Human Factors in Risk-Based Ship Design Methodology

Final Report Summary - FAROS (Human Factors in Risk-Based Ship Design Methodology)

Executive Summary:
The ultimate project objective has been the quantification and integration of the human error (human factors) into risk-based, concept ship design. It is a design process where risk is to be systematically reduced along with improvements in other conventional performance characteristics.

In the course of implementation, the project could not avoid the challenges currently pertinent to the maritime domain. One such challenge was related to the paucity of statistical data on the detailed realisation of human error in reported maritime accidents, incidents, and near-misses (MAINS). It was also found that little quantitative knowledge is available in the literature (incl. design standards) about the notoriously detrimental effect of noise, ship motions, vibration, deck layout and other global design factors (GDFs) on human performance. Particularly, knowledge about the failure in cognitive performance is scant. The consortium calls for decisive actions to establish proper reporting of MAINS and promote basic research on fundamentals of human performance in maritime settings to bridge this knowledge gap.

Nevertheless, the FAROS consortium offered solutions to some of these challenges. Thus, a theoretical framework was proposed and implemented to link GDFs to the human reliability (human error), although the framework still suffered from the data paucity problem described above. This, however, allowed developing a novel human reliability (HR) model and integrating it within risk models. The HR models are innovative, featuring new concepts (e.g. safe behaviour, attention management) that are well justified by scientific and experimental evidence. They reflect and amalgamate the state-of-the-art knowledge available about the human performance and its link to the occupational environment, i.e. GDFs. Therefore they have a wide spectrum of application.

The risk modelling focused on personal (individual) and societal (collision, grounding, and fire) risk contributions. Each risk model represents a combination of hazard probability and consequences. The HR models were maid as part of hazard probabilities, assuming
that failure in HR increases chances of unfavourable events. The risk models were then applied in the risk-based design process to achieve and demonstrate the improvements in design.

However when applied, the risk models showed low sensitivity—principally due to the data paucity problem—to certain GDFs when applying typical design modifications at the concept design stage. This was in particular significant for tanker ships, which have quite simple deck layouts and much less crew than on large passenger ships. Nevertheless, significant design improvements were achieved and recommendations made in relation to human factors in concept design. Thus, optimisation of tankers improved economic and environmental performance of the baseline designs by 90% (when considering through life operation) and 11% (when considering air emissions), respectively. And optimisation of RoPax ships reduced the total risk, improved economic and environmental performance by up to 67%, 3%, and 4%, respectively.

The application results of the risk models led to the realisation that those parts of risk models that link human performance to GDFs, i.e. the HR models, should be decoupled from risk and used separately for human reliability analysis (HRA) during normal ship operations. Then the ship design process would simply have an extra design objective aimed to improve HR by optimising GDFs. However, a full demonstration of this process was beyond the scope of FAROS.

In addition to these activities, the project conducted a series of experiments to learn about the link between GDFs and human performance. The experiments with seafarers were conducted on bridge simulators and machinery spaces simulated in virtual reality, studying the effect of noise and ship motions on navigational performance, and the effect of deck layout on safe execution of engineering tasks. It was concluded that the deck layout can have impact on crew safety, whereas noise on the ship's bridge may affect the navigational task performance. It is suggested that the use of watertight doors (WTD) has to be reduced to the minimum to avoid personal injuries or jeopardy to ship's damage stability. This can be achieved by reducing the number of WTD or crew tasks that require using them and enhancing damage stability calculations with open WTD scenarios. As for noise, the noise level on the ship bridge has to be reduced as low as practicable to facilitate crew performance during demanding tasks.

The project results and activities have been disseminated through public workshops, conference, journal and magazine publications, leaflets, and a promotional film.

Project Context and Objectives:
Over the last decades, reliability of onboard technology has increased dramatically. However, the human reliability has not been improving at the same pace and, consequently, has become a primary cause of maritime accidents. There are two basic, complimentary approaches to human error: person and system approaches. The person approach focuses on the errors of individuals, blaming them for forgetfulness, inattention, or moral weakness. The FAROS project adopted the system approach which concentrates on the conditions under which individuals work and tries to build defences to avert errors or mitigate their effects. Human errors are seen as consequences rather than causes, with their origins rooted in ship design on both meso (i.e. deck layout, arrangement of equipment and accessibility) and macro levels (i.e. hull and structural arrangement determining levels of ship motions, whole body vibration, and noise).

Design related factors that affect human performance are referred in FAROS as global design factors (GDFs) or performance shaping factors. Based on the existing literature and anecdotal evidence, GDFs are assumed to potentially contribute to risks associated with such hazards as collision, grounding, fire and personal injuries (occupational accidents). Specific performance-shaping factors used in FAROS are: ship Motion (motion-induced sickness (MIS) and motion induced interruption (MII)), noise, full body vibration, deck layout, and equipment arrangement and accessibility (DLEAA).

The adopted concept of maritime risk includes its two contributions: societal risk and individual (or personal) risk, as defined in the guidelines on Formal Safety Assessment by IMO. Societal risk is the average risk, in terms of fatalities, experienced by a whole group of people (e.g. crew, port employees, or society at large) exposed to an accident scenario. Societal risk is taken to be the risk of death and is typically expressed as Potential Loss of Life (PLL). Societal Risk is determined for the all exposed, even if only once a year. Societal risk is not person and location specific. In FAROS, societal risk comprised such hazards as fire and flooding caused by either a ship-to-ship collision or ship grounding. The societal risk combines the frequency (or probability) of a hazard and its consequences in terms of loss of life. Individual risk is the risk of death, injury and ill health as experienced by an individual at a given location, e.g. a crew member or passenger on board the ship, or belonging to third parties that could be affected by a ship accident. Usually IR is taken to be the risk of death and is determined for the maximally exposed individual. Individual risk is person and location specific.
The ultimate project's objective has been to improve the conditions under which crew works by mitigating the human error and its consequences. This objective was achieved through quantification and integration of the human error into risk-based, concept ship design. The risk-based design methodology uses developed risk models, along with other conventional disciplines, for design assessment. In FAROS the risk modelling focused on personal and societal risks with the human error integrated. The risk models were then applied in the risk-based design process to achieve and demonstrate the improvements. In addition to these activities, the project performed a comprehensive literature review concerning the effect of specific working conditions on human performance and conducted experiments to learn about the causality first-hand. The experiments with seafarers were conducted on bridge simulators and machinery spaces simulated in virtual reality, studying the effect of noise and ship motions on navigational performance, and the effect of deck layout on safe execution of engineering tasks.

The technical research programme was structured into four work-packages (WPs) focusing on individual areas essential to achieve the ultimate objective. Specific objectives in the WPs were:

1. Comprehensive literature review on human (crew) performance affected by ship motions, noise, whole body vibration, deck layout and arrangement of equipment and accessibility. The review involved the examination of scientific literature and current design rules and standards.

2. Conduction of experiments on bridge simulators and machinery spaces simulated in Virtual Reality. The former experiments were aimed to address the navigational human errors, whereas the latter addressed the errors leading to occupational accidents and safety the vessel as a whole (i.e. the interaction between deck layout and safe performance of crew tasks).

3. Development of individual and societal risk models with the human error integrated. The risk models were used in risk-based design to discriminate different design alternatives on the compartment and ship levels, and may also be used in cost-benefit of risk control measures.

4. Risk-based design of crude oil tanker and Ro-Ro passenger ships. This WP used the generated knowledge and developed tools in the preceding WPs to arrive at design improvements. Specifically, the risk levels of the baseline designs were to be improved cost effectively, ensuring safety for crew members and the entire ship.

5. The non-technical objectives included project dissemination activities, preparation of an exploitation plan, and submission of main project results to International Maritime Organisation (IMO) to inform the process of rule-making.

Project Results:

In the following, a concise summary of the results is given; results are preceded with a background. A detailed, editable summary of the main project results (incl. graphics and references) is found in the attachment.

Background: Scientific literature and experiential evidence refer to the negative effect of working environment onboard on physical and cognitive human performance. Current design rules and regulations set maximum allowable, and sometime just recommended, limits for noise, vibration, acceleration due to ship motions etc. Investigation reports on occurred maritime accidents emphasise the importance of human performance failure to probability of accidents. On this basis, the project FAROS undertook an extensive literature review to be able to quantify the causal link between global design factors (GDFs) and human performance and use this link to inform risk modelling. Considered GDFs were: ship motions, whole body vibration, noise, deck layout, equipment arrangement and its accessibility.

Results/conclusions: There is strong evidence and some quantitative data that describe the causal link between GDFs and human performance. However, the quantitative data is incomplete, fragmented and often generated in laboratory setting. Reporting of accidents, incidents, and near misses found to be poor and generally insufficient for comprehensive risk analysis. It was found that the current design standards on noise, vibration and other GDFs may not be able to protect from degradation in cognitive human performance, which is deemed to be a common precondition for maritime accidents. The main conclusion is that the detailed reporting of accidents, incidents, and near misses has to be significantly improved (underreporting to be eradicated) and basic research focusing on factors shaping cognitive human performance in the maritime domain has to be undertaken.
Background: The adopted risk-based design methodology uses risk models (inherently probabilistic), along with other conventional disciplines, for design assessment. Risk models had to be developed, or adopted, for this purpose and also integrate human factors (in terms of human error) into the risk assessment.

Results/conclusions: Human error-based risk models were developed for the main maritime hazards: collision, grounding, fire and personal injuries. The models were aimed to discriminate between different design alternatives.

Background: Nineteen Engineers participated in the second series of short scenarios using CAVE and head-mounted display virtual reality (VR) platforms. The experiments were designed to investigate the effect of deck layout of RoPax ships on personal (crew members only) and societal risks. The personal risk was associated with personal injuries by watertight (WT) doors and other hazardous objectives during normal operation. The societal risk was associated with the possibility of open WT doors – as a result of misuse of SOLAS regulations II-1/22 (paragraph 4) which permits open WT doors under special circumstances – during emergency situations such as water ingress following a collision or grounding event. The open WT doors during such emergency situations jeopardise ship's damage stability and often results in shorter time to capsize and greater life loss.

Results/conclusions: The use of watertight doors (WTD) has to be reduced to the minimum to avoid personal injuries or jeopardy to ship's damage stability. Reduce the frequency of crossing watertight doors (i.e. reduce the number of WTD or crew tasks that require to use them, or both). Shorten the walking distance between commonly used compartments (e.g. position the frequently accessed spaces vertically rather than horizontally across different WT compartments, move such spaces closer to each other). Increase the passage width in areas close to potentially hazardous objects.

Background: The second set of experiments was conducted at the bridge simulator to investigate the effects of noise and ship motion on navigation performance associating it with the probability of collision or grounding and hence the societal risk. The primary objective of the experiments was to assess the effect of noise on human performance in a simulated navigation task, as measured by the passing distance to a target ship or a grounding risk, deviation from the required track, and speed of reaction to on-board alarms within High Risk Events (such as rudder failure and radar failure) occurring during a simulated voyage.

Results/conclusions: Noise level on the ship bridge has to be reduced as low as practicable to avoid impact on crew performance during demanding tasks.

Background: The work involved two oil tanker baselines of Aframax and VLCC size. The ships were assumed to operate on the route between Port Rashid (UAE) and Chiba (Japan). Design speeds and required annual number of trips were assumed to be known. The redesign, or optimisation, process involved modifications to internal arrangements - to affect personal, flooding and fire risk contributions - and the hull shape, which changed the ship's behaviour in waves and consequently affected probability of grounding and collision. Additionally, the number of crew and payload capacity was subject to alteration. Such a comprehensive design exploration was aimed to investigate the benefits of the developments in the project, specifically the risk models and economic evaluation, and the degree of cost effective reduction in risk.

Results/conclusions: Optimisation of tanker designs improved economic and environmental performance of the baseline designs by 90% (when considering through life operation) and 11% (when considering air emissions), respectively.

Background: This is primarily due to issues specific to the human factors domain such as lack of data, however, there are also considerations relating to the specific application to tanker ships. The most notable issue affecting tanker ships is that their layout is highly constrained by the desire to provide the largest possible tankage on a given displacement, with the subsequent compression of almost all working spaces into a small part of the vessel. Due to such tanker-specific issues, the risk variation amongst the tanker design options was insignificant. The figures compare the NPV and total annual risk for each of the VLCC and Aframax variants, respectively, in both normal and worst-case sea conditions. For the both ship types, we found that the majority of the design alternatives had lower NPVs than the baseline, and that most had higher risk. Those variants with significantly higher NPVs were always those with longer hull forms, allowing for greater cargo capacity. For the VLCC options, using LNG fuel and Flettner Rotors (to reduce propulsion fuel use) improved NPV slightly without changes to the hull form. As the majority of the design alternatives lie within +/- 1% of the baseline risk level, it could also be concluded that such changes to ship design could be considered as risk neutral, with
the primary consideration being economics.

Results/conclusions: At concept design of tanker ships, consideration of human factors may be ignored.

Background: The work involved two RoPax baselines (1,925 and 5,746 DWT) of which specifications were provided by a design office. The small RoPax was assumed to operate in the North Sea, connecting Holland and UK, whereas the big RoPax was to operate in the Baltic Sea, connecting Estonia and Sweden. Design speeds and required annual number of trips were assumed to be known. The redesign, or optimisation, process involved modifications to internal arrangements—to affect personal, flooding and fire risk contributions—and the hull shape, which changed ship’s behaviour in waves and consequently affected probability of grounding and collision. Additionally, the number of passengers, crew and payload capacity was subject to alteration. Such a comprehensive design exploration was aimed to investigate the benefits of the developments in the project, namely the risk models and economic evaluation, and the degree of cost effective reduction in risk. The main reduction in the total risk resulted from a significant decrease in collision and grounding risk contributions, primarily due to improved damage stability. Other risk contributions (i.e. individual crew, fire) were higher in the optimised designs due to primarily bigger number of people onboard which outweighed the positive effect of lower ship motions and noise on the risk.

Results/conclusions: Optimisation of RoPax ships reduced the total risk and improved economic and environmental performance by up to 67%, 3%, and 4%, respectively.

Background: The experiments in virtual reality have confirmed the evidence that crew are tempted to leave watertight doors open depending on performed tasks and deck layout aspects such as the number of WT doors to pass through. Therefore, damage stability calculations should cater for possibility of open WTDs during flooding accidents. It is recommended to rank WTDs according their probability of being open during flooding accidents and perform the damage stability calculations with at least one WTD open. The open WTD might reduce the subdivision index below its minimal threshold and incite the designer to search for design improvements that rectify the potential loss of stability. Consequently, the ship design will become more robust to the flooding hazard. At this stage of knowledge, we recommend to estimate the probability of WTD to be open during a flooding accident as the frequency of WTD use over a single voyage. This implies that the crew task analysis should also become part of concept design.

Results/conclusions: At concept design of RoPax ships, damage stability calculations must accommodate the possibility of open watertight doors.

Background: Human reliability (HR) is related to the field of human factors and ergonomics, and refers to the reliability of humans in during maintenance, navigation, and other critical tasks. Human performance can be affected by global design factors (GDFs) as well as age, state of mind, physical health, attitude, emotions, propensity for certain common mistakes, errors and cognitive biases, etc. User-centered design and error-tolerant design are just two of many terms used to describe efforts to make technology better suited to operation by humans. In FAROS there was no specific objective to develop HR models as such, but instead focusing on risk models with human error (human factors) in mind. However, HR models would be a natural part of such risk models. Further application of the risk models to design of RoPax and tanker ships showed that the developed risk models are not generally good to discriminate between ship designs with different GDF values. The main reason for that was that the effect of GDFs was overshadowed by the effect of the parameters such as the structural arrangement of ships, number of people onboard, and payload capacity. However, such seemingly unfavourable results led to the realisation that those parts of risk models that link human performance to GDFs can be used independently from risk. These are novel HR models developed in the project and they should be used for human reliability analysis (HRA) during normal ship operations. HRA is part of standard risk assessment in maritime and other domains. As far as ship design is concerned, the ship design process would have an extra design objective aimed to improve HR by modifying GDFs, along with other design objectives including the maritime risk. And in terms of the consequences of this realisation, the improvements in HR during normal operations would not be any longer overshadowed by risk factors (e.g. passive safety barriers such watertight subdivision) relevant in emergency situations. However, a full demonstration of this process was beyond the scope of FAROS.

Results/conclusions: The project has also delivered novel HR models that can be applied to improve operational efficiency and wellbeing of crew during normal operation of ships. The models are novel because they link HR with GDFs that the crew face with daily, based on well justified scientific framework, and make a contribution to the critical discipline of human reliability analysis (HRA).
Potential Impact:

Impact

From the impact point of view, the ultimate objective of the project is "Improvement of safety of the maritime transport through new systems and concepts." The most significant improvement in maritime safety would be achieved if the summarised project findings—in the form of a suggested list of amendments, or extensions, to current design and operational requirements—were taken forward by IMO. This would stipulate implementation of the project results within the project target group: ship design offices and shipyards, class societies, and ship operators. Those project participants representing the project target group may take action and put into practice project findings already now, but such exploitation will generally be limited until it becomes a law to be enforced by regulatory bodies. Hence, the industrial exploitation of research findings is inherently delayed.

In view of the project results, each partner was asked to list specific exploitable results within their organisation, describe exploitation actions and their timing, and indicate the expected impact of the project results within their organisation. The impact was split into six areas as follows:

1. Productivity: Project findings have increased or are expected to increase productivity within the organisation.

2. Operating finances: Project findings have directly affected or are expected to affect operating cash flow within the organisation. For example, software/service developed within the project can be sold/provide straightaway.

3. Existing service scope and quality: Project findings have improved or are expected to improve existing services within the organisation.

4. Diversification and access to new markets: Project findings have enabled or are expected to enable to introduce new products/services or access new markets.

5. R&D capability: Participation in the project has increased the R&D capability within the organisation.

6. Human resource development: Participation in the project has helped develop human resources within the organisation.

The summary of project impact (graphics attached) has shown that in addition to natural impact on human resources and R&D capabilities, the project has already affected or is expected to affect the scope of existing services and their quality as well as productivity within the organisations. Diversification and access to new market, i.e. innovation, and direct impact on operating cash flow have also been indicated by project beneficiaries.

Main dissemination activities

During the early stages of FAROS the aim was to present objectives of the project and make stakeholders aware of it. Accordingly, first actions included the creation of the FAROS project website, which went live at M3 of the project with WPs and event pages later added at M5. The website has been kept continuously updated by incorporating new incomes through the duration of the project. Moreover, initial papers describing the FAROS objectives and early findings were presented at targeted conferences (M14). In later stages, around M19, as the project advanced the focus has been on disseminating specific results. This included technical papers in relevant peer-reviewed journals and international conferences.

The first paper in the peer-reviewed journal Reliability Engineering and System Safety was published at M19, and two more peer-reviewed papers were published in the same journal in M22 and M33. In M34 another peer-reviewed article was published in Safety Science journal. Further journal publications are also expected. A total of 12 papers have been presented at prestigious conferences such as COMPIT, TRA, ESREL, ICCAS, etc. Additionally, other publications have been used for enhancing the visibility of the project, namely The Naval Architect (a business-oriented magazine with a global reach) and human factors-related magazine Alert! (M20, M24). Also, two articles in books (M24, M33) and a doctoral thesis (M32) have been published in relationship to the project.

Another important dissemination activity has been annual public workshops. Three public workshops have been organised at the end
of each project year. The first public workshop took place in London (M12) targeting regulators, industrial associations and trade unions, whereas the second in Finland (M24) targeting ship operators and builders. The third public workshop (M36) was held in London with the additional inclusion of presentations from two other EU funded projects on human factors, CASCADe and CyClaDes.

Other dissemination activities described in this report are: dissemination of brochures at various events and the production of a promotional video that features certain activities and results of the project. The report also contains individual dissemination and exploitation activities of the project partners.

Detailed information is found in Deliverable D8.8.

Exploitation results

Exploitation of project results will generally be limited until it becomes a law to be enforced by regulatory bodies. Hence, the results of exploitation are inherently delayed.

However, the individual exploitation and its early results can be found in the editable attachment. The information is adopted from Deliverable D8.8.

List of Websites:
www.faros-project.eu

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Related documents

- final1-results.docx
- final1-impact.docx
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