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Working with the human element:
Human Factors and technical innovation from EfficienSea and on to ACCSEAS

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Abstract

The e-Navigation initiative of the International Maritime Organization (IMO) has sparked off several new projects working on new technological innovations for the benefit of marine safety. The IMO also acknowledges the necessity to work with the human element in both ends of the development process: innovation needs to be user-driven, and the result needs to be thoroughly tested in a user-centered design process to mitigate unexpected consequences.

In the just started ACCSEAS project we expect to work on problems of maritime safety. We expect to produce several suggestions to solutions to these problems. It is vital that we work with the stakeholders, both onboard and ashore, in this project. In this paper some examples of work with the human element in previous projects are presented. These are methods that we hope can inspire other development projects to do similar work.

1. Introduction

Shipping is becoming more and more safe. To provide perspective, it can be interesting to know that in the three years 1833-1835, on average 563 ships per year were reported wrecked or lost *in United Kingdom alone* (Crosbie, 2006). Today the total number of tankers, bulk carriers, containerships and multipurpose ships in the world fleet has risen from about 12,000 in 1996 to about 30,000 in 2011. In the same time, the number of ships totally lost per year (ships over 500 GT) declined from 225 in the year 1980, to 150 in 1996 and 55 in 2011 – and this is *worldwide* according to The International Union of Marine Insurance (IUMI, 2012). And even if the low 2011 figure for total losses will come to be adjusted somewhat upward once all data are processed, the fact still remains: Shipping has become much safer than it used to be.

But accidents do occur. One such accident that will become part of the 2012 statistics is the cruise ship Costa Concordia's grounding at the Italian island of Giglio in January 2012. At the time of writing this, the official accident commission has not yet released their final results but it is probable that this will be another accident labelled "human error." How a well maintained, well equipped ship with the highest safety standards in the world could leave its planned route for an improvised touristic "sail-by" to show off, breaching all safety barriers is just incredible, but also deeply human. "Human error" is part of the human condition, we cannot change that, *but we can change the conditions under which humans work* (Reason, 2000).

Human error has for many decades been reported as a major reason behind accidents in complex systems. A report by the American Bureau of Shipping (Baker & McCaffery, 2005), presented three years of reviews of accident databases from Australia, Canada, Norway, UK, and the US (Baker & McCafferty, 2005). Regarding the causes, the following conclusions were drawn:

- Human error continues to be a dominant factor in approximately 80 to 85% of maritime accidents;
- Failures of situation awareness and situation assessment overwhelmingly predominate, being a causal factor in the majority of those accidents attributed to human error;
- Human fatigue and task omission seem closely related to failures of situation awareness and the human errors and accidents that result.

So we can summarize the above saying that, thanks to technological advancements, we have a shipping industry that is safer than ever, but we have problems with the human operator that keeps being unsafe and error prone. While there are several issues that can be discussed one is undoubtedly the increased complexity of onboard information systems. The technological advancements that make shipping safer also make the information environment on the bridge more and more complex and difficult to handle for the mariner. One of the major problems is the wild growth of technical innovations that come on to the bridges of the world's ships; instruments that are unintegrated and create unwanted cognitive workload.

e-Navigation

To cope with this, IMO in 2007 launched a "strategic vision for e-navigation, to integrate existing and new navigational tools, in particular electronic tools, in an all-embracing system that will contribute to enhanced navigational safety while simultaneously reducing the burden on the navigator." (IMO, 2007) IMO have since 1997 had a vision in place "to significantly enhance maritime safety and the quality of the marine environment by addressing human element issues to improve performance." (IMO, 1997)

A number of e-Navigation related projects supported by the EU have in recent years targeted technological innovations. Most recently the ACCSEAS project, a part of the INTERREG IVB North Sea Programme, has been launched in the region, following earlier BLAST, EfficienSea and Mona Lisa projects in Europe, just to mention a few. ACCSEAS will implement a practical e-Navigation test-bed of prototype solutions in increasingly congested areas of the North Sea, building on innovation and tangible results from the earlier projects. The test-bed solutions will address safer and more operationally efficient access to busy ports and remote areas of the region. Human factors lie at the heart of successful innovation within the ACCSEAS test-bed, ensuring that navigational and route information is harmonized and integrated across systems onboard and ashore. The quality of e-Navigation test-bed data must be monitored end-to-end in respect of the informational content for the users and its portrayal must be designed from the outset using the human element principles and processes described in this paper and applying the lessons learned from past examples.

This paper wants to stress the need for using human element principles and methods to ensure that technical solutions coming out of these many projects should take into consideration human element principles at a very early stage of design, so that unexpected consequences do not come as a surprise once new standards have been put in place. We will do that by presenting examples of human elements work that have been done in some previous projects, and hoping that these examples can serve as inspiration for others to include human factors testing in the development process.

In the following, work with the human element at the Maritime Human Factors group at Chalmers University of Technology in Sweden is presented. This is work that has been done within a number of recent EU projects and which will continue in the current ACCEAS project.

2. Methods and Results

It is clearly stated in the IMO initiative that e-Navigation should be user driven and not technology driven (IMO, 2007), and the e-Navigation Correspondence Group has collected a number of high level user needs based on responses from a number of surveys conducted.
Solutions to concrete problems can come from any one individual or group, but it needs a receptive environment to make sure such suggestions are received and brought forward. Once a suggested solution is received it has to be tested to make sure it is usable and does not create other problems. The most cost effective way is to do this at a very early stage, on low fidelity prototypes that are being tested with the real uses. The most essential factor in human element oriented work is *meeting and talking* with the users. In the following, some examples of methods of doing so are presented.

Interviews and focus groups

One of the simplest and easiest approaches is to meet the users face to face. This can be done on neutral ground in interviews or focus groups. Such a meeting should have a concrete topic or theme of discussion and it can be useful to have an expert or a user introduce the meeting and provide context. The objective can for instance be to identify problems, or capture user requirements, or just brainstorming to find solutions to problems (see Figure 1).

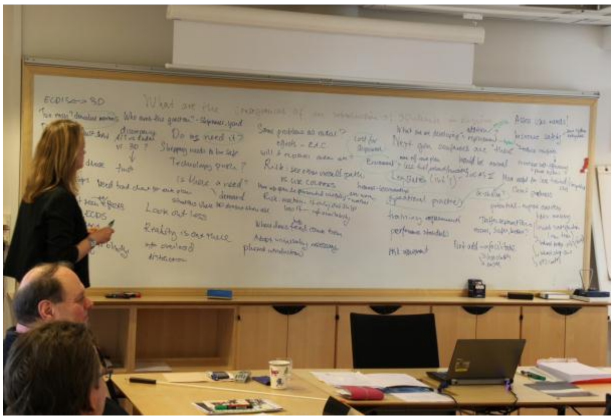

Fig. 1. The moderator collects and categorizes concepts and ideas as the focus group discussion continues.

As an example, a focus group invited to consider possible problems with a suggested innovation was invited to Chalmers University of Technology on 9 December 2010; with 10 experienced Swedish, Danish and Finnish master mariners, the usefulness and risks of displaying *intended routes* was discussed. (This is a service where ships use the AIS network to send out a number of future waypoints, which can be displayed on other ships' ECDIS screens, thus serving as an indication of the ships' intended routes. For more details see Porathe, 2012, and below.) The result from the discussion was that the pros were obvious if the ambiguity of the intentions of a vessel in the vicinity could be removed. A possible risk was that a ship could display one intention but then not follow it; much like a car would use its turn signal but then, instead of turning, go straight and thereby cause an accident.
Another benefit would be that Vessel Traffic Services (VTS) and pilots could easily detect in advance if a ship had the intention of going on the wrong side of a buoy and thereby risk grounding. They could then call up and warn the ship in question, or even better, send out a suggested alternative route, avoiding the danger. The ship could then either click “accept”, adding the new route to its active route, or dismiss the suggestion by clicking “reject”.

Contextual inquiries/field studies

Working in a maritime context means that the researcher has to go to sea and be present within the context of research. The researcher needs to spend time onboard. Much of the knowledge and procedures are “tacit,” cannot be verbalized but needs to be demonstrated and detected in context. Also, with expertise, the human factors researcher can infer cognitive bottlenecks and high workload situations that the user might not think of, being used to the familiar situation. Also many new ideas might come up based on a discussion in the particular situation.

As an example of a contextual inquiry a field study was conducted on 19-20 March 2011 during a training exercise with the volunteer Swedish Sea Rescue Society (SSRS) in the southern part of Sweden. The SSRS had for several days been training five local rescue stations and on the last night there was a rescue drill planned. At 2 o'clock in the morning an alarm came saying that two small boats with teenagers were missing. Units from the five rescue stations were called in to search. A search area was designated by the joint rescue coordinator and the larger rescue cutter was designated as On-Scene Commander (OSC). The OSC now had the choice of dividing the search area between the five units at his disposal or to perform a joint search. The first alternative would involve the OSC assigning a search polygon to each unit and letting that unit plan a parallel search pattern within that area, or possibly planning the parallel search pattern and sending it to the unit. Such a transmission of coordinates would have to be made over VHF and entered into the ECDIS of the unit, using keyboard inputs. But many of these units were small, open RIB boats with very limited abilities of keying anything into the chart computer due to exposure, motion and primitive on-screen keyboards (see Figure 2).


Fig. 2. An open" 8-meters class" boat in the Swedish Sea Rescue Services organization.

So even if the first option would be the best, the practical solution was (and most often is) to do a parallel search with all ships side by side: the OSC holds a course in the middle with all the other units one, two and three cables out on starboard and port beam.

The SSRS personnel who were interviewed expressed a need for the ability to send search polygons and patterns from OSC directly to each individual search unit, or to any ship equipped with an ECDIS participating in the search (Porathe, 2012). This idea was later developed in the EfficienSea project and tested in a live environment (see more below).

Simulator studies

A bridge simulator is a piece of laboratory hardware and software that simulates a ship's behavior from the vantage point of its bridge. Often it consists of a mock-up bridge (a more or less realistic bridge interior with consoles, screens, instruments and windows to the outer world) but often also a *visualization*, i.e. the egocentric 3D view of the surrounding world with ships, islands and ports projected on screens outside the windows. One important aspect of the simulator is that it realistically simulates a ship's behavior in different environments, this in turn paving the way for the other important aspect, that it allows the user to become immersed in the situation. Simulation thus may more or less realistically condition the user's frame of mind in the context of the real-world environment, all without the costs and possible dangers associated with using a real ship.

A simulator can be used for *contextual interviews*. This method is sometimes preferred to an ordinary interview taking place for instance in an office environment because it supposedly gives much richer output. As an example, a study was conducted on 20-21 June 2012 at the full mission bridge simulator at Chalmers, to collect input to the interface design for a *suggested route* service. A scenario was set up with a ship, southbound in Kattegat for Estonia by route of The Sound. At 2 o'clock in the morning, after 20 minutes in the simulator, the ship was called up by Sound VTS with the message that an accident had closed traffic through the Sound and a new route through the Great Belt was suggested. The route appeared at the same time on the screen of the ship with buttons to *accept* or *reject*. At this point the simulation was interrupted and the researchers on the bridge started to interview the watch officer about what information he now needed in such a message to be able to do what he had to do. This information will later be used to design the first prototype interface for this service in the Mona Lisa project. The fact is that we were in this context provided with much richer output from the interview.

New innovative navigation tools should always be thoroughly tested in a simulator, preferably in a user-centered design process starting with early prototypes. This is important to avoided unintended consequences. In two simulator studies, a new type of conning display, the egocentric view "3D chart", was tested at a simulator at Chalmers (Eskelinen & Gannve, 2011; Rigaud, et al., 2012). In a search and rescue scenario the 3D chart was used to display the search pattern to a rescue boat driver and compared with the same patterns displayed on a normal north-up oriented ECDIS screen (see Figure 3). In the other study, pilots, masters and maritime academy cadets were exposed to a navigation scenario in low visibility with 3D chart and ECDIS and with only ECDIS. In both cases situation awareness and workload data was collected.

Fig. 3. User testing of a "3D chart" in a smaller simulator. A rescue boat driver is conducting a parallel search in bad visibility. The search pattern he is following is displayed on the 3D chart in the window.

System simulations

A system simulation is a complex simulation involving more than one live ship and shore-based services. The purpose of a system simulation is to make observations of human behavior and cooperation in a complex maritime environment. These observations will then hopefully shed some light on interaction in larger social and technical networks. The goal is to analyze how people, involved in the navigation of ships, work and communicate (Lützhöft, Porathe, Jenvald & Dahman, 2010).

In a system simulation at Chalmers on 6-7 September 2011 two ships were assigned to pass through the Sound between Sweden and Denmark. The vessels were a small tanker and a bigger cruise ship. Several other "non-playing" target ships was also trafficking the area. The whole simulation was video monitored and ship movements recorded, as well as radio communication, and bridges' activities. Between Sweden and Denmark, 33 000 to 35 000 ships over 300 GT pass the Sound every year (not counting the many ferries going back and forward across the Sound). In later years there has occurred between 50 and 70 incidents every year where VTS operators have been forced to take action mostly to warn ships with too deep draughts or who were heading for shallows (Garbebring, 2011).

The two ships were manned by professional pilots and masters familiar with the area. The VTS center was manned by a professional Sound VTS operator (see Figure 4).

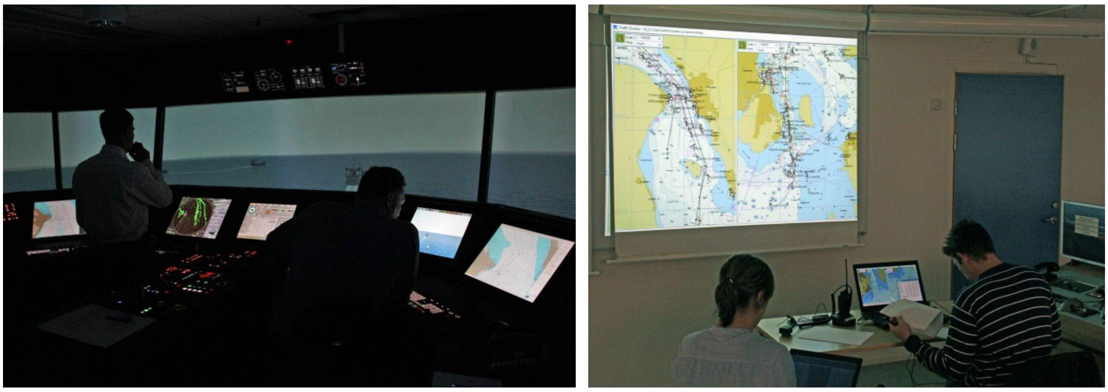

Fig. 4. Left: Captain and pilot on the simulator bridge. Right: The VTS operator (right) and the observer (left).

A prototype ECDIS capable of for sending and receiving waypoints through the AIS protocol was prepared by the Danish Maritime Safety Administration as a part of the EfficienSea project. The prototype allowed 16 waypoints ahead of the present leg to be transmitted to the other ship's prototype ECDIS and the VTS center in the same moment the crew chose to make its route "active" (which would then allow the autopilot to follow it). At any moment, changes to the route could be made by dragging existing waypoints or by adding new waypoints and dragging them. Once changes had been made, the route had to be made active once again. The VTS chart system also had the ability to send out to a designated ship specially designed routes or routes from a library.

The result of the study is more thoroughly presented in Porathe, Lützhöft, & Praetorius, 2012; only one example of how new technology and methods might lead to unintended new behavior will be given here.

The tank ship T.C. Gleisner was southbound in the Sound and was approaching the narrows at the ferry crossing between Helsingborg and Helsingor. Several ferries cross the Sound here every hour and they might suddenly appear from the two ports on either side (see Figure 5).

Fig. 5. An example of negotiating a conflicting situation using intended routes: Own ship T.C.Gleisner (red pointer) is the black symbol somewhat west of her (red) track in the upper left part of the screen in the left Figure. Tycko Brahe's (green pointer) green track shows, in the left Figure, that she first intends to go straight across the strait in front of T.C.Gleisner. In the middle T.C.Gleisner has published her intentions to go astern of Tycko Brahe (in accordance with COLREGS) by inserting a new waypoint and moving it west. This will bring T.C. Gleisner's track very close to the port entrance and in the right Figure Tycko Brahe has offered to yield and go astern of T.C.Gleisner, who has accepted by moving her waypoint back to her original track. Photos of T.C.Gleisners ECDIS screen 13:49, 13:54 and 13:55 respectively.

When T.C. Gleisner was approaching the ferry crossing from the north the ferry Tycko Brahe was departing from Helsingor, on the tanker’s starboard side. As the ferry started, she broadcast her intended route, a straight line over to Helsingborg (Figure 5, left picture). The intention of Tycko Brahe was picked up by T. C. Gleisner some 6-7 minutes away and as the give-way ship according to COLREGS (rule 15) she changed her course to go astern of Tycko Brahe by adding a waypoint to her active route and dragged it west, to just outside the port entrance. Her evasive manoeuvre was now broadcasted to all ships that had the “show intended routes” switched on in their ECDIS (see Figure 5, middle picture). But the practice in the Sound is that the ferries give way for passing traffic so Tycko Brahe added two new waypoints to her route and dragged one of them behind T.C. Gleisner showing her intentions to turn port, outside the pier head and go astern of the tanker. T. C. Gleisner accepted this by dragging her new waypoint back to resume her previous route (see Figure 5, right picture).

This example shows the necessity to do further studies into possible consequences of using intended routes, especially in close quarter situations when decision-time is very short.

User tests

Non contextual environments can sometimes be used to develop user interfaces for new technological systems. Complex technology like an integrated navigation system (INS) can sometimes be difficult to move from its industrial laboratory setting. Users might then have to be brought to the setting on order to confront the human element with the new technology. In a project that lasted from 2008-2010 Chalmers cooperated with the Hamburg based SAM Electronics to develop a new generation of NACOS Platinum INS. This development process was an experiment with using user-centered design and during the process pilots, civilian and navy officers were brought to the factory for user testing (see Figure 6). (Pedersen, 2010)

Fig. 6. A pilot is testing the new interface to the SAM NACOS Platinum radar. Video camera records comments as the user “thinks out loud”.

Field tests

At the end of a development process it is necessary to let new technological inventions meet the real context under safe forms. This often means that innovative equipment cannot be actively used in navigation, due to regulations, or must be tested elsewhere on the bridge.

One such an example is the test of using the *intended routes* service to send out SAR search patterns. The prototype ECDIS test application with the abilities to send and receive waypoints tested earlier in the system simulation was used during a search and rescue drill in the Great Belt outside Nyborg on 27-28 May 2011. In eastern Denmark, the search and rescue units are navy ships belonging to the Danish Marine Home Guard. They are all relatively large and of the same type (see Figure 7).

Fig. 7. Search and rescue boats from the Danish Marine Home Guard.

The test equipment was installed in three of the nine ships that participated. Equipment was also installed in one AIS transmitter mast for the Danish Maritime Safety Administration. The mast was used to transmit the AIS binary messages necessary for system operation. A laptop containing the prototype ECDIS was placed on the back bridge of the three units, one of which was the OSC and housed the exercise command. The prototype ECDIS was not allowed to be used for real navigation because the volunteer crew was supposed to train on their regular equipment, but when there was spare time we were allowed to demonstrate the functionality of the prototype system and gather comments and impressions.

When the exercise started, the OSC designated a search area for each unit. This search area was transmitted using VHF radio in spoken voice, transmitting 4 coordinates containing longitude and latitude (the words “north” and “east” and two times six digits). These coordinates were then received onboard each unit and were written down on a piece of paper by the radio operator. This piece of paper was then handed to the navigation officer at the front of the bridge who started to program the ships ECDIS system. Clicking through different menus and finally entering the same 12 numbers the search area finally appeared on the ECDIS. On the observation video from one of the ships, this process, from start of the VHF transmission until the search area appeared on the ECDIS screen, took 14 minutes. During this whole time, the search polygon was present on the prototype ECDIS, sent at the same time that the VHF transmission started (see Figure 8).

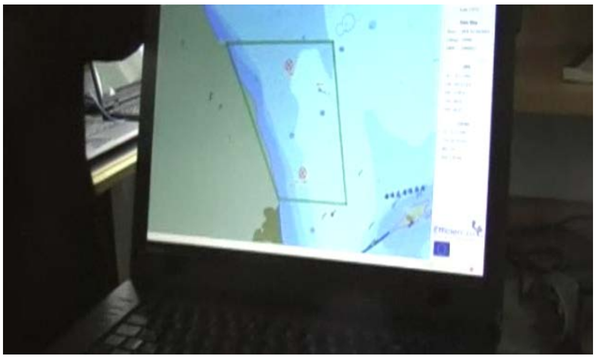

Fig. 8. The search polygon transmitted from the OSC directly to the prototype system.

For a professional and trained crew, this process would probably have gone a lot faster, but using volunteer crews with limited time for training is the reality for many sea rescue services around the world and even with a trained crew the risk of misinterpreting a number transmitted in voice and in hand writing still remains. The transmission through the AIS binary messages on the prototype ECDIS was produced by a graphical interface on the OSC ship and was instantly presented on the unit it was addressed to (Porathe, 2012).

3. Conclusions

In this paper we have presented some examples of work with the human element. The aim is to inspire developers of new processes and technology to work with user-centered design. In the wake of IMO’s e-Navigation initiative a lot of projects are working on innovations and the ACCSEAS project is an important opportunity to adopt best practice for design and implementation of prototype e-Navigation that embraces human factor principles from the outset.

ACCSEAS has commenced with an analysis of regional e-Navigation user requirements, based on the existing work from IMO, and will shortly engage a wide selection of users (including mariners, VTS operators, broader shore based service providers and ports) to consult on human elements of novel solutions. The test-bed implementation is planned to follow a systems engineering process with rapid prototyping iterations and continuous evaluation of human factors. Each stage of the implementation will explore the cognitive responses and workload of the users to identify methods of harmonizing data, extracting information and ensuring its effective portrayal to minimize human error and to capture the fallout from such error as it occurs.

The practical ACCSEAS test-bed will be complemented by extensive simulation facilities, representing the underpinning e-Navigation technologies with mathematical models at an appropriate level of fidelity. Simulation studies will be used to evaluate e-Navigation systems integration with ECDIS and other bridge systems to support the investigation of options for information portrayal. An example of this is the assessment of the combination of innovative *resilient positioning* solutions with *intended and suggested routes*. *Resilient positioning* recognizes the vulnerabilities of GPS to natural and deliberate interference, which have been shown to cause the portrayal of hazardously misleading information on the ECDIS in some circumstances and a plethora of confusing alarms from bridge systems in others (even from ship systems that may not be expected to use GPS). During ACCSEAS, *resilient positioning* will be implemented within a prototype ship's integrated navigation system, combining GPS with complementary and dissimilar systems such as *ranging mode* using synchronized transmissions from DGPS beacons or fixed AIS infrastructure (or existing independent systems such as *eLoran*). The resulting position and navigation information, including quality and integrity indicators, will be used by the *intended route* capability, adding robustness and improving safety and access of congested sea areas. However, the benefits of resilience and robustness will only be realized fully if the human factor elements are satisfactorily addressed at each stage of the project, starting with user consultation and progressing to simulation studies.

In 2014 and 2015, towards the end of the ACCSEAS project, a number of demonstrations of the North Sea e-Navigation test-bed will be provided as part of the continuous outreach to users and stakeholders. The evaluation and optimization of the human element of ACCSEAS solutions will be fundamental to the success of the demonstrations, which are planned to use a mixture of real-world and simulated systems and environments. This approach should ensure the greatest benefit for the evaluation of prototype solutions from the users' perspective, following the principles of 'system simulations' and 'field tests' described in this paper.

At each stage of ACCSEAS, the user experiences and feedback on designs, simulations and field tests will be an important contribution to the continuous evaluation of lessons learned and an overall training needs assessment. Key to improving maritime safety and accessibility in the North Sea region through the e-Navigation prototypes are the usability, natural cognitive response, workload reduction and reduced training burden for mariners and shore-based personnel that should be the natural benefits of a human-centred approach to e-Navigation solutions. ACCSEAS intends to contribute to the best-practice knowledge of e-Navigation development with the focus on the human element and to capture the legacy of this learning for future projects and to inform and advise the IMO's formal e-Navigation implementation plan.

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