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Abstract

This document contains synthesis of research performed under ongoing EU-7FP project FAROS, Human Factors in Risk-Based Ship Design Methodology, WP3, task 3.2 Synthesis of the effect of ship motions; task 3.3 Synthesis of the effect of vibrations; task 3.4 Synthesis of the effect of noise and task 3.5 Synthesis of the effect of deck layouts and equipment arrangement and access.

The full reports covering these issues have been published as the following deliverables: D3.2 *Quantitative models of crew performance linked to ship motions*; D3.3 *Quantitative models of crew performance linked to onboard noise and whole body vibrations*; and D3.4 *Quantitative models of crew performance linked to Deck layouts, Equipment Arrangement and its Access.*

The main goal of the work reported here was to summarize literature analysis and make synthesis of knowledge on the effect of ship motions, noise, vibrations and Deck layouts, Equipment Arrangement and its Access (DLEAA) as global ship design factors (GDFs) upon the human performance and failure modes (fatigue, sopite syndrome, gross and fine motor skills, seasickness, loss of motivation, etc.).
A second objective was to determine whether qualitative and quantitative mathematical models are available for linking the GDFs to the human failure modes. In this context, the term quantitative models denote mathematical models that map given GDF values (e.g., noise and vibration levels) into corresponding values of human performance metrics, allowing to monitor fluctuations in human performance as GDFs change.

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Table of content

0 Executive Summary

This document provides a comprehensive summary of the literature review made in the work-package 3. The summary is based on other summaries produced in deliverables:

- D3.2 *Quantitative models of crew performance linked to ship motions*;
- D3.3 *Quantitative models of crew performance linked to onboard noise and whole body vibrations*;
- D3.4 *Quantitative models of crew performance linked to Deck layouts, Equipment Arrangement and its Access.*

The findings from the literature are summarized here on the effect ship motion, noise, vibrations and Deck layouts, Equipment Arrangement and its Access as global ship design factors GDFs have upon the human performance and failure modes (fatigue, sopite syndrome, gross and fine motor skills, seasickness, loss of motivation, etc.).

In the course of the performed literature review, only quantitative models of binary nature were found. Such models set limit values for ship motions, noise and vibrations. According to the current design standards, exceedance of these limits is supposed to have detrimental effect on human performance, which is not affected otherwise. A direct application of such binary models in ship design, as design constraints, seems straightforward. However, such application would be only correct if the limits were indeed linked to human performance. Although it is seemingly the case with some of them (e.g., limits for ship motion components), there is insufficient evidence to claim that the current design standards are indeed linked to human performance (physiological and cognitive), and therefore safety at sea. Little research has been done in this area.

In the case of DLEAA, the literature review helped identify the most relevant methods to compare and assess alternative designs in terms of certain design features affecting task performance of the crew. These methods have been described in D3.4. They will represent a means of establishing the relative crew performance associated with vessel designs in FAROS. However, no quantitative models were proposed to link DLEAA and human performance at that stage.

1 Quantitative models of crew performance linked to ship motions

Authors – Antti Rantanen (VTT), Seppo Kivimaa (VTT), Barry Davies (LR)

This section contains synthesis of research performed under ongoing EU-7FP project FAROS, Human Factors in Risk-Based Ship Design Methodology, WP3, task 3.2 Synthesis of the effect of ship motions. The full report covering this issue has been published as deliverable D3.2 *Quantitative models of crew performance linked to ship motions,* see [1].

The main goal of the work reported therein was to carry out a thorough literature analysis and synthesis of knowledge on the effect of ship motion as a global ship design factor GDF upon the human performance and failure modes (fatigue, sopite syndrome, gross and fine motor skills, seasickness, loss of motivation, etc.). It was also targeted to study if qualitative and quantitative mathematical models are available for linking the global design factors to the human failure modes.

It has commonly been assumed that sea sickness is uniquely provoked by heave motion characteristics, with pitch and roll movements being ineffective. However, recent experimental studies with a ship motion simulator show, that in tests where subjects were exposed to pitch and roll motions in combination with rather weak heave motions that have no motion sickness-inducing potential, very high levels of motion sickness were observed in almost 50% of subjects [2]. So in addition to heave, also roll and pitch motions must be considered when calculating the vertical accelerations on board a ship.

Concepts of Motion Induced Sickness (MIS) and Motion Induced Interruption (MII) were introduced and calculation procedures to determine MIS and MII for a ship concept in given wave conditions and operation profile are presented. MIS and MII indexes can be used to analyze well-being of passengers, but they do not give very good prediction of possible problems for crew performance and failure.

Interviews of mariners conducted in the course of project FAROS showed that adaptation of mariners to ship motions is high and seasickness among experienced mariners is rare. Even though mariners' interview was rather simplified the results are very much in line with *The Maximal Adaptability Model* and *The Compensatory Control Model.* In heavy sea conditions experienced mariners adapt to the situation and focus on most critical tasks in terms of safety of the ship. However, ship motions may cause fatigue in the long term. Fatigue may be a result of poor quality of sleep caused by ship motions some hours before the person begins watch, rather than the motions experienced during the watch. Additionally, ship motions may interrupt demanding operations like maintenance on board the ship. Hence any ship motion that increases the propensity to call on additional cognitive resources to complete a task is likely to induce fatigue that may impact on performance during subsequent activity.

In the course of the performed research, quantitative models of binary nature have been found. For this purpose the limit values for ship motions have been reviewed and consolidated; see Table 1 - Table 4. If the limits are exceeded human performance is affected, otherwise human performance is unaffected.

Models for motion induced sickness and motion induced interruption on board have been presented. These models at least illustrate ship motion conditions, which clearly have influence on human performance on board.

		Parameter			
		Frequency (Hz)	RMS (m)	G	Angle (˚)
Axis	X (Roll)	0.05 - 0.07	n/a	0.003 - 0.014	7.1 - 9.9
	Y (Pitch)	0.08	n/a	0.01 - 0.022	4.9 - 9.9
	Z (Heave)	0.1	0.25-0.32	0.02 - 0.035	n/a

Table 1 - Motion parameters invoking MIS in 50% of subjects [2].

	NATO STANAG 41549 (US Navy)	US Coast Guard Cutter Certification Plan
Motion Sickness Incidence	20% of crew in 4 hrs	5% in a 30 minute exposure
Motion Induced Interruption	1 tip per minute	2.1 tips per minute
Roll amplitude	4.0˚ RMS	8.0˚ SSA
Pitch Amplitude	1.5˚ RMS	3.0˚ SSA
Vertical acceleration	0.2˚ RMS	0.4˚ SSA
Lateral acceleration	0.1˚ RMS	0.2˚ SSA

Table 2 - Operability criteria [3].

	Merchant ships	Naval vessels	Fast small craft
Vertical acceleration at forward perpendicular (RMS)	0.275g (L ≤ 100m) 0.05g (L ≥330m)	0.275g	0.65g
Vertical acceleration at bridge (RMS)	0.15g	0.20g	0.275g
Lateral acceleration at bridge (RMS)	0.12g	0.10g	0.10g
Roll (RMS)	6.0˚	4.0˚	4.0˚

Table 3 - General operability limiting criteria for ships [4].

	Vertical acceleration (RMS)	Lateral acceleration (RMS)	Roll (RMS)
Light manual work	0.20g	0.10g	6.0˚
Heavy manual work	0.15g	0.07g	4.0˚
Intellectual work	0.10g	0.05g	3.0˚
Transit passengers	0.05g	0.04g	2.5˚
Cruise liner	0.02g	0.03g	2.0˚

Table 4 - Criteria with regard to accelerations and roll [RMS] [4].

2 Quantitative models of crew performance linked to onboard noise and whole body vibrations

Authors – Antti Rantanen (VTT), Seppo Kivimaa (VTT), Toby Garner (LR), Barry Davies (LR)

This section contains synthesis of research performed under ongoing EU-7FP project FAROS, Human Factors in Risk-Based Ship Design Methodology, WP3, task 3.3 Synthesis of the effect of vibrations and task 3.4 Synthesis of the effect of noise.
The full report covering this issue has been published as deliverable D3.3 *Quantitative models of crew performance linked to onboard noise and whole body vibrations,* see [5].

The main goal of the work reported therein was to carry out a thorough literature analysis and synthesis of knowledge on the effect of noise and vibration as global ship design factors GDF upon the human performance and failure modes (fatigue, sopite syndrome, gross and fine motor skills, seasickness, loss of motivation, etc.).

No simplified models exist connecting the basic design parameters of the ship (like main particulars, installed SHP etc.) to the noise and vibration levels. The accurate prediction of noise and vibration can be performed during the design stages of the ship only by using elaborate numerical methods. Their results should be verified by specific measurements during sea trials. Apart from the low frequency elastic vibrations (whipping, springing), it should be noted that noise or high frequency vibrations onboard ships don't depend significantly on the operational parameters like ship route, heading or sea state.

The influence of different vibration components on human exposure depends on vibration frequency. At low frequencies people feel horizontal components more annoying while at higher frequencies vertical component has more weight in human exposure. Acceptable vibration and noise limits for different spaces by ship design rules were illustrated. Criteria for steady state noise and vibration are quite clearly set in the rules.

To describe the exposure to transient vibratory excitations Vibration Dose Value (VDV) can be used. There are proposed limits for acceptable VDV-values, but it is very difficult to say beforehand in which wave and operational conditions these can be achieved. There are studies, which give VDV-levels where passengers start to complain. However, no studies were found where human failure was connected to VDV-levels.

Noise and vibrations, as global design factors, have both specific influences upon crew performance although there is limited collective evidence to ascertain the magnitude of these effects. It is therefore not possible to derive mathematical models to quantify the effect of noise and vibrations upon human failure modes. This finding is in accordance with the Maximal Adaptability Theory, which suggests that a person's response, to noise and vibrations is mediated by their own compensatory mechanisms and their general ability to manage stress.

Ship crew experiences were gathered by interviewing mariners from RoPax and tankers. It seems that vibrations and noise have seldom strong influence on performance during normal watch of mariners. Vibrations and noise may cause fatigue or interrupt demanding operations like maintenance on board the ship. However, experienced mariners adapt to the situation and focus on safety critical tasks.

In the course of the performed research, quantitative models of binary nature have been found. For this purpose the limit values for noise and vibrations have been reviewed and consolidated; see Tables 5-7. If the limits are exceeded human performance is affected, otherwise human performance is unaffected. No other quantitative models have been found to link noise and vibrations and human failure on board.

		RINA	BV	GL	ABS	DNV	LR	IMO Code Res. A.468(XII)	IMO Under discussion		SILENV proposed
									1600-10000 GT	≥10000 GT	
Accommodation	Crew Cabins	55	52	52	50	50	52	60	60	55	50
	Day Cabins	-	-	-	-	-	55	-	-	-	-
	Officers Cabins	52	-	50	-	-	-	60	60	55	50
	Hospital	50	55	54	50	55	-	60	60	55	50
	Offices	58	57	57	55	60	55	65	65	60	53
	Open Deck Recreation	70	70	68	65	70	-	75	75	75	70
	Closed Public Spaces	60	57	90	-	55	-	-	-	-	-
	Mess Room	60	57	57	-	-	57	65	65	60	60
	Recreation	-	-	57	60	-	-	65	65	60	60
	Corridors	-	70	58	60	-	-	-	-	-	65
	Dining Spaces	-	-	-	55	-	-	-	-	-	60
Navig.	Radio Room	58	55	55	55	55	60	60	60	60	60
	Navigation Spaces	58	-	55	-	-	-	65	65	65	60
	Chart Rooms	-	-	-	55	-	-	65	65	65	60
	Radar Room	-	-	-	55	-	-	65	65	65	60
Work	Engine Control Room	70	70	67	65	70	75	75	75	75	65
	Workshops	-	85	80	80	-	85	85	85	85	75
	Open Deck Working Areas	70	-	75	-	-	63	85	85	85	70
	Laundries	-	-	-	75	-		-	-	-	75
	Continuously Manned Machinery Spaces	-	-	-	85	-	90	90	-	-	90
	Not Continuously Manned Machinery Spaces	-	-	110	108	-	110	110	110	110	105
	Cargo Handling Spaces/Areas Near Cargo Handling Equipment	-	-	-	80	-	-	-	-	-	-
	Fan Rooms	-	-	-	85	-	-	-	-	-	-
	Alleways, Changing Rooms	-	-	-	-	-	70	-	-	-	-
	Listening Posts, Bridge Wings	-	-	65	-	-	-	70	70	70	70
	Galleys	-	70	68	70	-	75	75	75	75	65
	Pantries	-	-	66	70	-	75	75	75	75	75
	Stores	-	-	80	70	-	-	90	90	90	75
	Wheelhouse	-	-	-	55	60	65	65	65	65	60

Table 5 - Noise limits for crew spaces given by classification societies and IMO (current and proposed values). Also the proposed values of EU project SILENV [6] are given.

Habitability	Area classification [a]					
	A		B		C	
	mm/s	mm/s²	mm/s	mm/s²	mm/s	mm/s²
Values above which adverse comments are probable	4	143	6	214	8	286
Values below which adverse comments are not probable	2	71,5	3	107	4	143
a The table gives frequency weighted r.m.s. values from 1 Hz to 80 Hz.						

Table 6 – ISO 6954:2000 [7] Guidelines for the habitability for different areas on a ship. Area classification: A Passenger areas, B crew accommodation areas, C working areas.

		BV	GL	SILENV Proposed
		rms 1<f<80 Hz [mm/s]	rms 1<f<80 Hz [mm/s]	rms 1<f<80 Hz [mm/s]
Accommodation	Crew cabins	2.8	1.6	1.6
	Officers cabins		1.2	1.2
	Hospital	2.8	1.2	1.2
	Offices	3.0		3.0
	Open deck recreation		2.6	2.6
	Closed public spaces	3.0	4.0	3.0
	Mess room	3.0	2.0	2.0
	Recreation		2.0	2.0
Navig.	Radio Room	2.8	2.0	2.0
	Navigation spaces		2.0	2.0
Work	Engine control room	4.0	2.4	2.4
	Workshops		3.2	3.2
	Not continuously manned machinery spaces		4.4	4.4
	Alleways, changing rooms	5.0		5.0
	Listing posts, bridge wings		2.8	2.8
	Galleys	5.0	2.0	2.0
	Pantries		2.4	2.4
	Stores		4.0	4.0

Table 7 - Vibration limits for crew spaces given by Bureau Veritas (BV), Germanische Lloyds (GL) and proposed limits in guidelines of EU project SILENV [6].

3 Quantitative models of crew performance linked to Deck layouts, Equipment Arrangement and its Access (DLEAA)

Authors – Yasmine Hifi (BBL), Toby Garner (LR)

This section contains synthesis of research performed under ongoing EU-7FP project FAROS, Human Factors in Risk-Based Ship Design Methodology, WP3, task 3.5 Synthesis of the effect of deck layouts and equipment arrangement and access.
The full report covering this issue has been published as deliverable D3.4 *Quantitative models of crew performance linked to Deck layouts, Equipment Arrangement and its Access,* see [8].

DLEAA may have both direct and indirect influences upon crew performance although there is very limited collective evidence to ascertain the exact nature of this effect.
Therefore it is not possible to derive mathematical models to quantify the effect of deck layout upon human failure modes or even to define a universal cognitive model to explain its effect upon crew performance.

However, it is clear that DLEAA presents certain physical and cognitive demands upon the seafarer, which they must be able to meet in order to perform a task. These may be physical, due to factors such as confined space or impaired accessibility, or cognitive and working memory demands, due to factors such as the distance and separation between functional areas.

Evidence from maritime studies suggest that restrictions to movement due to confined space & obstructions, physical expenditure due to distance traversed and overcoming impaired access, and task interruptions due to the separation of functional areas may be the predominant features of a design that contribute to performance and risks to personal safety.

When the effects of the deck layout were looked at through a possible indirect effect, it was found that the deck layout could affect the crew performance by either exposing them to motion, noise and vibration or by altering the way they perform their tasks.

In the first case, locating working and recreational/resting areas where crew members would be subjected to motion, noise and vibration would affect their performance. The effects of motion, and vibration and noise on the crew failure modes are detailed in FAROS deliverables D3.2 and D3.3 respectively. In the second case some design features can affect the way the crew perform their tasks. Methods to compare and assess alternative designs in terms of these design features were presented in D3.4 and may present a means for establishing the relative crew performance associated with vessel designs.

The following models/approaches are suggested as a means to model certain features of DLEAA and compare differences in vessel design:

i) Link Analysis
Certain human factors tools such as a 'link analysis' [9] would prove useful in determining the relative strength of associations between different functional areas and

help guide decisions for their relative locations on the vessel. This would ensure a close fit between the seafarers, the equipment location and their physical environment.

A Link Analysis focuses upon identifying and measuring the strengths of associations between elements of a design e.g. such as room areas. The strength of association is calculated through measuring factors such as the frequency with which people use each area during a particular scenario. Application of link analysis would therefore optimise deck layout by minimising the distance between ‘functionally related’ areas and, in doing so, potentially minimise the risks with regards to the extensive separation of areas e.g. physical expenditure and task interruption.

ii) Time Pressure

A time pressure workload model could provide a simplistic way of identifying circumstances when there is a high propensity for taking short-cuts, see for example [10]. Time pressure workload models determine the time taken to complete a scenario as a proportion of the time available. In circumstances when this nears or exceeds 100%, it could be speculated that people may take shortcuts in order to save time and alleviate their workload. Models incorporating the effects of self-imposed or external pressure on safe behaviours could be applied to determine the likelihood of violations when there is a need to traverse from one area of the vessel to another.

iii) Risk Assessment relating to performance

A risk assessment approach would examine DLEAA through identifying the hazards associated with operating within a workspace and the likelihood of the actions resulting in an undesirable outcome to performance and safety. This could be done by assessing designs against best practice principles associated with communication, traffic/routing, entrances/exits, space allocations etc.

Code of safe working practice

4 Conclusion

In the course of the performed research summarized in this document, only quantitative models of binary nature were found. Such models set limit values for ship motions, noise and vibrations, although these limit values are dispersed with no universal agreement of what values to use. According to the current design standards, exceedance of these limits is supposed to have detrimental effect on human performance, which is not affected otherwise. A direct application of such binary models in ship design, as design constraints, seems straightforward. However, such application would be only correct if the limits were indeed linked to human performance. Although it is seemingly the case with some of them (e.g., limits for ship motion components), there is insufficient evidence to claim that the current design standards are indeed linked to human performance (physiological and cognitive), and therefore safety at sea. Little research has been done in this area.

On this basis, the reported contribution is important because it has identified two major deficiencies in the current design standards. First, there are no universally accepted levels for rating the severity of ship motions, noise or whole-body vibrations on human performance. Second, the limit values for ship motions, noise and whole-body vibration are seemed to be set arbitrarily, as far as crew performance is concerned.

In the case of DLEAA, the literature review helped identify the most relevant methods to compare and assess alternative designs in terms of certain design features affecting task performance of the crew. These methods have been described in D3.4. They will represent a means of establishing the relative crew performance associated with vessel designs in FAROS. However, no quantitative models could be proposed to link DLEAA and human performance.

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5 Indexes

5.1 Index of Tables