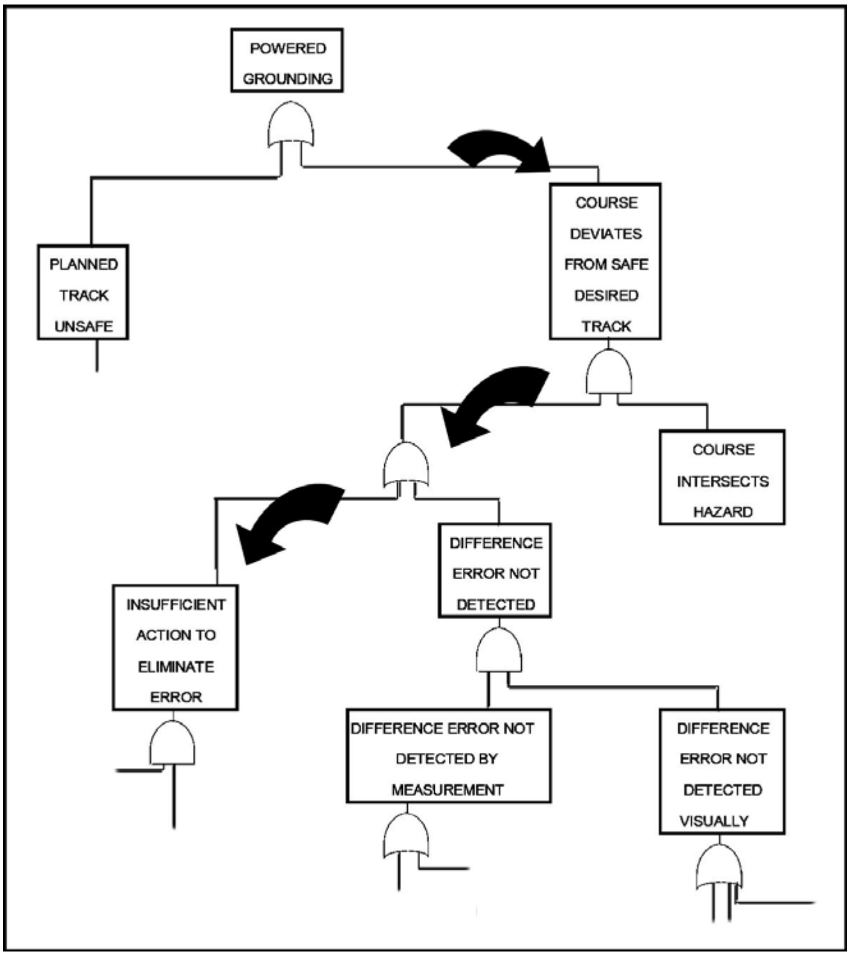

Figure 3 – Fault tree for power driven grounding used to analyze the students behavior and human errors

When the exercise starts, the own ship is 2 cables right of the intended track. Due to the tide current, the ship drifts to port, and in 30 minutes, if no action is undertaken, the XTE (cross track error) reaches 0.7 Nm, exceeding with 2 cables the maximum allowed XTE (as mentioned in the briefing of the exercise).

As you can see from figures 1 and 2, the first planned course alteration had to be done after the first 32-33 minutes. The “wheel over” (W/O) position was marked as abeam a navigation landmark (Bailly Head Lt.H.). The students are aware that they have to alter course after almost 30 minutes, because they had to calculate ETA for the first WP (WP1).

In all the six cases presented in figures 1 and 2, students were well aware about the ship position. In the first 35 minutes they plot on the chart at least 5-7 radar and/or GPS fixes.

These findings determine us to choose from the fault tree the “Course deviation from safe desired track” – “Insufficient action to eliminate error” branch.

As we can see in figures 1 and 2, all 6 groundings were caused by the course alteration to port, that was done when the Bailly Head Lt.H. was spotted abeam (cases 2,3,5,6) of when he was in the preplanned true bearing (cases 1 and 4). If no course alteration will be made until the ship’s course over ground intersects the second desired track, the own ship will pass safely north westerly from the Kish Bank cardinal mark. The new course chosen by the students lead own ship directly on the Kish Bank area where depth was less than 5 meters.

Normally, course correction action had to be started no later than 00.25 in order to reduce the XTE of the own ship under 0.5 Nm.

More than that, if we pay attention to cases 3 and 6, we can see that bridge teams had tried after 00.35 to reduce the deviation by altering course to starboard, but it was too late to avoid grounding.

In figure 4 we have another four cases of groundings (#7 to #10), from the same scenario, but

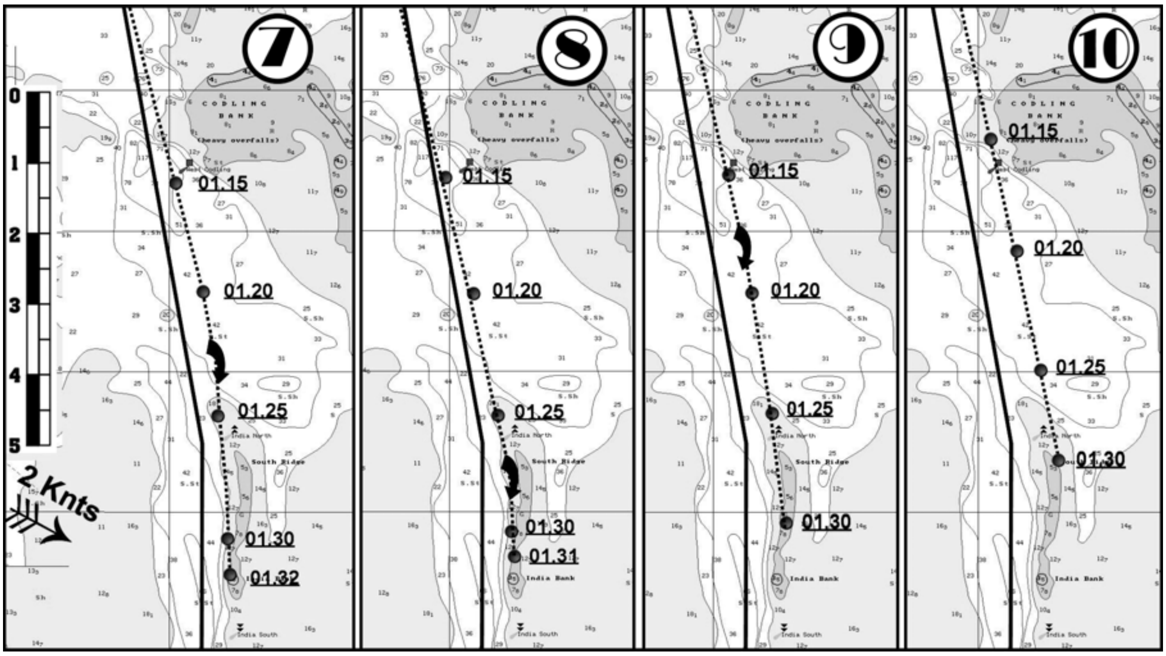

Figure 4 – Set of 4 groundings at the end of the scenario (India Bank)

this time the events can occur at the end of the exercise, 90 minutes after the starting of the scenario. The risk area is represented by the shallow water area at India Bank, the planned course of the own ship passing deliberately very close of this dangerous area (0.7 Nm). The tide current has the same characteristics as in the previous 6 cases.

When we have designed the scenario, we assumed that after one and a half hour of navigation the students' teams will have enough experience to read the navigation information from DGPS in order to maintain a XTE no greater then 0.3 Nm.

This time, the main causes of collision were:

- in case #7, an insufficient course alteration in order to reduce the existing XTE to port, to enter the next planned route leg and to counter balance the tide current effect;
- in case #8, a too late and too small course alteration;
- in case #9, an almost inexistent course alteration;
- in case #10, an omission to start course alteration, no action being carried on in the last 20 minutes.

As you can see from figure 4, in cases 7 and 8, the own ships could pass clear of the shallow area, if the new course had the correct value to counter balance drift.

There is another thing, of significant importance, that must be underlined. The paper chart used for navigation was the British Admiralty chart no. 1468, at a draw scale of 1/100000. No electronic chart system was available to the students.

5. CONCLUSIONS

After making this brief analysis of the technical factors that determined the ten grounding events, we can proceed to analyze the human behavior that generated the error chain. We have to remember that the human factor analysis is done in terms of workload and attention and how these factors had such an influence to determine a very serious event.

Without any doubt, speaking about the grounding fault tree, we have to choose path B, because in all ten cases the ship deviated from the safe desired track (see figure 5). The bridge

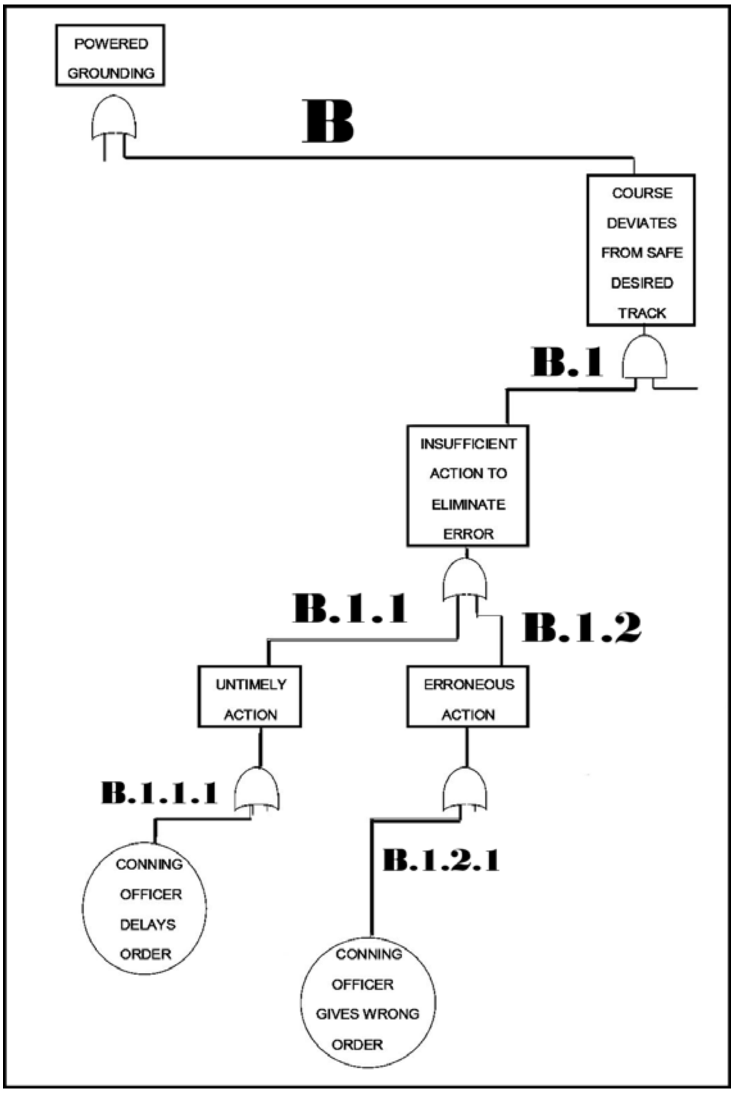

Figure 5 – Set of 4 groundings at the end of the scenario

teams take no action or the action was insufficient to eliminate the cross track error – path B.1.

In the first 6 cases, it was an “erroneous action” (path B.1.2) and we can consider that the leader of the students’ bridge team has given a wrong order (B.1.2.1) by choosing an appropriate new course.

In cases #8 to #10, the root causes go on to the B.1.1 route (untimely action) and consequently to the B.1.1.1 one, because the student in charge delayed the starting of the course alteration.

Why was that human error chain possible?

In the first place (cases #1- #6) the workload had overcome the safe capacities of the students’ team. Practically, all the paper and chart work activities were undertaken by a single student (navigating officer). He had to fill in the voyage planning sheet, to plot the position (at least one fix at every 5 minutes) and to read the master standing orders regarding the procedures for navigation at a reduced visibility. In all the cases, only one student performed all these tasks, without the help of the other two team members. As a consequence, the “navigating officer” tried to solve the ongoing situation, applying what he knew the best, meaning to start the course alteration at the calculated ETA for reaching the wheel over position or when the landmark was on the pre-planned bearing. Having a limited practical experience, he had not the capacity to foresee the effect of his action (order course alteration too early) and had no time to make other paper chart graphically projections in order to see that the ordered course will lead the own ship directly to danger.

If the “navigating officer” had focused only on the paper chart work and conning the ship, he had been more concern about the ship deviation and he had time to find and order a corrective course for counter balance the drift for the first leg of the route.

For the workload effect, we can conclude that all persons have a “breaking point”, when too much tasks that must be resolved simultaneously could trigger an error.

For the last four cases, attention was the main factor concurred to the grounding event. It was lack of attention and premature relaxation, because:

- they passed safely along Kish Bank, while some of their colleges had round aground there;
- the exercise was on last minutes;
- open sea was only 3 Nm away;
- after almost 2.5 hours from the beginning of the class a feel of boredom was already present;
- XTE of the ship was in the admitted tolerance (0.5 Nm);
- last course alteration was very small (only 10 degrees).

The feeling of safety was enhanced not only by the XTE that was 0.3-0.5 Nm, but also by the scale of the paper chart (1/100000), where a 2 cables error seams negligible and the ships could be easily considered as being on the desired track.

We think that by using these simulations we have demonstrated the major role that could be played be the human error induced by workload and lack of attention. The results of these tests were also used as the starting point in the OPTIMPORT project as part of the study related to possible human error occurrences during the piloting of ships in Constantza Port (OPTIMPORT project, 2007). Of course, we have worked in these tests with students and the lack of experience was the first reason for transforming a routine course alteration in the main technical cause of the grounding. In real onboard situations, due to the practical experience of the officer of the watch, the workload must be more intense or requiring a high level of concentration and time consumption.

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Sažetak

ANALIZA UTJECAJA FAKTORA OPTEREĆENJA I POZORNOSTI U OBAVLJANJU POSLOVA ČASNIKA PALUBE NA ZAPOVJEDNIČKOM MOSTU

Tradicionalni pristup proučavanju utjecaja ljudskog faktora na rad u pomorstva leži u analizi pomorskih nesreća. Te bi nam analize mogle dati dragocjene podatke koji, međutim, nisu dovoljni da bi se njima pokušala objasniti uzročna veza između faktora oblikovanja rada i njegovog svakodnevnog rutinskog obavljanja. Pri tome su vrlo važna mjerila sigurnost, učinkovitost i zadovoljstvo. Drugi, a ujedno i prihvatljiviji, pristup proučavanju utjecaja ljudskog faktora na obavljanje svakodnevnog rutinskog posla u pomorstvu je polueksperimentalna stručna analiza u kojoj se razlike u obavljanju poslova (npr. pozornost) mogu promatrati kao funkcija prirodnih varijanata kod faktora oblikovanja rada (npr. opterećenje).

Empirički prikaz, koji je u ovome radu opisan, predstavlja prikaz dvaju relevantnih koncepata ljudskog rada: opterećenja i pozornosti. Prikazano je kako se te prirodne varijante opterećenja mogu vrlo lako promatrati kao funkcija različitih etapa ili faza putovanja broda. Predložena je i jedna vrlo jednostavna metoda mjerenja pozornosti članova posade koja se *sastoji u mjerenju broja komunikacija koje se obavljaju na zapovjedničkom mostu. Nautički se simulator u potpunosti koristio pri analizi ljudskih pogrešaka kao dijela OPTIMPORT projekta.*

Ključne riječi: *ljudska pogreška, opterećenje, pozornost, časnici palube na mostu, simulacija, nasukavanje*

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