The ultimate technical objective of the FAROS project is to quantify and integrate the human error - which is found to be responsible for some 90% of maritime accidents - into risk-based ship design. Risk-based design is a design process supported by systematic risk assessment so that all significant design decisions are risk-informed. The FAROS project focuses on the concept design stage and adopts a system approach to the human error problem.

The basic assumptions of the system approach are that the crew are fallible and errors are to be expected. Such 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).

Hence the broader operational aim of the project is to improve the conditions under which the crew works, thereby reducing the occurrence of human error and mitigating its consequences.
The FAROS project consists of 8 Work Packages (WPs), addressing performance studies, risk models, design optimisation, and validation. The five technical WPs are closely interlinked.

- **WP3**: Crew performance studies
- **WP4**: Risk models with crew performance
- **WP5**: Risk-based design implementation
- **WP6**: Design optimisation studies
- **WP7**: Validation

The first project period included activities under WP3, 4, 5 and 6, was dedicated to the quantification and the integration of the human error into risk models and design. It essentially resulted in a design assessment toolbox to be used for performance optimisation of preselected RoPax and oil tanker ships in the second period of the project. Specific project findings are summarised as follows.

**Linking Design to Human Performance**

In order to integrate the human error into risk models, which are then applied in the risk assessment, the causal link between **Global Design Factors (GDFs)** and human performance had to be quantified. The GDFs considered were: ship motions, whole body vibration, noise, deck layout, arrangement of equipment and accessibility. The literature was extensively reviewed for this purpose. However, no quantitative models to represent the causalities were found. To rectify this setback, a high-level, scientifically justified framework was proposed by human factor specialists from Lloyd’s Register.

This framework bridges the knowledge gap and consequently enables design evaluation in terms of its effect on human performance. The framework specifically combines the principles behind the **Dynamic Adaptability Model**, the **Cognitive Control Model**, and the **Malleable Attentional Resources Theory**. Taken together these theories describe a mechanism that accounts for the impact of a ‘trinity of stress’ on human performance, based on the principles of attention management. A specific implementation of the framework can be validated by **Human Reliability Analysis (HRA)** techniques.

The key message from this investigation is that exposure to noise, vibration and ship motions degrades the crew’s attention management capability, which in turn may lead to human error. The deck layout, arrangement of equipment and accessibility were found to affect task (work) demand, i.e. making tasks easier or more difficult to complete. Hence the right design can be found to maximise the crew efficiency and make lapses, slips, fumbles, and procedural violations less frequent.
**ARBITRARY LEVELS OF ENVIRONMENTAL FACTORS**

The literature review on the effect of GDFs on human performance at sea also found that the current design rules and standards use a binary approach with maximum allowable GDF limits, with the assumption that exceedance of them would have detrimental effects on human performance, but that no degradation would occur at lower levels. Although some standards were indeed found to be linked to physiological functions (e.g., limits on ship motions), there was insufficient evidence to claim these links apply to all standards, and there was no evidence at all to support a link to crew cognitive functions.

As deficiencies in cognitive functions (e.g., situational awareness and decision-making) are the primary causes of human errors, the binary model and current limits on GDF values thus may not provide for some safety critical tasks performed by the crew. In other words, the limits are arbitrary with respect to safety. This observation is further reinforced by the fact that maximum limits on noise and whole body vibration significantly vary from class society to class society (e.g., noise limits in the wheelhouse range from 55 to 65 dB, according to ABS and LR respectively).

**VIRTUAL REALITY EXPERIMENTS**

Virtual Reality experiments were conducted by University of Strathclyde and CIS Galicia (which later became part of the Galician Innovation Agency), involving 12 engineers from Tallink Group. The experiments conducted in RoPax machinery spaces showed how deck layout may affect crew behaviour. It was observed that the propensity to keep watertight doors open - and significantly compromise the watertight integrity of the vessel - may be directly proportional to the frequency of passing through them. Additionally, it was noticed that a bigger engine room, or any other compartment with hazardous equipment inside, may be safer because the crew would utilise the extra space to keep further away from hazardous objects. However, both observations were inconclusive as the experimental data was insufficient to make a comprehensive statistical inference. As this subject is of great interest, future research - outside project FAROS - should involve experiments on a much larger scale to be fully confident about the studied phenomena.
BRIDGE SIMULATIONS

The negative effect of GDFs was also studied on bridge simulators provided by Hochschule Wismar, University of Applied Sciences, Technology, Business and Design. The experiments were conducted by University of Strathclyde on tanker and RoPax simulators. The deck officers were deployed by operators Tallink Group and Arcadia. The aim of the experiments was to test the effects of noise and ship motion on collision/grounding avoidance, which was quantified as the mean value of the closest point of approach (CPA). Whilst the mariners in almost all cases violated the safe navigation distance of 1nm from a collision threat or grounding line, no evidence of an influence of GDFs on navigation performance emerged on any of the measures. Task difficulty may have been too extreme in the experiment scenarios to enable a clear pattern to emerge regarding the influence of GDFs. However, there were clear findings regarding the effect of sleep restriction in RoPax scenarios. Mariners, when sleep restricted, were found to steer courses to be significantly further away from target vessels than when fully rested. This pattern was interpreted as reflecting effort on the part of the mariners to compensate for tiredness. On the whole, this experimental study was useful and it contributed to the subject of safe navigation, expanding the previous work in FP7 project Horizon (2012) in which collision avoidance was measured independently of the effect of ship motions and noise.

DEVELOPMENT OF RISK MODELS

The accumulated knowledge regarding the causal links affecting crew performance allowed the development of risk models concerning human error. The following risk models for RoPax and tanker ships were developed in the FAROS project jointly by consultancies, classification societies, and operators:

**Personal injury and death risk model:**
Lloyd’s Register, Deep Blue srl, and Brookes Bell R&D.

**Collision and grounding risk model:**
AALTO University, VTT Technical Research Centre of Finland, and Brookes Bell R&D.

**Fire risk model:**
Brookes Bell R&D, Tallink Group, and Alpha Marine Consulting.
The models were designed to account for the existing causal links between GDFs and crew performance. They were developed using a range of technical expertise and analysis methods, then integrated into a single overall approach to Risk-Based Design.

The causal chain that was integrated in the FAROS risk models

**PERSONAL RISK MODEL**

It is important to note that prior to the FAROS project, no personal risk model that linked GDFs with probability of injury and death had been available. This makes this development particularly significant. The model focuses on such incident types as; slips, trips, falls, falls from height, and impact by moving objects, and considers unsafe behaviour as the main antecedent condition for personal injuries and fatalities. A **Bayesian Belief Network (BNN)** was developed to represent this risk model.

Identified work-dependent and work-independent causal paths describing the effect of Global Design Factors on human performance, safety behaviour, and the occurrence of personal injury. (Courtesy of Lloyd's Register)
**COLLISION AND GROUNDING**

The collision and grounding risk model consists of two parts: the probability of a collision/grounding event occurring and its subsequent consequences. The model is based on the most recent casualty statistics from the Sea-web database and expert estimates of collision and grounding encounters on preselected routes. The consequence part of the model is underpinned by research work on damage stability recently funded by the European Maritime Safety Agency and European Commission (such as the FP7 project **GOALDS**).

► Causal chain developed to describe the relationship between crew exposure to Global Design Factors and the unwanted outcomes of collision or grounding (probability of collision per encounter).  
(Courtesy of AALTO University)

**FIRE RISK MODEL**

The work on the fire risk model was chiefly focused on the fire inception probability in different onboard spaces. The development was based on statistics from the Sea-web database, fire accident investigation reports, empirical data elicited from tanker and RoPax engineers, and other sources. The work resulted in:

- **Probabilistic ignition models** for the engine room, galley, Ro-Ro deck, cargo tanks, and cabins (both crew and passenger).
- **Ignition scenarios** for smoking, arson, and electrical fault caused ignitions.
- Statistically estimated **ignition probabilities** for other onboard spaces.

Interestingly but not surprisingly, the main cause of fire inception was found to be human error, as opposed to insufficient equipment reliability or other technological factors which are more significant in subsequent stages of fire development. Thus in general, a strict adherence to safety procedures (e.g. ISM Code) and best practices is essential to avoiding fire inception opportunities.

► Cumulative probability distributions of Time to Fail (TTF), i.e. time to leak, for machinery components liable to leaking flammable oil in the RoPax engine room  
(Courtesy of Brookes Bell LLP).
INTEGRATION OF THE RISK MODELS

To apply the risk models in design, they were integrated into an overall risk model (i.e. a holistic or total risk model) to be used in the risk assessment process of ship design alternatives. The overall risk model integrates hazards that may occur in both normal and emergency situations. This makes the risk assessment comprehensive and categorical. This property is very useful in design, especially at the concept design stage where a number of distinct design alternatives are assessed on the ship level, as opposed to the system level assessment for example. The aim is to find a ship design which remains safe should any hazardous incident happen versus a ship being safe with respect to only specific hazards A, B, or C etc. This is particularly relevant for a modern society primarily concerned with the loss of life itself, rather than loss of life under certain defined circumstances.

SHIP MODELLING AND PARAMETERISATION

In addition to the development of the risk models, the first project period has also seen extensive work on the modelling and parameterisation of RoPax (140 and 200 m in length) and oil tanker ships (VLCC and AFRAMAX sizes). Using reference design data provided by the design office Naval Architecture Progress, state of the art methods such as the Design Building Block Approach by University College London and the NAPA Parametric Modeller by Brookes Bell R&D were utilised for this purpose. In total, four parametric ship models were developed to be then optimised in the second project period with respect to the overall risk, commercial viability (NPV, RFR etc.), and energy efficiency (EEDI). The selected routes of operation are Baltic and North seas and the Indian Ocean. The design optimisation is expected to result in improvements of the hull, propulsion, and general arrangement.
SUMMARY OF PROGRESS SO FAR

In summary, the key technical deliverables of the first project period are:

**Comprehensive literature review** on human (crew) performance affected by ship motions, noise, whole body vibration, deck layout and arrangement of equipment and accessibility. The summary report is publically available on the project website.

**High-level, scientifically backed framework** that enables quantification of affected human performance and consequently human error.

**Personal and societal risk models** with the human error integrated. The risk models can be used in risk-based design, cost-benefit analysis of risk control options, inference of prescriptive design guidelines, etc.

**Parametric models of oil tanker and RoPax ships** to be optimised for low overall risk, high economic performance and energy efficiency.

The project findings and deliverables can already be used to enhance the training of crew members, upgrade internal safety procedures as a part of continuous improvement under the International Safety Management (ISM) Code, implement revisions and changes to plan approval processes, and improve ship design practices.

FUTURE RESEARCH OBJECTIVES

These findings in the FAROS project have identified potentially fundamental flaws in the current design requirements and their effect on safe human performance, highlighting the need for more research. The future research has to involve large scale experiments on bridge simulators, virtual reality environments simulating engine and other rooms, as well as on-board measurements. The ultimate objective would be to determine optimal conditions for human performance in normal operations, and compare them to corresponding design rules and guidelines.

DISSEMINATION

The project website, [www.faros-project.eu](http://www.faros-project.eu), contains a public area with access to all public project deliverables. The availability of new public reports is also announced on the social media network LinkedIn ([http://www.linkedin.com/company/3194994](http://www.linkedin.com/company/3194994)). A public workshop was held in London in September 2013 and the papers and presentations are available for download from the FAROS website, along with details of future events.

▲ The first public workshop saw extensive discussion of the 17 position papers presented
ACKNOWLEDGEMENTS

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FAROS CONSORTIUM MEMBERS

The FAROS project consortium consists of 12 members including industry, academia & research institutes:

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