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Doctoral Thesis

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ISBN 978-82-326-1367-0 (printed version)
ISBN 978-82-326-1366-3 (electronic version)
ISSN 1503-8181

Doctoral theses at NTNU, 2016:11

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Thesis for the degree of Philosophiae Doctor

Trondheim, January 2016

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Printed by Skipnes Kommunikasjon as

Abstract

Human error and other human related factors have long been identified as the main cause of accidents at sea. Inadequate design has been suggested as a significant reason triggering human actions. In this research, human factors in ship design and operation were investigated using several approaches: a literature review, empirical studies and a theoretical approach. The methods include: content analysis, exploratory survey, explanatory research and on-board measurements, combined with observations and questionnaires. A theoretical evaluation of the human factor construct is made and a model for integrating human factors into design is introduced. The work in this thesis can be classified into six themes:

RT1: Overview of the existing knowledge of human factors in ship design and operation
RT2: Overview of the implementation of human factor principles in ship design and operation
RT3: Overview of the relationships between human factors and other variables of interest
RT4: Overview of the standards and criteria and their relevance
RT5: Overview of the crew's wellbeing and performance
RT6: Overview of human factors theoretical construct in ship design and operation.

Two offshore supply vessels operating in the Norwegian Sea were chosen as the objects of the study; therefore generalisation of the findings is limited. The main contributions of the thesis are:

C1: To present a comprehensive list of documents related to human factors that includes the topics covered
C2: To develop qualitative and quantitative methods, and an on-board evaluation that can be used to distinguish factors related to vessels from those related to humans
C3: To present an example of how different methods were used to evaluate the implementation of human factors on the sampled vessels, including a presentation of results that may contribute to the existing body of knowledge
C4: To present feedback on the existing standards and criteria based on on-board measurements, and which shows their relevance when implemented on two offshore supply vessels operating in the Norwegian Sea
C5: To present a model showing the significant variables and their relationships to seafarers' wellbeing and performance on two offshore supply vessels during their operation in the Norwegian Sea
C6: To present theoretical feedback on the human factor construct in ship design and operation as represented by the sample
C7: To propose a preliminary model of how human factors could be integrated in offshore supply vessel design and operation

Dedication

To my parents who passed away during the journey,

To my children who rise along the way,

And to my wife who endures all the way.

Preface

This thesis is submitted to the Norwegian University of Science and Technology (NTNU) for partial fulfilment of the requirements for the degree of Philosophiae Doctor (PhD). It is constructed based on published and submitted journal papers. The project started in July 2008 and ended in July 2012. It was fully financed by the Department of Marine Technology, NTNU where the doctoral works were undertaken. The supervisor was Prof. Bjørn Egil Asbjørnslett.

The research can be divided into two phases. In the first two years, courses were undertaken, and literature studies and theoretical research were conducted. Three preliminary articles were produced:

1. A Content Analysis of Human Factors in the Design of Marine Systems; published and presented in the International Conference on Ship & Offshore Technology (ICSOT), Surabaya, 11-12 Nov 2010.
2. A Proposed Model to Account for Human Factors in Safety-critical Systems; published and presented in the European Safety and Reliability (ESREL) Conference, Rhodes, 9-11 Sept 2010.
3. Survivability of Ships at Sea: A Human Factors Perspective; published and presented in ERGOShip Conference, Gothenburg, 4-16 Sept 2011.

Those articles were improved and later published in journals:

4. A Content Analysis of Human Factors in Ship Design; published in the International Journal of Maritime Engineering (RINA Transactions Part A3, Vol 156, Jul – Sep 2014)
5. Survivability of Ships at Sea: A Proposed Model to Account for Human Factors in a Safety-critical System; published in the International Journal of Maritime Engineering (RINA Transactions Part A2, Vol 156, Apr – Jun 2014)

In the third year, field surveys were performed on board offshore supply vessels (OSV) operating in the Norwegian Sea. The candidate was given access to two OSVs with different designs. The first survey was conducted in October 2010 on OSV A. The second survey was conducted in February 2011 on OSV B. Results of the observations made on these preliminary visits were reported as an article:

6. Offshore Supply Vessel Design and Operation: A Human Factors Exploration; published and presented in the European Safety & Reliability (ESREL) Conference, Troyes, 18-22 Sep 2011.

This article was improved and published in a journal:

7. Exploratory Surveys of Human Factors on Offshore Supply Vessels in the Norwegian Sea, Naval Engineers Journal, Vol 125, issue 2, June 2013.

Follow-up surveys were conducted to confirm findings from the preliminary observations. Questionnaires regarding the implementation and evaluation of the human factors principles on OSVs were developed and distributed among all seafarers on both OSVs. The results are presented in an article:

8. Human Factors on Offshore Supply Vessels in the Norwegian Sea – An Explanatory Survey (accepted in the International Journal of Maritime Engineering, RINA Transactions, in Press)

Using the same questionnaires, the construct of human factors in ships design is analysed by means of factor analysis. The outcome is presented in a technical note:

9. Human Factors in Ship Design and Operation: A Preliminary Survey of the Theoretical Construct (accepted in the International Journal of Maritime Engineering, RINA Transactions, in Press)

Physical measurements were performed and daily diaries were administered on both OSVs to check the validity of the existing criteria. The surveys were conducted in July 2011 to represent summer conditions and in October 2011 to represent winter conditions. Two reports were written:

10. Human Factors Evaluation in Ship Design: A Case Study on Offshore Supply Vessels in the Norwegian Sea, Part I: Theoretical Background and Technical Constructs
11. Human Factors Evaluation in Ship Design: A Case Study on Offshore Supply Vessels in the Norwegian Sea, Part II: Multivariate Analyses and Structural Modelling

Both papers have been accepted in the Naval Engineers Journal (in Press).

Acknowledgements

I have spent the last seven years studying, researching and writing this thesis for my PhD. It was a difficult journey; the road was long and winding with many obstacles; some were expected and some were not. It was much more than just an academic endeavour. Thankfully it is finally coming to an end. *Fortunately,* the research topic is interesting, it has kept me going.

This journey could not have been completed without help from many people.

First of all, I would like to thank Prof. Stig Berge and Ir. Asjhar Imron, M.Sc. MSE, PED who opened doors for this quest to finally begin. Secondly, I would like to thank Prof. Bjørn Egil Asbjørnslett as the primary supervisor of this study and Prof. Harald Ellingsen who also supported me during this study. Without them, this thesis could not be concluded. Also, thank you very much to Marianne Kjølas and Astrid E Hansen for your kind attention, it means a lot. I would like to express my gratitude and respect to the late Prof. Stian Erichsen, Prof. Svein Kristiansen and Prof. Anders Endal for their dedication to their work, and especially for their interest in this research. Stian was very supportive, and Svein and Anders were very accommodating. I really enjoyed our discussions and appreciated their feedback. To my fellow PhD students and the staff in the Department of Marine Technology and in the Department of Production and Quality Engineering, thank you for your company. I would like to thank the companies that were willing to give me access to their facilities for this research and all the crews that participated in the survey for their kind cooperation and responses.

I would like to thank Erlend Meland, PhD, and Leonard van Duijn, PhD, who also helped me with the articles. Leonard was the reader who recognised the underlying problems in my study. It was a kind of relief to know that someone appreciated the struggle. Special thanks also to my friend Mustafa Sargin, for his kind attention.

To my mother, who first taught me about academic endeavour, and to my father who led by example. To my wife, Lemuella and to our children Anastasia and Amadio, who strived together, I express my gratitude. Also to my brother Stephanus and my sister Maria Magdalena who were always supportive.

Last but not least, I would like to express my gratitude to the my fellow brothers and sisters in Frikirke, Trondheim; the Indonesian Bible Study in Trondheim; the Indonesian Community in Trondheim; and the large family of Birralee International School, for their company and support during our stay in Trondheim.

Celoteh camar tolol dan cemar *)	The jabber of the silly & blackened gull
Api menjalar dari sebuah kapal	Fire spread from a ship
Jerit ketakutan	Screams of fear
Keras melebihi gemuruh gelombang	Louder than the rumbling waves
Yang datang	that arrives
Sejuta lumba lumba mengawasi cemas	Millions of dolphins watching frantically
Risau camar membawa kabar	Frightened seagulls carry the news
Tampomas terbakar	Tampomas is burning
Risau camar memberi salam	Worried seagulls greet
Tampomas Dua tenggelam	Tampomas II is sinking
Asap kematian	The smoke of death
Dan bau daging terbakar	And the smell of the burning flesh
Terus menggelepar dalam ingatan	Continue to flounder in memory
Hatiku rasa	My feeling
Bukan takdir Tuhan	It is not the God's destiny
Karena aku yakin itu tak mungkin	Because I'm sure it is impossible
Korbankan ratusan jiwa	Sacrificing hundreds of lives
Mereka yang belum tentu berdosa	Those who are not necessarily responsible
Korbankan ratusan jiwa	Sacrificing hundreds of lives
Demi peringatan manusia	Just to notify the others
Bukan bukan itu	No, not that
Aku rasa kita pun tahu	I think we also know
Petaka terjadi	Accidents happened
Karena salah kita sendiri	Because of our own fault
Datangnya pertolongan	The arrival of the rescue
Yang sangat diharapkan	Is very much expected
Bagai rindukan bulan	Is like longing for the moon
Lamban engkau pahlawan	Slow you heroes
Celoteh sang camar	Chirped the gull
Bermacam alasan	Lots of excuses
Tak mau kami dengar	We don't want to hear
Di pelupuk mata hanya terlihat	Our eyes only see
Jilat api dan jerit penumpang kapal	Fire licking and passengers screaming
Tampomas sebuah kapal bekas	Tampomas is a used ship
Tampomas terbakar di laut lepas	Tampomas is burning on the open sea
Tampomas tuh penumpang terjun bebas	Tampomas passengers plunge into the water
Tampomas beli lewat jalur culas	Tampomas was bought deceitfully
Tampomas hati siapa yang tak panas	Tampomas whose heart is not burning
Tampomas kasus ini wajib tuntas	Tampomas this case must be concluded
Tampomas koran koran seperti amblas	Tampomas newspapers vanish
Tampomas pahlawanmu kurang tangkas	Tampomas your heroes are incompetent
Tampomas cukup tamat bilang naas	Tampomas quite finished stated ill-fated

*) 27.01.81 KMP Tampomas II caught fire and sank in Java Sea. Approx. 580 fatalities.
An Indonesian revolutionary ballad singer, Iwan Fals documented the event in this song.

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Abbreviations

ABS	American Bureau of Shipping
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
BBN	Bayesian Belief Network
B mld	Breadth moulded
BS	British Standards
BV	Bureau Veritas
C	Contribution
CBA	Cost and benefits analysis
CEPAC	Crew and Embarked Personnel Accommodation Comfort
COMF	Comfort
CONT	Controllability
CP	Conference paper
crn	Comfort rating number
CyClaDes	Crew-centred Design and Operation of ships and ship systems
dB	Decibel
DGNSS	Differential Global Navigation Satellite System
DNV	Det Norske Veritas
DP	Dynamic Positioning
DVD	Digital video disc
DWT	Deadweight
ECDIS	Electronic Chart Display and Information System
EC	European Commission
ECR	Engine control room
ER	Engine room
EU	European Union
F	Fischer test, in analysis of variance (ANOVA)
FAROS	Human factors into risk-based design of ships
GL	Germanischer Lloyd
GPS	Global Positioning System
H	Hypothesis
HAB	Habitability
HDBK	Handbook
HF	Human factors
HFE	Human factors engineering
HFES	Human Factors and Ergonomics Society
HRM	Human resources management
Hs	Significant wave height
HSC	High-speed craft
HSE	Health, safety and environment
HVAC	Heating, ventilation and air conditioning
Hz	Hertz
IACS	International Association of Classification Societies Ltd

ICLL	International Convention of Load Lines
IEA	International Ergonomics Association
IJME	International Journal of Maritime Engineering
ILC	International Labour Conference
ILO	International Labour Organisation
IMO	International Maritime Organisation
ISM	International Safety Management
ISO	International Organization for Standardisation
KMO	Kaiser-Meyer-Olkin
KR	Korean Register of Shipping
LNG	Liquefied natural gas
LOA	Length overall
LR	Lloyd's Register
MAIN	Maintainability
MANV	Manoeuvrability
MARINTEK	Norsk Marinteknisk Forskningsinstitutt AS
MARPOL	International Convention for the Prevention of Pollution from Ships
MII	Motion-induced interruption
MIL	Military
MLC	Maritime Labour Convention
MoD	Ministry of Defence
MUNIN	Marine Unmanned Navigation through Intelligence in Network
MSI	Motion Sickness Incidence
NATO	North Atlantic Treaty Organisation
NEJ	Naval Engineers Journal
NORDFORSK	Nordic Co-operative Organisation for Applied Research
NKK	Nippon Kaiji Kyokai
NTNU	Norwegian University of Science and Technology
NWEA	North West European Area
OHS	Occupational health and safety
OSV	Offshore supply vessel
P	Journal paper
p	Significance level in statistical test
PAF	Principal axis factoring
PPE	Personal protective equipment
PSA	Petroleum Safety Authority
r	Correlation index in statistical analysis
RBA	Risk-based approach
RCI	Ride comfort index
RINA	Registro Italiano Navale
RINA	Royal Institution of Naval Architects
RMS	Root mean square
RQ	Research question
SEM	Structural equation model
SHIPS	Ship–Human Integration Performance System
SILENV	Ships oriented Innovative soLutions to rEduce Noise and Vibrations

SNAME	Society of Naval Architects and Marine Engineers
SOLAS	Safety of Life at Sea
SPSS	Statistical Package for the Social Sciences
SS	System safety
STANAG	Standardisation Agreement
STCW	Seafarers' Training, Certification and Watchkeeping
STD	Standard
SURV	Survivability
Tonnage	International Convention of Tonnage Measurement of Ships
Tp	Peak period
USCG	United States Coast Guard
WORK	Workability

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Chapter 1: Introduction

In the beginning … darkness was over the surface of the deep…

1.1. Problem Outline

This work was prompted by the number of fatal accidents in developing countries, where safety is in a different realm; characterised by overcrowded, overloaded and inadequate vessels with low operating standards, low safety awareness and ineffective regulatory systems (Lawson & Weisbrod, 2005; Spouge, 1991). It was realised that many problems in the field of maritime technology were related to humans. Research showed that most accidents at sea were caused by human errors (Baker & McCafferty, 2005; McCafferty & Baker, 2006). Despite this, it seemed that "human factors"[1,2] were barely a consideration when designing a ship. There was a gap between existing knowledge of ship design and needs in reality. It is true that safety-related issues were implemented, for instance by designing escape routes, installing firefighting equipment, putting safety signs, installing safety-related equipment, implementing safety procedures and performing safety training, but, whether consideration of human factors was integrated across the entire ship design needs to be investigated further.

This thesis involves several themes. First, it will discuss the "human factors" present in ship design and how this is included in existing documents such as rules, standards and guidelines. Secondly, it will investigate how human factors and aspects of human factors are taken into account in ship design. In this thesis the term "ship design" is limited to the object of the study: relatively newly built, offshore supply vessels operating in the Norwegian Sea. Thirdly, the thesis will examine whether the sampled supply vessels can be distinguished from the human factor perspective, and if a consideration of human factors has had an effect on the possibility of an accident. Fourth, the thesis will evaluate the effectiveness of the existing standards and criteria of human factors on offshore supply vessels during

[1] The term "human factors" refers to: "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system,… " (International Ergonomics Association, 2012).

[2] According to Merriam-Webster.com (2014) online dictionary the term "human factors" is a noun plural but singular in construction. Therefore, unless quoted from other sources and/or describe otherwise, the term "human factors" is treated as a singular noun in this thesis.

their operation. Fifth, the seafarers' well-being and performance will be studied in relation to offshore supply vessel design and other operational-related variables. Finally, the thesis will evaluate the theoretical construct of human factors in ship design by taking two offshore supply vessels as examples.

1.2. Research Context

The study was supported by the Department of Marine Technology, Norwegian University of Science and Technology (NTNU). It was purely academic and independent. This condition gave the researcher the flexibility to develop the research in accordance with the findings, however, it also put the researcher into a relatively limited situation when, for example, accessing the necessary information and collecting relevant data. It took more than two years from the formal beginning of the study to conduct the first field survey.

Research within the area of human factors is unique. It deals with people and their complexity where uncertainty is high and variance is wide. The object of the study is usually difficult to measure, particularly from the engineering perspective. It is also personal, subjective and prone to bias, and consequently, it is sensitive to controversy especially when referring to a particular body, organisation, company, shipbuilder or manufacturer, even to the colour of the flag. Anonymity is thus kept to the highest level possible. The methods implemented in this thesis encompass both approaches, from the engineering perspective as well as from the social sciences.

"Human factors" is a very broad topic with many branches. On every branch there is a separate, independent discipline, such as habitability, bridge design, vibration, noise and safety. This research is trying to present the human factors as a holistic entity. In consequence, the coverage is limited, in that it cannot explore any topic extensively. This research considers how ship design inherently accounts for human factors. The message is mainly addressed to naval architects, marine engineers, ship designers, ship builders, classification societies and all other parties involved in the design stage; especially when the design basis is specified until the ship is launched. It is not about health, safety and the environment (HSE), or human resource management (HRM), nor is it about human psychology or human reliability.

1.3. Research Questions

The purpose of the research was to discover whether "human factors" was sufficiently addressed in ship design, how it was implemented and how it affected the personnel on board. Several detailed questions were asked, such as: how did ship design affect human factors evaluation, did human factors have significant effects on operator conditions and incidents on board, which factors influenced operator wellbeing and performance at sea, what were the underlying factors of human factors in ship design, and how can human factors issues be addressed so that they could be effectively implemented in ship design and operation?

1.4. Research Design

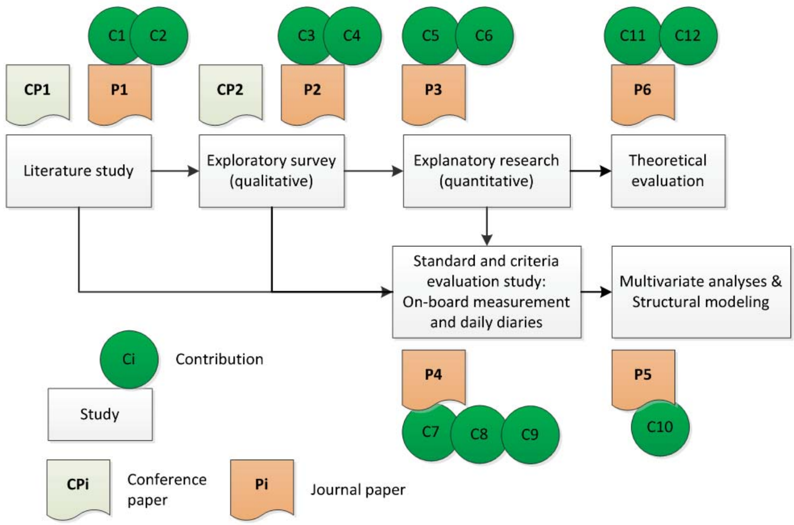

Figure 1 Framework of the thesis, studies, papers and contributions

The research was a kind of adventure. It was begun with one intention, to examine whether "human factors" were considered in ship design, and how. Different methods were used research to answer the questions. The first question asked: "Are human factors considered in ship design?" There was no simple answer to that particular question, and so the question was restated: "How are human factors and different aspects of human factors taken into account in ship design?" A literature study was performed as the first response to the enquiry, by reviewing the rules, regulations, standards, codes, recommended practice and guidelines used as a reference when designing and constructing a ship (see CP1 and P1 in Figure 1. The study at the same time also discussed the "human factors" found in ship design. The second response to the enquiry was to do a survey using a questionnaire developed to measure human factors implementations in ship design. The target respondents were seafarers in the oil and gas industry in the North Sea. This effort failed on the first attempt. A company provided communication access via email to five supply vessels operating along the Norwegian Continental Shelf. Questionnaires were sent to every officer on board. Not a single response was received.

It was not until the researcher came on board, met the seafarers in person, talked to them and observed them in their natural working environment that the research could continue. The results of these visits were reported in CP2 which was later improved to P2.

The initial questionnaires were then modified according to the findings and distributed in person on board the vessel. The results of the survey are presented in P3. An exploratory theoretical evaluation was performed to examine the underlying factors of human factors (presented in P6) using the same data collected from the questionnaires.

When following up the literature study, some of the criteria and standards were evaluated by means of on-board measurements combined with observations and daily diaries. Results of the field study are presented in P4. At the same time, the operators' performance and wellbeing were also examined. Significant influencing factors were identified and a human factors model for offshore supply vessel operation was developed by applying multivariate analyses and structural modelling where several variables of interest were analysed (P5).

Short descriptions of each paper, its relevance and contribution(s), are presented in the following section.

1.5. Papers, Relevance and Contributions

As many as six different studies reported in six papers are compiled in this thesis (Figure 1). Some study results were presented in conferences before they were improved and published in journals. Each journal article is presented as a separate appendix in the thesis.

The title of the first paper (P1) is "A Content Analysis of Human Factors in Ships Design." It was published in the International Journal of Maritime Engineering, RINA Transactions Part A3, Vol 156, Jul – Sep 2014. This paper covers most of the documents, rules, regulations and guidance addressing human factors in ship design. The paper acted as the basic reference for the continued research. The benefits of this paper are two-fold; for the users and for the regulatory bodies. It provides a comprehensive list of documents related to human factors which are beneficial for ship owners, designers and shipbuilders when addressing human factors in their design (C1). For classification societies and other related organisations this paper serves as a directory that can be used to review the existing topics within human factors that have been covered by the documents (C2).

The title of the second paper (P2) is: "Exploratory Surveys of Human Factors on Offshore Supply Vessels in the Norwegian Sea." It was published in Naval Engineers Journal, Vol 125, issue 2, June 2013. This paper provides qualitative evidence of how human factors principles were implemented on offshore supply vessels (OSVs) in the Norwegian Sea. It shows the ability of the industry to address human factors to date, based on observations and interviews. This paper established a foundation for further surveys. The contributions of the paper are identified. For the crews on offshore supply vessels, this paper serves as an opportunity to express their opinions and their assessment of the vessel's design, and to give formal feedback (C3). For the particular ship owners, designers and shipbuilders, this paper could be used as a source of input for improvements. It presents information regarding issues that have been addressed effectively, and issues that need to be improved (C4).

The third paper (P3) "Human Factors on Offshore Supply Vessels in the Norwegian Sea – An Explanatory Survey" has been accepted in The International Journal of Maritime Engineering, RINA Transactions (in Press). This paper provides quantitative evidence of how human factors implementation was assessed by the crews on two OSVs in the Norwegian Sea based on their subjective perceptions and experience, including the different dimensions of human factors: habitability, workability, controllability and maintainability. It confirms the findings of the qualitative study. This paper provides feedback to the particular ship owners and ship designers about how their product was quantitatively assessed by the users, as well as how it was related to incidences on board (C5). The paper also provides a method that can be used to systematically measure and to evaluate different aspects of human factors (C6).

The fourth paper (P4) "Human Factors Evaluation in Ship Design: A Case Study on Offshore Supply Vessels in the Norwegian Sea, Part I: Theoretical Background and Technical Constructs" has been accepted for publication in the Naval Engineers Journal (in Press). This paper plays an important role in the thesis. It demonstrates the relevance of the existing human factors criteria compared to on-board measurements, combined with observations and user evaluations of two OSVs in the Norwegian Sea. It provides authentic feedback regarding the existing human factors standards and criteria (C7) when they were implemented on the sampled vessels. This paper also provides a contribution of methods (C8) that could be replicated on other vessels for further validation. For the ship owners, designers, and ship operators, this paper could be used as guidance regarding how to perceive and how to address the existing human factors criteria on OSVs (C9).

The fifth paper (P5) "Human Factors Evaluation in Ship Design: A Case Study on Offshore Supply Vessels in the Norwegian Sea, Part II: Multivariate Analyses and Structural Modelling" has been accepted for publication in the Naval Engineers Journal (in Press). This paper introduces a method that is commonly used in social sciences to explain the effect of a number of independent variables on a certain dependent variable. It provides numerical evidence of how the variables are interconnected. A valid human factors model in offshore supply vessels operation in the Norwegian Sea related to the design is presented as a contribution of the study (C10). It shows factors influencing seafarers' wellbeing and performance during operation in the Norwegian Sea and it shows how variables relevant to human factors are interrelated. The model could be used as a reference to upgrade vessel design in order to obtain the most effective results, to ensure safety and to improve performance from the human factor perspective.

The title of the sixth paper (P6) is "Human Factors in Ship Design and Operation: A Preliminary Survey of the Theoretical Construct." The paper has been accepted in The International Journal of Maritime Engineering, RINA Transactions (in Press). This paper confirms some of the theoretical elements of the human factors dimensions in ship design and operation. It gives feedback on the human factors theoretical construct (C11). At the same time, the paper could be used as a strategy to integrate human factors in offshore supply vessel design and operation (C12).

The papers published in this thesis were entirely written by the candidate. The supervisor supported the candidate with proper access and adequate resources, gave his professional judgment throughout the process, guided the candidate in the right direction and assisted the candidate in improving the works. All the research work, including literature study, research plan, data collection, data processing, data analysis and synthesis, were mostly performed by the candidate. Mr Frode Gran (NTNU) helped the candidate to prepare the instrument used in this study to measure noise and motion, Mr Geir Spachmo (MARINTEK) helped the candidate process the motion data and Prof. Dr Christian A Klöckner (NTNU) helped the candidate build the model in P5 using the structural equation model (SEM) in MPlus.

1.6. Thesis Structure

The rest of the thesis is structured as follows:

- Chapter 2: State of the Art covers recent publications regarding the topics discussed in this thesis.
- Chapter 3: Research Design and Results consists of the research questions, the purpose or the objective(s) of the research, methods used to answer the enquiries and the scope of works. This chapter also presents a summary of the results of the studies in relation to answering the research questions.
- Chapter 4: Discussion of the results in relation to the research questions, including strengths and weaknesses of the studies, and further elaboration of some of the issues
- Chapter 5: Contributions presents the contributions of the thesis in general Chapter 6: Conclusions presents the conclusions of the research, recommendations and suggests future works.

Chapter 2: State of the Art

"Let there be light!"

Working and living as a seafarer is not easy. It is a high risk occupation with long hours and monotonous living and working conditions, in addition to the harsh situations that the seafarers have to cope with in their job. One statement quoted in the International Labour Organisation (ILO)'s book dramatically describes the outcome (Alderton, 2004):

> A seafarer is a peculiar animal. He is a stranger when he comes ashore and is the odd man out in almost any situation. We cater for the loneliness of the seafarer – that might sum the whole thing up. When you come home, you stick out like a sore thumb – the world has gone on without you and it is not going to stop to fit you into it. Often, this is part of the loneliness of seafarers. A man goes to sea, he begins to look forward to coming home. He begins to wish his time away at sea; that's a dangerous thing for a man to do. He is in danger of losing his soul, I would say – his sense of being. He comes ashore and it's fiesta time for him and nobody else. All too often the leave you look forward to falls flat on its face.
>
> Padre in charge of a Seaman's Mission[1]

2.1. Accidents and Human Errors

The frequency of maritime accidents in the world is declining, however, studies show that human error remains *the* dominant factor (80%-85%) in maritime accidents (Baker et al., 2005; McCafferty et al., 2006). Approximately 50% of maritime accidents are initiated by human error, while another 30% are due to the failure of humans to avoid accident. This 30% portion reflects the conditions that should have been countered by humans and were not adequately addressed (Baker & Seah, 2004).

A study to analyse accidents involving high-speed craft (HSC) and conventional ocean-going vessels shows that the HSC accidents are mainly related to bridge personnel and operations where the human element is the key causal factor identified (Antão & Guedes Soares, 2008). In ocean-going commercial vessels, it is navigational equipment and procedures that cause more accidents. Accidents involving HSC comprises the 50% initiated by human error and accidents involving ocean-going vessels the 30% proportion of the conditions described by Baker et al. (2004).

Reason (1990) defines error as: “a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency”. A series of planned actions may fail to achieve their desired outcome because the actions did not go as planned or because the plan itself was inadequate. Reason (1990) further describes: “slips and lapses are errors which result from failure in the execution and/or storage stage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective.”

Human error can be defined as ”not intended by the actor; not desired by a set of rules or an external observer; or that led the task or system outside its acceptable limits” (Senders, Moray, & North Atlanctic Treaty Organisation, 1991).

The human error problem can be viewed in two ways: the human approach and the system approach (Reason, 2000). The human approach points at the errors of individuals, blaming them for forgetfulness, inattention or moral weakness. The system approach focuses on the conditions under which individuals work and tries to build defences to avert errors or mitigate their effects.

In this thesis human error is defined as an error made by a human who does not intend to make the mistake, however, the focus of this thesis will be on the conditions where, and in which, humans work and perform their duties.

The International Maritime Organisation (IMO) report on casualty statistics from 2006 to 2011 shows that the number of casualties of ship per year continues to decline, by approximately 27% per annum (International Maritime Organization, 2012a). Most of the losses are centred on South China and the South East Asia region (Seafarers International Research Centre, 2012). This is not surprising, as already described in Section 1.1 in this thesis. Spouge (1991) and Lawson and Weisbrod (2005) reported that the conditions of sea transportation in developing countries were terrible, characterised by the use of substandard vessels, minimum maintenance and low safety awareness. Another figure from 2000 to 2014 supports the finding that most shipping accidents with high numbers of fatalities worldwide, took place in developing countries (Statista, 2014). Only two out of twenty four shipping accidents in the last fourteen years took place in Europe, the *Express Samina* (September 2000 in Greece) and *Costa Concordia* (January 2012, in Italy). Two other major accidents that occurred in Europe took place before 2000: the capsizing of the *Herald of Free Enterprise* (at least 188 casualties) (Kristiansen, 2005) and *MV Estonia* (852 casualties) (The Joint Accident Investigation Commission of Estonia, 1997). Those accidents happened in 1987 and in 1994 respectively.

2.2. Design and Human Factors

In contrast to the fact that human error and human related factors were still the dominant types of accidents at sea, the human element seems to be neglected in ship design. The human element here is defined as “the people operating the ship” (Lloyd's Register, 2008). There have been quite a few critiques of this particular situation.

Reason (1990) demonstrated that rather than being the main instigator of an accident, operators tend to be the inheritors of systems defects created by poor design, incorrect installation, faulty maintenance and bad management decisions. Their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in cooking. Reason (2000) added that the human condition cannot be changed, but the conditions under which humans work can be changed.

One of the most emphasised messages was quoted (Miller, 1999; Miller & McSweeney, 2000):

> “YOU CANNOT OVERCOME HUMAN ERRORS INDUCED BY POOR DESIGN OF THE WORKPLACE WITH MORE TRAINING, MORE MANUALS OR WRITTEN PROCEDURES, EXHORTATIONS TO WORK MORE SAFELY, OR THREATS OF PUNITIVE ACTIONS FOR JOB ACCIDENTS.”

Another frustration was raised by Graveson (2002) who noted that it was hard to believe that the human element that had been identified as a key factor in marine incidents was not taken seriously in ship design.

2.3. Human Factors in Ship Design

Several definitions related to human factors in ship design are given in this section, including those for the human element, human engineering, human factors, ergonomics and human-centred design.

First, the International Maritime Organisation (IMO) defines the “human element” as (International Maritime Organization, 2004):

> “… a complex multi-dimensional issue that affects maritime safety, security and marine environmental protection. It involves the entire spectrum of human activities performed by ship’s crews, shore-base management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to co-operate to address human element issues effectively.”

The Department of Defence differentiates between “human engineering” and “human factors”. The term “human engineering” is defined as (Department of Defense, 1999):

> “…the application of knowledge about human capabilities and limitations to system or equipment design and development to achieve efficient, effective, and safe system performance at minimum cost and manpower, skill, and training demands. Human engineering assures that the system or equipment design, required human tasks, and work environment are compatible with the sensory, perceptual, mental, and physical attributes of the personnel who will operate, maintain, control and support it”.

The term “human factors” is defined as (Department of Defense, 1999):

> “… a body of scientific facts about human characteristics. The term covers all biomedical and psychosocial considerations; it includes, but is not limited to, principles and applications in the areas of human engineering, personnel selection, training, life support, job performance aids, and human performance evaluation.”

“Human factors” is a relatively novel concept in the field of naval architecture and marine engineering. As a term, “human factors” was popular in America, while the term “ergonomics” was used in Europe. As described by the International Ergonomics Association (IEA) the terms “human factors” and “ergonomics” can be used interchangeably (International Ergonomics Association, 2012):

> “Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance.”

Kristiansen (2005) made a distinction between the concept of ergonomics and human factors. Ergonomics emphasises the design of displays, controls and the workplace, where anthropometry and human physical capacity with respect to sensing and control ability are taken into consideration. Human factors on the other hand is assessed in the light of psychological factors, and the mental capacity to process information, motivation and interaction with colleagues are taken into consideration.

In the basic textbook for naval architects and marine engineers (Calhoun & Stevens, 2003), “human factors” is described as a comprehensive term that involves all biomedical and psychosocial considerations applying to a human in the system. It is concerned with every consideration of the human in the system. In contrast, “human factors engineering” (HFE) is one of many aspects of design that are addressed within human factors. HFE involves issues of layout, equipment design, and workplace environment. It also addresses human-machine interface, including displays and controls. HFE in ship design also includes techniques to define the role of the human, simulation and modelling of crew workload, advanced man-machine interfaces, and ship design methods and data.

CETENA (The Italian Ship Research Company) defines "ergonomics" as the study of human performance and its application to the design of technological systems. The goal of this activity is to enhance productivity, safety, convenience and quality of life. Topics include models and theories of human performance, design and analytical methodology, human-computer interface issues, environmental and work design, and physical and mental workload assessment. Human factors engineering requires input from disciplines ranging from psychology and environmental medicine to statistics (Human Factors and Ergonomics Society, 2009).

Human-centred design (HCD) is a relatively new concept in ship design. It focuses on making systems usable by exploiting the knowledge and operational experience of the various users so as to mitigate the risks from mismatches between the operators and the systems they operate (Lloyd's Register, 2008). HCD is the process of systematically applying human factors and ergonomics knowledge and techniques to minimise human error, enhance effectiveness and efficiency, improve human working conditions, and counteract the possible adverse effects of use on the health, safety and performance of the mariner (Squire, 2007). A European Union (EU) funded research called the CyClaDes project (Crew-centred Design and Operation of ships and ship systems) was launched to promote human element in shipping through design and operational lifecycle (Cyclades Framework, 2015).

Lloyd's Register (LR) defines "human factors" as concerned with the task people perform and the environment they do it in – fitting the job to the person. The topic of human factors is divided into several considerations (Lloyd's Register, 2008): habitability, maintainability, workability, controllability, manoeuvrability, survivability, occupational health and safety (OHS) and system safety.

This thesis adopts the general definition of "human factors" provided by International Ergonomics Association (2012) and adjusts the term to be used in ship design. "Human factors" in ship design is thus defined as a scientific discipline concerned with understanding interactions among humans and other elements on a ship and the work that applies theory, principles, data, and other methods to design the ship in order to optimise safety and performance, as well as the comfort, of personnel. More specifically, this thesis follows the framework provided by Lloyd's Register (2008, 2009) that divides human factors into eight aspects or dimensions. This is the most comprehensive and complete scope of human factors in ship design.

Habitability is defined as the qualities which specify whether a ship is suitable to live in, including proper accommodation to sleep and rest, facilities to store and prepare food and to dine, washing, bathroom and toilet facilities, and recreational facilities to relax and to socialise. Workability involves the qualities and conditions which facilitate the seafarer in working on and operating the vessel properly, comprising appropriate and dependable equipment, tools, signage, sufficient access, competent users/colleagues, and required information, including system and procedures, and communication facilities. Controllability is defined as the qualities that allow the operator to perceive the state of the equipment, systems and interfaces and to control the ship or the equipment with proper response, good reliability and sufficient feedback. Included in the controllability dimension are design of the ship control centre, engine control console, switches, displays, alarms/warnings and automation. Maintainability involves the qualities and conditions which facilitate the crew to undertake proper maintenance of the ship, which includes feasible access, good information, proper diagnostics and schematics, required tools, equipment, spare parts and provisions, and also available storage and procedures. Manoeuvrability is defined as the ability of the ship to be manoeuvred as demanded and to behave as expected in any weather or sea conditions as intended. This includes the hull shape, the available propulsion system, steering system, conning system and a crew that is trained to manoeuvre the vessel. Survivability is defined as the qualities that allow the crews to prevent hazards from developing further and to survive themselves, along with the vessel and the cargo. Included in survivability are escape routes (ship layout), firefighting facilities, damage control facilities and lifesaving facilities. Occupational health and safety comprises the conditions and qualities that allow the crews to work safely and keep them healthy, including effect of work, working environment, living conditions, OHS policy, procedures, personal protective equipment (PPE) and diet. System safety embraces the risks of any possible scenario that might threaten the integrity of the ship, including personnel and cargo. System safety involves hazard identification, the potential for human error, equipment error, external hazard, and risk analysis and management.

2.4. Rules and Regulations

Ships are designed and constructed according to certain criteria, rules and regulations, codes, standards and guidance. There are three different sources from which these criteria can be obtained and applied as the acceptability of a vessel: classification society rules, regulatory requirements and ship-owners requirements (Ashe & Lantz, 2003). Usually ship-owners will refer to rules and requirements published by a classification society and government statutory requirements.

Classification societies serve public interest by promoting the safety of life, property, and natural environment, primarily by developing and standards for the design, construction and maintenance of marine facilities. On the one hand, the classification societies have realised that they should better address the human element. On the other hand, maritime safety organisations have made a greater contribution to addressing the human element in maritime casualties and accidents (Card, Baker, McSweeney, McCafferty, Moore, & Khandpur, 2006).

Since most ships may sail internationally, it is necessary to accommodate various standards issued by different countries and authorities. An international standard was developed, ratified and implemented through the International Maritime Organisation (Ashe et al., 2003). The IMO is an international forum under the United Nations (UN) which has no power of enforcement or initiative but develops conventions, protocols, codes and recommendations. The four most referred to conventions issued by IMO are the International Convention for Safety of Life at Sea (SOLAS), the International Convention for the Prevention of Pollution from Ships (MARPOL), the International Convention of Load Lines (ICLL) and the International Convention of Tonnage Measurement of Ships (Tonnage). SOLAS was adopted on 20th January 1914 after the sinking of the Titanic in 1912. The first ICLL was adopted in 1930 (International Maritime Organization, 2012b), and MARPOL was adopted on 2nd November 1973. Seafarers working and living conditions are regulated by another UN agency: the International Labour Organisation (ILO). Although the problems experienced by people working and living at sea have long been recognised, it was not until 2006 that the Maritime Labour Convention (MLC) was formally established (International Labour Conference, 2006). The convention was enforced on 20 August 2013.

Several documents are listed in the maritime industry as guidance with which to address human factors in design, categorised as structure, hull form, machinery, general arrangement and human-machine interface (Ross, 2009a). The tables provide good information for naval architects and marine engineers about where to look up information regarding human factors in ship design. Further investigation of how human factors were considered in ship design as reflected in the existing standards, rules, regulations, codes and guidance was conducted in the early stage of this research (Rumawas & Asbjørnslett, 2010, 2014).

In the Asia-Pacific Heads of Maritime Safety Agencies Forum, Commander Bryan R. Edmond, chief of the Human Element and Ship Division, USCG presented a paper about the current state of international considerations of human factors (Edmond, 2005). It was acknowledged as a considerable effort by nations, international rulemaking bodies, classification societies and others, to address human factors to reduce the risk of maritime accidents, pollution and security incidents, however, it was also admitted that the effectiveness of those efforts was difficult to gauge.

The maritime industry has taken another step by developing a methodology integrating a risk-based approach in the design and approval processes for ships and ship system (Skjong, 2009b). Unfortunately, human factors is not covered specifically in the scope (Skjong, 2009a). The limitation of the risk-based approach was soon recognised. An attempt to facilitate the missing link was made, specifically for ship collision and grounding scenarios (Montewka, Goerlandt, Innes-Jones, Owen, Hifi, & Porthin, 2012). Ship motion, noise and vibration were seen as the design factors that influence human performance. The Bayesian Belief Networks (BBN) was applied in concert with three other theories, the Dynamic

Adaptability Model, Cognitive Control Model and Malleable Attentional Resources Theory.

It seems that "human factors" is developing rapidly in the maritime industry. In the last two years, ABS has published several new rules and guides related to human factors (American Bureau of Shipping, 2015). Publication #201 the Guide for Ergonomic Notations and #209 Guidance Notes on Noise and Vibration Control for Inhabited Spaces are of interest and considered relevant to this thesis.

Lloyd's Register also published several new documents related to the human-centred approach for ship designers and manufacturers (Lloyd's Register, 2015). The contents of most of the documents are somewhat similar to the previous publications (Lloyd's Register, 2008, 2009). These new titles are the improved versions of the existing Lloyd's Register's documents which were referred to in this thesis.

2.5. Evaluation of Human Factors Principles on Ships

A number of studies were performed by a number of researchers in the maritime industry to evaluate the implementation of human factors principles in ship design. Some relevant findings are presented and summarised according to different dimensions of human factors in the following sections.

2.5.1. Habitability

Habitability and accommodation facilities were evaluated on naval ships (Hardwick, 2000; Strong, 2000). The findings suggest improvements such as a drive toward cabin-based accommodations, increased sleeping space and personal storage, improved ambient conditions and the provision of other facilities.

A North Atlantic Treaty Organisation (NATO) human performance assessment was developed in the form of a questionnaire and used on seven frigates and destroyers in the NATO Standing Naval Forces Atlantic fleet for two weeks, involving 1026 participants and 16,000 completions (Colwell, 2000). Empirical models relating to ship motions, sleep, fatigue, motion sickness and task performance were developed (Colwell, 2009). A method for calculating motion sickness with habituation for a changing motion environment was proposed. Another method was also proposed to calculate task duration effects from ship motions experienced while sleeping (or trying to sleep) prior to being on watch, and from motion sickness symptoms experienced while on watch. The final aim was to find the relationship between tasks not completed and motion sickness.

The well-being of seafarers was discussed from a vessel design perspective (Ellis, 2009), including noise, light levels, the view from the 'window', aesthetics, confinement and other indirect factors such as social support, social networks and restoration. The research indicated the negative effects of noise exposure during rest periods which may lead to increase fatigue. Several inexpensive solutions to increase the wellbeing of seafarers were proposed, such as fitting 'daylight' bulbs rather than neon strip lights and decorating accommodation facilities with aesthetically pleasing colours. Altough artificial light could not fully substitute natural sunlight, high intensity lighting proved to be effective to stimulate seafarers, to improve human performance by increasing alertness (Vagias, 2010).

Ship motion

Ship motions was identified as one of the significant factors interfering in crew's sleep besides noise and toilet visit (P. Matsagas & Miller, 2006). Ship motion was evident to reduce sleep and to disrupt sleep quality. Ship motion was measured, and a ride comfort index (RCI) was developed to show the passenger's evaluation of ride quality on car ferries in Japan (Arima & Tamura, 2006; Arima, Tamura, & Yoshihira, 2006; Tamura & Arima, 2006). The research shows that lateral and vertical motions are good predictors of ride comfort and motion sickness on board high-speed craft as well as displacement-type ships.

Another study measuring ship motion was conducted on an offshore oil production and storage vessel. The relationships between the motion and the crew performance on board were analysed (Haward, Lewis, & Griffin, 2009). Daily diaries were used to measure difficulties with tasks, effort level, motion sickness, health symptoms, fatigue and sleep. It was revealed that crew difficulties increase when vessel motions increase.

A comprehensive literature survey regarding the effects of motion at sea on crew performance was made (Stevens & Parsons, 2002). Their report covered historical information regarding motion sickness, symptomatology, susceptibility and physiological causes of motion sickness and theories explaining motion sickness. Implications for performance were also discussed, together with operability criteria. Some approaches to prevent and mitigate adverse effects of ship motion on crew were suggested (Stevens and Parsons 2002, after Bittner and Guignard 1985). The approach was divided into five different areas: (1) ship design and system engineering, (2) human factors engineering, (3) enhancing natural human resistance to motion effects, (4) modifying adverse physiological reactions to motion, and (5) operation solutions. Areas (1) and (2) are within the scope and the interest of this research. Some of the methods to mitigate the adverse effects of ship motion included in area (1) were hull design, ship arrangement, motion attenuation devices and vibration isolation, damping treatments, and the arrangement and design of crew space. Some methods included in area (2) were the location and orientation of crew stations, work and task design, display control design and placement, optimisation of ship environmental factors and individual anti-vibration devices.

The Office of Naval Research supported a project called "Ship–Human Integration Performance System (SHIPS)" and investigated how well the existing standards for ship motion address human performance issue (P Matsagas, McCaulay, &

Papoulias, 2009). Their preliminary analysis showed that there was a gap between the existing standards and human performance. Furthermore, they claimed that there were no standards or guidance covering sleep disturbances, sopite syndrome and motion induced fatigue to date.

The assessment of the seakeeping performance of a vessel in a specified area is a common procedure that includes the prediction of transfer functions for different speed and headings for each response (Sarioz & Narli, 2005). Combining transfer functions with a spectral formulation of a particular sea area will give predicted motion characteristics of the vessel in different sea states for each speed and heading combination. The habitability of a vessel can thus be estimated. Sarioz and Narli (2005) pointed out that there were no universally agreed criteria for comparing the seakeeping performance of alternative designs. The habitability of a vessel depends strongly on the limiting acceleration level selected.

A European Commission (EC) project was launched to develop an approach to incorporate human factors into the risk-based design of ships (FAROS, 2013). One of the goals was to identify the relationship between ship design features and crew performance. One report presents an on-going study that was performed to determine the effect of ship motion, vibration and noise on the crew's performance and well-being (Kivimaa, Rantanen, Nyman, Owen, Garner, & Davies, 2014). So far, they have interviewed eleven mariners and revealed a high adaptation of mariners to ship motions. Another notable finding was that ship motions may cause fatigue or interrupt operation, but vibration and noise were described as seldom disturbing performance on watch.

Noise

Another EC project called SILENV (Ships oriented Innovative soLutions to rEduce Noise and Vibrations) was launched to study noise and vibration on board ships, as well as noise pollution in the environment of ports and noise radiated in water (SILENV, 2012). One of the studies within the SILENV project was an evaluation of the Comfort Class notation where criteria from classification societies (GL, DNV and BV) were checked against noise and vibration field measurements (Cotta & Tincani, 2011). They concluded: *"…it is probably not strictly necessary for a new ship to have a comfort class…"* Another study evaluated the criteria for noise annoyance on ships (Badino, Borelli, Gaggero, Rizzuto, & Schenone, 2011). This report implies that the existing criteria for noise on ships does not correlate with the comfort or annoyance caused by the noise. Alternative methods were proposed where noise spectra, low frequency pulsation and sound reverberation can be included.

Seafarer fatigue

Seafarer fatigue at sea was extensively studied by means of various methods including a review of literature, a questionnaire survey, physiological assays (salivary cortisol check), instrument recordings of sleep, ship motion and noise, self-report diaries and other kinds of assessments (Smith, Allen, & Wadsworth, 2006). In total, 1856 seafarers including workers on offshore oil installations participated in the study. Evidence demonstrated that seafarer shifts and working patterns were conducive to fatigue. Excessive working hours seemed to be common in the seafaring industry. The effect of working as a seafarer may be felt in terms of health and psychosocial outcomes. The link between fatigue and shipping accidents became apparent. Fatigue was persistently related to poor sleep quality, negative environmental factors, high job demands and high stress. Human fatigue was evaluated with the usage of Bayesian Networks (Ventikos, Lykos, & Vagias, 2012). The research showed that the quality of sleep and other factors such as the non-disturbance of circadian rhythms as important aspects for safe and efficient operations.

According to another study (Houtman, Miedema, Jettinghoff, Starren, Gort, Wulder, & Wubbolts, 2005), which was also cited by Smith, Allen, et al. (2006), the measures that were considered most necessary and effective to reduce fatigue were proper implementation of the International Safety Management (ISM) Code, optimising the organisation of work on board vessels, lengthening rest periods and reducing administrative tasks on board vessels.

2.5.2. Workability and Controllability

A four year study was conducted, where fifteen passenger and cargo ships were visited and observed, and forty bridge officers were interviewed (Lützhöft, 2005). It was found that many ostensibly technically integrated maritime systems were neither well integrated from a human cooperative point of view, nor from a technical point of view. Seafarers must be able to cope with problems by *outsmarting* the system, performing integration work, and sometimes by compromise. Similar surveys were conducted to assess the engine control room (ECR) design on various merchant vessels in Sweden (Andersson & Lützhöft, 2007; Grundevik, Lundh, & Wagner, 2009). The results showed many deficiencies in engine rooms (ER) that did not comply with ergonomics principles or even the OHS requirements.

Human-machine interaction

Poorly-designed controls have the potential to puzzle the operator, decrease operator awareness and cause fatal accidents (Ross, 2009b). The grounding of the *Royal Majesty* was one example of imperfect automation implemented on the bridge which ended in an accident (National Transportation Safety Board, 1997). The global positioning system (GPS) receiver antenna cable connection had separated causing the GPS to switch to dead-reckoning mode, and the autopilot was not programmed to detect such a deficiency and was not corrected for the effects of wind, current or sea. Being 'confident' with the equipment on board, the crews did not keep a proper lookout. The vessel grounded on a shoal near Nantucket, Massachusetts. The CyClaDes project pointed out that there was a lack of regulatory framework for crew-centered design, and therefore made an attempt to fill in the gap (Cyclades Framework, 2015).

2.6. Elimination of the Human Element

There is a current project to develop ships without skippers (Dragland, 2014) under the European Union project MUNIN (Marine Unmanned Navigation through Intelligence in Network). One of the goals is to avoid human error by eliminating the humans on board. At the same time, fewer people in Europe were interested in working at sea. Slower sailing speeds have become favourable for economic reasons, and this is considered a burden by sailors.

The idea of unmanned craft is not a novel concept at sea. The United States Warfare Centre has been working on similar projects in decades, however, it has been implied that eliminating the human element did not necessarily mean reducing the human factors challenges at all (Masakowski, 2009).

2.7. Conclusion

This chapter presented the state of the art, including a brief description of recent developments regarding human factors in ship design, where accidents were taken as the background. It can be seen that much has been accomplished within the field. The substance of human factors in ship design was discussed, definitions were presented, and the way that different topics of human factors were addressed and researched were also described. Some connections were identified between variables such as seafarer performance, fatigue and well-being, noise, ship motion and vibration. A number of standards and other documents related to human factors in ship design were described. It was noted that some questions and scepticism remains. Two issues worth noting include the question of how effective the efforts to address human factors in ship design have been, including methods of measurement, and how to take into account the relationships between human-related ship design features and crew performance. These two remaining questions will be discussed, answered and confirmed in the following chapters. Various methods will be applied to examine the status of human factors implementation in ship design and operation, and relationships between variables of interest are investigated and quantified.

Chapter 3: Research Design and Results

So God created mankind in his own image,…

This chapter presents the research design that follows the sequence of the research questions (RQ) raised in the thesis. First, it describes the motivation and the rationale for each research question, and the research method is explained under the corresponding study which answers the question. Finally, the results of the study are presented.

3.1. Introduction

This thesis was designed based on the system approach (Reason, 2000) which puts the focus on the conditions in which people work instead of blaming individuals for the errors they make. In the system approach, error is treated as a consequence rather than a cause. In accordance with the context in which the research was performed, this thesis focuses on the ship, at sea, the conditions in which the seafarers work.

Based on this background, research questions are raised and described in the following section.

3.2. Research Questions

It was reported that most accidents at sea are caused by human error or human-related factors, and that poor design was identified as a significant causal factor. The first research question in this thesis (RQ1) is thus as follows.

3.2.1. How are human factors and different aspects of human factors taken into account in ship design?

There are several ways to answer this question. The first method is to check the existing rules, regulations and standards available as references for designing a ship through a literature study. The second method is to review the product itself, the ship, by means of a field survey where the researcher observes and examines the ship, and interrogates the users. Another method would be to interrogate the designers and those who were involved in the process of designing and constructing the vessel. The latter approach is not covered in this study due to limited access.

In this thesis RQ1 was investigated sequentially using a literature study, qualitative study and quantitative study. These approaches are described in the following studies; Study 1, Study 2 and Study 3[3].

Study 1: Literature Study

A literature study was conducted based on the notion that ships are designed according to a certain rules and regulations, and so checking these documents would provide information about the intended product: it would provide facts on paper. The study was performed using a content analysis methodology. Content analysis is a research technique for making replicable and valid inferences from texts, or other meaningful matter, to the context of their use (Krippendorff, 2004). The definition of human factors in ship design was documented, then, a coding sheet (Table 1) was developed. Due to the novelty and the variety of the topic of human factors in ship design, the coding sheet expanded throughout the process of data collection. Consequently, the coding process was performed in iterations.

The research content was specified as being documents, standards, rules, regulations, recommended practice and guides published by classification societies and other relevant international bodies which regulate certain aspects of ship design that could affect human performance, health and/or safety on board. Three classification societies were taken as the sample: the American Bureau of Shipping (ABS), Det Norske Veritas[4] (DNV) and Lloyd's Register (LR). Three other organisations are: International Maritime Organisation (IMO), International Organisation for Standardization (ISO) and American Society for Testing and Materials (ASTM).

Two levels of data exploration were conducted. The titles of the documents were checked and identified as to whether they were related to any dimension from the human factors framework. The topics covered in each document were examined and categorised according to the topics within the human factors framework. Tallies were implemented and the results were tabulated.

Results

As many as 95 documents were found to be relevant to human factors in ship design and operation. Table 2 shows a summary of the results, coded according to different aspects of human factors called dimensions. Judging from the number of references noted in Table 2, it is sensible to conclude that human factors and different aspects of human factors have been comprehensively taken into account in ship design.

[3] The term "study" in this chapter and in the following chapters refers to "journal paper" (Pi) as described in Figure 1.

[4] Now, it is called DNV GL, after DNV merged with Germanischer Llyod (GL).

Table 1 Coding sheet

Dimension	Component	Aspect / object
Habitability (HAB)	Accommodation	Galleys, mess room
		Recreational spaces
		Cabins
	Seafarer variation	Size
		Shape
		Gender
	Environmental stressors	Noise, sound
	Environmental condition	Heat, temperature
	Indoor climate	Air velocity, ventilation
	Comfort	Air quality, smell
		Motion
		Vibration
		Lighting
Maintainability (MAIN)	Maintenance tasks	Layout, access, removal routes
		Tools
		Expertise
		Disposal
		Through-life support
Workability (WORK)	Users	Accessibility
	Tasks	Layout
	Equipment & software	Space
	Material & procedures	
	Physical & social environment	
Controllability (CONT)	Control centres	Bridge
		Engine control room
		Cargo control facilities
	People-system integration	Communication facilities
		Controls and switches
	Man-machine interface	Displays, video-display unit
		Alarms
		Automation
		Computer stations
Manoeuvrability (MANV)	Propulsion system	
	Steering system	
	Thrusters	
Survivability (SURV)	Firefighting	
	Damage control	
	Lifesaving facilities	
Occupational Health and Safety (OHS)	Effect to work	
	Working environment	
	Living conditions	
System safety (SS)	Risk consideration	

Table 2 Summary results of documents involving HF in ship design

Publishing institutions	Number of documents	Human Factors / Ergonomics	Habitability	Maintainability	Workability	Controllability	Manoeuvrability	Survivability	Occupational Health and Safety	System Safety
ABS	17	2	6	1	7	4	1	3	3	9
DNV	18	0	1	1	6	7	3	3	0	11
LR	16	0	2	1	2	6	3	6	1	7
IMO	29	2	2	1	6	8	3	11	4	14
ISO (TC8)	13	0	7	0	3	2	0	4	0	2
ASTM	2	2	1	1	2	1	0	1	1	2
Total	95	6	17	5	25	28	10	29	9	45

The study implied that apart from safety and safety-related topics, the implementation of human factors principles in ship design was optional. There is no document that can ensure a ship is built following human factors principles unless in relation to system safety, survivability and OHS, which issues have been regulated since the sinking of the *Titanic*. Should anybody with to address human factors in ship design, there is abundant knowledge to which they can refer, but if someone should choose to disregard it, there is no single document that can prevent this.

The table shows that "System Safety" was issue most covered by the documents, while "Maintainability" was the least covered. A more detailed exploration of each topic within each dimension shows that "Habitability" (or "Comfort") and "Controllability" were the most extensively addressed in the body of documents (ref. Table A.2. in Appendix A). Issues discussed under "Habitability" were predominantly noise, vibration, indoor climate and lighting or illumination problems, while "Controllability" predominantly covered alarms, control centres, workstations and control, and switches. Some topics were less covered and some were not covered at all, such as human reliability, decision making and social factors. The literature study also identified significant improvement in the number of published documents in the last couple of years (American Bureau of Shipping, 2015; Lloyd's Register, 2015).

Study 2: Qualitative Study

Field surveys were conducted to examine the way that human factors and different aspects of human factors were taken into account in recent ship design. The surveys were intended to compare the existing knowledge of human factors on paper with the reality, the manifestations of the rules, regulations and guides. Two types of surveys were prepared: an exploratory survey which was qualitative, and an explanatory research which was quantitative. The exploratory survey was also performed as a preliminary effort to comprehend the objects of the study in their natural context, in addition to answering RQ1. The qualitative approach that was utilised in this study included observations and interviews. Ethnography, a method described as "thick description" (Geertz, 1973) was applied to acquire information during the surveys.

And offshore supply vessel (OSV) operating in the Norwegian Sea was taken as the object of the study. The offshore supply vessel was a perfect candidate for the study because this type of vessel embodies one of the most advanced technologies in ship design. Many improvements were made throughout the development of the ship (Gibson, 2007). An OSV also serves as a good representation of other vessels, through its functions as a combination bulk carrier, for general cargo, a container vessel and a tanker. It also involves the functions of several multi-purpose working vessels including firefighting, oil recovery and as a tug.

Prior to the survey, reports of incidents on offshore vessels and design flaws (Hansson, 2003, 2006; Petroleum Safety Authoritiy Norway, 2011; Petroleum Safety Authority Norway, 2009) were examined and documented (Rumawas & Asbjørnslett, 2011). These reports were used as a reference when conducting the surveys on board, to check whether lessons were learnt.

The surveys were undertaken on two different OSV designs (Figure 2)[5] in both summer and winter. Both vessels were operating in the same area in the Norwegian Sea, serving the same offshore platforms, transporting more or less similar cargoes to and from the installations. Interviews were conducted with most of the crews on board. Some focus discussions were also conducted to review issues that were relevant to the crew, such as the number of procedures and forms that they have to fill in, and how to reduce and to simplify them.

Table 3 shows a summary of the main class and dimensions of the vessels. OSV A follows the traditional design, which represents most supply vessels available on the market. The superstructure, including the accommodation and the bridge, is located at the bow. She is equipped with two sets of bridge console; one facing forward (used during normal sailing operation) and the other facing stern (used during loading and unloading operations).

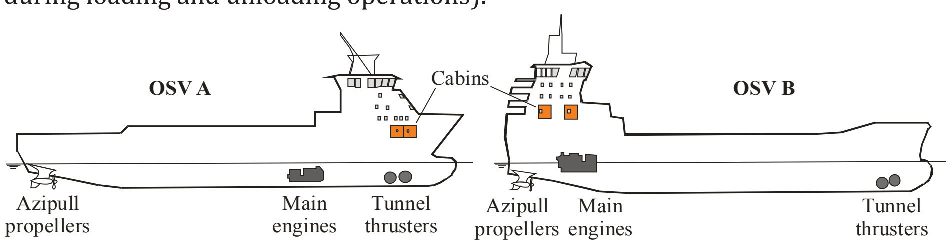

Figure 2 Two different OSV designs

[5] These two vessels, OSV A and OSV B were taken as the samples for the exploratory study (P2) and also for the other studies (P3, P4, P5 and P6).

Table 3 Main class and dimensions[6]

	OSV A (built in 2008)	OSV B (built in 2007)
Main Class, DNV (not all mentioned)	✠1A1, Supply vessel COMF-V(3) Clean E0, DYNPOS-AUTR NAUT OSV (A) Oil Rec	✠1A1, Supply vessel E0, COMF-V(3) Clean Design E0, DYNPOS-AUTR in compliance with NAUT OSV Oil Rec Ice C, Gas Fuelled
LOA / B mld / draft / DWT (approx.) *)	93.90 m / 21.00 m / 6.6 m / 5000 mt	92.20 / 21 m / 7.3 m / 6000 mt

*) LOA: length overall; B mld: breadth moulded; DWT: deadweight

OSV B is an alternative design where the superstructure is at the aft, thus she only needs one bridge console. OSV B applies a dual fuel system: diesel oil with liquefied natural gas (LNG) as an alternative. OSV B is slightly taller than OSV A. The location of the main engine and thrusters relative to the accommodation also differs. Hypothetically, all these variations in the design could have a considerable effect on the human operators on board. Both vessels were relatively newly built and among the top of the line in their corresponding fleets. Both vessels were classed as ✠1A1 supply vessels by DNV and both carry COMF-V(3) class and E0, DYNPOS-AUTR notations.

The human factors framework based on Lloyd's Register (2008, 2009) was employed as guidance in examining whether the existing ship design complied with human factors principles.

Results

The results of the exploratory surveys were divided into two parts. The first part was to check whether lessons had been learnt in relation to previous incidents or

[6] Description of class notation (Det Norske Veritas, 2011):

✠ Vessel built under the supervision of DNV

1A1: Vessel for which periodical surveys are stipulated in relation to special (main) periodical survey intervals of 5 years

COMF-V(3): Vessels with controlled environmental standards (comfort class), V=noise and vibration

E0: Vessel with machinery spaces for unattended operation during normal service as well as alongside quay

DYNPOS: Vessel with dynamic positioning systems

AUTR: an automatic position keeping system with redundancy in technical design

NAUT: Craft built to a special nautical safety standard given by the Rules

CLEAN: Basic requirements for controlling and limiting operational emissions and discharge

CLEAN DESIGN: Additional requirements for controlling and limiting operational emissions and discharges. In addition, this notation specifies design requirements for protection against accidents and for limited their consequences

Oil rec: Vessel for occasional handling, storage and transportation of oil with flash point below 60° recovered from a spill of oil in emergency situations

Ice C: Vessel which may operate in light ice conditions accidents. The second part was to check the implementation of human factors principles compared to the existing framework – used as a checklist and compared to previously documented criticism.

Lessons learnt

Some improvements were noted in both OSVs, implemented as lessons learnt by the industry, involving modifications of the system, developing new procedures (North West European Area, 2009), developing new hardware and systems, and modification of the existing design, such as converting a ladder into stairs and increasing the height of the bulwarks to prevent green water. More examples were noted, such as development of a new cargo securing system and an automatic hose-securing system to improve safety and performance on deck. A modification of autopilot design was implemented on both vessels in parallel with the corresponding code, as a response to several accidents related to autopilot. An example of the new procedures includes voyage planning where a platform can no longer be assigned as the target destination. The vessel should point to a location quite a distance from the platform and which is not in line with her route, to avoid direct collision in case of something goes wrong. A 500m safety zone was stipulated.

Human factors implementation

The results of the survey revealed some development compared to the previously documented criticisms (ref. Section 2.5), especially in habitability, workability and controllability, in addition to safety. Some of the findings are presented in the following sections.

Habitability

Several issues related to the accommodation facilities have been resolved in both vessels surveyed. An adequate standard of accommodation facilities were found on both OSVs. Every crew member was assigned their own cabin (Figure 3) with personal toilet and shower. Cabins are also equipped with a bed, wardrobe, table, chairs, television and sound system. Both OSVs were designed with appropriated facilities such as the galley (Figure 4), the mess room, the (smoking) lounge, the laundry and the gym. Big-screen television sets with satellite connections, leather sofas, and personal computers with internet connections were among the standard facilities on board. Issues related to lighting and indoor climate such as air temperature, relative humidity and air velocity have been addressed satisfactorily on both vessels, however, a subset of beds on OSV A lay perpendicular to the longitudinal axis of the ship, which was in contradiction to crew expectation (Hardwick, 2000). Some issues were identified, such as a considerable rolling motion and vibration during hard weather on OSV A. Slamming was found to be disturbing due to the splash zone location which was adjacent to a subset of cabins. High-pitched noise from the tunnel thrusters was disturbing and interrupted sleep on OSV A. On OSV B the pitch motion was found to be troubling in a particular sea state, but in general the crews appeared to be satisfied with their vessel.

Figure 3 Cabin facilities for the ordinary seamen (non-officers) on OSV A (left) and on OSV B (right)

Figure 4 The galley on one of the OSVs visited has good accommodation facilities

Workability
It was found that both OSVs provided advance workability standards comprising the most recent technology, equipment (hardware) and software, development of working procedures and proper user training programmes including simulator training. Some issues in workability remained, such as inadequate personnel access, including the design of ladders and poor layout plans. There are documents available regarding design of ladders and access (ABS, 2001; Bureau Veritas, 2014; IACS, 2013). The fact that there were several sets of vertical ladders installed on one of the OSV indicated that there are rooms for improvement. Some novel problems were identified: software compatibility issues, operating system problems, expiration date issue, data validity, and overloaded system. Excessive communications on the bridge, excessive alarms and irrelevant alarms/warnings were also discovered during the survey.

Controllability
The ship control centres and engine control rooms on the OSVs were fully computerised, with a high degree of automation. The way the crews operate the vessel has changed significantly. There was no traditional wheel to steer the vessel on the bridge and there was no engine telegraph to regulate the engine speed from the bridge. Some problems found on both OSVs include: bright lights that cannot be dimmed on the bridge, which disturbs visibility at night, and ergonomics issues at the workstations. False alarms and broken sensors were also found.

Some critical incidents which could lead to fatal accidents were identified: dynamic dynamic positioning (DP) failure on OSV A while loading unloading beside an installation, and a blackout on OSV B after loading and unloading was finished and the vessel was about to set sail to another destination. An explanation was given by the maker to the officer on OSV A who experienced the DP failure incident that he was very “lucky” hitting that very small probability of event, it was like winning the lottery. On OSV B, LNG apparently had a different characteristic of which the officer and the maker did not aware, in that it was less responsive to variation of power requirements. A follow up investigation was conducted by contacting the designers and the makers of those systems. The maker of OSV A responded:

1. “Regarding the «OSV A» incident you are referring to, this has happend only once on the entire «maker XX» equipped fleet. We have found the root cause for this, and implemented a solution for it. This failure will not happened again.”
2. “Regarding the other other failures you are referring to, like sensor lost etc, this are failures that happends not in the DP-system itself, but by DP-connected units. …”
3. “Our experience with failures on DP operation are often the human factor. We have examples of DPO's that get alarm for bad DGNSS reception, and still pushes on with the operation, and something unwanted happends. We have users that might be excellent seamen, but when the position reference system gives a warning or an alarm, they don't have experience to understand the effect of it. From our point of view, as specialists on our system, it is important to know that the users are

> specialists on the entire vessel, with some knowledge to all systems. Not deep into the systems as we are."

It can be inferred from the explanation above that the corresponding DP error was a systematic failure (Rausand & Høyland, 2004) and unknown prior to the incident. The maker made a strict division between their system (DP) and the rest of the system, when the system failed. The maker had considerable expectations of the users and did not anticipate random action, given the DP system was not working as expected.

Maintainability
The way maintenance is performed on these supply vessels has changed fundamentally, as the crews knew less and less of what was going on behind their computer screen or display unit. The crew followed the maintenance programme generated by the system, which is not always 100% accurate. Restarting and updating systems and data became a routine procedure on board, and climbing and crawling remained. There was no "acrobatic activity", no "outsmarting the system" and no "performing integration work" required by the crews in the engine rooms. Some issues were found, involving the lack of storage for supplies and tools.

Survivability and Occupational Health and Safety (OHS)
It was found that the crews on both OSVs have strong concerns regarding safety, health and security issues. They applied permits to work, checklists, safety meetings, toolbox talks and risk assessments. Safety drills were conducted regularly. Some of the crews thought that it was too much and they were tired of the drills.

Conclusion
The exploratory survey implied that human factors and different aspects of human factors have been comprehensively taken into account on these two offshore supply vessels. Lessons have been learnt and much has been accomplished; *unfortunately* not all were successful or perfect. The learning process was still ongoing. There was room for improvements. The potential of the ship building industry, which was reflected in supply vessel design, to address human factors issues in their products was recognised. Some classic problems were discovered, such as lack of communication between users and designers, problems of distrust and blame-shifting between parties. The exploratory study confirmed that among other human factors dimensions, maintainability was found to be the least satisfactory and safety-related dimensions were fulfilled without compromise.

3.2.2. Is there any significant effect of human factors with consideration to incidences on board?

The second research question was raised to verify the relationships between accidents (or incidents) and human factor considerations on a ship (RQ2). An explanatory research study was prepared to answer RQ2. This study applied inferential statistics to draw conclusions and to provide evidence. The study was also performed to answer RQ1 from the quantitative perspective. There were two questions that required clarification before RQ2 could be answered:

a. Does ship design have any significant effect on human factors evaluation on board?
b. Does ship design have any significant effect on incidents on board?

Study 3: Quantitative Study

The explanatory research was completed using questionnaires (Appendix G) as the tool of measurement. The research design is presented in Figure 5. Three variables were defined: OSV design, human factors evaluation and incidences. Two different scales were developed and used to measure human factors implementation: direct evaluation (section A, 26 items) and the Likert-scale (Section D, 65 items). Two types of incidents were defined: personnel incidents (Section B, 8 items) and vessel incidents (Section C, 8 items). The personnel incidents included motion sickness incidents (MSI), fatigue, stumble, hitting an object by accident or being hit by an object, slip, fall, motion-induced interrupted (MII), misoperating a switch or a control, being confused with a system, failure to follow a system or procedure and sleep disturbances/interruption. The vessel incidents comprised loss of power (blackout), loss of navigation control, contact, collision, water on deck, loosening cargo on deck, falling objects, fire or explosions and cargo spills.

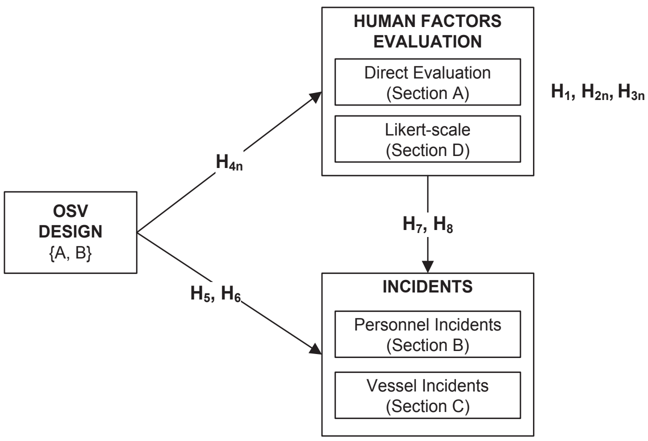

Figure 5 Research design and hypotheses for explanatory study

Four groups of hypotheses were proposed in relation to the research questions. The first group (H1, H2n and H3n) was to verify whether human factors in general (H1), and specifically (H2n), were significantly considered on OSVs (RQ1) and to determine whether different dimensions of human factors were implemented equally (H3n). The second group (H4n) was to determine whether ship design could have a significant effect on human factors evaluation (RQa). The third group (H5, H6) was to verify the effect of different OSV design on incidents on board

(RQb). The fourth group (H7, H8) was to check the relationship between human factors and incidents on board (RQ2). In total 42 respondents from both OSV A and OSV B completed the questionnaires. Various inferential statistics were used to test the hypotheses. Due to a relatively limited number of respondents, analysis was performed with caution and assumptions were checked at all times.

Results

The explanatory research revealed that the "concept of human factors" is quantitatively measurable and its validity can be verified. It was confirmed that human factors in general, and different aspects of human factors, were considered adequately on offshore supply vessels surveyed in the Norwegian Sea. The level of implementation of human factors differed from one aspect to another. The highest satisfactory aspect or dimension was OHS (Figure 6). Habitability was very satisfactory, workability was satisfactory, and maintainability was the lowest but still acceptable (above 3.0[7]). These findings confirmed the results of the literature study and exploratory study.

The study indicated that OSV design had the potential to affect human factors evaluation on board. There were some differences in the level of accomplishment of human factors on OSV A compared to OSV B. The crews on OSV B were more satisfied in general than the crews on OSV A, especially with respect to habitability and workability (Figure 7).

The results demonstrated that there was no significant variation in the overall average number of personnel incidents (Figure 8) or the vessel's incidents (Figure 9) across OSVs. Figure 8 shows in detail that there was a considerable difference in fatigue as perceived by the crews on OSV A compared to those on OSV B and there was a slight variation in the incidence of seasickness and sleep disturbance, but the difference was inconclusive ($p<0.10$). Figure 9 shows that there was a significant difference in specific cases of water on deck and moving (or loosening) cargo on deck. The crews on OSV B reported less incidence of "water on deck" and "moving cargo on deck". They also reported a higher frequency of loss of power incidents, which confirms the finding from the exploratory study, but the difference was statistically insignificant.

Further analyses of the explanatory study revealed that habitability had a positive impact on motion sickness incidents (MSI), fatigue and sleep disturbances. The better the habitability as assessed by the crew, the lower the frequency of the MSI reported. The crews became more fit and reported better sleep. Around 12% to 14% variance of these incidents can be explained by habitability. It was also revealed that maintainability had a significant effect on the probability of fire and explosions. The relationship was nevertheless counter-productive, meaning that the higher the maintainability the higher the frequency of fire or explosion on board.

[7] Scale description: 1: very poor, 2: poor, 3: neutral, 4: good, 5: very good

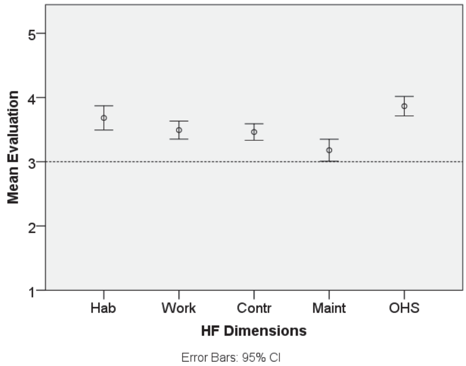

Figure 6 Human factors Likert-scale evaluation result: Mean plot with error bar for each dimension
(Scale description: 1: very poor, 2: poor, 3: neither, 4: good, 5: very good)

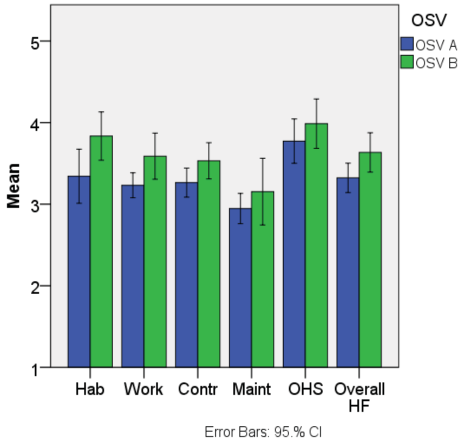

Figure 7 Human factors evaluation on two different OSV designs
(Scale description: 1: very poor, 2: poor, 3: neither, 4: good, 5: very good)

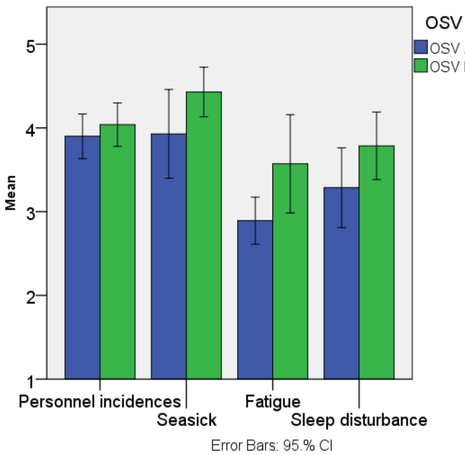

Figure 8 Mean frequencies of personal incidents perceived by the crew
(Scale description: 1: very often, 2: quite often, 3: sometimes, 4: seldom, 5: never)

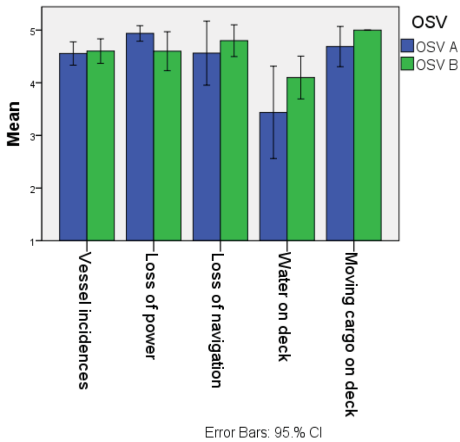

Figure 9 Mean frequencies of vessel related incidents perceived by the crew
(Scale description: 1: very often, 2: quite often, 3: sometimes, 4: seldom, 5: never)

3.2.3. Are the existing standards for human factors in ship design effective?

Classification societies provide additional notations such as Habitability (HAB) (ABS, 2001), Comfort Class (COMF) (Det Norske Veritas, 2009) and Crew and Embarked Personnel Accommodation Comfort (CEPAC) (Lloyd's Register, 2012) in order for ships to be designed using human factors considerations. IMO published a number of codes and guidelines within the area, such as the code on noise levels (International Maritime Organisation, 1981), guidelines for engine-room layout, design (International Maritime Organization, 1998) and arrangement and guidelines on ergonomic criteria for bridge equipment and layout (International Maritime Organization, 2000). The third research question was raised to determine whether these standards were effective.

Study 4: Standard and Criteria Evaluation Study

An evaluation study was prepared to examine the effectiveness of the existing human factors standards and criteria on offshore supply vessels in the Norwegian Sea (Figure 10). Human factors criteria were documented, including noise, motion and slamming, motion-induced interruptions (MII) and motion sickness incidents (MSI) including risk levels. On-board measurements were performed on OSV A and OSV B during their missions serving offshore platforms that covered noise, motion and environmental conditions. The sleeping behaviour, wellbeing and performance of the crew were also monitored through the survey.

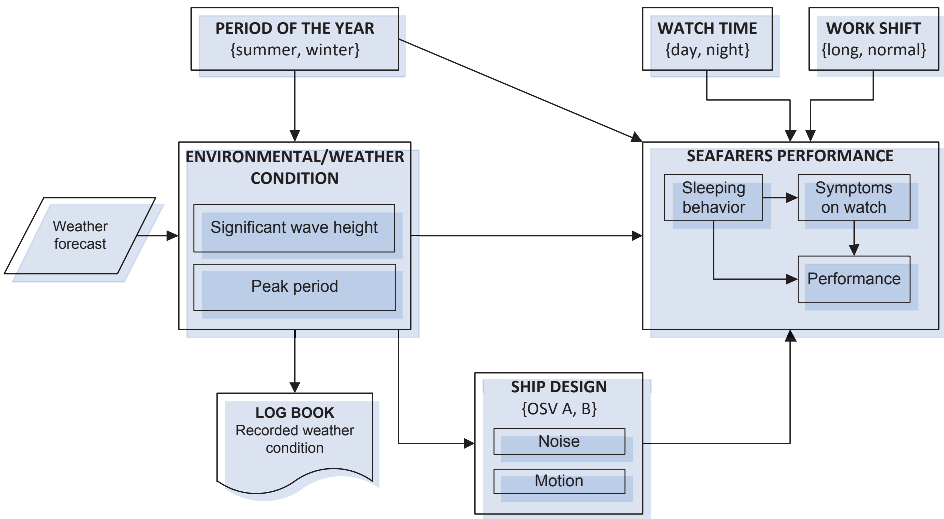

Figure 10 Research design for criteria evaluation and multivariate analysis

Information regarding the environmental conditions, such as wave heights and wind speed, were provided by the weather forecasts. Wind speed was measured during the voyage by an anemometer on the vessel and wave heights were observed visually by the officers on the bridge and documented in the logbook. Motion was measured by means of an ADIS16364 accelerometer located on the cabin floor and recorded throughout the voyage. Noise was measured in the cabin, on the bridge, in the engine room, in the engine control room, and several other areas on the vessel using a Class 2 sound level meter Bruel & Kjaer Type 2236 in accordance with ISO 2923 (ISO, 1996) and ISO 20283-2 (ISO, 2008). A frequency weighting was applied.

The crews were asked to fill in a daily diary (Appendix E) after every watch. The diary was developed based on NATO questionnaires (Colwell, 2000) and adjusted for offshore supply vessel operation. It measured sleeping/resting condition before watch, symptoms experienced on watch, performance on watch and problems encountered on watch. The crews on each OSV could be split into three groups. Two groups worked alternately in a normal shift arrangement and one group worked long shifts.

Results

The noise level measurements on both vessels showed that all the criteria set by the standards were satisfied, even though the room was noisy. Disturbing noises such as slamming, high-pitched noise from the thrusters, a hissing noise from the heating, ventilation and air conditioning (HVAC) system and a squeaking noise were neither captured nor reflected in the results of measurement. Table 4 provides a summary of the existing noise criteria compared to the results of measurements. Table 5 shows a summary of the motion measurements compared to the criteria. Results of motion measurement on both OSVs are presented in Figure 11 (roll motion), Figure 12 (vertical acceleration) and Figure 13 (motion-induced interruptions and motion sickness incidents).

Table 4 Summary of criteria vs. results of noise measurement

Description	**DNV COMF-V(3)**	**IMO (1981)**	**Maximum field measurement**	
Bridge	60 dB		59.7	
Cabins	60 dB		45.4 dB (normal)	56.7 dB (on DP)
Engine room		110 dB	105.9 dB	
Engine control room		75 dB	66.7 (normal)	71.2 (with music and people chatting)

Table 5 Summary of criteria vs. results of motion measurement

Description	**NATO (2000)**	**NORDFORSK (1987)**	**Maximum field measurement**
Roll	4°	6°	0.54°
Pitch	1.5°		0.74°
Vertical acceleration	0.2 g	0.15 g	0.149 g
Lateral acceleration	0.1 g	0.12 g	0.065g
MII	1/min		0.14/min
MSI	20% of crew, 4 hrs exposure		50% (calculated after McCauley et al., based on motion data) < 5% (based on data collected by the daily diaries)

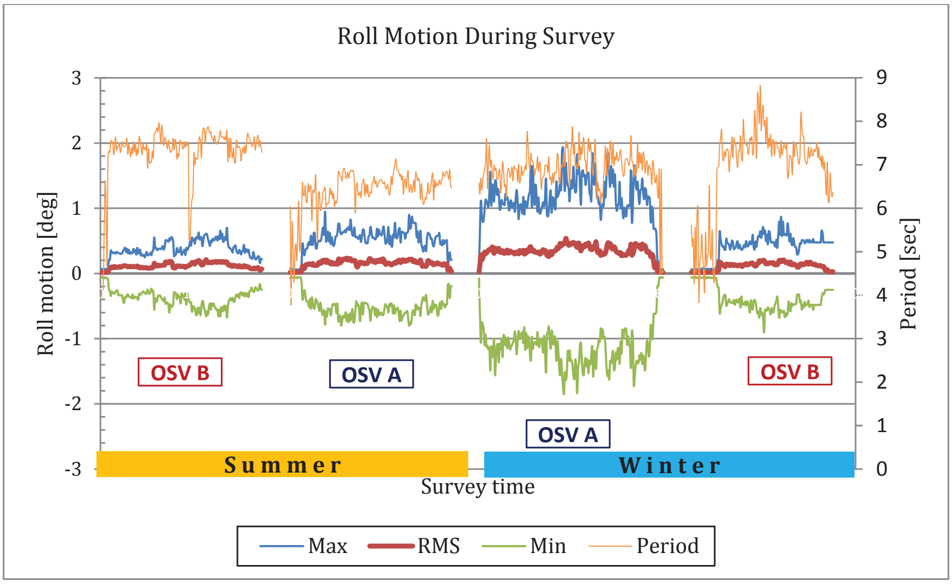

Figure 11 Roll motion

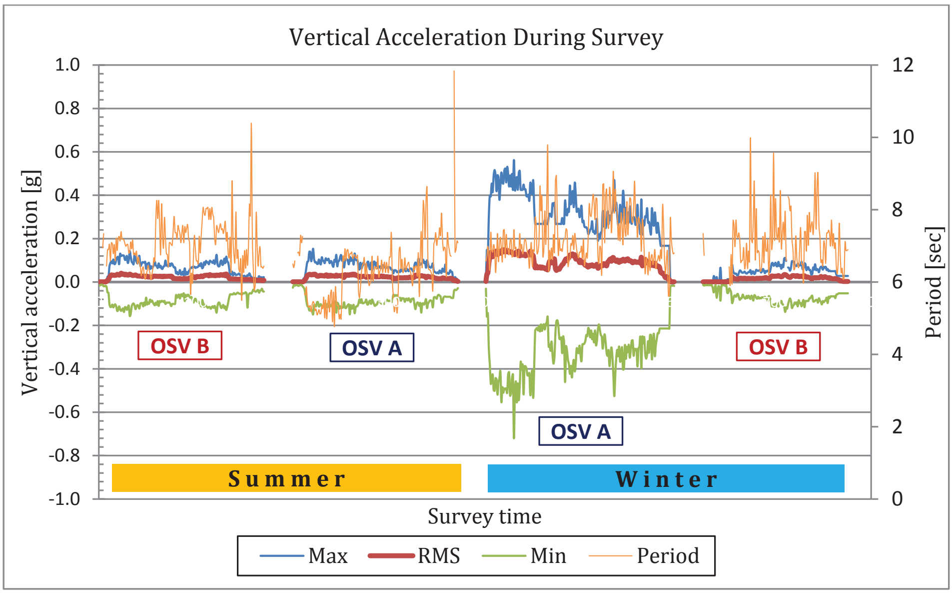

Figure 12 Vertical acceleration

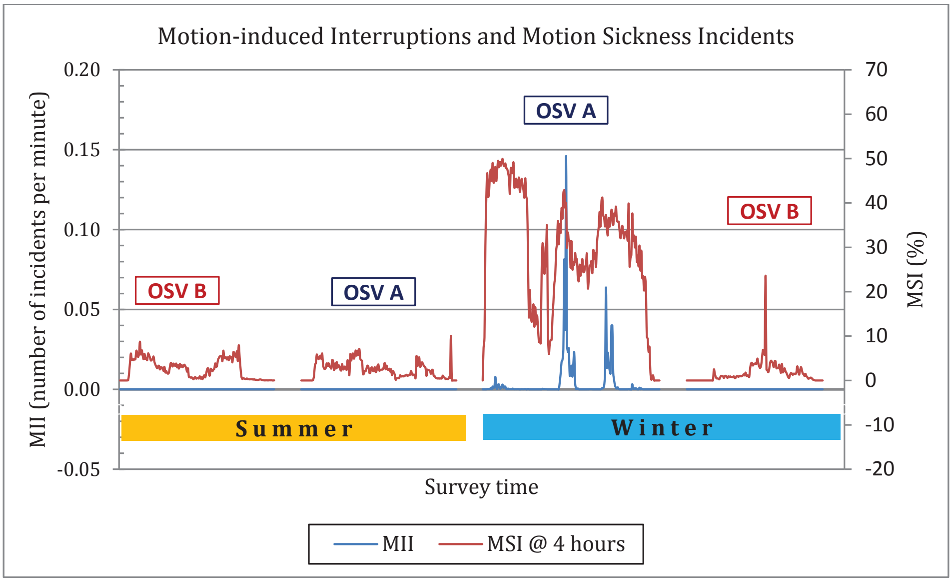

Figure 13 MII and MSI

The highest noise level measured in the cabin on OSV A while operating on DP was 56.7 dB. The conditions inside the cabin were uncomfortable due to a screeching noise produced by the bow thrusters. Often this high pitched noise interrupted sleep.

The study measured the highest roll motion of 0.54° RMS in winter on OSV A (Figure 11). The general criterion for roll is 4° according to NATO (2000) or 6° according to NORDFORSK (1987). The highest vertical acceleration was measured 0.149 g RMS, which occurred in heavy weather, and approximately 14 m wave height (Figure 12, thick red line, OSV A, winter). The criteria still allowed "heavy manual work" to be performed on the vessel with a vertical acceleration up to 0.15 g and 4.0° of roll motion (NORDFORSK, 1987). Experience on the vessel showed that it was hard for anybody to walk safely on the vessel without bumping into the wall or hitting other objects. The idea that "heavy manual work" could take place safely in such a condition is inconceivable. It was also discovered that slamming criterion 0.03 (NORDFORSK, 1987) was too high, in that it interrupted sleep. A stricter limit is required for OSV operation in the Norwegian Sea.

The MII calculation, after Graham (1990), throughout the survey showed a maximum of 0.14 MII/min at the highest sea state (Figure 13). The risk level was classified as "Probable" to "Possible" (Graham, 1990). As observed on board, when the wave height reached 14 m on a 94 m. long vessel, not much can be done except to sit tight, or stand still and hold on to something safe to keep balance. The existing criteria for MII was not realistic and could not be applied by the crew on these vessels.

There was a gap between the calculated MSI index based on McCauley, Royal, Wylie, O'Hanlon, and Mackie (1976) and the actual MSI reported by the crews during the survey. The MSI standard was extremely conservative for the crews working on OSVs. The MSI criteria set a standard maximum of 20% crew showing motion sickness in a four hour exposure (NATO, 2000). The calculated MSI index (after McCauley et al., 1976) during the survey on OSV A in winter was predominantly higher than 20% (up to 50%) which means that the ship should not be sailing, however, the ship kept sailing and the crews still performed their jobs. The actual MSI reported by the crews was lower than 5%. The MSI criteria needs to be adjusted. Most of the crews on OSVs have adapted to motion sickness.

Based on this study, it can be concluded that some of the existing human factors criteria are cannot be implemented on offshore supply vessels operating in the Norwegian Sea. They need to be adjusted.

3.2.4. What factors strongly influence crew performance at sea?

It was recognised that crew performance on offshore supply vessels was not solely influenced by the habitability or comfort of the ships, but also by a number of other factors such as watch schedule, work shift, season and environmental conditions. For that reason, RQ4 was asked.

Study 5: Multivariate Analyses and Structural Modelling

Multivariate analyses were performed to discover important factors that were relevant to the crew's wellbeing and performance on offshore supply vessels operating in the Norwegian Sea. Variables of interest include sleeping conditions, symptoms on watch, performance on watch and problems encountered on watch.

The same data collected in the previous study (Study 4) was used in this analysis. Various statistical analyses were employed. First, descriptive statistics were presented to illustrate the results from the survey, then, inferential statistics were applied to reveal the relationships between variables based on the research design (Figure 10). The correlations between the data obtained from the weather forecasts and the results from the survey, including ship motions (roll, pitch, vertical acceleration and transversal acceleration), were analysed.

The relationships between ship motion, sleeping behaviour, sleeping problems, and symptoms experienced by the seafarers on watch were also examined. Finally, a structural equation model was used to explain the seafarers' overall performance and overall symptoms in connection with other variables of interest.

Results

The results showed that the crews on OSV A experienced more sleeping problems than those on OSV B. This was due to slamming, motion, vibration and noise issues on board. In general, more sleeping problems were reported in winter compared to summer. Slamming was given as the most frequent event disturbing sleep on OSV A, but was never mentioned on OSV B. The crews on OSV B did not admit to any ship-related sleep problems in the winter. According to the observations performed on board, the vessel was quite stable in the winter. In summer the crews tended to open the doors in the accommodation which allowed noise to enter from outside (the deck and the engine room). This explains why the crews on OSV B reported more noise disturbing sleep in the summer. Slamming was identified as the most common factor disturbing sleep (13.8%), noise was the second (10.6%), and ship motion was the third (9.6%). Temperature or indoor climate was consistently reported as a problem on OSV A in summer as well as in winter, but not on OSV B.

In general, the crews experienced worse symptoms in winter. They were more tired (physically), $F(1, 170)=3.931$, $p<.05$, experienced more motion-induced interruptions, $F(1, 165)=5.620$, $p<.05$ and experienced more stomach awareness, $F(1, 164)=3.649$, $p<.10$. Sleepiness and tiredness were the worst symptoms reported by the crews of both OSVs in both periods of the survey.

The difference in the overall performance on OSV A in summer compared to that in winter is worth noting: $F(1, 186)=12.844$, $p<.001$. Motoric performance dropped the most, while communication, accuracy and number of tasks completed dropped significantly. On the other hand, the difference reported by the crew of OSV B in summer compared to winter was insignificant.

Slamming (11.7%) and ship motion (11.7%) were also predominantly reported as the problems disturbing watches, but not noise (2.7%). There was a highly significant difference in ship motion, slamming and vibration across OSVs ($p<.01$), and the differences in noise level and indoor climate were significant ($p<.05$).

Table 6 shows the correlation between wave height prediction (Hs, from weather forecast) and ship motion (on-board measurement). Data was transformed into watch group time scales (N=32). The results shows that all correlation indices were highly significant. It can be gathered from the survey that 69% variance of the vertical accelerations, 59% of pitch, 53% of lateral accelerations and 47% of roll motions could be explained by the significant wave height predicted from the weather forecast (Table 6).

Table 6 Correlation between wave height prediction and ship motions

Pearson Correlation *)	Hs	Roll	Pitch	Y_acc	Z_acc
Hs	1.000	0.683	0.768	0.728	0.829
Roll		1.000	0.783	0.927	0.892
Pitch			1.000	0.830	0.922
Y_acc				1.000	0.913
Z_acc					1.000

*) All Sig. (2-tailed) = 0.000; N = 32

Table 7 Correlation between ship motion and sleeping behaviour

		Ship-related sleep problems	Non-ship related sleep problems	Sleep quality	Sleep amount
Roll	Pearson Correlation	0.427***	-0.105	-0.268***	-0.099
	N	188	188	179	176
Pitch	Pearson Correlation	0.448***	-0.075	-0.241**	-0.075
	N	188	188	179	176
Y_acc	Pearson Correlation	0.395***	-0.128#	-0.309***	-0.152*
	N	188	188	179	176
Z_acc	Pearson Correlation	0.477***	-0.139#	-0.349***	-0.200**
	N	188	188	179	176

*** $p < .001$; ** $p < .01$; * $p < .05$; # $p < .10$

Table 7 shows the correlation between ship motion and sleeping behaviour; sleep problems, sleep quality and amount of sleep. It was demonstrated that vertical acceleration correlated highly significantly with ship-related sleep problems (r=0.477, p<.001), sleep quality (r=-0.349, p<.001) and thus amount of sleep (r=-0.200, p<.01). Table 7 shows that ship-related sleep problems had very significant correlations with all ship motion components: roll, pitch, lateral acceleration and vertical acceleration and non-ship related sleep problems had insignificant correlations (p>0.05). It can be seen that sleep quality had a rather close relationship to all ship motion components: roll (p<.001), pitch (p<.01), lateral acceleration (p<.001) and vertical acceleration (p<.001), but sleep amount *only* correlates significantly with vertical acceleration (p<.05). It can be inferred from these results that vertical acceleration played an important role in sleeping behaviour on board.

A structural model was developed using path analysis and the result, as presented in Figure 14, answered RQ4. Ship-related sleep problems (motion, noise, vibration, slamming and indoor climate) had a very significant effect on sleep quality and sleep amount (p<.001). Non-ship related problems had some effect on sleep quality and amount of sleep, but to a smaller degree. Amount of sleep was important to both overall symptoms (p<.001) and overall performance (p<.05). Sleep quality on the other hand marginally influenced overall symptoms (p<.1) but not performance (p>.10).

This model shows that pitch motion before watch was meaningful in ship-related sleep problems (p<.001), slightly different from the result of the correlation analysis (Table 7) but not so different to require discussion at this point. In contrast to sleeping behaviour, the roll motion had more impact on seafarers' overall performance when they were on watch (p<.01). Work shift had a significant impact on non-ship related sleep problems and overall performance. Crews who worked long shifts showed less non-ship related sleep problems and performed better than those who worked normal shifts.

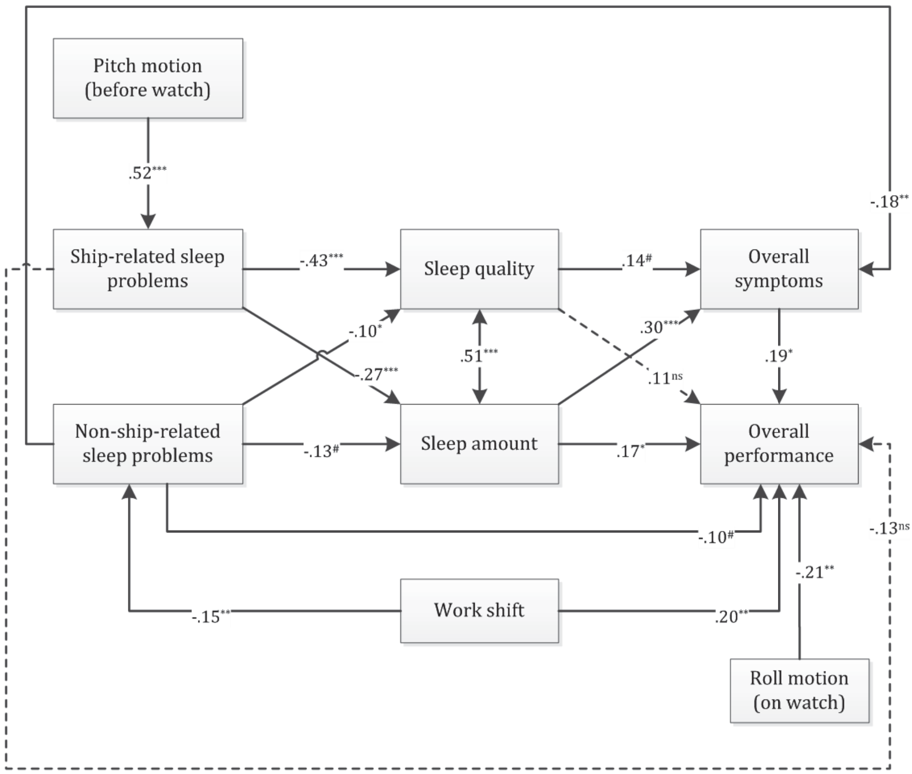

Figure 14 Path analysis of human factors on offshore supply vessels operating in the Norwegian Sea (*** p<.001; ** p<.01; * p<.05; $^{\#}$ p<.10; ^{ns} not significant)

3.2.5. What are the underlying factors of human factors in offshore supply vessel design?

The subject of human factors in the field of naval architecture and marine engineering is evolving. In the beginning most publications focused on safety. Afterwards, the focus altered to other aspects: habitability and workability, then controllability. The framework referenced in this study did not satisfy the mutually exclusive and collectively exhaustive principles, thus a theoretical evaluation regarding the concept of human factors in ship design was explored, in this case, human factors in offshore supply vessels design and operation. A research question was defined for the theoretical exploration (RQ5).

Study 6: Theoretical Evaluation

A theoretical evaluation study was conducted to evaluate the theoretical construct of human factors in ship design and operation. Questionnaires were developed and used to test the existing framework. This was the same set of questionnaires and data that were employed in the explanatory survey (Study 3).

Factor analysis was used to examine the underlying factors of human factors on offshore supply vessels. It is a statistical approach used to reveal relationships between a number of variables and to look for common factors that can explain variations in different measurements, in this case dimensions, which are measured by items in the questionnaires. It is common to use factor analysis for data reduction or structure detection and to identify the *collinearity* of variables. The analysis was conducted using Statistical Package for the Social Sciences (SPSS) version 14.1 software for Windows. It was realised that the number of the respondents was too low for factor analysis, however, assumption testing was always performed before the factor analysis was performed. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is expected to be higher than 0.5 and Bartlett's test of sphericity should be significant (<.05) (SPSS Inc, 2010). This evaluation was intended as an introduction and as an encouragement for other fellow researchers to use similar methods to establish a firm human factors construct in ship design.

Results

The theoretical evaluation study presents an analysis of the underlying factors of human factors in ship design based on the questionnaires (Appendix G) that were distributed on two OSVs (N=42). Factor analysis was applied to human factors direct evaluation (26 items). Principal axis factoring (PAF) extraction method was applied. The oblimin rotation method with Kaiser normalisation was used. All 26 items were entered into the analysis; KMO measure and Bartlett's test of sphericity were determined. Some bridging variables indicated by low index loadings distributed on several components were identified and excluded. Another iteration of factor analysis was conducted without these bridging variables.

Table 8 shows the final output of the pattern matrix on the human factors direct evaluation questionnaires, where five components were revealed and named:

1. Controllability; consists of Autopilot, Navigation System and DP System
2. Workability; consists of System Procedures, General Arrangement, Layout, Storage, Equipment, Overall Working Condition, Space and Communication
3. Habitability; consists of Vibration, Sound, Noise, Motion, ECR, Comfort and Accommodation
4. Cargo facilities; consists of Cargo Deck and Cargo Tanks
5. Reliability, automation and maintainability.

Factor analysis was performed on the 65-item human factors Likert-scale. It was not suitable for this type of analysis, which involves only 42 responses, and should have been omitted. An exploratory experimentation was pursued nonetheless. All 65 items were entered into the analysis.

Table 8 Pattern matrix of human factors direct evaluation questionnaires

	Component				
	1	2	3	4	5
Autopilot	0.87				
Navigation system	0.77				
DP system	0.48				0.30
System procedure		0.77			
General arrangement, layout		0.72		0.33	
Storage		0.67			
Equipment	0.34	0.60			
Overall working conditions		0.57		0.37	
Space		0.51		0.31	
Communication system and equipment		0.36			
Vibration			0.83		
Sound, noise			0.79		
Motion			0.70		
Engine Control Room (ECR)	-0.31		0.66		0.36
Overall comfort			0.44		
Accommodation			0.36		
Cargo deck				0.93	
Cargo tanks				0.71	
Overall reliability					0.78
Control & maintenance					0.71
Automation					0.67

Extraction Method: Principal Axis Factoring
Rotation Method: Oblimin with Kaiser normalisation

The KMO measure and Bartlett's test of sphericity criteria were determined and were not fulfilled at the first run. Vague items and items with no significant loadings were eliminated, then the process was repeated. The principal component extraction method was used and eigenvalue criterion of greater than 1. The direct oblimin factor rotation method was employed. Table 9 shows the output pattern matrix. After several iterations seven robust components were revealed and named:

1. Operability, maintenance and reliability
2. Interfacing complexity
3. Ship handling, manoeuvrability
4. Systems and procedures
5. Deck working condition
6. Engine room and engine control room (ER/ECR)
7. Habitability

Table 9 Pattern matrix on human factors Likert-scale questionnaires

	Component						
	1	2	3	4	5	6	7
It is easy to do maintenance of the vessel	0.91						
It is easy to operate the equipment on board	0.76						
The system on the bridge is quite informative	0.73						
The vessel has a good layout	0.71						
Most systems have good reliability	0.69						
We have too many alarms on board		0.92	0.31				
We have too much automation on board		0.79					
The computer menu system is too complicated		0.77					
Sometimes the alarm system is confusing		0.71					
It's not easy to manoeuvre the vessel			-0.91				
The vessel has a good manoeuvring capability			-0.85				
The vessel has good & reliable DP system			-0.79				
It is easy to manoeuvre the vessel			-0.74				
Sometimes we cannot rely on the autopilot			-0.65				
There are so many forms & checklists to fill in				0.89			
We have too many procedures to follow				0.77			
Some areas of the vessel are very noisy					-0.82		
The cargo deck is well designed					0.80		
The ECR is designed so it can be monitored and operated easily						0.81	
The ER can be maintained without any trouble						0.77	
Sometimes I can't sleep well on the vessel							-0.93
Sometimes we can feel that the vessel is moving too much							-0.84

Extraction Method: Principal Component Analysis
Rotation Method: Oblimin with Kaiser normalisation

During this process it was realised that factor analysis can be used not only to examine the theoretical construct of human factors in ship design, but also to explain the relationships between parts or components on the supply vessels, human factor dimensions, and other related concepts. Bridging variables should not be excluded from the process because they can be interpreted in a specific way. A model was developed by re-arranging the components obtained from the analysis (Figure 15) where several bridging variables were recollected and assigned to the model. The model provides information about *"who should account for what and when"*. It seems that the model demonstrates a way of integrating human factors into offshore supply vessel design and operation in the Norwegian Sea.

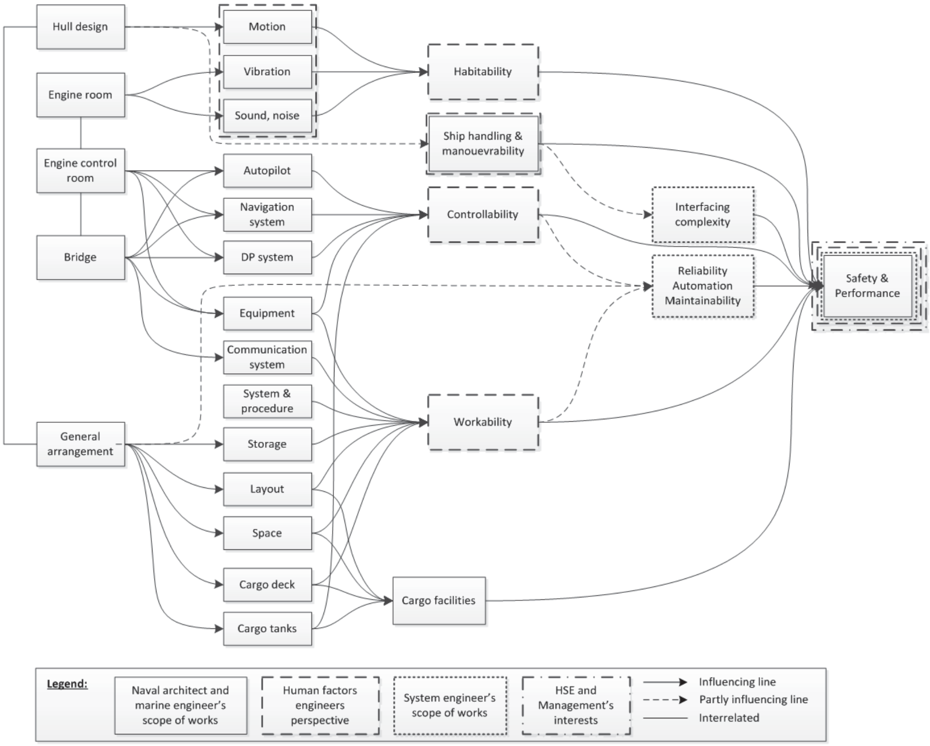

Figure 15 Inter-connectivity of human factors in offshore supply vessel design and operation

At this point, it can be concluded that the primary factors showing the essence of the human factors in offshore supply vessel design and operation are:

- Habitability
- Ship handing and manoeuvrability
- Controllability
- Workability

The model presented in Figure 15 is a preliminary model based on a very small sample which needs to be improved and expanded.

3.3. Summary

This chapter presents the overall research design that involves the background of the studies, the research questions that were raised, the research methods that were used, the objects and the results of the studies. To summarise, five research questions were asked and six studies were reported from responses to the enquiries. The relationships between the questions and the studies are shown in Figure 16.

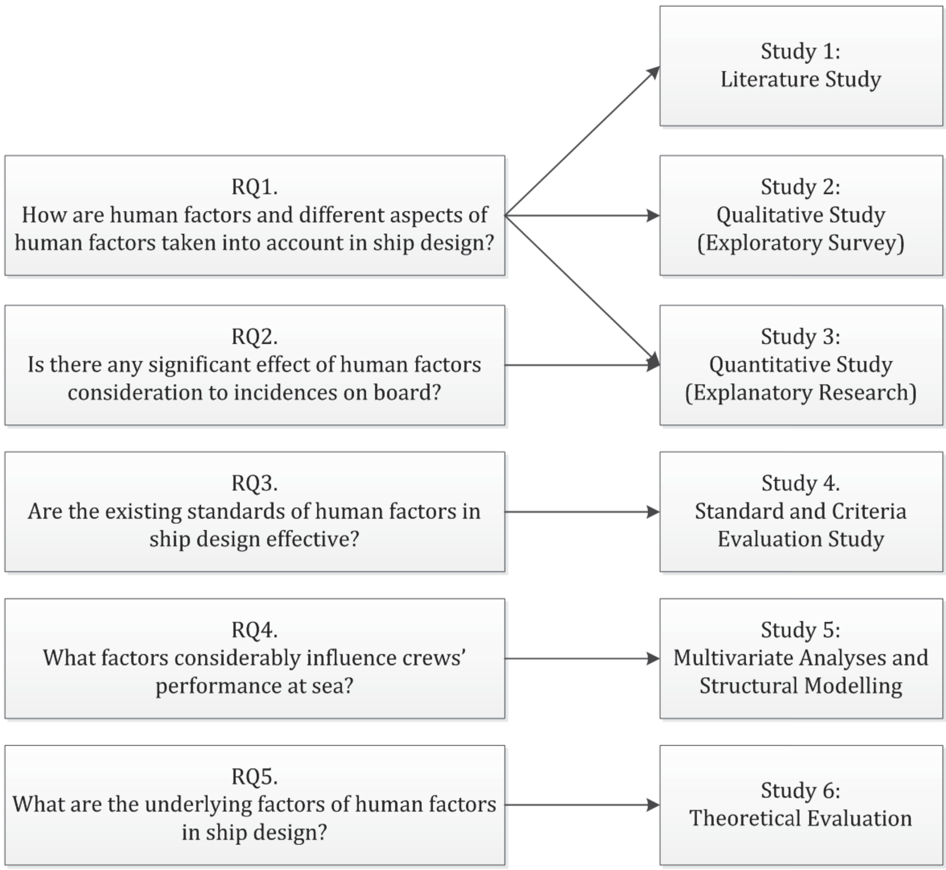

Figure 16 Relationships between research questions and studies

The first research question probed the implementation of human factors principles in ship design and operation. Three studies were performed using different methods: content analysis, exploratory survey and explanatory research. Explanatory research was also used to answer the second research question, verifying the correlation between human factors implementation and incidents on board. The third research question asked about the effectiveness of the existing human factors standards in ship design and the criteria for supply vessel operation in the

Norwegian Sea. A field survey with physical measurements and environmental monitoring (including noise, motion, wave height and wind speed) combined with daily diaries and observations was prepared. The fourth research question dealt with a number of variables that had the potential to influence personnel wellbeing and performance on board. A multivariate analysis and structural modelling were used to answer the inquiry, to find the factors that were significant to seafarer wellbeing and performance. The fifth research question asked about the underlying factors of human factors in ship design and operation. Factor analysis was used in the theoretical evaluation study to resolve this particular issue.

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Chapter 4: Discussion

Ac proinde haec cognition, ego cogito, ergo sum,..

The results of the studies show that human factors and different aspects of human factors have been extensively taken into account in offshore supply vessel design and even more in operation. Lessons were learnt and there was implementation of human factors principles. There was a variation in the level of implementation of human factors across different dimensions and also across offshore supply vessel designs. A relationship between the existing documents, standards and references addressing human factors and the level of implementation in reality was recognised. Some of the existing standards were evaluated and shown to be ineffective in the study. Some factors that considerably influence crews' performance at sea were identified and some underlying factors of human factors in ship design were also revealed. This chapter presents discussion based on the research questions answered in the previous chapter.

4.1. Limitations of the Study

Before discussion is presented and conclusions are drawn, it should be remembered again that this research had quite limited data and access. As a consequence, generalisation is limited to the population represented in the sample. Most of this thesis involves offshore supply vessels around 93 to 94 m LOA, relatively newly built, approximately two to three years old. The crews were well-trained, qualified and competent personnel. The operations took place in the Norwegian Sea, serving offshore facilities. Each mission took three to four days on average to complete. The positive findings revealed in this thesis may not be found in other types of vessels or in other sectors of the maritime industry or in other parts of the world. Conversely, the disadvantages discovered here are very likely to be found in the rest of the industry.

Some of the findings may be limited for generalisation due to typical characteristics of the Nordic population and the Norwegian shipbuilding and petroleum industries, which include culture and working environment. Some of the research was based on subjective evaluation which was naturally influenced by the researcher and the crew's personal background, and might not apply to others. Another researcher is in fact required to confirm the reliability and the validity of the findings of the literature study which applied content analysis as the research method and the exploratory study which applied qualitative methods. Limited access to the designers, manufacturers and regulators also places this research in a rather weak position in not being able to pursue the analysis and not being able to present the complete story. Efforts to contact all the relevant parties had been made nonetheless.

Some of the models that were constructed in this thesis (Figure 14 and Figure 15) may change when the sample of the study is extended: more ships are included and more respondents participated in the research. Some variables may influence the models: types of vessel, main dimensions, areas of operation, types and length of missions.

4.2. Research Questions and Results of Studies

There were issues regarding the first question about how human factors and different aspects of human factors were taken into account in ship design. This involved the existing documents and standards of human factors in ship design, which were optional. An interpretation may be that the industry was somewhat timid in expressing the message. The criticisms as documented in Section 2.2 to some extent remain. The rapid rate of human factors development indicated by the number of new rules and guides published in the last couple of years shows that something is happening. As revealed in this thesis, the industry has the ability to do what could be done, and more.

Second, new technology has developed very rapidly, much faster than the rules and the traditional shipbuilding industry. Some advances were made because they could be done, not because they were needed, and, sometimes they were developed without much consideration for the users. More automated equipment has been, and will be, installed on supply vessels, providing fewer roles for crews operating ships. Some examples covered in the thesis were the autopilot design, the dynamic positioning system and automatic fuel-switching design. These advanced technologies have been and will be installed in other vessels. During this study two dangerous undetected failures were discovered. These failures served as a reminder that new technology contains uncertainties and problems could arise in other systems on other ships. It would be beneficial if the study could examine the development process of these new technologies from the designer perspective, including quality assurance.

Thirdly, there were issues of “abundance” and “complexity” found during the surveys on two offshore supply vessels operating in the Norwegian Sea, including the alarms, communications, procedures and checklists on board. It was hard to understand how a supply vessel operating in the Norwegian Sea should monitor and respond to a distress call coming from the Caribbean. It was *fortunate* that the message came when the vessel was sailing and the crew was relatively unoccupied. It could disturb the crew if it took place inside the 500m safety zone or even more when they were lying alongside an offshore facility. The effect of the distraction on other working vessels in the area such as drilling vessels, anchor handling or tugs could be worse. These distress signals are regulated by international codes, therefore apply to any ship within reach of the ship and equipped with the system.

The studies showed that the level of implementation of human factors varied from one aspect to another. Different aspects of human factors to a certain degree reflect specific parts of the ship which also indicate different departments on the ship. Controllability is more likely to represent the deck department and maintainability to represent the engine department. Habitability obviously represents the steward's department. During the exploratory survey, it was discovered that more criticisms were published highlighting the engine room and engine control room. The interviews conducted during the survey also revealed more complaints addressed by the crews in the engine department. The disappointments voiced by marine engineers regarding the engine room and the engine control room are plausible. The nature of their job is different from the others. They deal more with problems and troubleshooting, alongside routine maintenance activities. Uncertainty and the unknowns are dominant in their work. In addition, they usually have quite limited working space and their working environment is often demanding: exposed to heat/cold, loud noise, exhaust gas, oil, unpleasant smell, darkness and heights, however, it was seen during the studies that significant improvements in the ER/ECR were under way. Almost all the issues raised had already been responded to positively on the vessels surveyed. In addition, a number of new ergonomic notations (American Bureau of Shipping, 2013) were developed to promote an ergonomically-focused design and construction on vessels, specifically with respect to enclosed spaces (ERGO ES) and maintenance (ERGO MAINT), as well as topsides (ERGO TOP) and valves (ERGO VALVE). It was also discovered in the survey, as described by the crews, that different types of vessel may have different characteristics of maintainability. Bigger vessels can afford more space to perform maintenance activities, provide more rooms to store spare parts and tools, and thus better consideration from the human factors perspective. In general, the outcome of the study of how different aspects of human factors were taken into account cannot be generalised to other vessels. It may vary according to the types of vessels, the size of vessels, the year of construction, the builder, etc., although safety is generally considered the highest.

The quantitative survey confirmed that OSV design could be distinguished from the human factors perspective. The level of accomplishment of different dimensions of human factors evidently influences a particular incident or symptom on board. The sample size in this research was rather small (N=42). Based on the outcome of the survey so far, it is possible to perform a reliable cost and benefit analysis on investments in habitability. The relationship between habitability and the frequency of the personnel being seasick or fatigued, and experiencing sleep disturbance was found to be significant. An improvement in the accommodation could be proposed which would benefit the crews' wellbeing. An interesting discovery showing that the better the maintainability facilities the higher probability of fire/explosion incidents appears anomalous, however, this phenomenon is not unexpected. Yerkes-Dodson law explains that the relationship between arousal and performance can be described by an inverted U curve (Yerkes & Dodson, 1908); where performance increases with arousal to a certain point, then decreases with higher levels of stress. Better maintainability in this case provides lower arousal, thus lower performance. Naturally, a more accurate result would be expected by expanding the sample size. The incident data in this survey was obtained via questionnaires which are subjective and sensitive to bias. A more accurate source of information can be acquired from the ship records and the company databases.

The criteria for the evaluation study performed in this thesis have shown that efforts towards human factors can be gauged and their effectiveness can be measured. The results showed that some of the criteria were substandard and less effective on the offshore supply vessels surveyed operating in the Norwegian Sea. Further validation is required before generalisation can be made, , by expanding the population of the survey on other types of vessels and on other locations. As indicated by the institution that published the criteria (NATO, 2000), they may be valid for military purposes.

The nature of human factors standards is apparently different from that of other standards in general. Other standards guarantee the conditions or qualities that are set in their criteria or notation. For example, a ship that carries Ice Class notation must be capable of navigating through ice, however, a ship with a Comfort Class notation does not necessarily guarantee the comfort of the personnel on board.

The evaluation study compared the calculated motion sickness incidence and motion-induced interruption based on their theoretical reference, against the subjective evaluation reported by the crews. McCauley et al. (1976) suggested the use of vertical acceleration as the basic predictor to explain motion sickness incidents. This study indicated that pitch motion was more dominant, explaining the MSI of the crews on both vessels. Vertical acceleration nevertheless, was found more influential on motion-induced interruption, instead of the lateral components, as indicated by the original reference (Graham, 1990). This finding seems intriguing, and it is worth investigating further.

The multivariate analyses demonstrated that sleep was very important to the crews' well-being and performance (Figure 14). Sleep was influenced by ship-related problems, such as slamming, noise and motion. This finding applied to typical offshore supply vessels operating in the Norwegian Sea. The survey can be extended and applied to other types of vessel and other populations. A different model is expected. This method has the potential to answer the enquiry about connecting the standards to human performance and fatigue. The multivariate analyses measured seafarer performance, including sleeping behaviour, motion sickness, motion-induced interruption, symptoms and wellbeing by using the daily diaries. There are other methods however that can provide more accurate, more objective and more valid information. For example, physiological assays (salivary cortisol test), polysomnography and circadian rhythms measurement can be used to measure fatigue. Actiwatch can be used to monitor sleep and a psychomotor vigilance task (PVT) can be used to measure performance. Obviously, these methods require more expertise and more effort. They are also more expensive and some are more time consuming. The development of gadget technologies to date makes it possible to use smart watches, sport watches and smart phones to monitor heart rate, blood pressure and location on a real-time basis.

For feedback regarding OSV design, it would be ideal to build a human-friendly ship that has the potential to encourage good sleep by minimising motion, noise and slamming. The survey indicated that OSV B could be specified as a good example of human-friendly design in which the accommodation facility is located far from the splashing zone and from the tunnel thrusters, therefore resulting in less slamming and noise. Her design is to some extent similar to the majority of container vessels, bulk carriers and tankers. Naturally, there are some drawbacks to deal with. The appearance of OSV B is rather unconventional for a working boat. The vessel has slightly less flexibility in serving offshore platforms, and she was more expensive than the conventional OSV design because of the full DP3 capability and the dual fuel system. It would ideal to build an offshore supply vessel following OSV B design where the superstructure is located at the aft, with one bridge console system, equipped with DP3 capability and using diesel oil as its fuel. One engine room compartment is considered sufficient instead of two separate independent compartments, such as those on OSV B. They were built for fire protection reasons, due to the use of LNG as an alternative fuel.

It was revealed that slamming and ship motions were quite problematic on the conventional offshore supply vessel operating in the Norwegian Sea. The problems were reported by the crewmembers who were off watch and supposed to sleep, and mostly took place during high seas. Obviously, these issues will not be a problem in calm to moderate seas, or in short-term operations which take place within a single day, where the crews do not need to go to sleep on board. Nonetheless, slamming and ship motion can be reduced by modifying the shape of the hull. There are quite a few alternatives available in the market such as wave-piercing hulls, axe bow, inverted bow and X-bow designs. Another problem reported by the crew on a conventional supply vessel was the disturbing noises coming from the tunnel thruster when the vessel was lying alongside an offshore facility. This is a typical problem in offshore supply vessels and other types of vessel whose operations to a great extent relies on DP. This issue can be reduced by installing a low noise or super silent system if the accommodation facilities cannot be moved away from the bow. An effort to reduce the disturbing noise created by the cavitation could be implemented by optimising the blade design and increasing the size of the thrusters.

There was a problem in addressing human factors to naval architects and marine engineers. They did not speak the same language with the human factors engineers, who on the other hand, tried very hard to convey their message. The terms used in human factors engineering are slightly different from those terms with which the designers are familiar. Speaking the right *language* at the right time with the right people is important. The model presented in Figure 15 proposes an initial model that could be used as a strategy for integrating human factors in OSV design. The model was derived from a relatively small number of respondents; more respondents are absolutely required before the model can be employed. This initial model looks quite promising and realistic nonetheless. It shows the inter-connectivity of ship parts, elements and systems to different aspects of human factors where safety and performance are identified as the ultimate goals. Naturally, different types of vessel will have variations regarding the parts and the elements that are involved in the model.

4.3. Validity of the Study

Regardless of its limitations, there are some conclusions that can be drawn from this study. Some conclusions do not need a great quantity of data in order to be generalised, such as the output from the literature study and the criteria/standard validation. Guidelines and standards apply as a general rule regardless of the population. In practice, nobody needs to go through a 14m wave twice to notice that it is impossible to conduct “heavy manual work” on a 93m long vessel. Obviously, this conclusion applies to smaller vessels, but not necessarily to larger ones. A similar phenomenon occurred in noise evaluation. Nobody needs to do multiple measurements to realise that the existing method to evaluate noise cannot capture specific disturbing noises. The methods applied in this thesis can be used on other vessels and in other populations.

The scope of the thesis is very broad. It involves most of the dimensions comprised in the human factors theoretical framework. As the consequence, the thesis does not focus on any single aspect of the human factors, and therefore, the findings and the discussions may seem too brief. Some experts may intend to challenge the findings by going deeper and with more detailed analysis and arguments, however, the limitation of the thesis should be recognised, as it cannot cover all human factors dimensions in detail. Fewer topics could be selected for further investigations.

Chapter 5: Contributions

but to serve

This thesis brought together two different traditions, psychology and engineering, and served as an intermediary that could link various disciplines such as naval architecture and marine engineering, human factors engineering, reliability engineering, technical safety and OHS together in one topic of interest: human factors in ship design.

This thesis provides authentic methods that can be replicated to evaluate the implementation of human factors principles in ship design and operation. As an example, a comprehensive picture of how human factors and aspects of human factors were addressed and evaluated in offshore supply vessel is presented. It shows the strengths and the weaknesses of the implementation to date using a multi-traits/multi-methods approach. Methods to evaluate the relationships between variables of interest such as the environmental conditions, ship's parts and elements, and the human factors implementations to safety and performance are also presented.

This thesis provides some feedback on the existing body of knowledge of human factors in ship design and especially on specific standards and criteria. It could serve as a background against which to perceive and to interpret some of the human factors standards covered: motions, noise and slamming. The thesis could also be used as an example of how to associate different ship parts and elements to various aspects of human factors in the design in order to reduce incidents, to increase safety and performance. For the seafarers, it is expected that this thesis could convey their point of view regarding ship design, and later bring some improvements.

The detailed contributions of each study have been described in Section 1.5.

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Chapter 6: Conclusions

It is done.

A series of studies have been conducted to investigate human factors in ship design and operation. Various publications were documented and a literature study was conducted. A number of criticisms regarding the way ships were designed with a lack of human factors consideration in mind were acknowledged. User expectations of how a vessel should be designed and constructed were also presented. Offshore supply vessels were taken as the real case samples in the study. The existing criteria and standards were evaluated. Several models were presented to account for human factors. Some conclusions, recommendations, future works and concluding remarks are presented in the following sections.

6.1. Conclusions

Human factors in ship design and operation is a broad and comprehensive subject that involves a number of dimensions: habitability, maintainability, workability, controllability, manoeuvrability, survivability and safety.

In general, human factors issues have been comprehensively addressed by various documents which are related to ship design and operation, including publications by classification societies such as the American Bureau of Shipping, the Lloyd's Register and Det Norske Veritas, and other international organisations such as the International Maritime Organisation, the International Organisation for Standardisation and the American Society for Testing Materials, however, most of the documents are not compulsory, so there is insufficient regulatory enforcement for addressing human factors in ship design.

Survey of offshore supply vessels operating in the Norwegian Sea revealed that the human factors considerations vary from one dimension to another. The study showed that safety-related dimensions were taken into account without compromise. Habitability was considered very satisfactory, workability was satisfactory and maintainability was the least satisfactory, but still above the acceptable limit. Many lessons have been learnt in relation to human factors related incidents on the Norwegian shelf in the past. Significant improvements were noted, but there was room for improvement, especially with respect to layout and access, ergonomics, complexity, slamming, motion and noise. Many new technologies have been implemented on offshore supply vessels which revolutionise the way people operate the vessel. New types of problems came along with the new technologies. The crews comprehended less and less of their vessel and relied more and more on the maker/manufacturer, especially for maintenance and troubleshooting. Communication channels and flows of communication expanded significantly in parallel with the advance in technology. The ability of the industry to address human factors was recognised.

There was a gap in communication identified between the users and the designers, including between the makers or the manufacturers. Some phenomena of distrust and blame-shifting were also identified among different makers, shipbuilders and users, and need to be noted.

OSV design has the potential to influence human factors evaluation on board vessels. For instance, good habitability can reduce seasickness incidents, and lessen fatigue and sleep disturbances.

Some of the existing human factors criteria and standards were either insufficient or less effective in ensuring safety and comfort on offshore supply vessels according to the standard and criteria evaluation study conducted in this thesis. The motion criteria were too lenient, including motion-induced interruption and slamming. The existing noise criteria did not cover the disturbing noises on board, however, the motion sickness incident calculation was too conservative for the seafarer population working on offshore supply vessels in the Norwegian Sea.

A model was developed to show the relationships between variables of interest and the crews' overall performance on two offshore supply vessels. Pitch motion has a highly significant impact on inducing ship-related sleep problems (motion, noise, vibration and slamming) which in turn have a very significant effect on sleep quality and amount of sleep. Adequate sleep is important for the crews to be able to perform well on their watch. The overall performance of the crews on watch is also influenced by work shifts and rolling motions.

6.2. Recommendations

An increase in the level of enforcement of the existing standards, from being optional to obligatory, is recommended. Efforts could be made gradually for a selected range of topics and for a particular type of vessel on a specific market. It is also recommended that standards and criteria be re-examined within a reasonable period of time in case an incident occurs related to human factors implementation at sea.

Use of the existing criteria of motions (NATO, 2000; NORDFORSK, 1987) is not recommended, including the corresponding risk level (Graham, 1990) on offshore supply vessels operations in the Norwegian Sea.

The standards and criteria evaluation study need to be expanded to cover more vessels with different characteristics and dimensions which sail on different seas. Revision and improvement of the motion criteria (including the motion-induced interruption and motion-sickness incidents), noise criteria and slamming may be expected.

It is important for designers to experience sailing, living and working at sea and to establish good communication with the crews as their ‘customers’. With the current technology, many on-board measurements can be performed instantly and recorded for further analysis. It is also important to understand the way people behave on board and more importantly the way the crews are used to operating the vessel in their natural environment.

It is recommended that offshore supply vessels with the superstructure located at the aft be designed and built for the Norwegian Sea. For offshore supply vessels in which accommodation facilities are located at the bow, the installation of the super silent type of tunnel thrusters, and modification of their hull to minimise slamming is recommended.

It is important to manage information on board in a smarter way, to present relevant information for a particular vessel at the right time. Unnecessary irrelevant and invalid information should be avoided. This includes communications and the communication channels.

Human factors considerations should be inserted as one of the criteria in the ship design spiral. A human factors engineer or expert should be involved in the process of designing a new vessel. User opinions which cover all departments on the ship should be taken into consideration. In practice, from the human factors perspective, radical design change should be avoided. Step-by-step improvement is advised.

Ship designers, naval architects, marine engineers and system developers should design and build a product that is user-friendly and takes into account the user’s perspective. It is important to address the right issue of human factors at the right stage using the right terms with the right people.

6.3. Future Works

Some recommendations for future work can be proposed as follows:

Fewer topics should be selected for further human factors investigations such as controllability, comfort and the implementation of new technologies. In this way, more extensive research can be performed and issues can be resolved from top to toe.

More accurate methods could be used to improve the explanatory study and the evaluation study, for instance by exploring the incident record and by using other less subjective measurements, including the latest gadget technology (actiwatches, smart watches and smart phones) to ensure validity.

Developing a human factors standard which essentially increases performance and comfort, in addition to safety and wellbeing of personnel on board is recommended. For example, noise criteria that includes noise spectra evaluation, impulse noise, high pitch noise and other potential disturbing noises besides the maximum energy level (in dB).

A further validation of motion criteria based on on-board measurements combined with observations is required. A theoretical improvement to predict motion induced interruption should be performed based on these methods. Some of the existing motion criteria developed based on expert judgment and laboratory experiments were indicated as unrealistic for offshore supply vessel operations.

A study to determine an adaptation factor to predict motion sickness incident for a particular population such as seafarers is proposed. As indicated in the study, the existing motion sickness incident is extremely conservative for crews.

A standardised model to assess the level of human factors implementation on ships should be developed and implemented. This kind of assessment can help shipbuilders to recognise issues that need to be improved related to safety and performance. This kind of evaluation can also help to distinguish better ships from the human factors perspective.

Development of the hull design on offshore supply vessels to minimise slamming and to reduce motion is endorsed. It is also recommended that the existing alternative designs such as the wave-piercing, the axe bow, the inverted bow and the X-bow, be evaluated from the human factors perspective using field survey and on-board measurement.

Last but not least, it will be interesting to extend this study by involving the designers, inseminating the ideas.

6.4. Concluding Remarks

It was noted that good innovations and improvements could be made, especially if the industry has other goals than maximising profit and reducing cost. The development of human factors on ships is not an arena for rivalry, but cooperation. All the players must agree to some extent not to create confusion for the (future) operators.

References

ABS. (2001). *Guide for Crew Habitability on Ships*. Houston, TX: American Bureau of Shipping.

Alderton, T. (2004). *The Global Seafarer: Living and Working Conditions in a Globalized Industry*. Geneva: International Labour Office.

American Bureau of Shipping. (2013). *Guide for Ergonomic Notations*. Houston, TX: American Bureau of Shipping.

American Bureau of Shipping. (2015). Rules & Guides Retrieved 2 Mar, 2015, from http://ww2.eagle.org/content/eagle/en/rules-and-resources/rules-and-guides.html

Andersson, M., & Lützhöft, M. (2007). *Engine Control Rooms - Human Factors*. Paper presented at the International Conference on Human Factors in Ship Design, Safety and Operation, London.21 - 22 March 2007

Antão, P., & Guedes Soares, C. (2008). Causal factors in accidents of high-speed craft and conventional ocean-going vessels. *Reliability Engineering & System Safety, 93*(9), 1292-1304. doi: DOI: 10.1016/j.ress.2007.07.010

Arima, M., & Tamura, Y. (2006). Evaluation of Ride Comfort of High-speed Passenger Craft (2nd report) - Measurement and Analysis of Psychological Response. *Journal of the Japan Society of Naval Architects and Ocean Engineers, 3*, 177-181.

Arima, M., Tamura, Y., & Yoshihira, M. (2006). *Evaluation of Ride Comfort of Passenger Craft*. Paper presented at the IEEE International Conference on Systems, Man and Cybernetics.8-11 Oct. 2006

Ashe, G., & Lantz, J. (2003). Classification and Regulatory Requirements. In T. Lamb (Ed.), *Ship Design and Construction* (Vol. I). Jersey City, NJ: The Society of Naval Architects and Marine Engineers.

Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., & Schenone, C. (2011). Criteria for Noise Annoyance Evaluation On Board Ships. In E. Rizzuto & C. Soares (Eds.), *Sustainable Maritime Transportation and Exploitation of Sea Resources* (pp. 971-980). Boca Raton, FL: CRC Press.

Baker, C. C., & McCafferty, D. B. (2005). *Accident Database Review of Human-element Concerns: What Do the Results Mean for Classification?* Paper presented at the International Conference on Human Factors in Ship Design, Safety and Operation, London.23 - 24 Feb 2005

Baker, C. C., & Seah, A. K. (2004). *Maritime Accidents and Human Performance: the Statistical Trail*. Paper presented at the MARTECH 2004, Singapore.21-23 Sept 2004

Bureau Veritas. (2014). Rules for the Classification of Steel Ships *Part B - Hull and Stability* (Vol. NR 467.B1 DT R07 E). Cedex, France: Bureau Veritas.

Calhoun, S. R., & Stevens, S. C. (Eds.). (2003). *Human Factors in Ship Design* (Vol. I). Jersey City, NJ: The Society of Naval Architects and Marine Engineers.

Card, J. C., Baker, C. C., McSweeney, K. P., McCafferty, D. B., Moore, W. H., & Khandpur, R. (2006). *Human Factors in Classification and Certification*. Paper presented at the Society of Naval Architects and Marine Engineers Annual Meeting, Houston, TX.19-21 Oct 2005

Colwell, J. L. (2000). *NATO Questionnaire: Correlation Between Ship Motions, Fatigue, Seasickness and Naval Task Performance*. Paper presented at the International Conference Human Factors in Ship Design and Operation, London.27-29 Sept 2000

Colwell, J. L. (2009). *Empirical Models Relating Ship Motions, Sleep, Fatigue, Motion Sickness and Task Performance in the Naval Environment*. Paper presented at the International Conference of Human Factors in Ship Design, Safety and Operation, London.25-26 Feb 2009

Cotta, A., & Tincani, E. P. (2011). Impact of comfort class requirements in a new building ship and possible advantages for owners. In E. Rizzuto & C. Soares (Eds.), *Sustainable Maritime Transportation and Exploitation of Sea Resources* (pp. 1011-1018). Boca Raton, FL: CRC Press.

Cyclades Framework. (2015). Crew-centred Design and Operation of ships and ship systems Retrieved 11 Dec 2015, 2015, from http://www.cyclades-project.eu/CyClaDes/index.xhtml

Department of Defense. (1999). *Definitions of Human Factors Terms*. Department of Defense.

Det Norske Veritas. (2009). *Rules for Classification of Ships Comfort Class: Special Service and Type Additional Class* (Vol. Part 5 Chapter 12). Høvik, Norway: Det Norske Veritas.

Det Norske Veritas. (2011). Class Notations Retrieved 26 Nov, 2011, from http://www.dnv.com/industry/maritime/servicessolutions/classification/notations/

Dragland, Å. (2014). Ships Without Skippers. *GEMINI*. Retrieved from http://gemini.no/en/2014/09/ships-without-skippers/

Edmond, B. R. (2005). *Current State of International Consideration of Human Factors*. Paper presented at the Asia-Pacific Heads of Maritime Safety Agencies Forum, Busan, South Korea.12-15 April 2005

Ellis, N. (2009). *Vessel Design and the Wellbeing of Seafarers*. Paper presented at the Seafarers International Research Centre Symposium, Cardiff, UK.8-9 July 2009

FAROS. (2013). FAROS, Human Factors in Risk-Based Design Methodology. *Seventh Framework Programme* Retrieved 13 Nov, 2014, from http://www.silenv.eu/

Geertz, C. (1973). *The Interpretation of Cultures: Selected Essays*. New York, NY: Basic Books.
Gibson, V. (2007). *The History of the Supply Ship*. Aberdeen: Madrila.
Graham, R. (1990). Motion-Induced Interruptions as Ship Operability Criteria. *Naval Engineers Journal, 102*(2), 65-71. doi: 10.1111/j.1559-3584.1990.tb02556.x
Graveson, A. (2002). *Human Factors in Ship Design and Operation*. Paper presented at the International Conference on Human Factors in Ship Design and Operation, London.2-3 Oct 2002
Grundevik, P., Lundh, M., & Wagner, E. (2009). *Engine Control Room - Human Factors*. Paper presented at the International Conference of Human Factors in Ship Design, Safety and Operation, London.25-26 Feb 2009
Hansson, L. (2003). *Improved Vessel Safety in Offshore Supply Services*. Paper presented at the European Safety & Reliability Conference, Maastricht.15-18 June 2003
Hansson, L. (2006). *Safety Management for Prevention of Occupational Accidents: the SMO-Methodology.* [Ph.D. thesis], Norges teknisk-naturvitenskapelige universitet, Trondheim. (2006:13)
Hardwick, C. (2000). *A Comparative Assessment of Priorities for Accommodation Standards between Royal Naval and Merchant Naval Fleets*. Paper presented at the International Conference on Human Factors in Ship Design and Operation, London.27-29 Sept 2000
Haward, B. M., Lewis, C. H., & Griffin, M. J. (2009). Motions and crew responses on an offshore oil production and storage vessel. *Applied Ergonomics, 40*(5), 904-914. doi: 10.1016/j.apergo.2009.01.001
Houtman, I., Miedema, M., Jettinghoff, K., Starren, A., Gort, J., Wulder, J., & Wubbolts, S. (2005). *Fatigue in the Shipping Industry*. Hoofddorp, The Netherlands: TNO.
Human Factors and Ergonomics Society. (2009). Definition of Human Factors and Ergonomics Retrieved 13 Mar, 2009, from www.hfes.org/Web/EducationalResources/HFEdefinitionsmain.html
IACS. (2013). *Human Element Recommendation for structural design of lighting, ventilation, vibration, noise, access and egress arrangements*. Rec. No. 132. International Association of Classification Societies, Ltd.
International Ergonomics Association. (2012). What is Ergonomics? , from http://www.iea.cc/01_what/What%20is%20Ergonomics.html
International Labour Conference. (2006). *Maritime Labour Convention*.
International Maritime Organisation. (1981). *Code on Noise Levels On Board Ships*. Res A.468(XII). London: IMO
International Maritime Organization. (1998). *Guidelines for Engine Room Layout, Design and Arrangement*. MSC/Circ.834. London: IMO
International Maritime Organization. (2000). *Guidelines on Ergonomic Criteria for Bridge Equipment and Layout*. MSC/Circ.982. London: IMO
International Maritime Organization. (2004). *Human Element Vision, Principles and Goals for the Organization*. A.947(23). London: IMO

International Maritime Organization. (2012a). *Casualty Statistics and Investigations Loss of Life from 2006 to Date*. London: IMO.
International Maritime Organization. (2012b). Introduction to IMO Retrieved 16 Mar, 2012, from http://www.imo.org/About/Pages/Default.aspx
ISO. (1996). *Acoustics - Measurement of Noise On Board Vessels*. 2923. Geneva, Switzerland: The International Organization for Standardization
ISO. (2008). *Mechanical Vibration - Measurement of Vibration on Ships - Part 2: Measurement of Structural Vibration*. 20283-2:2008. Geneva, Switzerland: The International Organization for Standardization
Kivimaa, S., Rantanen, A., Nyman, T., Owen, D., Garner, T., & Davies, B. (2014). *Ship motions, vibration and noise influence on crew performance and well-being studies in FAROS project*. Paper presented at the Transport Research Arena Conference, Paris.14-17 Apr 2014
Krippendorff, K. (2004). *Content Analysis: An Introduction to Its Methodology*. Thousand Oaks, California: Sage.
Kristiansen, S. (2005). *Maritime Transportation: Safety Management and Risk Analysis*. Amsterdam: Elsevier.
Lawson, C. T., & Weisbrod, R. E. (2005). Ferry Transport: the Realm of Responsibility for Ferry Disasters in Developing Nations. *Journal of Public Transportation, 8*(4), 15.
Lloyd's Register. (2008). *The Human Element: An Introduction*. London: Lloyd's Register.
Lloyd's Register. (2009). *The Human Element Best Practice for Ship Operators*. London: Lloyd's Register.
Lloyd's Register. (2012). *Rules and Regulations for the Classification of Naval Ships Vol 3 Part 2 Additional Environment and Safety Features*. 2012. London: Lloyd's Register
Lloyd's Register. (2015). Rules and Regulations Retrieved 2 Mar 2015, from http://www.lr.org/en/RulesandRegulations/
Lützhöft, M. (2005). *Human Integration of Bridge Technology*. Paper presented at the International Conference on Human Factors in Ship Design, Safety & Operation, London.22-24 Feb 2005
Masakowski, Y. (2009). *Trade-offs in Performance: Autonomous Unmanned Systems and Their Impact on Human Performance*. Paper presented at the International Conference on Human Factors in Ship Design, Safety and Operation, London.25-26 Feb 2009
Matsagas, P., McCaulay, M. E., & Papoulias, F. (2009). *Human Performance Standards for Ship Motion: A Review and a Preliminary Gap Analysis*. Paper presented at the Maritime Systems and Technology (MAST), Stockholm, Sweden.21-23 Oct 2009
Matsagas, P., & Miller, N. L. (2006). The Effects of Ship Motion on the Sleeping Patterns of Crewmembers aboard a High Speed Naval Vessel *Calhoun Institutional Archive of the Naval Postgraduate School* (Vol. 2006-06).
McCafferty, D. B., & Baker, C. C. (2006). *Trending the Cause of Marine Incidents*. Paper presented at the International Conference on Learning from Marine Incidents, London.25-26 Jan 2006

McCauley, M. E., Royal, J. W., Wylie, C. D., O'Hanlon, J. F., & Mackie, R. R. (1976). *Motion Sickness Incidence: Exploratory Studies of Habituation, Pitch and Roll, and the Refinement of a Mathematical Model*. Santa Barbara, California: Human Factors Research, Inc.

Merriam-Webster.com. (2014). "human factors". Retrieved 9 Dec 2014 http://www.merriam-webster.com/dictionary/human%20factors

Miller, G. E. (1999). *Human Factors Engineering (HFE): What It Is And How It Can Be Used To Reduce Human Errors In The Offshore Industry*. Paper presented at the Offshore Technology Conference, Houston, Texas.3-6 May 1999

Miller, G. E., & McSweeney, K. (2000). *A Brief History of the Utilization of Human and Organizational Factors (HOF) in the Design of Military and Commercial Ships and Offshore Structures in the United States*. Paper presented at the International Conference on Human Factors in Ship Design and Operation, London.27-29 Sept 2000

Montewka, J., Goerlandt, F., Innes-Jones, G., Owen, D., Hifi, Y., & Porthin, M. (2012). *Quantifying the Eeffect of Noise, Vibration and Motion on Human Performance in Ship Collision and Grounding Risk Assessment*. Paper presented at the Probabilistic Safety Assessment and Management Conference, Honolulu, Hawaii.12 Jun 2012

National Transportation Safety Board. (1997). *Grounding of the Panamanian Passenger Ship Royal Majesty on Rose and Crown Shoal near Nantucket, Massachusetts June 10, 1995*. MAR-97-01. Washington, DC: NTSB

NATO. (2000). *Standardization Agreement (STANAG): Subject: Common Procedures for Seakeeping in the Ship Design Process*: NATO, Military Agency for Standardization.

NORDFORSK. (1987). *Assessment of Ship Performance in a Seaway*. Copenhagen: Nordforsk.

North West European Area. (2009). *NWEA Guidelines for the Safe Management of Offshore Supply and Rig Move Operations*. London: Chamber of Shipping, Danish Shipowners Association, Netherlands Oil and Gas Exploration and Production Association, Norwegian Ship Owners Association, United Kingdom Offshore Operators Association

Petroleum Safety Authoritiy Norway. (2011). Risk of Collisions with Visiting Vessels Retrieved 10 Oct 2011, from http://www.ptil.no/news/risk-of-collisions-with-visiting-vessels-article7524-79.html

Petroleum Safety Authority Norway. (2009). Investigation Report Following Collision between Big Orange XVIII and Ekofisk 2/4-W Retrieved 5 Dec 2011, from http://www.ptil.no/news/investigation-report-following-collision-between-big-orange-xviii-and-ekofisk-2-4-w-article5985-79.html?lang=en_US

Rausand, M., & Høyland, A. (2004). *System reliability theory: models, statistical methods, and applications*: John Wiley & Sons.

Reason, J. (1990). *Human Error*. New York: Cambridge University Press.

Reason, J. (2000). Human Error: Models and Management. *Western Journal of Medicine, 172*(6), 393-396. doi: 10.1136/ewjm.172.6.393

Ross, J. M. (2009a). *Human Factors Considerations for Marine Vehicle Design*. Paper presented at the International Conference on Human Factors in Ship Design, Safety and Operation, London.25-26 Feb 2009

Ross, J. M. (2009b). *Human Factors for Naval Marine Vehicle Design and Operation*. Surrey: Ashgate.

Rumawas, V., & Asbjørnslett, B. E. (2010). *A Content Analysis of Human Factors in the Design of Marine Systems*. Paper presented at the International Conference on Ship and Offshore Technology (ICSOT) Surabaya.11-12 Nov 2010

Rumawas, V., & Asbjørnslett, B. E. (2011). *Offshore Supply Vessels Design and Operation: A Human Factors Exploration*. Paper presented at the European Safety and Reliability Conference (ESREL), Troyes.18-22 Sept 2011

Rumawas, V., & Asbjørnslett, B. E. (2014). A Content Analysis of Human Factors in Ship Design. *Trans RINA International Journal of Maritime Engineering, 156*(Part A3). doi: 10.3940/rina.ijme.2014.a3.299

Sarioz, K., & Narli, E. (2005). Effect of Criteria on Seakeeping Performance Assessment. *Ocean Engineering, 32*, 1161-1173. doi: 10.1016/j.oceaneng.2004.12.006

Seafarers International Research Centre. (2012). *Safety and Shipping 1912-2012 From Titanic to Costa Concordia*. Cardiff, UK: Cardiff University and Allianz.

Senders, J. W., Moray, N. P., & North Atlanctic Treaty Organisation. (1991). *Human Error: Cause, Prediction, and Reduction*: Taylor & Francis.

SILENV. (2012). Ships oriented Innovative soLutions to rEduce Noise and Vibrations (N&V) Retrieved 13 Nov 2014, 2014, from http://www.silenv.eu/

Skjong, R. (2009a, 29 Sept 2009). [Personal communication on SAFEDOR].

Skjong, R. (2009b). *Risk Based Regulation, Risk Based Design in the Maritime Industry & SAFEDOR*. Guess lecture. DNV. NTNU.

Smith, A., Allen, P., & Wadsworth, E. (2006). *Seafarer Fatigue: The Cardiff Research Programme*. Cardiff, UK: Centre for Occupational and Health Psychology, Cardiff University.

Spouge, J. (1991). Passenger Ferry Safety in the Philippines. *Naval Architect, May 1991*, 179-199.

SPSS Inc. (2010). SPSS for Windows, Version 14.1. Chicago.

Squire, D. (2007). *'Fit for Purpose' - Keeping the Crew in Mind*. Paper presented at the International Conference on Human Factors in Ship Design, Safety and Operation, London.21-22 March 2007

Statista. (2014). Selected Shipping Accidents Worldwide from 2000 to August 2014, Sorted by Number of Fatalities. Available from Statista Retrieved 4 Nov 2014 http://www.statista.com/statistics/277003/victims-of-shipping-accidents-worldwide/

Stevens, S. C., & Parsons, M. G. (2002). Effects of Motion at Sea on Crew Performance: A Survey. *Marine Technology, 39*, 29-47.

Strong, R. (2000). *RN Habitability Survey: Ship Design Implications: Some Important Social and Architectural Issues in the Design of Accommodation Spaces*. Paper presented at the International Conference on Human Factors in Ship Design and Operation, London.27-29 Sept 2000

Tamura, Y., & Arima, M. (2006). A Questionnaire Survey for Evaluating Ride Comfort of a Passenger Ship (1st report) - Relationship between Ship Motion and Motion Sickness. *Japan Society of Naval Architects and Ocean Engineers, 4*(Dec), 8.

The Joint Accident Investigation Commission of Estonia. (1997). *Final Report on the Capsizing on 28 September 1994 in the Baltic Sea of the Ro-Ro Passenger Vessel MV Estonia*. Helsinki: Edita.

Vagias, N. A. (2010). *A Bayesian Network Application for the Prediction of Human Fatigue in the Marine Industry.* National Technical University of Athens, Athens.

Ventikos, N., Lykos, G., & Vagias, N. (2012). Human Fatigue: Evaluation with the Usage of Bayesian Networks. In C. Kahraman (Ed.), *Computational Intelligence Systems in Industrial Engineering* (Vol. 6, pp. 651-676): Atlantis Press.

Yerkes, R. M., & Dodson, J. D. (1908). The Relation of Strength of Stimulus to Rapidity of Habit-formation. *Journal of Comparative Neurology and Psychology, 18*(5), 459-482. doi: 10.1002/cne.920180503

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Appendix A: Literature Study

A Content Analysis of Human Factors in Ships Design

The International Journal of Maritime Engineering, RINA Transactions Part A3, Vol 156, Jul – Sep 2014

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A CONTENT ANALYSIS OF HUMAN FACTORS IN SHIPS DESIGN

(DOI No: 10.3940/rina.ijme.2014.a3.299)

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SUMMARY

Research shows that more than 80% of accidents at sea were caused by human related factors. Some experts implied that less than adequate design is one significant element that may lead to human errors. There are several ways to discover whether a design has considered human factors, i.e., to refer to the design specification, to consult the designers, to conduct a direct observation through a site visit or through a model, to interview the users, or to look into the system that regulates the design. This paper applied a content analysis methodology to explore how human factors have been covered in the design of marine systems. Various documents such as rules, regulations, design guidelines, standards and other texts have been analysed. The results indicate that there are extensive references that cover human factors in designing ships. They are published with different degrees of enforcement, some are prescriptive and some are obligatory but *still* optional. The topic is developing very rapidly. A more assertive measure is required from the regulators to endorse human factors into implementation.

NOMENCLATURE

ABS	American Bureau of Shipping
ASTM	American Society for Testing and Materials
BS	British Standards
BV	Bureau Veritas
CEPAC	Crew and Embarked Personnel Accommodation Comfort
COMF	Comfort
DNV	Det Norske Veritas
ECR	Engine control room
ER	Engine room
GL	Germanischer Lloyd
HAB	Habitability
HF	Human factors
HFES	Human Factors and Ergonomics Society
HVAC	Heating, ventilation and air conditioning
IEA	International Ergonomics Association
IMO	International Maritime Organization
ISO	International Organization for Standardization
LR	Lloyd's Register
NKK	Nippon Kaiji Kyokai
OHS	Occupational health and safety
RINA	Royal Institution of Naval Architects
SNAME	Society of Naval Architects and Marine Engineers
SOLAS	Safety of Life at Sea
STCW	Seafarers' Training, Certification and Watchkeeping

1. INTRODUCTION

This paper explores how human factors have been covered in marine system design. Extensive studies have been conducted to better understand the role of human factors in maritime accidents by examining available maritime casualty databases [1, 2],claiming that human error continues to be the dominant factor in maritime accidents, contributing to 80-85% of all accidents. Whereof, about 50% initiated by human error, while another 30% associated with human error.

In contrast to the fact mentioned above, designers seem to avoid this so-called human factor. Reason mentions that rather than being the instigator of an accident, operators tend to be the inheritors of system's defects created by poor design, incorrect installation, faulty maintenance and bad management decisions [3]. Squire quoted one ship master stating that it is frustrating for the personnel to sail a vessel which was designed with no crew input and whatsoever [4]. Miller emphasized his message in capital letters [5, 6]:

"YOU CANNOT OVERCOME HUMAN ERRORS INDUCED BY POOR DESIGN OF THE WORKPLACE WITH MORE TRAINING, MORE MANUALS OR WRITTEN PROCEDURES, EXHORTATIONS TO WORK MORE SAFELY, OR THREATS OF PUNITIVE ACTIONS FOR JOB ACCIDENTS."

Graveson mentions similar statement that human factors in shipping draws attention but is rarely addressed and is not taken seriously [7].

A question worth asking is: "Is human factors neglected in ship design?"

There are several ways to find out if a design is good and human-friendly. First, one can do an evaluation through the design itself. For instance, a human factors review in ship design was conducted by means of a 3D computer model [8]. Several onboard surveys were conducted to evaluate engine control rooms and bridge design with regard to human factors [9, 10, 11, 12]. Second, one can do interviews with the designers [13]. Third, one can study the rules and regulations for designing the systems.

Naval architects, marine engineers, and offshore engineers should refer to codes, rules, regulations and guidelines when designing their products. Some of these referrals are compulsory and some are voluntary. To be approved by any classification society, the design obviously must follow the rules and regulations published by the corresponding society, for instance ABS, BV, DNV, GL, LR or NKK. Ross identifies which standards and regulations correspond to which ship design discipline: structure, hull-form, machinery, general arrangements and human-machine interface [15, 16]. The presentation is simple, but beneficial for the designers who intend to apply the specific know-how to their work.

The research presented in this paper applies a content analysis to explore how human factors have been covered in marine system design. The concept of human factors in ship design is explored and relevant literature is reviewed. Applicable codes, rules, regulations and guidelines will be examined. The aim is to investigate which aspects of human factors are mentioned and how they are addressed. The results should be beneficial for those who are involved in the design of marine systems and intend to apply principles related to human factors in their design. The remaining part of the paper will first give an introduction to relevant literature, and then describe the content analysis methodology applied, before results are presented and discussed.

2. LITERATURE REVIEW

A literature review is performed to clarify the concept of human factors in ships design. First, definitions of human factors from its own societies are explored. Then, the process of ships design is discussed. Finally, the application of human factors in ship design is presented.

2.1 HUMAN FACTORS

The International Ergonomics Association (IEA) defines human factors as [18]:

"The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance."

A definition developed by the Human Factors and Ergonomics Society (HFES), stated that "Human Factors is concerned with the application of what we know about people, their abilities, characteristics, and limitations to the design of equipment they use, environments in which they function, and jobs they perform" [19]. Another definition provided by HFES declared that:

"Human factors is that field which is involved in conducting research regarding human psychological, social, physical, and biological characteristics, maintaining the information obtained from that research, and working to apply that information with respect to the design, operation, or use of products or systems for optimizing human performance, health, safety, and/or habitability."

The International Maritime Organization (IMO) uses the term "human element" for this purpose, and defines [20]: "The human element is a complex multi-dimensional issue that affects maritime safety, security and marine environmental protection. It involves the entire spectrum of human activities performed by ships' crews, shore-based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to co-operate to address human element issues effectively."

2.2 SHIPS DESIGN

The design process consists of developing requirements, conducting analyses, developing drawings, building electronic models and writing specifications [15]. Ship design is a long and iterative process, divided into stages or phases. The way people divide and name the stages or the phases varies across sources and across time. In the 1980 edition of the Ship Design and Construction textbook, Kiss following Evans (1959) distinguished four phases of ship design process [21]: concept design, preliminary design, contract design and detail design. While, in the latter version of the textbook, Gale, following Lamb (1985, 1986) differentiates two ship design stages [22]: basic design and product engineering. The first stage is then subdivided into four phases: concept design, preliminary design, contract design and functional design. The second stage is subdivided into two phases: transition design and workstation/zone information preparation. Rawson and Tupper propose three major design stages: concept design, feasibility design and full design [23].

Each design stage covers specific issues and considerations. Usually the process will start with the mission statement, like what kind of vessel to be built to carry how much quantity of which particular cargoes in which area of the world. The further the process the more detail the issues cover, for instance the dimensions of the vessel, type of hull that is going to be used, type of machineries that will be installed, layout and arrangement of the vessel, bridge design, ER and ECR design, to plumbing and fixture list, accommodation arrangement, electrical equipment and installation diagram, and HVAC diagram and equipment list. Obviously, most of the topics covered above are typical marine related problems, but not all are under the responsibility of a naval architect or a marine engineer. Furthermore, not all issues are related to human factors, but may still have an effect on people and their safety and effectiveness and efficiency of work.

2.3 HUMAN FACTORS IN SHIPS DESIGN

Humans are involved in the ship life cycle from procurement to disposal. They include the owners, the designers - naval architects, the classification societies, the regulatory authorities, the shipbuilders, the equipment suppliers, the ship managers/operators, the seafarers/unions and the insurers [7]. All of them have a different but significant impact on safety, effectiveness and efficiency. Shipowners play important roles that may have profound consequences on safety. They determine which flag state and which classification society their vessels will carry. The maritime administration, acting as the flag state control, has the job to ensure that regulations are obeyed [24]. Classification societies develop standards and set technical rules. They also have the responsibility to ensure that the design and construction follow the standards. It is a common practice that classification societies carry out the control functions on behalf of the flag state. Much of this knowledge is captured in standards and guides for non-expert use, thus reducing the cost of human centred design.

According to Rawson and Tupper, the human element in design is covered by multi-disciplinary human factors teams. These teams include physiologists, psychologists, engineers and scientists. These human factors teams can advise the naval architect on how to design a system or equipment so that the human can perform more effectively, increase system efficiency, improve human performance and inform the levels of environmental parameters which should not be exceeded [23].

In the ship design and construction textbook published by SNAME, human factors is defined as a comprehensive term that covers all biomedical and psychological considerations applying to the human in the system. Human factors is also stated to cover human engineering and life support, personnel selection, training and training equipment, job performance aids, and performance measures and evaluation as well. Human factors engineering in ship design is defined separately. Human factors engineering includes techniques to define the role of the human in complex systems, simulation and modelling of crew workloads for manning reduction, assessing operator/maintainer workloads, advanced man-machine interfaces, decision aids to reduce human error and accidents and enhance human performance and safety, and ship design methods and data [17]. The role of the naval architects and marine engineers is highlighted to influence the final product of marine design by adequately addressing human factors in the ship design process. The importance of designing for human factors correctly from the bottom up is also emphasized.

Lloyd's Register (LR) described human factors as something that is concerned with the task people do and the environment they do it in - fitting the job to the person [25]. When applied to the design and operation of a ship and its systems, the term human factors means taking human capabilities, skills, limitations and needs, and the use of people as a component of the system into account. Ergonomics is defined as the study and design of the working environment for the benefit of the workers' safety, efficiency, effectiveness, health and comfort. Working environments include ship bridges, machinery control rooms, galleys, and the related components, work practices and work procedures. It is mentioned that for any ship to operate safely and effectively, the ship must be designed to support the people who work onboard, without detriment to their health, safety and overall performance.

Examples of ship design elements related to human factors are [14, 15, 25]: ship motions, design arrangement, layout and location of operation, berthing and maintenance spaces, access, gangways, ladders, stairs and work platform, ergonomics and anthropometric considerations, accommodation criteria, maintainability, habitability, survivability and comfort of personnel, indoor climate, lighting, view, sight, visibility, noise, sound, vibration, ventilation, and temperature, human-machine interfaces and interaction, incl. symbols, signs, labels, and job-performance aid, control, display, screen, alarms, workstations, consoles, and manual valve operation.

There are three references to date which particularly cover human factors in ship design: "High Speed Craft Human Factors Engineering Design Guide" [26], "Human Factors in the Maritime Domain" [27] and "Human Factors for Naval Marine Vehicle Design and Operation" [17]. Nine areas of human factors in ship design have been identified [26]: motions, sight, sound, environment, health and safety, man-machine interface, habitability, maintainability, and design review.

LR systematically distinguished several different design qualities in relation to human factors. These include [25]:

- Habitability – the provision of adequate and comfortable accommodation, including furnishings and washing facilities, such as galleys, messrooms and recreational spaces. This provision must take into account seafarer's variation in size, shape and gender, and various environmental stressors: noise, heat and vibration.
- Maintainability – designing operational maintenance tasks to be rapid, safe and effective, to allow equipment and systems to achieve a specified level of performance. This includes consideration of access, removal routes, tools, expertise, disposal and through-life support.
- Workability – due consideration must be given to the users, tasks, equipment (including any software), materials and procedures, and the

physical and social environments in which a system is used.
- Controllability – designing the layout of ship control centers, machinery control rooms, cargo control rooms etc., considering integration of people with equipment, systems and interfaces, such as communication facilities, controls, displays, alarms, video-display units, and computer stations.
- Manoeuvrability – having the most appropriate manoeuvring capabilities consistent with the intended role, manning and operational pattern of the ship, including the type, number and power of propulsion systems, steering systems and thrusters.
- Survivability – the provision of adequate fire-fighting, damage control and lifesaving facilities (including manpower), and of security arrangements.

In a subsequent publication, LR adds two other qualities to human factors [31]:
- Occupational health and safety (OHS) – consideration of the effect of work, the working environment and living conditions on the health, safety and wellbeing of workers.
- System safety – consideration of the risks from people using (or mis-using) ship systems.

3. METHODOLOGY

To answer the question whether human factors has been considered in marine design by means of published documents such as rules, regulations, standards, and guides, a method of systematic literature survey as for instance content analysis is required.

3.1 CONTENT ANALYSIS

Content analysis is a research technique for making replicable and valid inferences from texts, or other meaningful matter, to the context of their use [28]. Leedy & Omrod and Neuendorf defined content analysis as a careful, detailed, systematic examination and interpretation of a particular body of material in an effort to identify patterns, themes, biases, and meanings [29]. Content analysis can be applied deductively in quantitative research, producing frequencies of pre-selected categories or values associated with particular variables [30]. This method is considered to be relevant to answer the problems that are being addressed in this study. Content analysis will be utilized as a structured and quantified literature study, to see if human factors is covered in the process of designing marine systems and how it is taken into account.

Based on a theoretical construct of human factors in ship design, a coding sheet is developed. It can be seen that the construct is rather complex and multi-dimensional.

Table 1 Coding Sheet

Dimension	Component	Aspect / object
Habitability (HAB)	Accommodation Seafarer's variation Environmental stressors Environmental condition Indoor climate Comfort	Galleys, messroom Recreational spaces Cabins Size Shape Gender Noise, sound Heat, temperature Air velocity, ventilation Air quality, smell Motion Vibration Lighting
Maintainability (MAIN)	Maintenance tasks	Layout, access, removal routes Tools Expertise Disposal Through-life support
Workability (WORK)	Users Tasks Equipment & software Material & procedures Physical & social environment	Accessibility Layout Space
Controllability (CONT)	Control centres	Bridge Engine control room Cargo control facilities
	People-system integration Man-machine interface	Communication facilities Controls and switches Displays, video- display unit Alarms Automation Computer stations
Manoeuvrability (MANV)	Propulsion system Steering system Thrusters	
Survivability (SURV)	Firefighting Damage control Lifesaving facilities	
Occupational Health and Safety (OHS)	Effect to work Working environment Living conditions	
System safety (SS)	Risk consideration	

There is no formal taxonomy of human factors in the maritime domain available to date. The framework provided by LR [31] is regarded as the most logical and comprehensive one, and is therefore employed as the basic skeleton. Eight design qualities are identified and for the coding sheet purpose they are named as dimensions: habitability, maintainability, workability, controllability, manoeuvrability, survivability, occupational health and safety, and system safety. Under each dimension, several components and or aspects are identified. In the process of developing the coding sheet, it is realized that the framework does not really satisfy the mutually exclusive and collectively exhaustive principle; overlapping occurs and there are some inconsistencies in classifying components or aspects. The initial coding sheet is presented in Table 1 which is developed together with the coding process.

3.2 POPULATION AND SAMPLE

There are many documents that can be explored to show how human factors are accounted for in ship design. A good source to start with is existing textbooks and handbooks of ship design, as presented above in section 2.3. Next, periodicals like journal publications, conference papers, reports, bulletins and magazines will be essential sources of information. And finally, but often regarded as most important are codes, standards, rules, regulations, guides and recommended practices, published by the classification societies. Such publications from the class societies can be said to truly represent the reality in the industry, as they are required to class a ship.

This research focus on commercial ship design, thus documents with military, aeronautics and nuclear reactor background is excluded. Documents provided for general purpose design, such as BS 6841:1987 Guide to Measurement and Evaluation of Human Exposure to Whole-body Mechanical Vibration and Repeated Shock and ISO 6385:2004 Ergonomic Principles in the Design of Work Systems, and documents not specifically addressing design issues, such as STCW, SOLAS and Maritime Labour Convention (MLC) 2006 are also excluded from the scope of this research.

The population of the research is defined as those documents, standards, rules, or guides published by classification societies and other relevant international bodies which regulate certain aspects of ship design that can affect human performance, health, and or safety on board. Three classification societies are taken as the samples in the research: ABS, DNV and LR. Three international organizations are also sampled: IMO, and the standards organisations ISO and ASTM.

Two levels of data exploration will be conducted according to the level of the unit analysis. First, a thorough look into the list of publications on each source will be carried out. At this stage, the title of the document will be identified. Next, on each document selected, detail content analysis will be done by applying a pre-defined coding sheet, covering human factors related keywords.

3.2 (a) Classification Societies

ABS, DNV and LR are three major classification societies, representing a considerable part of the ship classification market, and they show a particular interest for human factors considerations in marine design. Each society addresses the human factors issue in its own way. ABS provides quite a few guides addressing human factors issues and offers additional notations like HAB and COMF. DNV offers additional COMF notation. LR offers CEPAC notation and does a lot of efforts in addition to the rules and regulations.

American Bureau of Shipping [32]

ABS publishes 138 rules and guides that are applied in marine industry, covering ships, offshore structures, floating structures, underwater vehicles, equipment, components and materials. As many as seventeen publications can be categorized as targeted documents in this research (see Table 2).

Table 2 ABS rules and guides related to human factors in ship design

Pub#	Title
86	Application of Ergonomics to Marine Systems
94	Bridge Design and Navigational Equipment/Systems
97	Risk Assessment Applications for the Marine and Offshore Oil and Gas Industries
102	Crew Habitability on Ships
103	Passenger Comfort on Ships
116	Review and Approval of Novel Concepts
117	Risk Evaluations for the Classification of Marine-Related Facilities
119	Ergonomic Design of Navigation Bridges
122	Alternative Design and Arrangements for Fire Safety
141	Fire-Fighting Systems
145	Vessel Maneuverability
147	Ship Vibration
151	Vessels Operating in Low Temperature Environments
154	Means of Access to Tanks and Holds for Inspection
163	Crew Habitability on Workboats
170	Rapid Response Damage Assessment
185	Integrated Software Quality Management (ISQM)

Det Norske Veritas [33]

DNV differentiates their rules and standards into: Rules for Classification of Ships, Rules for Classification of High Speed, Light Craft and Naval Surface Craft, Statutory Interpretations, Service Specifications, Offshore Service Specifications, Offshore Standards, Recommended Practices, etc.

Table 3 shows documents published by DNV that are presumed to accommodate human factors in commercial ship design.

Not all documents mentioned in Table 3 are developed based on the human factors viewpoint. For instance, Part 6, Chapter 15 Vibration Class is established considering that vibration may influence function of some essential machineries and equipment as well as cause fatigue damage to some important structures. Chapter 24 SILENT class notation is applied to ensure that those equipment used by the vessel can function properly.

Table 3 DNV rules for classification of ships and craft related to human factors

Rules for Classification of Ships		
Part 3	Hull and Equipment - Main Class	
	Ch 3	Hull Equipment and Safety
Part 4	Machinery and Systems - Main Class	
	Ch 9	Control and Monitoring Systems
	Ch 10	Fire Safety
	Ch 14	Steering Gear
Part 5	Special Service and Type - Additional Class	
	Ch 12	Comfort Class
Part 6	Special Equipment and Systems- Additional Class	
	Ch 2	Redundant Propulsion
	Ch 3	Periodically Unattended Machinery Space
	Ch 4	Additional Fire Protection (F-AMC)
	Ch 6	Centralised Cargo Control for Liquid Cargoes
	Ch 7	Dynamic Positioning Systems
	Ch 8	Nautical Safety
	Ch 9	Loading Computer Systems (LCS) for Stability and Longitudinal Strength
	Ch 15	Vibration Class*)
	Ch 20	Nautical Safety - Offshore Service Vessels
	Ch 24	SILENT Class Notation*)
	Ch 26	Dynamic Positioning System - Enhanced Reliability DYNPOS-ER
*) not developed based on human factors perspective		

Table 4 shows the rest of DNV documents addressing human factors in the design stage.

Table 4 DNV documents related to human factors in design phase

Recommended Practices (DNV-RP)	
A203	Qualification of New Technology
C205	Environmental Conditions and Environmental Loads
D102	Failure Mode and Effect Analysis (FMEA) of Redundant Systems
D201	Integrated Software Dependent Systems

Lloyd's Register [34]

LR differentiates their rules and regulations into two categories: marine and energy. There are 130 documents under the marine category and 25 documents under the energy. Table 5 presents a list of LR documents that are relevant to HF in ship design.

3.2 (b) International Standards and Industry Standards

In addition to those classification societies, three other relevant organizations in the global regulatory and standardization domain are evaluated: IMO, ISO and ASTM.

The International Maritime Organization [35]

IMO is a specialized agency of the United Nations which is responsible for measures to improve the safety and security of international shipping and to prevent marine pollution from ships. IMO is responsible for keeping legislation up to date, ensuring that it is ratified by as many countries as possible, and to ensure that theses conventions and other treaties are properly implemented by the countries that have accepted them. A considerable share of IMO's publications is related to human factors in ship operations. IMO publishes documents in different format: agreements, circulars, codes, conventions, guidelines, manuals, model courses, procedures, recommendations, regulations, rules and resolutions.

Table 5 LR documents related to HF in design

Rules & Regulations for the Classification of Ships		
Part 3	Ship Structures (General)	
	Ch 13	Ship Control System
Part 5	Main and Auxiliary Machinery	
	Ch 18	Integrated Propulsion Systems
	Ch 19	Steering Gear
	Ch 21	Requirements for Condition Monitoring Systems
	Ch 22	Propulsion and Steering Machinery Redundancy
	Ch 23	Safe Return to Port and Orderly Evacuation and Abandonment in Passenger Ships
Part 6	Control, Electrical, Refrigeration and Fire	
	Ch 1	Control Engineering Systems
	Ch 2	Electrical Engineering
	Ch 4	Fire Protection, Detection and Extinction Requirements
Part 7	Other Ship Types and Systems	
	Ch 4	Dynamic Positioning Systems
	Ch 9	Navigational Arrangements and Integrated Bridge Systems
	Ch 11	Arrangements and Equipment for Environmental Protection
	Ch 12	Integrated Fire Protection (IFP) Systems
	Ch 13	Passenger and Crew Accommodation Comfort
	Ch 15	Requirements for Machinery and Engineering Systems of Unconventional Design
Guidance Note		
	Ship Vibration and Noise Guidance Notes	

Several conventions are significantly important for the human factors' perspective:

- COLREGS – International Regulations for Preventing Collisions at Sea

- Load Lines, 1966 – International Convention on Load Lines
- SOLAS – International Convention for the Safety of Life at Sea
- STCW – International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

IMO codes related to human factors are:
- Code on Alerts and Indicators, 2009
- FSS Code – Fire Safety System
- LSA Code – International Life-Saving Appliance Code
- Noise Levels – Code on Noise Levels on Board Ships
- STCW Code – Seafarers' Training, Certification and Watchkeeping

Examples of other IMO publications that are relevant to human factors in ship design include:

Table 6 IMO publications relevant to HF in ship design

Assembly Resolutions (RES)	
A.342(IX)	Recommendation on Performance Standards for Automatic Pilots
A.468(XII)	Code on Noise Levels on Board Ships
A.601(15)	Provision and Display of Manoeuvring Information on Board Ships
A.708(17)	Navigation Bridge Visibility and Functions
A.817(19)	Performance Standards for Electronic Chart Display and Information Systems (ECDIS)
A.861(20)	Performance Standards for Shipborne Voyage Data Recorders (VDRs)
A.947(23)	Human Element Vision, Principles and Goals for the Organization
A.1021 (26)	Code on Alerts and Indicators
Maritime Safety Committee (MSC) Resolutions	
128(75)	Performance Standards for a Bridge Navigational Watch Alarm System (BNWAS)
137(76)	Standards for Ship Manoeuvrability
190(79)	Performance Standards for the Presentation of Navigation-Related Information on Shipborne Navigational Displays
IMO Circulars, MSC Circulars	
587	Life Saving Appliances
601	Fire Protection in Machinery Spaces
616	Evaluation of Free-Fall Lifeboat Launch Performance
645	Guidelines for Vessels with Dynamic Positioning Systems
834	Guidelines for Engine-Room Layout, Design and Arrangement
846	Guidelines on Human Element Considerations for the Design and Management of Emergency Escape Arrangements on Passenger Ships
849	Guidelines for the performance, location, use and care of emergency escape breathing devices (EEBD's)
982	Guidelines on Ergonomic Criteria for Bridge Equipment and Layout
1002	Guidelines on Alternative Design and Arrangements for Fire Safety

Some topics are addressed more than once in IMO publications. For instance, the STCW is published as a convention and also as a code, and noise levels on board is mentioned as a code as well as a resolution. To avoid redundancy, these topics are considered as one.

The International Organization for Standardization [36]

ISO is a non-governmental organization who develops and publishes international standards. Browsing ISO standards can be done in two ways. Through the international classification for standards (ICS) or by the technical committee (TC) responsible to prepare the standard. Standards in shipbuilding and marine structures are covered in ICS number 47, while TC 8 covers standards regarding ship and marine technology. Ergonomics is regulated separately in TC 159.

The scope of this research is covered in ICS 47.020 and 47.040, and TC 8/SC 1, TC 8/SC 6 and TC8/SC 8. Examples of ISO documents that are related to human factors in ships design are presented in Table 7.

Table 7 ISO documents related to HF

ISO	Title of document
2631-1:1997	Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration -- Part 1: General requirements
2923:1996	Acoustics -- Measurement of noise on board vessels
3797:1976	Shipbuilding -- Vertical steel ladders
5488:1979	Shipbuilding -- Accommodation ladders
5489:2008	Ships and marine technology -- Embarkation ladders
6954:2000	Mechanical vibration -- Guidelines for the measurement, reporting and evaluation of vibration with regard to habitability on passenger and merchant ships
17631:2002	Ships and marine technology -- Shipboard plans for fire protection, life-saving appliances and means of escape
17894:2005	Ships and marine technology – Computer applications – General principles for the development and use of programmable electronic systems in marine applications
20283-2:2008	Mechanical vibration -- Measurement of vibration on ships -- Part 2: Measurement of structural vibration
20283-4	Mechanical vibration -- Measurement of vibration on ships -- Part 4: Measurement and evaluation of vibration of the ship propulsion machinery
24409-1:2010	Ships and marine technology -- Design, location and use of shipboard safety signs, safety-related signs, safety notices and safety markings -- Part 1: Design principles
27991:2008	Ships and marine technology -- Marine evacuation systems -- Means of communication
8468:2007	Ships and marine technology -- Ship's bridge layout and associated equipment -- Requirements and guidelines
2412:1982	Shipbuilding -- Colours of indicator lights

Documents under TC 159 exclusively cover ergonomics, such as:

- ISO 6385:2004 Ergonomic principles in the design of work systems
- ISO 26800:2011 Ergonomics -- General approach, principles and concepts
- ISO 9241-1:1997 Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 1: General introduction
- ISO 9241-210:2010 Ergonomics of human-system interaction – Part 210: Human-centered design for interactive systems
- ISO 11064-3:1999 Ergonomic design of control centres -- Part 3: Control room layout
- ISO/TR 16982:2002 Ergonomics of human-system interaction -- Usability methods supporting human-centered design

Since those publications are broadly applied in any domain, they are excluded from this study.

ASTM International [37]

ASTM International develops and delivers international voluntary consensus standards. ASTM formed a committee called F25 to develop standards on Ships and Marine Technology in 1978. Two specific standards are in accordance with the scope of this research:

- F1166 – 07 Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities
- F1337 – 10 Standard Practice for Human Engineering Program Requirements for Ships and Marine Systems, Equipment, and Facilities

4. RESULTS AND ANALYSIS

Two levels of data analyses were conducted with different units of analysis. First, all related publications from six institutions were being processed. The title of the documents was taken as the unit of analysis where the HF dimensions (Table 1) were used as the coding framework. Second, several most significant and most relevant documents were selected and then analysed in detail manner, where components and aspects of human factors were used as the coding framework.

4.1. DOCUMENT ANALYSIS

95 document titles were coded according to human factors dimensions. Detail results are presented in Table A1 in the Appendix while the summary is presented in Table 8.

It should be noted that some documents are very thin; only two pages while some are comprehensive, counting hundreds of pages. Some titles represent one complete document while some others represent chapters from a compiled document. Therefore, those statistics in Table 8 should be interpreted carefully.

Table 8 Summary results of documents covering HF in ship design

Publishing institutions	Number of documents	Human Factors / Ergonomics	Habitability	Maintainability	Workability	Controllability	Maneuverability	Survivability	Occupational Health and Safety	System Safety
ABS	17	2	6	1	7	4	1	3	3	9
DNV	18	0	1	1	6	7	3	3	0	11
LR	16	0	2	1	2	6	3	6	1	7
IMO	27	2	2	1	6	8	3	11	4	14
ISO (TC8)	13	0	7	0	3	2	0	4	0	2
ASTM	2	2	1	1	2	1	0	1	1	2
Total	93	6	17	5	25	28	10	29	9	45

Table 8 shows that all human factors dimensions are covered by the existing documents: codes, rules, regulations, guidelines, etc. Clearly, as safety has long been the main concern in the industry, “System Safety” is the most mentioned by the documents while "Maintainability" is the least covered. This finding confirms the criticism raised by Andersson and Lützhöft [9] regarding how poor the engine control rooms were designed. Similar complaints are also mentioned by the engineers during the exploratory surveys in the study [12][1]. Quite a significant number of documents are available in "Survivability", "Controllability" and "Workability". "Habitability" is sufficiently covered, but not so many documents cover the "OHS" given that the focus of this study is on the ‘design’ part.

4.2. CONTENT ANALYSIS

As mentioned, detailed explorations were conducted by using the components and aspects of each HF dimension. As the coding process took place, more components and aspects were *discovered* and then included to the framework, which then became quite a long list. The coding process was done iteratively as the framework developed. The final result is presented in Table A2 in the Appendix. Some documents that cover a very specific topic such as risk management, software, fire safety, steering gear and life-saving appliances were excluded.

From the results of tabulating the content of the documents it can be seen that "Habitability" (or "Comfort") and "Controllability" are covered the most on the dimensions level. These two dimensions dominate

[1] To be noted, ABS launched a new guide for Ergonomic notations (July 2013).

the content of HF in ship design. Following those are "Workability" and "System safety".

In "Habitability", noise, vibration, indoor climate and lighting or illumination are the most common topics covered by the documents. In “Controllability”, alarms, control centres, workstations and control and switches are the most common topics covered. It can be seen that the basic HF issues on board have been addressed by the documents. However, as the basic issues are covered, more specific problems appear. For example, noise was recognized to be a problem on board. As many as 15 documents in this survey are found to regulate the maximum level of noise on board. Apparently, noise is no longer identified as a substantial problem on board. This is consistent with field survey findings [12] which recognize a comfortable level of noises; in general. However, more specific noise problems are recognized. It is the high pitch, impulsive and intermittent types of noise that disturb people on board. Most of those 15 documents do not deal with the specific issues. ISO 2923 is the only document that mentions "impulsive noise" and "tonal sound", but it does not indicate how to deal with them.

Another basic HF issue that has been addressed adequately is "vibration". It is covered by 14 documents according to this survey. Vibration generally should no longer be considered as an intimidating problem. But, some particular types of "vibration" emerge to be problematic [12]: ship motion and slamming. One document discusses ship motion from the HF perspective: ISO 2631-1. This is the only document found that differentiates vibrations into two regimes: high frequencies (>0.5 Hz; for health, comfort and perception) and low frequencies (<0.5 Hz; for motion sickness). ABS 147 and 103 are referring to ISO 2631 as well as BS 6841 to consider Motion Sickness Dose Value (MSDV) on board. Among all documents surveyed in this study, only ABS 86 deals with slamming. Similar pattern occurs also in “alarms” which are sufficiently covered by 14 documents in the survey. The basic issue of alarms has been resolved, but in reality, more specific issues of alarms are discovered, such as overwhelming number of alarms and irrelevant alarms that disturb the operators. *Fortunately,* IMO A.1021(26) points out some of these issues: reducing the variety of alerts and indicators to provide unambiguous information.

4.3. DISCUSSION

Although the human factors issues have been sufficiently addressed by various documents, they are not really mandatory. The rules and regulations published by the class societies are optional or voluntary while the rest are guidelines. The actual implementation of human factors principles primarily relies on the shipowner’s commitment. Obviously, shipyards play a significant role. The cargo owner or the clients and the crew may have some contribution to make it happen. But, the classification societies and the regulators could go further. Some basic human factors issues should be made compulsory without exception, such as noise, vibration, motion, and indoor climate. Some of these subjects also need to be introduced to future naval architects and ship designers, such as basic ergonomics, habitability, controllability, workability and human-related criteria in ship design.

It should be noted that the application of HF standard is rather different with the other standards. For instance, a ship that carries COMF class does not guarantee that the people on board will feel comfortable, while a ship that carries Ice Class must be capable to handle ice loads.

Three documents are found to be comprehensive covering the topics of human factors: ABS 86, DNV Nautical Safety and ASTM F1166. These three are the most recommended documents to address human factors in ships design disregarding the colors of the flags, wherever the ships are registered and classed. Some issues were identified in the development stage of the coding sheet but not covered in any document, i.e. seafarer’s variations in gender, religious differences and disabilities.

Due to limited resources, the study does not come with any reliability index. However, the validity across time is confirmed. Compared to the findings that were published earlier [38] this study reveals a rapid development of human factor applications in ship design, characterized by the increasing number of documents published. The pattern is relatively consistent. Among all human factors aspects, it was found that noise, vibration, and alarms are covered abundantly, while maintainability still lacks attention, especially related to the engine room. A more intelligent endeavour should be performed to select which aspect of human factors in ship design should be developed in relation with the least considered, but problematic issues on board, such as high pitch intermittent noise, ship motion, slamming, smell, and gender issues, as reported in [12]. A quick comparison with a HF reference [39] shows that human reliability, decision making, and social factors are not yet covered by any of the documents surveyed in this research.

5. CONCLUSIONS

A literature survey on various documents was conducted using a content analysis methodology. The study was carried out to answer if human factors are neglected in ships design. At least 95 documents were identified to be relevant in addressing human factors in ships design, and the numbers keep growing rapidly. Thirty documents were explored in detail. From the study it can be concluded that human factors are not neglected in ship design requirements. A lot of effort has been carried out in the industry to explore human factors and to implement it. Human factors turns to be a broad discipline that covers many dimensions and elements of the ships, but the level of intensity and coverage vary across the dimensions. Safety and survivability are the two dimensions mostly covered, shown by the total number of documents published in the topics. Habitability (comfort) and controllability comprise the broadest spectrum of coverage, shown by the number of aspects found within the dimensions. A more assertive action is recommended to endorse human factors principles to be implemented in ship designs. Further studies by interviewing ship owners, naval architects, marine engineers, and shipyards/shipbuilders are recommended.

6. REFERENCES

1. Baker, C. C. and D. B. McCafferty (2005). Accident database review of human-element concerns: What do the results mean for classification? RINA, Royal Institution of Naval Architects International Conference - Human Factors in Ship Design, Safety and Operation, Feb 23, 2005 - Feb 24, 2005, London, UK, Royal Institution of Naval Architects.
2. McCafferty, D. B. and C. C. Baker (2006). Trending the Cause of Marine Incidents. Learning from Marine Incidents. London, UK, The Royal Institution of Naval Architects.
3. Reason, J. (1990). Human Error. New York, Cambridge University Press.
4. Squire, D. (2007). 'Fit for Purpose' - Keeping the Crew in Mind. Human Factors in Ship Design, Safety and Operation. London, UK, RINA.
5. Miller, G. E. (1999). Human Factors Engineering (HFE): What It Is And How It Can Be Used To Reduce Human Errors In The Offshore Industry. Offshore Technology Conference. Houston, Texas.
6. Miller, G. E. and K. McSweeney (2000). A Brief History of the Utilization of Human and Organizational Factors (HOF) in the Design of Military and Commercial Ships and Offshore Structures in the United States. Human Factors in Ship Design and Operation. London, Royal Institution of Naval Architecture (RINA).
7. Graveson, A. (2002). Human Factors in Ship Design and Operation. Human Factors in Ship Design and Operation. London, The Royal Institution of Naval Architects.
8. Dalpiaz, T. M., M. Emmrich, et al. (2005). Conducting a human factors engineering 3-D computer modeling ship design review. RINA, Royal Institution of Naval Architects International Conference - Human Factors in Ship Design, Safety and Operation, Febrary 23, 2005 - Febrary 24, 2005, London, United kingdom, Royal Institution of Naval Architects.
9. Andersson, M. and M. Lützhöft (2007). Engine control rooms - Human factors. Human Factors in Ship Design, Safety and Operation, London, United Kingdom, Royal Institution of Naval Architects.
10. Lützhöft, M. and J. M. Nyce (2008). "Integration Work on the Ship's Bridge." Journal of Maritime Research V(2): 15.
11. Grundevik, P., M. Lundh, et al. (2009). Engine control room - Human factors. RINA, Royal Institution of Naval Architects International Conference - Human Factors in Ship Design, Safety and Operation, February 25, 2009 - February 26, 2009, London, United kingdom, Royal Institution of Naval Architects.
12. Rumawas, V. and B. E. Asbjørnslett (2011). Offshore supply vessels design and operation: A human factors exploration. Advances in Safety, Reliability and Risk Management - proceedings of the European Safety and Reliability Conference, ESREL 2011, CRC Press.
13. Meck, U., S. Strohschneider, et al. (2009). "Interaction design in ship building: An investigation into the integration of the user perspective into ship bridge design." Journal of Maritime Research 6(1): 15-32.
14. Card, J. C., C. C. Baker, et al. (2006). Human factors in classification and certification. 2005 Society of Naval Architects and Marine Engineers Annual Meeting, October 19, 2005 - October 21, 2005, Houston, TX, United states, Society of Naval Architects and Marine Engineers.
15. Ross, J. M. (2009). Human factors considerations for marine vehicle design. RINA, Royal Institution of Naval Architects International Conference - Human Factors in Ship Design, Safety and Operation, February 25, 2009 - February 26, 2009, London, United Kingdom, Royal Institution of Naval Architects.
16. Ross, J. M. (2009). Human factors for naval marine vehicle design and operation. Cornwall, MPG Books Ltd.
17. Calhoun, S. R. and S. C. Stevens (2003). Human Factors in Ship Design. Ship Design and Construction. T. Lamb. Jersey City, NJ, The Society of Naval Architects and Marine Engineers.
18. International Ergonomics Association. (2012). "What is Ergonomics." from http://www.iea.cc/01_what/What%20is%20Ergonomics.html.
19. HFES. (2009). "Definition of Human Factors and Ergonomics." Retrieved March 2009, 2009, from http://www.hfes.org/Web/EducationalResources/HFEdefinitionsmain.html
20. IMO (2004). Human Element Vision, Principles and Goals for the Organization. A 23/Res. 947. IMO. A.947(23).
21. Kiss, R. K. (1980). Mission Analysis and Basic Design. Ship Design and Construction. R.

Taggart. New York, NY, The Society of Naval Architects and Marine Engineers.

22. Gale, P. A. (2003). The Ship Design Process. Ship Design and Construction. T. Lamb. Jersey City, NJ, The Society of Naval Architects and Marine Engineers.
23. Rawson, K. J. and E. C. Tupper (2001). Basic ship theory. Oxford, Butterworth-Heinemann.
24. Kristiansen, S. (2005). Maritime transportation: safety management and risk analysis. Amsterdam, Elsevier.
25. Lloyd's Register (2008). The Human Element: An Introduction. London, Lloyd's Register.
26. UK Ministry of Defence (2008). High Speed Craft Human Factors Engineering Design Guide, ABCD Working Group on Human Performance at Sea. ABCD-TR-08-01 V1.0.
27. Grech, M. R., T. Horberry, et al. (2008). Human factors in the maritime domain. Boca Raton, FL, CRC Press.
28. Krippendorff, K. (2004). Content analysis: an introduction to its methodology. Thousand Oaks, Calif., Sage.
29. Berg, B. L. (2007). Qualitative research methods for the social sciences. Boston, Pearson.
30. Heidi, J. (2008). Content Analysis. Thousand Oaks, USA, 'SAGE Publications'.
31. Lloyd's Register (2009). The Human Element Best Practice for Ship Operators. London, Lloyd's Register.
32. American Bureau of Shipping. (2012). "Rules and Guides Downloads." Retrieved from http://www.eagle.org/eagleExternalPortalWEB/appmanager/absEagle/absEagleDesktop?_nfpb=true&_pageLabel=abs_eagle_portal_marine_rules_guides_download_page.
33. DNV. (2012). "DNV Rules and Standards." Retrieved 20 March 2012, from http://exchange.dnv.com/publishing/ServiceDocs.asp.
34. Lloyd's Register (2012). "Rules and Regulations, Leading expertise for a safer world." Retrieved March 2012 from http://www.lr.org/sectors/marine/Compliance/RulesandRegulations.aspx.
35. IMO. (2012). "Introduction to IMO." Retrieved 16 Mar 2012, 2012, from http://www.imo.org/About/Pages/Default.aspx
36. ISO. (2012). "About ISO." from http://www.iso.org/iso/about.htm. Retrieved Mar 2012.
37. ASTM. (2012). "ASTM Overview." Retrieved 12 April 2012, 2012, from http://www.astm.org/ABOUT/overview.html.27.
38 Rumawas, V. and B. E. Asbjørnslett (2010). A Content Analysis of Human Factors in the Design of Marine Systems. International Conference on Ship and Offshore Technology (ICSOT) 11-12 Nov. Surabaya, Indonesia. Royal Institution of Naval Architects.
39. Wickens, C.D., et.al., "An Introduction to Human Factors Engineering", 2nd ed. Pearson Education Inc. Upper Saddle River, NJ, 2004.

Appendix: Table A.1. Document analysis

No	SOURCE	ID *)	HF	HAB	MAIN	WORK	CONT	MANV	SURV	OHS	SS
1	ABS	86	1	1	1	1	1	0	0	1	1
2	ABS	94	0	0	0	1	1	0	0	0	0
3	ABS	97	0	0	0	0	0	0	0	0	1
4	ABS	102	0	1	0	0	0	0	0	0	0
5	ABS	103	0	1	0	0	0	0	0	0	0
6	ABS	116	0	0	0	0	0	0	0	0	1
7	ABS	117	0	0	0	0	0	0	0	0	1
8	ABS	119	1	0	0	1	1	0	0	0	0
9	ABS	122	0	0	0	0	0	0	1	0	1
10	ABS	141	0	0	0	0	0	0	1	0	0
11	ABS	145	0	0	0	0	0	1	0	0	0
12	ABS	147	0	1	0	1	0	0	0	0	0
13	ABS	151	0	1	0	1	0	0	0	1	1
14	ABS	154	0	0	0	1	0	0	0	1	1
15	ABS	163	0	1	0	0	0	0	0	0	0
16	ABS	170	0	0	0	0	0	0	1	0	1
17	ABS	185	0	0	0	1	1	0	0	0	1
	ABS		**2**	**6**	**1**	**7**	**4**	**1**	**3**	**3**	**9**
18	DNV	Pt 3 Ch 3	0	0	0	0	0	1	0	0	0
19	DNV	Pt 4 Ch 9	0	0	0	1	1	0	0	0	1
20	DNV	Pt 4 Ch 10	0	0	0	0	0	0	1	0	1
21	DNV	Pt 4 Ch 14	0	0	0	0	1	0	0	0	0
22	DNV	Pt 5 Ch 12	0	1	0	0	0	0	0	0	0
23	DNV	Pt 6 Ch 2	0	0	0	0	0	0	0	0	1
24	DNV	Pt 6 Ch 3	0	0	1	0	0	0	0	0	1
25	DNV	Pt 6 Ch 4	0	0	0	0	0	0	1	0	1
26	DNV	Pt 6 Ch 6	0	0	0	0	1	0	0	0	0
27	DNV	Pt 6 Ch 7	0	0	0	0	1	0	0	0	0
28	DNV	Pt 6 Ch 8	0	0	0	1	1	1	0	0	1
29	DNV	Pt 6 Ch 9	0	0	0	0	0	0	0	0	1
30	DNV	Pt 6 Ch 20	0	0	0	1	1	1	1	0	1
31	DNV	Pt 6 Ch 26	0	0	0	1	1	0	0	0	0
32	DNV	A203	0	0	0	1	0	0	0	0	1
33	DNV	C205	0	0	0	0	0	0	0	0	0
34	DNV	D102	0	0	0	0	0	0	0	0	1
35	DNV	D201	0	0	0	1	0	0	0	0	1
	DNV		**0**	**1**	**1**	**6**	**7**	**3**	**3**	**0**	**11**
36	LR	Pt 3 Ch 13	0	0	0	0	0	0	0	0	0
37	LR	Pt 5 Ch 18	0	0	0	0	1	1	0	0	0
38	LR	Pt 5 Ch 19	0	0	0	0	0	0	0	0	0
39	LR	Pt 5 Ch 21	0	0	1	0	0	0	0	0	0
40	LR	Pt 5 Ch 22	0	0	0	0	1	1	1	0	1
41	LR	Pt5 Ch 23	0	0	0	0	0	0	1	0	1
42	LR	Pt 6 Ch 1	0	0	0	0	1	0	1	0	1
43	LR	Pt 6 Ch 2	0	0	0	0	1	1	1	0	1
44	LR	Pt 6 Ch 4	0	0	0	0	0	0	1	0	1
45	LR	Pt 6 Ch 1	0	0	0	0	0	0	0	0	0
46	LR	Pt 7 Ch 4	0	0	0	1	1	0	0	0	0
47	LR	Pt 7 Ch 9	0	0	0	1	1	0	0	0	0
48	LR	Pt 7 Ch 12	0	0	0	0	0	0	1	1	1
49	LR	Pt 7 Ch 13	0	1	0	0	0	0	0	0	0
50	LR	Pt 7Ch 15	0	0	0	0	0	0	0	0	1
51	LR	GN	0	1	0	0	0	0	0	0	0
	LR		**0**	**2**	**1**	**2**	**6**	**3**	**6**	**1**	**7**
52	IMO	COLREGS	0	0	0	0	1	0	0	0	1
53	IMO	LL	0	0	0	0	0	0	0	0	1
54	IMO	SOLAS	0	0	0	0	0	0	0	0	1
55	IMO	STCW	0	0	0	1	0	0	0	0	0
56	IMO	ALI	0	0	0	0	0	0	1	0	1
57	IMO	CAI	0	0	0	0	0	0	1	0	1
58	IMO	FSS	0	0	0	0	0	0	1	0	1
59	IMO	LSA	0	0	0	0	0	0	1	0	1
60	IMO	NOISE	0	1	0	0	0	0	0	0	0
61	IMO	A 342(IX)	0	0	0	0	1	0	0	0	1
62	IMO	A 468(XII)	0	1	0	0	0	0	0	0	0
63	IMO	A 601(15)	0	0	0	0	0	1	0	0	0
64	IMO	A 708(17)	0	0	0	0	1	0	0	0	0
65	IMO	A 817(19)	0	0	0	1	1	1	0	0	0
66	IMO	A 830(19)	0	0	0	0	0	0	0	0	0
67	IMO	A 861(20)	0	0	0	0	0	0	0	0	1
68	IMO	A 947(23)	1	0	0	0	0	0	0	0	0
69	IMO	Res 128(75)	0	0	0	0	0	0	1	1	1
70	IMO	Res 137(76)	0	0	0	0	0	1	0	0	0
71	IMO	Res 190(79)	0	0	0	1	1	0	0	0	0
72	IMO	Circ 587	0	0	0	0	0	0	0	0	0
73	IMO	Circ 601	0	0	0	0	0	0	1	0	1
74	IMO	Circ 616	0	0	0	0	0	0	1	0	1
75	IMO	Circ 645	0	0	0	1	1	0	0	0	0
76	IMO	Circ 834	0	0	1	1	1	0	1	1	1
77	IMO	Circ 846	0	0	0	0	0	0	1	0	0
78	IMO	Circ 849	0	0	0	0	0	0	1	1	0
79	IMO	Circ 982	1	0	0	1	1	0	0	0	0
80	IMO	Circ 1002	0	0	0	0	0	0	1	0	1
	IMO		**2**	**2**	**1**	**6**	**8**	**3**	**11**	**3**	**14**
81	ISO	2631-1:1997	0	1	0	0	0	0	0	0	0
82	ISO	2923:1996	0	1	0	0	0	0	0	0	0
83	ISO	3797:1976	0	0	0	1	0	0	0	0	0
84	ISO	5488:1979	0	1	0	0	0	0	0	0	0
85	ISO	5489:2008	0	1	0	0	0	0	1	0	0
86	ISO	6954:2000	0	1	0	0	0	0	0	0	0
87	ISO	17631:2002	0	0	0	0	0	0	1	0	1
88	ISO	20283-2:2008	0	1	0	0	0	0	0	0	0
89	ISO	20283-4	0	1	0	1	1	0	0	0	0
90	ISO	24409-1:2010	0	0	0	0	0	0	1	0	1
91	ISO	27991:2008	0	0	0	0	0	0	1	0	0
92	ISO	8468:2007	0	0	0	1	0	0	0	0	0
93	ISO	2412:1982	0	0	0	0	1	0	0	0	0
	ISO		**0**	**7**	**0**	**3**	**2**	**0**	**4**	**0**	**2**
94	ASTM	F1166 - 07	1	1	1	1	1	0	1	1	1
95	ASTM	F1337 - 10	1	0	0	1	0	0	0	0	1
	ASTM		**2**	**1**	**1**	**2**	**1**	**0**	**1**	**1**	**2**

*) For detail ID see Section 3.2 in the text

Appendix: Table A.2. Content analysis

	ABS								DNV								LR					IMO			ISO					AS TM	
	86	94	97	102	103	145	147	163	Pt 3 Ch 3	Pt 4 Ch 9	Pt 5 Ch 12	Part 6 Ch 2	Part 6 Ch 3	Pt 6 Ch 7	Pt 6 Ch 8	Pt 6 Ch 20	Pt 3	Pt 5	Pt 6	Pt 7 Ch 9	Pt 7 Ch 13	834	982	137 (76)	2631-1	2923	6954	24409-1	8468	F1166	Sub total
HUMAN FACTORS	1		1												1	1						1								1	6
application of human factors to design	1	1	1			1									1	1															6
previous design, user feedback	1																														1
task analysis	1		1																												2
Habitability, comfort	1			1	1		1	1			1				1	1				1	1				1	1	1			1	14
accommodation	1			1	1			1			1										1					1	1				8
doors				1					1																						2
furniture				1																											1
toilet, sanitary, bathroom				1	1			1																							3
seating	1			1	1																										3
access, layout, arrangement	1			1	1			1																							4
cabins				1	1			1			1										1					1					6
galleys				1	1			1													1										4
messrooms				1	1			1			1										1										5
recreational spaces				1	1			1			1										1					1					6
washing, laundry				1	1			1			1																				4
hospital & medical facilities				1	1			1			1																				4
seafarer's variation	1			1				1																						1	4
size, shape, gender, anthropometric	1	1		1				1								1														1	6
race, religion, disabilities																															0
environment, comfort, (indoor) climate	1			1	1			1			1				1	1				1		1	1		1					1	12
temperature, heat	1	1		1	1			1			1				1	1				1		1	1						1		12
humidity	1			1	1			1			1					1				1											7
thermal gradient	1			1	1			1			1																				5
air velocity, ventilation	1			1	1			1			1					1				1		1	1								9
air quality, smell, odor, effluvia	1			1	1			1																							4
noise, sound, acoustics	1	1		1	1			1			1				1	1				1	1	1	1			1			1	1	15
impulsive noise																										1					1
intermittent noise				1																											1
tonal sound																										1					1
measurement					1			1			1										1					1					5
acoustic/sound insulation				1	1						1										1										4
motion																									1						1
vibration	1			1	1		1	1			1				1	1					1	1	1		1		1		1		14
acceleration	1			1	1		1	1																	1		1				7
frequency	1			1	1		1	1			1																1				7
measurement				1	1		1	1			1										1						1				7
single-impulse shock loads (slamming)	1																														1
radiation, electromagnetic field																				1											1
lighting, illumination	1	1		1	1			1							1	1				1		1	1						1	1	12
red or low-level white illuminance				1				1																							2
specular reflections, glare															1	1				1											3
surfaces		1													1	1				1	1										5
Maintainability	1	1	1							1			1				1					1								1	8
maintenance tasks	1																					1									2
expertise																															0
manuals, diagnostics, schematics	1																													1	2
access, layout, arrangement, routes	1																1					1								1	4
bench space, work platform	1																														1
tools, equipment	1		1																			1								1	4
handling of heavy parts	1																					1									2
spare parts & supplies																						1									1
storage (for spare parts and supplies)																						1									1
Workability	1	1								1			1		1	1						1	1							1	9
users	1		1			1									1	1															5
tasks	1	1				1									1	1															5
equipment & software	1	1	1							1			1		1	1			1	1			1							1	11
materials & material handling	1		1																			1								1	4
procedures, manual			1			1									1	1													1	1	6
physical and social environment	1	1	1												1	1							1		1	1			1	1	10

Continue on the next page

	ABS								DNV								LR					IMO			ISO					ASTM	
	86	94	97	102	103	145	147	163	Pt 3 Ch 3	Pt 4 Ch 9	Pt 5 Ch 12	Part 6 Ch 2	Part 6 Ch 3	Pt 6 Ch 7	Pt 6 Ch 8	Pt 6 Ch 20	Pt 3	Pt 5	Pt 6	Pt 7 Ch 9	Pt 7 Ch 13	834	982	137 (76)	2631-1	2923	6954	24409-1	8468	F1166	Sub total
Workability (cont'd)																															
accessibility, layout, arrangement	1	1							1						1	1				1		1	1							1	9
doors, openings, hatches	1	1							1																						3
stairs, ladders	1	1																													2
seating, chairs	1														1	1				1											4
communication		1	1			1									1	1				1									1	1	8
signage, labeling, symbols	1	1	1																1			1						1		1	7
Controllability	1	1								1			1	1	1	1			1	1		1	1						1	1	13
control centers	1	1				1				1			1	1	1	1	1			1			1						1	1	13
bridge control center		1				1							1	1	1	1				1			1						1	1	10
engine control room, engine room													1						1			1								1	4
cargo control																	1														1
man-machine interface	1	1								1			1	1	1	1				1			1						1	1	11
workstations	1	1								1			1	1	1	1				1		1	1						1	1	12
communication facilities		1				1									1	1			1	1			1						1	1	9
controls and switches	1	1											1	1	1	1		1		1		1	1						1	1	12
view, vision, visibility	1	1													1	1				1			1						1	1	8
displays, video-display units	1	1								1			1		1	1				1			1							1	9
alarms	1	1								1			1	1	1	1		1	1	1		1	1						1	1	14
automation, automatic system	1	1								1			1	1	1	1		1	1	1										1	11
integration	1	1								1				1	1	1			1	1										1	9
monitoring system		1								1				1	1	1		1	1	1											8
remote control										1						1			1												3
potential of human error, slips, lapses	1	1	1			1																								1	5
Maneuverability						1						1	1	1	1	1	1			1				1							9
propulsion system									1			1		1			1	1													5
steering system									1			1		1	1	1	1	1													7
thrusters									1					1			1	1													4
maneuvering capability						1									1	1								1							4
turning ability						1									1									1							3
initial turning ability						1									1									1							3
yaw-checking & coure-keeping abilities						1									1									1							3
stopping ability						1									1									1							3
Survivability	1												1				1	1				1						1		1	7
fire safety measures															1	1			1									1			4
fire detection systems & alarms													1		1				1				1					1			5
firefighting equipment																						1						1			2
damage control									1							1	1	1													4
livesaving facilities																						1						1			2
emergency response / services										1			1	1	1	1	1	1												1	8
failure / hazard detection										1				1		1															3
emergency exit / escape	1								1				1						1			1						1			6
emergency equipment	1																					1									2
security (arrangement)																															0
Occupational health and safety (OHS)	1		1																			1	1		1					1	6
effect of work	1																			1					1						3
working environment	1	1	1						1		1				1	1				1		1	1		1	1				1	13
living conditions	1		1	1					1		1														1	1					7
safety of personnel	1	1	1						1						1	1						1						1	1		9
personal protection equipment (PPE)			1																			1						1			3
System safety	1		1							1		1			1		1	1	1			1						1	1	1	12
vessel's safety			1						1						1	1			1												5
risk considerations	1		1							1		1	1	1	1	1		1	1			1							1		12
hazardous area, situation, or operation	1		1						1			1	1					1													6
hazardous material			1																												1
single failure criterion		1	1							1		1		1																	5
reliability	1		1							1			1	1	1	1															7
worst-case scenario	1		1							1				1	1	1		1	1												8
collision avoidance															1	1															2
risk categorization, prioritization			1																												1
	64	33	27	31	25	15	5	26	13	20	20	7	21	20	50	50	12	14	17	30	12	34	23	6	10	11	6	10	19	38	669

Appendix B: Preliminary Qualitative Study

Exploratory Surveys of Human Factors on Offshore Supply Vessels in the Norwegian Sea

Naval Engineers Journal, Vol 125, issue 2, June 2013.

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Exploratory Surveys of Human Factors on Offshore Supply Vessels in the Norwegian Sea

ABSTRACT

Surveys of human factors on offshore supply vessels (OSV) were conducted using the qualitative approaches of observations, interviews, and discussions. The purpose of this study was to explore how "human factors" is considered in ship design. Certain problems that were mentioned in previous studies were reexamined. A human factors framework was adopted, further developed, and subsequently applied for the survey. Two different state-of-the-art offshore supply vessel designs (OSVs) were selected as samples. The results of human factors application in ship design are presented. Selected significant improvements are identified, both in design and operation, but several issues still remain. Typical problems that are recognized include noise disturbance, ergonomics issues, layout limitations, and limited space. Novel problems due to the application of new technologies are also identified. Common problems are also noted, such as an overwhelming number of alarms, communications, checklists, and procedures. Different levels of compliance in various human factor dimensions are recognized, of which habitability was the most satisfactory and maintainability was the least satisfactory.

KEYWORDS
Human factors
Marine design
Offshore supply vessel (OSV)

Introduction

This article is a subset of a larger study that investigates human factors in marine system design. The study was triggered by previous findings, which stated that most accidents at sea are caused by human errors or human-related factors (Moore, Bea and Roberts 1993; McCafferty and Baker, 2006). Within this context, certain experts argue that less-than-adequate design is one significant factor that leads to human errors. Meister (1971, p. 266) states that the typical design engineer does not consider human factors in the design process. Moreover, Reason (1990, p. 173) argues that:

> *"Rather than being the main instigator of an accident, operators tend to be the inheritors of systems defects created by poor design, incorrect installation, faulty maintenance, and bad management decisions. Their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in cooking."*

Squire (2007) cites one master who complained of being frustrated with sailing the vessel on which he was assigned to work because it was designed without input from the crew. Graveson (2002) claims that the influence of human factors on the shipping industry is a topic that draws attention, but is rarely addressed and is not taken seriously. Calhoun and Stevens (2003) state that system and equipment failures are the common factor for accidents in many industries. The systems and equipment are not sufficiently designed to meet human physical or cognitive capabilities.

From a research study into this context, the larger expected effect is a reduction in the probability of accidents at sea by taking human factors into account in ship and marine system design. Therefore, the main research question is directed toward assessing whether ship design includes sufficient consideration of human factors, and how well this information has been applied.

Several methods exist to answer the points addressed above. First, we can directly query the owners and the designers. Second, we can perform an evaluation of the design either by conducting a field survey or by reviewing the vessel plans. Third, we can ask the users for an assessment of the vessel via interviews or questionnaires. Last but not least, we can carry out an evaluation through the documents that regulate the shipbuilding industry.

Rumawas and Asbjørnslett (2010) found that numerous standards and guidelines exist as references for designers on the topic of human factors in marine system design. Given the redundant rules, standards, and guidelines that address the human factors in marine system design, although not all of these are mandatory, one might ask whether the reality is in agreement with the regulations. This paper aims to answer that particular question through field surveys.

A number of field studies conducted by other researchers are documented in this study. Strong (2000) performed a survey to investigate ship habitability. Based on a literature review, initial interviews, and a pilot survey, Strong reported on the crew's evaluation of the existing ships and their preferences for the design of future warships. Adequate levels of privacy and facilities for both individual and social relaxation are considered important aspects in the ship's accommodations. Hardwick (2000) carried out a comparative study on accommodations in the Royal Navy and merchant naval fleets by visiting ships and submarines and interviewing their crews. The suggested factors include a drive toward cabin-based accommodations for all cabin crew, increased space for sleeping and personal storage, improved ambient conditions (noise and temperature), and provision of other facilities.

Lutzhoft (2005) noted illumination problems on the bridge, displays that are too bright and cannot be dimmed, improperly attached equipment to which the operator must apply duct tape, and similar problems on the 15 vessels that she visited. Andersson and Lutzhoft (2007) found many deficiencies in the engine room (ER) of a merchant ship that do not comply with ergonomic principles or occupational, health, and safety (OHS) requirements. This study also described a situation in which an engineer must climb and stand on the turning gear's electric motor in order to reach the start air valve. Grundevik, Lundh and Wagner (2009) conducted surveys on seven Swedish merchant vessels to evaluate the design of the engine control room (ECR), the layout, the consoles, and the workstations. Their results showed that the ECR design was not sufficiently developed to meet the demand and are not in accordance with technological progress. Ergonomic issues have also been reported, including insufficient leg space, improper positioning of consoles, and problems of visibility. Defective hardware components, software bugs, and defective software are among the most common system/equipment failures mentioned.

Dalpiaz, Emmrich, Miller, and McQuillan (2005) used a 3-D computer model to review a new U.S. Navy ship design. They reported incorrect height/orientations for equipment, machinery, and other manually operated technology as the most common mistakes. Stair, ladder, step, and walkway designs were also found to be inadequate. Other deficiencies included inaccessibility to valves, hand wheels, and hand pumps; incorrect control panel, console, control, and display designs; and problems with personnel access and movement.

This study reexamines the issues reported previously, and reviews the current implementation of human factors in ship and marine system design. The concept of human factors in marine design is summarized, and the objective of the study is to present a holistic picture of human factors application in ship design. A qualitative research methodology is applied, and selected findings of interest are highlighted. The results are discussed and may be used as a reference for further investigations.

Research Methodology

This study applied qualitative approaches to the examination of human factors in marine design. Qualitative research is defined as a research strategy that commonly emphasizes words rather than quantities to collect and analyze data (Bryman, 2001). A portion of the research methodology included field research in which the study begins with a loosely formulated idea or topic. The researchers subsequently observe and interact in the field setting for a period of time, conduct informal interviews, take notes, refine their ideas, and subsequently retreat to write their reports (Neuman, 2006).

The present study regarding human factors in marine design was conducted in a natural setting in which the author acted as an observer on two offshore supply vessels (OSV) operating in the Norwegian Sea. Several different data collection techniques were used, including observations, in-depth interviews, and focus discussions.

Informal interviews were conducted in English and included all onboard departments. Almost all personnel on the ships were surveyed. The questions asked varied from a general type of question, such as, "How long have you been working on this vessel?", and "How do you like working here?", to more specific questions, such as "Do you experience difficulties in your job?", "What is the most severe incident that you have experienced onboard?", etc. The interviews and discussions were documented and summarized. The observations were conducted primarily when personnel were physically located at their working stations and engaged in performing their jobs. Pictures were taken and also documented as evidence. Further investigation into particular issues was carried out by contacting other relevant parties, including manufacturers and classification societies.

Lloyd's Register (LR) describes human factors as "something that is concerned with the task people do and the environment they do it in, fitting the job to the person" (LR, 2008). Human factors considerations in marine design can be broken down into eight categories (LR, 2009):

- **HABITABILITY:** ensuring that accommodations, washing and toilet facilities, mess rooms, and group meeting and exercise areas are comfortable, clean (or cleanable), and convivial
- **MANEUVERABILITY:** ensuring that ships contain the most appropriate maneuvering capabilities
- **WORKABILITY:** ensuring that ships and systems are appropriate for the work situation (context of use)
- **MAINTAINABILITY:** ensuring that availability of operational maintenance tasks, manuals, diagnostics, and schematics are rapid, safe, and effective to allow equipment and systems to achieve a specified level of performance
- **CONTROLLABILITY:** ensuring appropriate integration of people with equipment, systems, and interfaces
- **SURVIVABILITY:** ensuring that there are adequate fire fighting, damage control, lifesaving, and security facilities to ensure the safety and security of crew, visitors, and passengers
- **OCCUPATIONAL HEALTH AND SAFETY (OHS):** ensuring appropriate consideration of the effects of work, the work environment, and living conditions on the health, safety, and well-being of workers
- **SYSTEM SAFETY:** ensuring appropriate consideration of the risks from people using (or misusing) the ship systems.

It must be stated that the human factors framework presented by LR is still evolving. The earlier version (LR, 2008) contained six categories, and the latter (LR, 2009) has been expanded to eight. The description and the checklist provided do not adequately fulfill the mutually exclusive and collectively exhaustive principles. For the purpose of this study, the human factors framework presented by LR is combined and matched with other documents (ABS, 2000, 2001a, 2001b, 2003) and subsequently expanded (see Appendix). This expanded framework is applied as a guide in the study. No further standardized questionnaire is prepared for the survey, but simple and direct questions (e.g., "What do you think of the cabin, the galley, the system, the safety on the vessel?") are applied instead.

The objects of the study are the vessel as a complete entity and her elements, including the accommodations, the ship control center (SCC) or the bridge, the ER, the ECR, the cargo facilities, and the layout of the vessel as separate units.

The Scope of the Study: Offshore Supply Vessel (OSV)

An OSV represents one of the most advanced technologies in the maritime industry. The level of design changes rapidly and has leapt forward beyond that of most conventional vessels. Many improvements have been made along with the ship. Gibson (2007, p. 23) states that: "All the craft (supply) require a degree of sophistication unheard of previously and even currently in much of the marine world." Furthermore, the operational effectiveness, low fuel consumption, low emissions, and safety are the most important factors in OSV design (Blenkey, 2004). An OSV can be described as a combination of a bulk vessel, a general cargo vessel, a container vessel, and a tanker, with the added capabilities of fire fighting and oil recovery.

Over the last ten years, a total of 26 collisions were recorded between visiting vessels and facilities in the Norwegian shelf (Petroleum Safety Authority Norway, 2011). Six of these collisions are considered a high hazard potential (see Table 1). Three of the accidents involved autopilot operation and can be categorized as man-machine interface problems. Other types of accidents recognized in the OSV operations include a deckhand hit in the head by a hook, a person squeezed between moving containers on deck, a deckhand falling against a hose coupling when

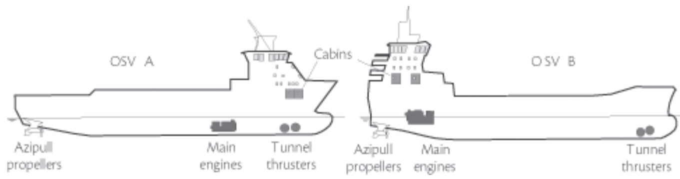


FIGURE 1. Two different OSV designs.

a large wave hit the vessel, persons slipping or twisting an ankle, a fall caused by a slippery deck or obstacles, a fall down a ladder, and unsecured cargo or loose objects in cargo (Hansson, 2006). This research investigates if these problems are still likely to occur, or if appropriate countermeasures have been implemented.

In this research, two different OSVs were chosen as the samples (Figure 1). These vessels were employed by the same oil companies in the same region, and both were among the top of the line in the respective ship owners' fleets. However, the vessels were designed and built by different groups of companies, and most of the equipment onboard was supplied by different manufacturers. OSV A designates a type of vessel that represents most of the OSVs available today, while OSV B indicates an alternative design built with the superstructure located at the aft of the vessel. In addition, a dual fuel system is applied that uses diesel oil and liquefied natural gas (LNG). Table 2 presents the principal information regarding the two types of OSVs.

The surveys were conducted in October 2010, February 2011 and July 2011.

Results of Onboard Surveys

The results of the field surveys that were carried out can be divided into two parts. The first part is associated with previous incidents or accidents, and confirms the measures that have been taken to improve conditions. The second part assesses the extent to which human factors frameworks are taken into consideration in the design of the researched ships.

Date	Collision Between (Vessel) and (Installation)	Cause and Descriptions
7 March 2004	*Far Symphony* and West Venture	The duty officer did not recognize that autopilot was engaged and could not take control of the vessel.
2 June 2005	*Ocean Carrier* and Ekofisk 2/4 P bridge	The 1st officer navigated the vessel in poor visibility due to fog. The captain entered the bridge with the vessel passing the safety zone at 10 knots. Misunderstandings occurred as to who was responsible for navigation.
13 Nov 2006	*Navion Hispania* (tanker) and Njord B	Polluted fuel, system malfunction, blackout, and propeller halt. Vessel drifted toward the installation.
18 July 2007	*Bourbon Surf* and Grane	The platform was identified as a target for the autopilot. The master misjudged the ship's speed and distance to the platform. He did not keep a proper lookout at the time.
6 June 2009	*Big Orange XVIII* and Ekofisk 2/4 W	The vessel approached the installation with the autopilot engaged. The captain could not override the autopilot to control the vessel.
18 Jan 2010	*Far Grimshader* and Songa Dee	The vessel was working on the lee side of the installation and was asked to move to the windward side. During the move, the vessel's propeller was caught in a wire attached to the facility's anchoring. The vessel lost control and hit the installation.

TABLE 1. Collisions between visiting vessels and offshore facilities. (PSA Norway, 2011)

IMPROVEMENTS IN RELATION TO PREVIOUSLY DOCUMENTED INCIDENTS

Design

Several design improvements and developments are identified as "lessons learned" from previous incidents:

- To avoid water on deck, both OSVs are designed with high bulwarks or sidewalls. The cargo deck remains dry most of the time.
- To secure tubular cargo on deck, automated cargo securing systems have been developed and installed on OSV A. The system consists of portable stanchions that run transversely across the full width of the deck on a series of tracks. However, no such facility is installed on OSV B.
- To improve safety in bulk cargo transfer, two different hose-securing systems are under development and testing. On OSV B, the system was shown to work well; unfortunately, this was not the case on OSV A. The oil company or the client pays for the development.

There have been no additional autopilot incidents on either OSV. However, measures have been taken to modify the systems. Currently, the autopilot is automatically deactivated when the crew operates the joystick. This action is a consequence of carrying the NAUT OSV notation (DNV, 2012).

Procedures

In 2006, a joint project between maritime and offshore organizations in Denmark, the Netherlands, Norway, and the U.K. resulted in the development of the North West European (NWEA) Guidelines for the Safety Management of Offshore Supply and Anchor Handling Operations (NWEA, 2011). These guidelines were revised during 2008-2009, and were updated in June 2009 (NWEA, 2009). Certain items in the guidelines that are related to the previously mentioned incidents are discussed as follows:

- To avoid injury to the crew while loading at sea, it is now forbidden for the deckhands to assist in positioning of suspended lifts. The crane operator must be able to place the lift in position without any assistance from the deckhands (section 3.3.6.5). Cherry picking (i.e., selective discharge of cargo from within the stow) is also forbidden (section 3.3.6.3).
- To avoid collisions between the vessel and the offshore installation, a 500 m safety zone is stipulated. The vessel is not allowed to enter the safety zone before permission is granted by the offshore installation. The vessel must contact the offshore installation approximately one hour before arrival. Both parties must complete checklists before the vessel can approach the installation and must ensure the safety of the loading/unloading process with respect to environmental conditions. In practice, the vessel must stop outside of the 500 m safety zone before approaching the installation. Should any person feel unsafe in the conduction of loading/unloading, that person can refuse to proceed without any pressure.
- To reduce the risk of collision, the offshore installation and the vessel should also minimize the frequency of visits and the time spent alongside the installation. It is

	OSV A (built in 2008)	OSV B (built in 2007)
Main Class, DNV (not all mentioned)	✠1A1, Supply Vessel COMF-V(3) Clean E0, DYNPOS-AUTR NAUT OSV (A) Oil Rec	✠1A1, Supply Vessel E0, COMF-V(3) Clean Design E0, DYNPOS-AUTR in compliance with NAUT OSV Oil Rec Ice C, Gas Fuelled
LOA / B mld / draft / DWT (approx.)	93.90 m / 21.00 m / 6.6 m / 5000 mt	92.20 / 21 m / 7.3 m / 6000 mt

TABLE 2. Main class and dimensions.

> preferable for the vessel to work on the lee side of the installation when working with cargo. It is the master's decision as to whether the vessel should work on the weather side, if required. Each scenario incurs its own restrictions with respect to environmental conditions, including maximum wind speed, significant wave height, and current speed.

Due to these measures, the probability of accidents on deck should be minimized, as should the probability of the vessel hitting the installation (see Table 3).

Discussions were also held with the captains with respect to the previously mentioned incidents and accidents. One issue was left out of the six collision cases presented in Table 1, and that is the case of the *Far Grimshader* and Songa Dee. According to one of the captains, the design of the Songa Dee platform is unique because it uses spread mooring lines. This type of design restricts the movement of visiting vessels. Visiting vessels must be exceptionally cautious in maneuvering around the platform, and the operators should be familiar with the conditions. According to the captain, it is fortunate that notably few platforms were built with such an arrangement.

RESULTS OF THE HUMAN FACTORS EXPLORATORY SURVEY

Exploratory surveys were conducted onboard both OSVs from a human factors perspective. The human factors framework presented in the Appendix was used as a guide. The key findings are reported and discussed in this section, and comparisons with previous studies are discussed.

Habitability

The crew members on both OSVs had no complaints regarding the onboard accommodation facilities. Most issues brought up by Strong (2000) and Hardwick (2000) garnered positive responses for recent OSV designs. Both vessels have excellent standards in their facilities. Every crew member has his/her own cabin equipped with a bed, TV set, Internet connection, table, sofa, wardrobe, and a toilet and shower located inside the cabin. The galley, the mess room, the lounge, the laundry, and all related facilities are

Previous incidents	Causal problems and related issues	Countermeasures
Collisions	Autopilot, man-machine interface.	Modification of the system. Autopilot will automatically be deactivated when the crew operates the joystick.
	Platform identified as a target in the voyage planning. Human error, improper lookout.	Procedure applied: NWEA (2009); platform cannot be identified as a target in the voyage planning. A 500 m safety zone is stipulated. Checklists used.
Deckhand hit by a hook. Deckhand falling against a hose coupling.	Motions of the hook (and hose coupling) caused by the wind. Motions of the ship induced by the sea.	Procedures applied: NWEA (2009); adverse weather working guidelines used. Development of an automatic hose securing system, reduction of direct intervention of the deckhand with the hose coupling.
Person squeezed between moving containers.	Water on deck, move-away containers. Motion of the vessel. Cherry picking.	Increase in the height of the bulwark to minimize water on deck. Procedure applied: no deckhand allowed on deck during rough weather, adverse weather working guidelines used.
Person slipping, fall caused by slippery deck.	Wet deck, slippery deck.	Increase in the height of the bulwark.
A deck hand twisted an ankle, fall caused by obstacles.	Unstable stack of cargo. Moving cargoes on deck.	Development of an automated cargo-securing system on deck.
Fall down a ladder.	Slippery surface. Steep ladder.	Conversion of ladder to stairs.

TABLE 3. List of previously documented incidents and countermeasures.

available, are in good condition and are considered to be more than sufficient. Large screen televisions with satellite connections, leather sofas, reclining seats, DVD movies, game consoles, and personal computers with an Internet connection are among the standard facilities on both OSVs. OSV A is even equipped with a sauna facility.

However, one issue in the accommodation facilities on both OSVs that was raised by the crew is that of the gym facility. On one vessel, the gym is located in an inconvenient location that makes crew members reluctant to visit the facility. On the other vessel, the gym is too small. The crews on both OSVs mentioned that the company has recognized the problem, and has made necessary modifications for the next line of vessels to be built.

OSV B is noted as a being relatively tall vessel, and this is reflected in the height of stairs and ladders. The stairs on OSV B are relatively steep. At first, personnel might totter while walking down the stairs and stumble going up, but eventually become acclimated to the steep height.

The two OSVs display different characteristics in terms of motion, vibration, and noise. OSV A is quite sensitive to rolling. Vibrations occur when the vessel must travel through harsh weather or requires high power. At times, in high seas, those onboard feel that the entire ship is quivering, and the cabin is shuddering. During such conditions, slamming also occurs and can be disturbing because the slammed area is quite close to a subset of cabins. High-pitched noise caused by the tunnel thrusters can be heard inside the cabins, and was reported to occasionally interrupt sleep. Noise produced by such deck machinery as winches and windlasses was identified on both OSVs as being an issue. Fortunately, this type of noise occurs quite rarely and usually takes place during relatively short periods (i.e., when berthing).

In general, OSV B is a quite stable ship, particularly with respect to rolling and heaving motions. However, in particular sea states (i.e., moderate seas), OSV B is sensitive to pitching motions. Small amplitude/high frequency vibrations are perceived in the cabins and even in bed while sleeping. These are caused by engines, thrusters, and funnels located close to the accommodation facilities. A constant hissing noise from the air ducts is also noticeable. Because the accommodation facilities are located far away from the bow thrusters and the slamming area, no sleep disturbances were reported during the surveys. However, a type of creaking sound was heard during severe or rough weather due to twisting.

Vomit incidences took place on both vessels, particularly when the vessels were steaming and experienced considerable motions. On OSV A the incidences occurred on high seas due to a combination of heave, pitch, and roll, while on OSV B the incidences occurred with a 2 to 3 m significant wave height and were mostly due to pitch.

The seafarers on OSV B appear to be quite happy with their vessel. One officer said: “You know when I decided to go back to work in the North Sea, I was worried. I easily get seasick. It is not a nice condition for a seaman. But, I’m happy that the company put me on this ship. Here, I never got seasick.” One deckhand mentioned: “I have been working and sailing in more than 30 different vessels, small, large, and even on a 300 m tanker. But this vessel is the best!”

On OSV A, a subset of the beds lie perpendicular to the length of the ship, while on OSV B, all of the bed are oriented parallel with the ship’s longitudinal axis. A subset of the arrangements on OSV A are in conflict with the crew’s expectations (Hardwick, 2000), but the benefit was recognized during heavy weather when the vessel experienced severe rolling motions. Unlike the crew members who sometimes found themselves thrown out of their beds, those who slept transversal to the ship’s longitudinal axis never had this unpleasant experience.

The smell of fuel was detected inside the accommodations on both vessels during the summer season. Certain odors are quite strong and can be disturbing, affecting the crew’s well being, interfering with the respiratory system, and occasionally causing dizziness if inhaled for too long. Odors seem to travel from the tanks through the vent pipes. The relatively high onboard temperature creates additional vaporization, and thus a greater amount of gas is released through the vent pipes. At the same time, the crew tends to leave doors open in warmer weather, which allows the gas particles to flow into the accommodation unit.

Workability

Both OSVs display a high level of workability, adopting the standards to which the oil and gas industries adhere, including the hardware, the software, and the users. Certain interesting findings are listed as follows:

USERS

Several issues exist in the recruitment of onboard personnel. Because the industry is developing quite rapidly, the need for human resources has increased in terms of quantity and competence. In contrast, the supply is limited, and recruiting of foreign crews cannot be avoided. A subset of female crew members was onboard; two worked on the bridge and two were assigned to the ER. Female crew members reported additional issues regarding their careers and private lives. They expressed the difficulty of raising children while still working at sea.

On average, the newer generation of seafarers is taller than their predecessors. During the survey, a number of notably tall crew members were encountered, with heights greater than 180 cm. Their heads almost touch the ceiling of the vessel in certain cases, and this anthropometric issue requires adjustments in the design of accommodations and workstations.

Due to the novelty and uniqueness of the systems, new user adaptation and familiarization is required on both OSVs. This practice has been formalized in training programs. Simulator-based training has become obligatory for OSV operators, and new training facilities are being built and upgraded all over Norway.

In contrast to the findings of Squire (2007), which claim a lack of user feedback in ship design, most senior officers and engineers on OSV A and B were involved in the process of designing and building the vessel.

EQUIPMENT AND SOFTWARE

Many systems on both OSVs are digital and computerized. The methods by which the vessel is operated have changed, and have become quite similar to playing a game console. New types of problems associated with this technology have been identified, including compatibility issues, operating system problems, software expiration dates, system overloads, unresponsive systems, data validity, and software bug problems. Some officers stated that too much information is presented on the screens. Not all information is necessary, but particularly crucial information appears vague at times because of the underlying complexity.

No traditional wheel exists to steer the vessel, and an engine telegraph is no longer used to regulate the speed. Most of the traditional controls have been replaced by joystick, trackball, button, mouse, keyboard, and touch-screen controls. Given an emergency situation, intervention with the system becomes less straightforward and less intuitive.

Most systems on the bridge are redundant, including all of the displays. However, the systems do not always show the most valid information. The operators have learned which systems are flawed and simply ignore them. For example, the conning systems on both vessels occasionally show faulty information.

With respect to the workability of the equipment and software, one of the engineers recalled the problems that surfaced just after the vessel was launched. Many systems were not 100% ready for use, and crewmembers had to contend

FIGURE 2. The "normal" position for operating the OSV when steaming, arm reaching back to push the buttons.

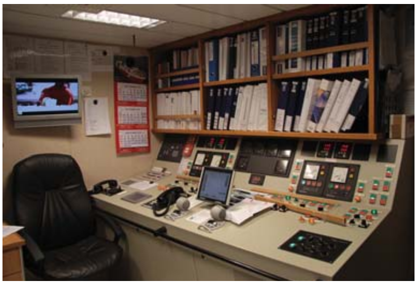


FIGURE 3. Engine console designed without any leg space. Note the rack above that is full of manuals.

with sixteen pages of warnings and alarm notifications. However, the situation was much different on the other vessel, where the systems were ready from the start, to the high satisfaction of the engineers.

Problems that were encountered on both OSVs include the following:

- Bright lights on the bridge that cannot be dimmed, thus disturbing visibility at night, as addressed by Lutzhoft (2005).
- A large number of alarms on the bridge. Certain audio alarms are considered to be annoying by the officers, and a subset of the warnings is considered irrelevant.
- Overabundant communications on the bridge. Such a large number of communication channels must be monitored, and the crew can be overwhelmed with calls at times.
- Ergonomic Issues. Placement of switches or other controls are not in line with ergonomic principles. At times, the crew must bend over or reach backward to operate certain functions (Figure 2). One engine console was designed with no leg space for the operator (Figure 3). This issue was criticized in Grundevik et al. (2009).
- Limited internet bandwidth. Almost everybody onboard brings computer notebooks and smart phones and/or tablets for personal use during spare time. Most of the time, these devices are connected to the Internet. During the survey period, both vessels experienced problems with Internet bandwidth, and subsequently initiated a "no YouTube and no video streaming" policy. The same Internet connection is used as one of the primary communication lines in the vessel operation.

The most critical incident on each OSV has been identified as:

- **DYNAMIC POSITIONING (DP) INCIDENT ON OSV A**
  An officer shared his experience when the DP system failed without any warning. OSV A was lying beside an installation on DP. Instead of holding steady on the specified spot, the vessel began to move toward the installation. The officer took over the controls, shut down the DP system, and backed the ship away from the structure. One hose was still connected to the installation and snapped off. The system ascertained that the vessel was more than 100 m away from the installation, while in reality it was approximately 20 m away. The manufacturer explained to the crew that the probability of this particular incident occurring is even smaller than that of winning the lottery. However, during further investigation as a part this study, the manufacturer stated: "… this has happened only once on the entire DP X equipped fleet. We have found the root cause for this, and implemented a solution for it. This failure will not happen again." This statement indicates that the manufacturer was not aware that this problem existed when the system was delivered. An accident with a high hazard potential may have occurred if a human operator had not reacted to the problem to prevent an incident.
- **BLACKOUT ON OSV B**
  A critical situation that OSV B experienced was a blackout. This incident occurred when the vessel was preparing to maneuver away from an installation. To cruise to the next installation, the bridge asked for a sudden increase of power that the system was unable to accommodate. At the time, the system was running on LNG fuel and attempted to automatically switch over to diesel, but the switchover failed. Apparently, LNG fuel has a characteristic of which the operator had not been made aware: it is less responsive to variations in the power requirements. In this case, it is suspected that both the designer and the manufacturer of the system had not considered this characteristic of LNG fuel. If they had been aware of this, they failed to inform users. However, the OSV B is equipped with a DYNPOS-AUTRO system, also known as the DP3 system, which only allows a blackout to take place for a short time (seconds) before the system returns to normal.

Other problems found on each OSV:

- On OSV A, releasing the DP system from automatic mode to manual mode requires a specific response time. Without full control, this delay can be critical when the vessel is located close to the installation. Normally, the operator will use the joystick to bring the vessel away from the installation before switching to full manual mode. On OSV B, this does not occur because the transition

occurs instantaneously. One expert from a classification society stated that the transfer of control between modes of operation should be immediate. A delay of 10 seconds is not acceptable for this class. The fact that the vessel is approved to operate and carry the associated class notation causes confusion. However, this expert admits that there are many factors that may influence the need to transfer control among different modes of operation, including the design of bridge workstations, the functions of different systems, the layout of different operator interfaces, the responses of mechanical systems, and operator procedures and training. It is likely that the issue was not recognized before the system became operational.
- On OSV B, certain buttons on the bridge are difficult to press, leaving the operators confused at times as to whether he or she has already activated (or deactivated) the system. However, according to the designers, the defect has been noted, and the system has been improved for the next line of vessels.

Procedures
Abundant procedures, checklists, and forms must be filled out during OSV operations. Some of these items are recognized as necessary, but others are found to be irritating. A small focus discussion was conducted to examine the issue. One of the main questions asked was: "Which procedures should be eliminated?" Certain people realized the importance of the procedures, but others expressed reluctance, especially when they are required to make the same entry repeatedly. A subset of the crew admitted that they do not always follow the procedures, but preferred "different ways" of completing the tasks. Finally, they agreed to not omit any of the procedures, forms, or checklists, but they also expected certain types of improvements, including better design of the forms and the checklists.

Physical Environment
The crews of both OSVs identified environmental conditions as one of the most difficult situations to which they must acclimate. When the mean wind speed is above 35 knots, and/or significant wave heights are above 4 m, operations are ceased (NWEA, 2009). The vessel is asked to move away from the installation and to wait until the environmental situation improves. However, waiting on a vessel for hours in high seas is an unpleasant experience, and sailing the high seas is even worse. If notably bad weather occurs, usually in the winter months, the vessels will be called into the base.

In certain locations of the vessel, noise is identified as a problem. On OSV B, the area used as the muster station in the deck and the workshop, often used as the dirty mess, are noisy due to the close proximity of the ER air intake.

Thus far, there have been no complaints associated with high/low temperature, lighting, and ventilation.

The ECRs on both OSVs are located on the main deck. This location is favorable to the human operators because they are spared from electromagnetic fields, high noise levels, vibrations, and the probability of CO_2 exposure. Additionally, they can breathe fresh air and can see the horizon.

The ECR on OSV A is too small for adequate mobility. There is no space to open technical drawings, and the electrician, who must work shoulder-to-shoulder with the engineers, is located in a separate workplace three levels higher. The ECR on OSV B is rather spacious, and even contains a seating area for drinking coffee. A small room is available for the electrician to work inside the ECR.

Several layout and arrangement issues related to onboard workability were identified on both vessels:
- On OSV A, the previously designed "linen room" was converted to a server room.
- On OSV B, there is no dirty mess where the deckhands can spend time while waiting for operations at sea, and they use the workshop instead. The workshop is a narrow room without proper seating, located 10 m away from the cargo deck and it is not well oriented to the deck.
- On both OSVs, there is a special room known as the "ship's office" that is almost never in use. In contrast, there is no particular place for the entire crew to hold a meeting.

Accessibility
Based on the observations made in this study, it seems that in both of the OSV designs in this

FIGURE 4. Short entry hatchet; one deckhand hit his head when passing under it.

FIGURE 5. Long and high ladders; the steps are not flat but curvy to anticipate changes in the ladder angle due to draft variations; the handrails are made of steel wire and are not rigid.

FIGURE 6. Vertical ladders. Note the hand wheel on top that must be operated to get through when one is near the top.

study, personnel accessibility is still problematic. OSV A contains an entry hatchet that requires people to duck under it to pass or risk a head injury (Figure 4). OSV B contains a long and high ladder (Figure 5) that must be carefully climbed before entering a narrow and winding gangway. A set of ladders is installed in one of the engine rooms without a safety cage (fortunately, it is rarely in use). Just before we conducted our survey on OSV B, a vertical ladder (such as the one shown in Figure 6) was modified into stairs in response to the crew's request.

In the ERs on both OSV A and B, there are locations where personnel are required duck and climb. However, no such acrobatic activity is required by the crew on either OSV during normal operation, as mentioned by Andersson and Lutzhoft (2007). There are no cited cases of incorrect height, poor orientation of equipment, or inaccessibility to valves, hand wheels, and hand pumps, as reported in Dalpiaz et al. (2005).

The OSVs adhere to proper standards for most safety equipment and facilities, as well as for fire fighting, damage control, lifesaving, and security facilities. One issue was noted regarding the location of the fire fighting equipment storage. The room directly faces the main deck with no alternative access. In the case of a fire on deck, it would be difficult for the fire squad to enter this storage area and equip themselves expediently. The accessibility of the paint and chemical storeroom was also noted as an issue, which is located adjacent to the crew's cabin.

Maintainability

Methods of onboard maintenance have changed drastically in the last decade. Restarting, testing, and updating systems, software, and data has become a routine onboard procedure. The operators follow the maintenance program generated by the system. Obviously, the system is not 100% accurate. According to the engineers, certain corrections and adjustments must be made. For instance, the standard running hours required for some maintenance activities must be manually altered. False alarms or warnings sometimes occur as the result of a broken sensor.

Lack of storage for supplies, tools, and provisions is a common complaint. It was noted that OSV B is significantly more spacious than A, but both crews complained at approximately the same level of lack of storage. When this study took place, the crews on OSV B were in the process of constructing a new storage space using select corners of the vessel.

Limited space for conducting maintenance is another issue. Climbing and crawling are actions common in maintenance. Those with experience on other larger vessels understand the constraints on OSVs; their typical size simply limits the available space.

Most systems on the both OSVs are more complex than those of the older ones. The engineers are able to perform only limited troubleshooting. Should problems remain, supplier technical support is required, often onboard. An azipull propeller demonstrated a problem when it failed to point in the right direction. The engineers attempted to repair it by restarting and reconfiguring the system and following the instructions in the manual, but the problem was not solved. They had to call for support from the manufacturer, who subsequently came onboard with a computerized unit to make the necessary adjustments.

One incident related to the application of a new maintenance system was related to testing an ozone treatment used to clean the water system. The results were rather satisfactory in cleaning the pipes, valves, strainers, and tanks, and in reducing the requirement for maintenance. Several deckhands were working on the deck when a full tank of ozone was filled with water. The ozone gas was pushed upward, was forced out through a vent pipe, and was inhaled by the deckhands, leaving them choked for air and experiencing respiratory problems for almost an hour.

Discussion

Much progress has been accomplished using the lessons learned from previous incidents (Table 3). Compared with the problems previously raised by other researchers, this research indicates that there have been significant improvements (Table 4). Therefore, most of the issues addressed by Meister (1971), Reason (1990), Graveson (2002) and Squire (2007) have been rectified. Human factors has been sufficiently considered in recent design of OSVs, so the topic is being taken seriously. The results are not perfect yet, but the learning process is noticeable. Excellent standards of accommodation facilities, bridge facilities, deck facilities, and engine rooms are provided onboard. Most systems were designed so that the crew can operate the vessel more safely and more effectively. However, minor flaws still remain (e.g., illumination problems on the bridge, ergonomics of the workstations as well as certain layout issues, including access and a lack of storage) that could be fixed with minimal effort.

Noise, vibration, motion, and slamming were recognized as a more important issue onboard. Tunnel thrusters were identified as one major source of noise. On OSVs, tunnel thrusters are frequently activated, and running on DP is their main activity. A solution via silent type tunnel thrusters is available on the market, and is highly recommended for those vessels in which cabins are located close to the thrusters.

Locating the superstructure at the aft provides several benefits from the operators' perspective: they are safe from slamming, and they experience lower motion amplitude and thus additional comfort. In terms of controllability, they require only one control unit to operate the vessel, which reduces the potential for confusion. Regular OSVs are equipped with two control units, one facing forward and the other facing astern. However, there are several disadvantages to locating the superstructure at the aft: the vessel is less flexible while positioning

Previous studies and publications	Claims and evaluation	Status and comments based on OSV surveys
Meister (1971)	Design engineer does not consider human factors in his design.	Human-related factors have been sufficiently addressed. The learning process is taking place.
Reason (1990)	Poor design, incorrect installation, faulty maintenance, and bad management decisions.	Good vessel design, no incorrect installation, no faulty maintenance identified, supportive management decisions for human factors.
Calhoun and Stevens (2003)	Systems and equipment failures as common factor for accidents in many industries. Systems and equipment are not well designed to meet human physical or cognitive capabilities.	Systems and equipment failures are still identified as a potential cause for accidents; DP system failure and blackout are examples found in this study. Most systems and equipment are designed to meet human capabilities. Certain ergonomics problems and problems of too much information are still found, but are not disturbing.
Squire (2007)	Ship was designed without input from the crew.	Officers from both OSVs were involved in the process of designing and constructing the vessels.
Strong (2000)	Adequate levels of privacy are expected.	Fulfilled—all crewmembers are assigned their own cabins.
	Facilities for social relaxation are expected.	Fulfilled—plenty of facilities are available onboard: satellite TV, video games, DVD movies, stereo sets, gym, etc.
Hardwick (2000)	Drive toward cabin-based accommodations is suggested.	Fulfilled on OSV B and partly fulfilled on OSV A; there are certain cabins on OSV A in which beds lie transversal to the ship's length.
	Increased space for sleeping & personal stowage is expected.	Fulfilled—all crewmembers get their own cabins and lockers.
	Improved ambient conditions are expected.	Fulfilled—the vessels are equipped with sufficient air-conditioning systems and built with comfort class notation.
Lutzhoft (2005)	Illumination problems on the bridge.	Illumination problems are still found on both OSVs, but there are only one or two displays on each OSV that cannot be dimmed properly.
	Equipment not attached properly; operator mush use duct tape.	No equipment found not attached properly on both OSVs. No sign of duct tape used.
Grundevik et al. (2009)	Insufficient leg space.	One console on one OSV built without sufficient leg space, but the console is rarely used.
	Bad position of the consoles.	No console is found in such a bad position that it is hard to operate. However, the autopilot buttons are located somewhat behind the operators so they must reach backward to operate them. Certain keyboards are located far enough away that the operator must bend over to reach them.
	Visibility problems.	No visibility problems found on either OSV.
	Defective hardware components.	No defective hardware components found on both OSVs. However, broken sensors are quite often found.
	Software bugs. Defective software.	Problems related to software are still found in this study. Revisions, corrections, and improvements are in progress.
Dalpiaz et al. (2005)	Incorrect height/orientation.	No equipment found with incorrect height/orientation.
	Stairs, ladders, steps, and walkways.	Problems with stairs and ladders are still found on both OSVs.
	Inaccessibility to valves, hand wheels, and hand pumps.	No valves, hand wheels, or hand pumps found that cannot be accessed.
	Incorrect control panel, console design, control, and display design.	No incorrect control panels, console designs, or display designs found, but there are buttons that are hard to press.
	Problems with access and personnel movement.	Access of personnel from the pier onto the vessel is still problematic on both OSVs.

TABLE 4. Status and comparison between current surveys and issues raised in previous studies.

alongside the installation, and the deck is more complicated. This design of OSV B is perceived as rather odd for the market.

Certain improvements and innovations that occurred on these vessels were stimulated and sponsored by the client (i.e., the oil and gas companies), which in turn are driven by tax incentives and other governmental policies. It can be observed that if profit is not the only goal, and if competition is not the principal motivation, then opportunities exist to develop additional aspects of the vessels in addition to those that maximize productivity and minimize cost. Human factors engineering is not a suitable arena for competition. Issues exist that must be agreed upon in the development of human-related technology to avoid those characteristics in the final product that might create confusion or frustration for the operators.

There is another intangible consideration that was identified to significantly encourage improvements on the OSVs, particularly for human factors concerns, and that is the egalitarian culture of a society that induces effective communications between the seafarers and the ship owners. The willingness of the ship owners and the designers to listen to the seafarers' opinions and assessments and to involve them in the design process are valuable not only to improve the quality of the vessel, but also to increase the sense of belonging and familiarity of the seafarers with their vessel.

Based on this study, two keywords are highlighted: novelty and abundance.

Novelty

New technologies and new systems are important issues that must be regarded cautiously, because unknown uncertainties are implicitly contained in a novel system that may eventually be discovered. The autopilot-related accidents mentioned in Table 1 serve as hard evidence of this fact. In this research, we found that an LNG characteristic in a dual fuel system has a potential to cause blackouts. Imperfect development of the DP system led to a dangerous situation in which the vessel almost collided with an installation. The application of the new ozone water treatment system with unrecognized potential side effects is among those hazards that could not be avoided.

Technology development currently occurs at a rapid pace, much faster than the pace of the traditional shipbuilding industry, and too fast for the average operator to cope with. Therefore, it is important to differentiate between "what can be done" and "what should be done".

Abundance

An abundance of alarms, procedures, checklists, information, and communications must be dealt with onboard. Reasonable modifiers following abundance are naturally those of organization and optimization. It is important to select the alarms, procedures, checklists, information, or communications that are necessary, and those that are irrelevant, and to prioritize the arrangement of the system accordingly. An SOS signal sent from a vessel sailing in the Caribbean Sea thousands of miles away is meaningless, and could even be disturbing to those working on the Norwegian Continental Shelf.

Conclusions

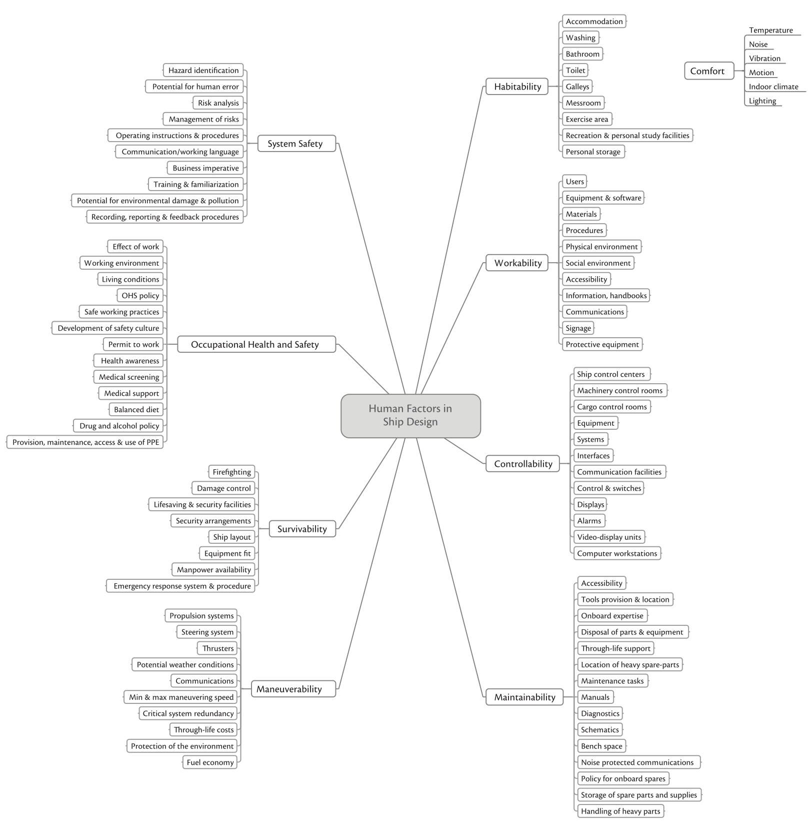
Exploratory surveys on OSVs have been conducted to investigate human factors application in marine system design. A qualitative research methodology was applied. Two up-to-date OSVs were selected as the research samples. It can be concluded that human factors has been well considered in the design of OSVs. Considerable improvements have been made compared with the previously reported incidents and with those noted in past publications, and continuing development is also noted. The scope of human factors application is quite broad, and not all of its dimensions are considered equally. Based on observations made in this study, it can be concluded that habitability has been considered appropriately, but there are still issues in maintainability that require improvement. However, the overall conditions are above the acceptable limit. A significant difference in the human factors evaluation was found on two different OSVs. The vessel with the superstructure located at the aft has the benefit of better comfort, while locating the superstructure at the fore gives additional flexibility in serving the installations.

Novel problems due to the application of new technologies and systems were recognized, including a blackout caused by a dual fuel system, and an imperfect dynamic positioning system that led to vessel-platform contact. Many problems were also reported with respect to numerous alarms, communications, checklists, and procedures. The risk of a ship/platform collision during cargo transfer still exists, but the risk when the vessel approaches installation has been minimized.

Selected practical recommendations are summarized as follows:

- A human factors evaluation of a new design before commencing construction is highly recommended. User feedback and user involvement is one alternative to the evaluation, and consultation with a human factors expert is another alternative.
- Step-by-step improvement and a longer development time allow the users to absorb and adapt to new design. A radical change of design that can alter the way in which people operate the vessel is not recommended.
- Collaboration between different groups of designers and manufacturers for agreement on certain basic principles in human-related development in ship design is recommended.
- A comprehensive proof test on each critical system is highly recommended, in addition to those validations that are required by authorities.
- To reduce noise disturbances experienced by the crew, the super silent type of tunnel thrusters should be used on vessels that have accommodations located close to the thrusters.
- The amount of alarms, communications, checklists, and procedures should be limited; screening should identify only the relevant ones, which can be subsequently prioritized and optimized. Further research for evaluating the existing conditions is advised.
- To reduce the risks of collision and contact between the ship and platform, minimization of the time spent operating alongside installations is advised.

APPENDIX



REFERENCES

American Bureau of Shipping (ABS), *Guide for Crew Habitability on Ships*, Houston, TX, 2001a.

American Bureau of Shipping (ABS), *Guide for Passenger Comfort on Ships*, Houston, TX, 2001b.

American Bureau of Shipping (ABS), *Guidance Notes for the Application of Ergonomics to Marine Systems*, Houston, TX, 2003.

American Bureau of Shipping (ABS), *Guide for Bridge Design and Navigational Equipment/Systems*, Houston, TX, 2000.

Andersson, M. and Lutzhoft, M., "Engine Control Rooms - Human Factors", Human Factors in Ship Design, Safety and Operation Conference. 21-22 March. RINA HQ, London, U.K., 2007.

Blenkey, N., "OSV Designers Eye the Future". *Marine Log*, Vol. 109(11), pp. 21-27, 2004.

Bryman, A., *Social Research Methods*, New York: Oxford University Press, 2001.

Calhoun, S.R. and Stevens, S.C., "Human Factors in Ship Design, in Lamb T (Ed)", *Ship Design and Construction*, Vol. 1, NJ: The Society of Naval Architects and Marine Engineers.

Dalpiaz, T.M., Emmrich, M., Miller, G., and McQuillan, D., "Conducting a human factors engineering 3-D computer modeling ship design review", Human Factors in Ship Design, Safety and Operation Conference. 23-24 Feb. RINA HQ, London, U.K., 2005.

Det Norske Veritas (DNV), *Rules for Classification of Ships*, Part 6, Chapter 20, Newbuildings Special Equipment and Systems – Additional Class Nautical Safety – Offshore Service Vessels, January, Det Norske Veritas AS, 2012.

Gibson, V., *The History of the Supply Ship*, Aberdeen: La Madrila Press, 2007.

Gibson, V., *Supply Ship Operations A Handbook*, 3rd ed. Aberdeen: La Madrila Press, 2009.

Graveson, A., "Human Factors in Ship Design and Operation", Human Factors in Ship Design and Operation Conference, 2-3 Oct., RINA HQ, London, U.K., 2002.

Grundevik, P., Lundh, M. and Wagner, E., Engine Control Room - Human Factors. Human Factors in Ship Design and Operation Conference, 25-26 Feb. RINA HQ, London, U.K., 2009.

Hansson, L., "Safety Management for Prevention of Occupational Accidents." Doctoral thesis at Norwegian University of Science and Technology, IMT-2006-17, Trondheim: Tapir Uttrykk, 2006.

Hardwick, C., "A Comparative Assessment of Priorities for Accommodation Standards Between Royal Naval and Merchant Naval Fleets", Human Factors in Ship Design and Operation Conference, 27-29 Sept. RINA HQ, London, U.K., 2000.

Lloyd's Register Group (LR), *The Human Element Best Practice for Ship Operators Continuous Improvement of the Human Element*, July, Version 1.1, 2009.

Lloyd's Register (LR), *The Human Element An Introduction*, Booklet, ISBN 1-900839-31-8, 2008.

Lutzhoft, M., "Human Integration of Bridge Technology. Human Factors in Ship Design", Safety and Operation Conference, 23-24 Feb, RINA HQ, London, U.K., 2005.

McCafferty, D.B. and Baker, C.C., "Trending the Cause of Marine Incidents", Learning from Marine Incidents Conference, 25-26 January, RINA HQ, London, U.K., 2006.

Meister, D., *Human Factors: Theory and Practice*, Wiley Series in Human Factors, USA: John Wiley and Sons, Inc., 1971.

Moore W.H., Bea, R.G., and Roberts, K.H., "Improving the Management of Human and Organization Errors (HOE) in Tanker Operations." Ship Structures Symposium, Arlington, Virginia, 1971.

Neuman, W.L., *Social Research Methods: Qualitative and Quantitative Approaches*, Boston, Pearson, 2006.

North West European Area (NWEA), Common Guidelines Info. Online: http://www.nwea.info/ (last accessed: 8 March 2011), 2011.

North West European Area (NWEA), "Guidelines for the Safe Management of Offshore Supply and Rig Move Operations. Version 2." Updated June 2009. Online: http://www.nwea.info/ (last accessed: 8 March 2011), 2009.

Petroleum Safety Authority (PSA) Norway, "Risk of Collisions with Visiting Vessels", [Online: http://www.ptil.no/news/risk-of-collisions-with-visiting-vessels-article7524-79.html?lang=en_US], 2009.

Reason, J., *Human Error,* Cambridge: Cambridge University Press, 1990.

Rumawas, V. and Asbjørnslett, B.E., "A content analysis of human factors in the design of marine systems", International Conference on Ship and Offshore Technology Developments in Ship Design and Construction (ICSOT), 11-12 Nov., RINA, Surabaya, Indonesia, 2010.

Squire, D., "Fit for Purpose' - Keeping the Crew in Mind", Conference on Human Factors in Ship Design, Safety and Operation, 21-22 March, RINA, London, U.K., 2007.

Strong, R., RN "Habitability Survey: Ship Design Implications: Some Important Social and Architectural Issues in the Design of Accommodation Spaces", Human Factors in Ship Design and Operation Conference, 27-29 Sept., RINA HQ, London, U.K., 2000.

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Appendix C: Explanatory Study

Human Factors on Offshore Supply Vessels in the Norwegian Sea – An Explanatory Survey

The International Journal of Maritime Engineering,
RINA Transactions (accepted)

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HUMAN FACTORS ON OFFSHORE SUPPLY VESSELS IN THE NORWEGIAN SEA – AN EXPLANATORY SURVEY

(DOI No: 10.3940/rina.ijme.20XX.a?.???)

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SUMMARY

A survey of human factors on two state-of-the-art offshore supply vessels (OSVs) operating in the Norwegian Sea was performed by means of questionnaires. The purpose of the study was to examine whether human factors had been adequately addressed in ship design, how they were regarded by the crews, and whether design decisions were believed to have an effect on incidents on-board. The concept of human factors in ship design was operationalised into eight dimensions: habitability, workability, controllability, maintainability, manoeuvrability, survivability, occupational health and safety (OHS), and system safety. Inferential statistics were applied in order to draw conclusions, including means comparisons and multivariate regression analyses. The results show that human factors were given significant importance in the ship design. The level of accomplishment of human factors differs from one dimension to another. The highest satisfactory dimension was OHS and maintainability was the lowest, but still considered adequate. Design is revealed to have an impact on human factor ratings. Further, OSV design and human factor ratings are identified as having effects on particular incidents on board.

NOMENCLATURE

ABS	American Bureau of Shipping
ANOVA	Analysis of variance
COG	Centre of gravity
Contr	Controllability
DNV	Det Norske Veritas
df	degrees of freedom
ECR	Engine control room
ER	Engine room
F	Fischer test
Hab	Habitability
H	Hypothesis
HF	Human factors
HFES	Human Factors and Ergonomics Society
IEA	International Ergonomics Association
IMO	International Maritime Organization
LNG	Liquefied natural gas
LR	Lloyd's Register
Maint	Maintainability
N	number of sample
OHS	Occupational health and safety
OSV	Offshore supply vessel
p	significance level
RINA	Royal Institution of Naval Architects
sig	significance
SPSS	Statistical Package for the Social Sciences
Work	Workability

1. INTRODUCTION

This paper reports on part of a study investigating the application of human factors in ship design. The research was instigated from the notion that most accidents at sea are caused by human errors or human-related factors [1-4]. Experts claim that some errors were inherited from the design stage [5-8]. Human factors are also often overlooked in the design of marine systems [9, 10].

A comprehensive literature survey was conducted to reveal standards and documents involving human factors in ship design [11, 12]. The results included extensive references to human factors in ships design. The term "human factors" in ship design is quite a broad term and can be divided into several different aspects, such as safety, habitability, controllability and maintainability[1]. The survey also revealed that coverage varied across different aspects of human factors where safety-related element was addressed the most often, followed by habitability and controllability, with maintainability the least reported. A follow up field survey using a qualitative approach was performed to examine the implementation of human factors principles in the industry by through the study of two offshore supply vessels (OSV) [13, 14]. The survey aimed to compare the existing knowledge of human factors on paper, with the reality. Prior to the survey, a number of reports regarding ship design flaws and incidents on offshore vessels were documented, which included poor layout, some ergonomics-related issues, poor automation and inadequate procedures. The reports were used as a reference to check whether lessons had been learned. The results showed that the designs of the existing OSVs addressed human factors to a significant degree.. Many human factors issues were considered,, but not all issues addressed to the same level; some were very satisfactory addressed and some were not.

This paper reports a quantitative survey that was conducted as a continuation of the study of human factors in two OSVs. The objective was to verify the preliminary findings [11-14] by asking users to fill in a custom-made questionnaire. The aim of the research was to refine the qualitative findings about how human

[1] A detailed description of each term is presented in Section 2.

factors are implemented, and to assess the role of human factors on design and operation and the degree to which a lack of focus on human factors may lead to incidents. The previous study indicated that the crews were in general pleased with the habitability and workability but less satisfied with the maintainability [13, 14]. Survivability, OHS and system safety were considered the most satisfactory of the other aspects of human factors in ship design, as also revealed in the literature survey [11, 12]. This study also aims to provide quantitative evidence regarding the "existence" of human factors, which is still hard for some people, especially engineers to grasp.

2. LITERATURE REVIEW

The definition of human factors or ergonomics is briefly covered in this section. Lloyd's Register (LR) provides a definition: [15]

> 'Ergonomics is the study and design of working environments for the benefit of the workers' safety, efficiency, effectiveness, health and comfort. Working environments include ship bridges, machinery control rooms and galleys, and their components, work practices and work procedures.'

The International Maritime Organisation (IMO) defines ergonomics as follows: [16]

> '…the study and design of working environments (e.g., workstation, cockpit, ship bridges) and their components, work practices, and work procedures for the benefit of the worker's productivity, health, comfort, and safety. Application of the human factor in the analysis and design of equipment, work and working environment'.

Human factors considerations in ship design can be categorised into eight dimensions as follows [15, 17]:

- Habitability: the provision of adequate and comfortable accommodation
- Workability: condition of users, equipment, software, materials, procedures and environments that are appropriate for work
- Controllability: the design of the navigation bridge, engine control room, cargo control room, etc. in a manner that integrates people with equipment, systems and interfaces
- Maintainability: the design of systems in a way that allows maintenance tasks to be performed rapidly, safely and effectively
- Manoeuvrability: the capability of the ship to manoeuvre according to operating requirements in terms of speed and course parameters
- Survivability: the provision of adequate firefighting, damage control and lifesaving facilities
- Occupational health and safety (OHS): appropriate consideration of the effect of work, the working environment and living conditions on the health, safety and wellbeing of workers
- System safety: appropriate consideration of the risks related to the human operation of ship systems

Table 1 shows in greater detail the elements of human factors in ship design based on the exploration of different sources [15, 17-21].

3. RESEARCH DESIGN

The logic of the research model is presented in Figure 1 where three variables are defined: (1) OSV design, (2) human factors rating and (3) incidents. Two different rating methods are developed for validity purposes: direct evaluation and a Likert-scale. A distinction is made between personnel incidents and vessel incidents.

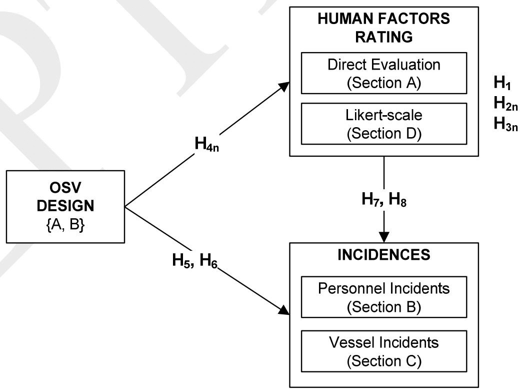

Figure 1 Research design and defined hypotheses

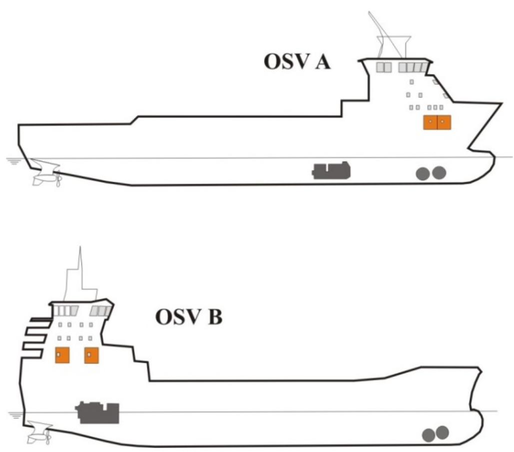

Figure 2 Offshore supply vessels [14]

Table 1 Human factors considerations

Habitability
- Accommodation
- Washing
- Bathroom
- Toilet
- Galleys
- Messroom
- Exercise area
- Recreation & personal study facilities
- Personal storage

Workability
- Users
- Equipment & software
- Materials
- Procedures
- Physical environment
- Social environment
- Accessibility
- Information, handbooks
- Communications
- Signage
- Protective equipment

Controllability
- Ship control centres
- Machinery control rooms
- Cargo control rooms
- Equipment
- Systems
- Interfaces
- Communication facilities
- Control & switches
- Displays
- Alarms
- Video-display units
- Computer workstations

Maintainability
- Accessibility
- Tools provision & location
- On board expertise
- Disposal of parts & equipment
- Through-life support
- Location of heavy spare-parts
- Maintenance tasks
- Manuals
- Diagnostics
- Schematics
- Bench space
- Noise protected communications
- Policy for on board spares
- Storage of spare parts and supplies
- Handling of heavy parts

Manoeuvrability
- Propulsion systems
- Steering system
- Thrusters
- Potential weather conditions
- Communications
- Min & max manoeuvring speed
- Critical system redundancy
- Through-life costs
- Protection of the environment
- Fuel economy

Survivability
- Firefighting
- Damage control
- Lifesaving & security facilities
- Security arrangements
- Ship layout
- Equipment fit
- Manpower availability
- Emergency response system & procedure

Occupational Health and Safety
- Effect of work
- Working environment
- Living conditions
- OHS policy
- Safe working practices
- Development of safety culture
- Permit to work
- Health awareness
- Medical screening
- Medical support
- Balanced diet
- Drug and alcohol policy
- Provision, maintenance, access & use of PPE

System Safety
- Hazard identification
- Potential for human error
- Risk analysis
- Management of risks
- Operating instructions & procedures
- Communication/working language
- Business imperative
- Training & familiarisation
- Potential for environmental damage & pollution
- Recording, reporting & feedback procedures

Two advanced OSVs of different design were chosen for the survey as objects for study. OSV A follows the traditional design of most OSVs, with the superstructure at the fore end (see Figure 2). OSV B is of an alternative design with the superstructure at the aft.

Several research questions and their corresponding hypotheses are proposed in this study.

The first main research question asks: "Are human factors addressed in the design of marine systems?" To answer the question the following hypotheses are specified and will be tested by statistical analysis:

H_1 : Human factors are addressed in the design of marine systems.

H_{2i} : Habitability is addressed in the design of marine systems.

H_{2ii} : Workability is addressed in the design of marine systems.

The second research question: "How are human factors applied in the design of marine systems?" is more complicate. As mentioned above, safety has been implemented at the highest level. Habitability and workability on OSVs have been addressed satisfactory for the crew members. Maintainability seems to be the least satisfactory issue. The crews on OSV B seemed to be more satisfied with the habitability and the workability of their vessel compared to those on OSV A.

Several hypotheses are specified to test the second research question:

H_3 : The human factors dimensions are not rated equally in the design of marine systems.

H_{3i} : Survivability, OHS and system safety are rated more highly compared to the other human factors dimensions.

H_{3ii} : Maintainability is rated lower compared to the other human factors dimensions.

H_4 : There is a difference in human factors rating as the result of OSV design.

H_{4i} : There is a difference in habitability rating as the result of OSV design.

H_{4ii} : There is a difference in workability rating as the result of OSV design.

The third research question: "Is there any significant effect of human factors rating to incidents on board" is assessed by the following hypotheses:

H_5 : There is a difference in personnel incidents as a result of OSV design
H_{5i} : There is a difference in seasickness incident as a result of OSV design
H_{5ii} : There is a difference in the fatigue level of personnel as a result of OSV design
H_{5iii} : There is a difference in sleep disturbance incident as a result of OSV design
H_6 : There is a difference in vessel incidents as the result of OSV design
H_{6i} : There is a difference in water on deck incidents as a result of OSV design
H_{6ii} : There is a difference in moving cargo on deck incidents as a result of OSV design
H_7 : Human factors rating has a positive effect on reducing personnel related incidents
H_8 : Human factors rating has a positive effect on reducing vessel related incidents

4. METHODOLOGY

Questionnaires were used as a tool of measurement to answer the questions raised above and to test the hypotheses proposed.

4.1. QUESTIONNAIRES ABOUT HUMAN FACTORS ON SHIPS

A set of questionnaires was developed based on the framework outlined in Table 1. Typical issues in OSV design and operation were also customised to complement the object of the study. Examples of these issues are motion, slamming, dynamic positioning, automation, reliability, procedures, and deck cargo and bulk cargo facilities. The initial questionnaire consisted of 112 items, divided into four sections. The first part, Section A contained 26 questions about how human factors in general, and human factors dimensions, were rated by the crews. The respondents were, for instance asked the following question: "How would you rate the following characteristics of the vessel?" Five alternatives were available from very poor to very good with scores from one to five. An option for "no answer" was also provided for people who found the question irrelevant or hard to answer. For example, a cook would probably not have an opinion regarding manoeuvrability. The second part, Section B contained eight items involving the symptoms and personal related incidents that had been experienced by the crew. The third part, Section C contained eight items involving vessel related incidents. In both Section B and C the respondents were asked to give their assessment of the frequency of each incident, ranging from very often to never. The "no answer" option was also available. The last part, Section D was a supplementary list of human factors questions regarding the vessel. There were 70 items where the respondents were asked their opinions about a statement and offered a 5-point Likert-scale: from strongly disagree to strongly agree with a midpoint of being neutral. Table 2 shows a selection of items in the questionnaire. Before distributing the questionnaire on board, it was checked by a number of experts in ship design, marine engineers, ship officers, ship operators and terminal operators.

4.2. PILOT TEST

A pilot test was conducted in February 2011 with twelve respondents on OSV B. Reliability analyses were performed to ensure the internal consistency of the measurements in Section A and Section D, with alpha (α) Cronbach coefficients calculated using SPSS software version 14.1 for Windows. Five items from Section D were eliminated for showing poor validity. The final results showed high reliability indices: 0.949 for the 26-items of direct measurement on Section A and 0.955 for the remaining 65-item Likert-scale in Section D. Reliability analyses were also conducted on each dimension of the Likert-scale questionnaires. Table 3 presents the detailed results, calculated based upon 42 respondents including respondents from the pilot test and the target respondents from OSV A and OSV B.

4.3. SAMPLE AND POPULATION

The population of the study was that of offshore supply vessels operating in the Norwegian Sea. Three OSVs with long-term contracts served the offshore installations on a regular basis. Two of them were used as samples in the study. Long-term contracts mean that the vessel has fixed revenues all year long irrespective of the number of trips they make or the amount of cargo they carry. Each OSV had a crew of thirteen to eighteen persons, including a captain, a first officer, a chief engineer, a cook, two deck officers, one electrician, two engineers and four deckhands. A crew worked four weeks on board and had four weeks off. Sometimes trainees and students were on board. It was not uncommon that visitors were on board. The whole crew worked in shifts, for approximately twelve hours a day (1-in-2). There were two different watch systems adopted; the traditional 6-on/6-off/6-on/6-off system on OSV A and the 8-on/4-off/4-on/8-off system on OSV B.

Questionnaires were distributed on board in person, in July 2011. We explained the background of the study to the crew, ensured the confidentiality of their responses and encouraged them to participate in the survey. It is important that the respondents answer the questions as it is, according to their opinion and their experience, not according to what they think it should be. Sixteen out of seventeen crewmembers on OSV A and fourteen out of eighteen on OSV B answered the questionnaires. These did not include the same people who filled in the questionnaires in the pilot test. The survey was completely anonymous. No demographic information was collected about the respondents.

Table 2 Human factors in ship design questionnaire (sample items)

A	How would you rate the following characteristics of the vessel:	very poor	poor	neither	good	very good	no answer
1	The overall comfort						
2	Accommodation facilities						
3	Bridge design						
…	…						
26	Vessel's manoeuvring capability						

B	How often do the people on board experience the following:	very often	quite often	some times	seldom	never	no answer
27	Get seasick						
28	Fatigue, tired						
29	Stumble, hit an object by accident, hit by an object						
…	…						
34	Sleep disturbance, sleep interrupted						

C	How often does the vessel experience the following:	very often	quite often	some times	seldom	never	no answer
35	Loss of power, black out						
36	Loss of navigation control						
37	Contact, collide, collision with platform or other objects						
…	…						
42	Bulk cargo spill, pollution						

D	Please indicate whether you agree with the following statements:	strongly disagree	disagree	neutral	agree	strongly agree
43	The vessel is comfortable					
44	The vessel is quite stable					
45	It is easy to operate the equipment on board					
46	The vessel has a good layout					
…	…					
112	It is 'safe' to make mistakes because the system has been design with sufficient redundancies					

Table 3 Results of Reliability Analyses of Human Factors in Ship Design Questionnaires ($N = 42$)$^{*)}$

Measurement Dimension	No of items	Cronbach's Alpha
Section A, direct questions	26	0.949
Section B, personnel incidents	8	0.760
Section C, vessel incidents	8	0.619
Section D, Likert-scale	65	0.955
Habitability	13	0.907
Workability	11	0.746
Controllability	26	0.882
Maintainability	4	0.579
Manoeuvrability	3	0.843

$^{*)}$ $N = N_{\text{pilot study}} + N_{\text{OSV A}} + N_{\text{OSV B}} = 12 + 16 + 14$

5. RESULTS AND STATISTICAL ANALYSIS

Inferential statistics were used to draw conclusions from the hypotheses constructed. Due to the limited number of respondents, inferential statistics were performed with some caution. Parametric statistics were applied when assumptions were satisfied: normality, homogeneity of variances, linearity and independence. Should any of the assumptions be violated, robust estimates were utilised. For instance, the Brown-Forsythe test was used as an alternative in analysis of variance when the group variances were not homogeneous. A Bonferonni correction was applied as multiple tests were performed to one data set; the p value was corrected by dividing p value for one test by the number of tests performed (n): $p < 0.5/n$ for accepting significant results.

5.1. DATA EXPLORATION

Note that there were many missing values in the answers. The people who worked on the bridge did not respond to the questions regarding the engine control room, and *vice versa*. Missing values were non-random; therefore they were left as they were. Tests of normality were conducted on Section A and Section D, and both were satisfied for each OSV. Detailed human factors dimensions data in Section D were also analysed. Habitability, workability, controllability, maintainability and OHS fulfilled the normal distribution requirement ($p > .05$).

5.2. HUMAN FACTORS RATINGS: MEANS COMPARISONS

One-sample *t*-tests were applied to analyse H_1 and H_{2n}. In total, 42 respondents were included in this analysis. The test value was set at 3.0 which was the midpoint of the "neutral" response. The null hypothesis was defined as: $x = 3.0$. If the null hypothesis is accepted, it means that human factors are addressed indifferently. The results of analysis showed that the null hypotheses were rejected, meaning that the measurements were significantly different from, or in this case higher than 3.0 (see Figure 3). It can therefore be concluded that habitability is significantly addressed in these two OSVs ($t = 7.315$, $df = 41$, $p < .001$) and so is workability ($t = 7.082$, $df = 41$, $p < .001$). The result also shows that human factors in general (overall) is significantly addressed in these two OSVs ($t = 8.576$, $df = 41$, $p < .001$) as rated by the crews. Detailed results are presented in Table 4 and Table 5.

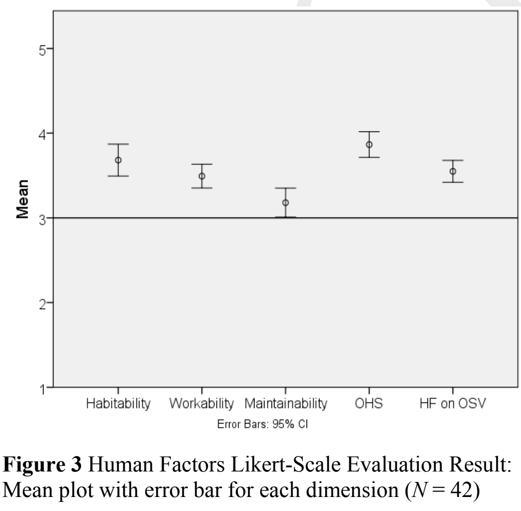

Figure 3 Human Factors Likert-Scale Evaluation Result: Mean plot with error bar for each dimension ($N = 42$)

Analysis of variance and paired-samples *t*-tests were conducted to determine whether there were different levels of assessment among human factors dimensions (H_3); habitability, workability, maintainability and OHS. A significant difference between groups can be seen in the results ($F = 13.015$, $p < 0.001$). OHS is the most highly rated aspect in the human factors dimensions ($x = 3.865$). The level of OHS is significantly higher than workability ($t = 5.535$, $p < 0.01$) and maintainability ($t = 7.795$, $p < 0.01$), but not habitability ($t = 2.269$, $p = 0.029$). The results verify that maintainability ($x = 3.179$) is the lowest rated dimension of human factors on OSVs ($p < 0.008$). There is a significant difference between maintainability and habitability ($t = -6.527$, $p = 0.000$) and workability ($t = -5.181$, $p = 0.000$). Detailed results are presented in Table 6 and Table 7.

Table 4 One-Sample Statistics of Human Factors Likert-Scale

	N	Mean	Std. Dev	Std. Error Mean
Habitability	42	3.682	0.604	0.093
Workability	42	3.492	0.451	0.070
Maintainability	42	3.179	0.550	0.085
OHS	42	3.865	0.487	0.075
Overall HF	42	3.549	0.415	0.064

Table 5 One-Sample Test of Human Factors Liker-Scale ($df = 41$)

	Test Value = 3				
	t	Sig. (2-tailed) *)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Hab	7.315	0.000	0.682	0.493	0.870
Work	7.082	0.000	0.492	0.352	0.633
Overall HF	8.576	0.000	0.549	0.420	0.678

*) Bonferronni correction was applied; p < 0.05/3; $p < 0.017$ for significant results

Table 6 ANOVA table for HF dimensions comparison: Habitability, Workability, Maintainability and OHS

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10.810	3	3.603	13.015	0.000
Within Groups	45.402	164	0.277		
Total	56.212	167			

Table 7 Paired Samples Test ($df = 41$)

Pair	Mean	Std Dev	Std Error Mean	t	Sig. *) (2-tailed)
1 OHS - Hab	.184	.524	.081	2.269	.029
2 OHS - Work	.373	.437	.067	5.535	.000
3 OHS - Maint	.686	.570	.088	7.795	.000
4 Maint - Hab	-.502	.499	.077	-6.527	.000
5 Maint - Work	-.313	.392	.060	-5.181	.000

*) Bonferronni correction was applied; p < 0.05/5; $p < 0.01$ for significant results

Hypothesis H_3 can be confirmed; human factors dimensions are rated unequally in the design of marine systems. OHS have been most addressed (H_{3i}) while maintainability is perceived as the least satisfactory (H_{3ii}) by the crews.

5.3. THE EFFECT OF DESIGN ON HUMAN FACTORS RATINGS

Analysis of variance was run to examine H_4 and H_{4i}. To ensure unbiased results, only data collected during summer 2011 was used in these analyses: one group from OSV A ($N_A = 16$) and one group from OSV B ($N_B = 14$), data from the pilot study was excluded. The results of the analyses show that OSV design has a tendency to influence the human factors rating on both OSVs ($F = 5.071$, $p = 0.032$). The crews on OSV B gave a better assessment regarding human factors on board their vessel. The variation is not the same across all dimensions. The most prominent difference is habitability ($F = 5.498$, $p = 0.026$). The results also show that different OSV design provides different levels of workability ($F = 6.086$, $p = 0.020$). Figure 4 shows a summary of the measurement in bar graphs. Detailed results are presented in Table 8. Due to the Bonferonni-correction, the p-level in these analyses was lowered to $p < 0.017$, and thus all these outcomes in testing H_4 and H_{4i} become inconclusive.

5.4. THE EFFECT OF DESIGN ON INCIDENTS ON BOARD

Analysis of variance was applied in order to verify the effect of OSV design on incidents (H_5 and H_6). The results demonstrate that there is no significant variation in the overall average of personnel incidents (Figure 5), as reflected by the scores of Section B ($F = 0.799$, $p = 0.379$), however, more detailed analysis show that there is a difference in seasickness incident ($F = 3.339$, $p = 0.079$) and sleep disturbance incident ($F = 2.991$, $p = 0.096$) as perceived by the crew on OSV A compared to the crews on OSV B. Due to Bonferonni-correction, the conclusion should be rejected. Detailed results are presented in Table 9.

The homogeneity test of fatigue data showed that the variances on OSV A and B were not equal ($p < 0.05$), and so Welch and Brown-Forsythe tests were applied in addition to the analysis of variance and confirmed the difference ($F = 5.091$, $p = 0.037$). Again, the conclusion should be rejected due to the numerical correction.

Results of the analysis demonstrate that there is no significant difference in the overall average of the vessels' incidents ($F = 0.558$, $p = 0.461$) as presented in Figure 6. Detailed analyses also show more variations between the two OSVs. Significant differences are confirmed in the case of water on deck ($F = 7.310$, $p = 0.012$) and moving cargo on deck ($F = 7.039$, $p = 0.015$). The results are presented in Table 10.

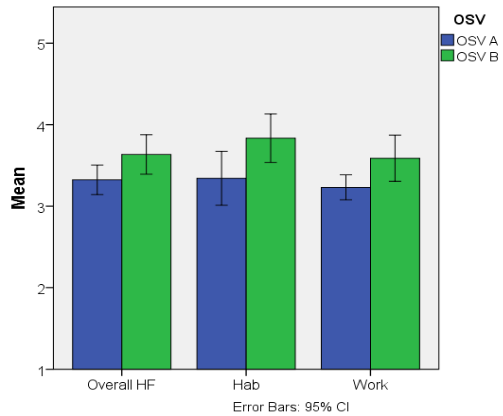

Figure 4 Human factors assessment on two different OSV designs in the Norwegian Sea

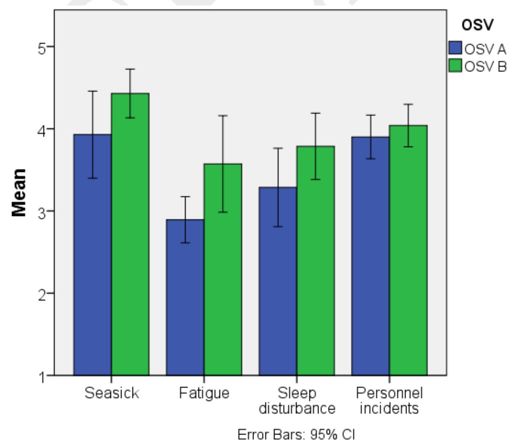

Figure 5 Mean frequencies of personal incidents perceived by the crew

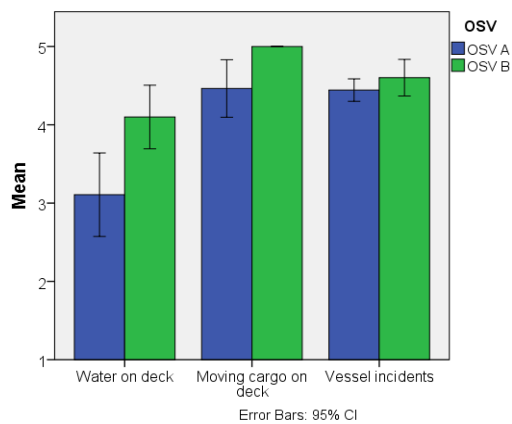

Figure 6 Mean frequencies of related incidents on vessels, as perceived by the crew of two OSVs

Table 8 Descriptive statistics and ANOVA table for human factors evaluation as a result of different OSV design

		Descriptives				ANOVA					
		N	Mean	Standard Dev	Standard Error		Sum of Squares	Df	Mean Square	F	Sig.*)
Habitability	OSV A	16	3.343	0.622	0.155	Between Groups	1.811	1	1.811		
	OSV B	14	3.835	0.513	0.137	Within Groups	9.224	28	0.329	5.498	0.026
	Total	30	3.572	0.617	0.113	Total	11.035	29			
Workability	OSV A	16	3.232	0.287	0.072	Between Groups	0.950	1	0.950		
	OSV B	14	3.589	0.491	0.131	Within Groups	4.371	28	0.156	6.086	0.020
	Total	30	3.398	0.428	0.078	Total	5.321	29			
HF on OSV	OSV A	16	3.323	0.339	0.085	Between Groups	0.723	1	0.723		
	OSV B	14	3.634	0.418	0.112	Within Groups	3.992	28	0.143	5.071	0.032
	Total	30	3.468	0.403	0.074	Total	4.715	29			

*) Bonferonni correction was applied; $p < 0.05/3$; $p < 0.017$ for significant results

Table 9 Descriptives statistics and ANOVA table for personnel incidents

		Descriptives				ANOVA					
		N	Mean	Standar Dev	Standard Error		Sum of Squares	df	Mean Square	F	Sig. *)
Seasick	OSV A	15	3.933	0.884	0.228	Between Groups	1.776	1	1.776		
	OSV B	14	4.429	0.514	0.137	Within Groups	14.362	27	0.532	3.339	0.079
	Total	29	4.172	0.759	0.141	Total	16.138	28			
Fatigue	OSV A	15	2.900	0.471	0.121	Between Groups	3.265	1	3.265		
	OSV B	14	3.571	1.016	0.272	Within Groups	16.529	27	0.612	5.333	0.029
	Total	29	3.224	0.841	0.156	Total	19.793	28			
Sleep disturbance	OSV A	14	3.286	0.825	0.221	Between Groups	1.750	1	1.750		
	OSV B	14	3.786	0.699	0.187	Within Groups	15.214	26	0.585	2.991	0.096
	Total	28	3.536	0.793	0.150	Total	16.964	27			
Personnel Incidents (Overall)	OSV A	15	3.890	0.446	0.115	Between Groups	0.160	1	0.160		
	OSV B	14	4.039	0.448	0.120	Within Groups	5.399	27	0.200	0.799	0.379
	Total	29	3.962	0.446	0.083	Total	5.559	28			

*) Bonferonni correction was applied; $p < 0.05/4$; $p < 0.013$ for significant results

Table 10 Descriptive statistics and ANOVA table for vessel incidents

		Descriptives				ANOVA					
		N	Mean	Std Dev	Std Error		Sum of Squares	df	Mean Square	F	Sig. *)
Water on deck	OSV A	15	3.167	0.919	0.237	Between Groups	4.630	1	4.630		
	OSV B	12	4.000	0.603	0.174	Within Groups	15.833	25	0.633	7.310	0.012
	Total	27	3.537	0.887	0.171	Total	20.463	26			
Moving cargo on deck	OSV A	14	4.464	0.634	0.170	Between Groups	1.674	1	1.674		
	OSV B	10	5.000	0.000	0.000	Within Groups	5.232	22	0.238	7.039	0.015
	Total	24	4.688	0.548	0.112	Total	6.906	23			
Vessels' Incidents	OSV A	16	4.401	0.262	0.065	Between Groups	0.425	1	0.425		
	OSV B	14	4.162	1.249	0.334	Within Groups	21.306	28	0.761	0.558	0.461
	Total	30	4.289	0.866	0.158	Total	21.731	29			

*) Bonferonni correction was applied; $p < 0.05/3$; $p < 0.017$ for significant results

The moving cargo on deck data did not satisfy the assumption of equal variance. All crew on OSV B answered "never", meaning there was no variation in the moving cargo data from OSV B. Instead, a *t*-test was used to examine the situation of moving cargo on OSV A by defining the test value of 5.0. The result verifies the difference in moving cargo on OSV A compared to OSV B ($t = -2.876$, $p = 0.013$).

Table 11 Results of stepwise linear regression analysis of personnel incidents on board

Dependent variable	Independent variables entered	Adjusted R^2	Coef	Const	F	Sig
Seasickness	Hab	0.120	0.456	2.494	6.474	0.015
Fatigue/tired	Hab	0.138	0.501	1.464	7.402	0.010
Stumble or hit an object	N/A					
Slip, fall or loss of balance	N/A					
Misoperate a switch/control	N/A					
Confused by the system	N/A					
Fail to follow the system/procedure	N/A					
Sleep disturbance or sleep interrupted	Hab	0.143	0.472	1.844	7.519	0.009

Table 12 Results of stepwise linear regression analysis of vessel related incidents on board

Dependent variable	Independent variables entered	Adjusted R^2	Coef	Const	F	Sig
Loss of power/black out	N/A					
Loss of navigation/control	N/A					
Contact/collision	N/A					
Water on deck	N/A					
Moving cargo on deck	N/A					
Falling objects	N/A					
Fire or explosions	Maint	0.181	-0.282	5.757	9.393	0.004
Bulk cargo spill	N/A					

5.5. THE EFFECT OF HUMAN FACTORS RATING TO INCIDENTS ON BOARD

A stepwise regression analysis was performed to test the effect of human factors rating to incidents on board (H_7 and H_8). Stepping criteria of 0.05 for entry level and 0.10 for removal were used. The average overall score for personnel incidents (Section B) was regressed by the human factors ratings: the overall score and the dimensions habitability, workability, controllability, maintainability and OHS. The result show that there was no significant variable entering the equation. The same method was applied to related incidents on the vessels (Section C), and no human factor dimension were found significant, affecting the equation.

More detailed analysis was conducted for each personnel incident; seasickness, fatigue, stumble, slip, misoperate a switch, confused by the system, fail to follow procedure and sleep disturbance, as well as vessel incident: loss of power, loss of navigation/control, water on deck, moving cargo on deck, falling objects, fire and cargo spill. The results are presented in Table 11 and Table 12. No specific hypothesis was defined explicitly at this stage of the study, but it is obvious that a significant relationship between relevant variables should be expected: for instance habitability would have an impact on sleep disturbance, fatigue and seasickness. A relationship between habitability and misoperating a switch/control incident would not be expected. Controllability was expected to have a significant effect on misoperating a switch/control.

The results show that habitability has a positive effect on the frequency in which personnel on board are seasick, or experience fatigue and sleep disturbances. The better the habitability the lower the frequency of crew seasickness. Simultaneously, they become more fit and experience fewer sleep disturbances. Some 12% to 14% variance in the incidents can be explained by habitability as shown by the adjusted R^2 (in Table 11).

Maintainability had a significant effect on the probability of fire or explosion, in incidents on the vessel; however the relationship is counter-intuitive. It means that the higher the maintainability level the higher the frequency of fire or explosion on board. About 18.1% of the variance of fire or explosion can be explained by maintainability.

6. DISCUSSIONS

6.1. HUMAN FACTORS RATING

The main conclusion from the literature survey [11, 12] and the exploratory surveys [13, 14] is that human factors have been addressed in OSV design and been taken seriously. Quantitative measurements and inferential statistics in this study support that finding. There is no doubt that human factors are addressed in these two OSVs, as rated by the crews. It was recognised during the exploratory surveys that the crews were satisfied with habitability and less satisfied with the maintainability. It was also revealed in the exploratory study that OHS was addressed without compromise. The literature survey indicated that habitability (or comfort) was the most comprehensive dimension covered by the existing documents, and safety-related elements were the only dimension made compulsory. These findings are all verified in this study. Habitability is rated as satisfactory, OHS is rated most highly and maintainability lowest. The relationships between the existing rules, regulations and other documents about implementation are convincing.

The findings provide a response to the claim that human factors are overlooked in the design of marine systems [9, 10]. As revealed in this study, human factors are not overlooked; but have been addressed adequately in OSV design. The conclusion is obviously limited for generalisation, but it certainly shows the ability of the industry to include human factors considerations in marine systems design.

It is also important to point out that the concept of “human factors” is quantifiable and measurable. The method used in this study can be improved further and used to analyse the implementation of human factors on marine systems.

6.2. THE EFFECT OF DESIGN ON HUMAN FACTORS RATING

The results of the analysis show a strong indication that design can have a considerable impact on human factors assessment. It is also evident that design can influence dimensions such as habitability and workability, despite the numeric corrections that must be taken into consideration in the study. The number of respondents was rather small and the number of hypotheses was one too many that it lowered the *p*-level. The vessels were also similar. The study did signify the ability to differentiate a good ship design in relation to human factors. The two OSVs surveyed were built for the same purpose, in approximately the same period of time, following the same regulations and class, and operating in the same area, but designed by two different groups and yet demonstrate different levels of human factors ratings. The crew on OSV B are more satisfied with their vessel than the crew on OSV A with their vessel. This may be because the superstructure on OSV B is located at the aft where motion is usually less compared to the bow. The crews are located far away from the splash zone where slamming occurs and also away from the bow thrusters which are noisy and disturbing. The disadvantage of having the superstructure at the aft is the appearance. OSV B looks unusual compared to the traditional OSVs. Some of the equipment installed on OSV B is of a higher standard than that on OSV A, such as the dynamic positioning system level 3 used on OSV B, where OSV A uses level 2 system. Naturally, there is a price that must be paid for the extra investment. The questions is who will pay the price and at what expense?

6.3. THE EFFECT OF DESIGN ON INCIDENTS ON BOARD

The effect of different OSV design in relation to comfort was recognised in the previous survey [13, 14] and is partly confirmed in this study using quantitative methods. The crew on OSV B experiences less fatigue, due to a more stable, less motion sensitive vessel. It is possible that the difference in fatigue level may be caused by different watch keeping regimes rather than the design. A number of studies under the HORIZON project indicated that the 6-on/6-off regime was more tiring that a 4-on/8-off system [22]. This finding verifies the fact that the crews on OSV B report less fatigue, as they implemented the 4-on/8-off system, however, a study of four supply vessels in the Norwegian Sea showed that different watch keeping regimes had no significant effect on the fatigue level experienced by the seafarers [23]. We did question the crews on both OSVs regarding the watch regimes. The company had endorsed vessels working in the area implementing the 4-on/8-off system, instead of the 6-on/6-off. The crews on OSV A insisted on keeping the old 6-on/6-off system with which they were more comfortable. Most also believed that there would be no difference in terms of their performance, and they tried to convince the management of this. Apparently, further investigations are required to clarify the relationships between these variables of interest. It will be interesting to determine the effects of habitability and watch regime on fatigue.

The difference with respect to seasickness and sleep disturbance is indicative but not convincing. The quantitative survey was conducted in summer, when the sea state is generally gentle. This situation probably explains why the variations in seasickness and sleep disturbance are somewhat inconclusive. Another possible explanation could be the adaptability of the crews. Typically adaptation to motion sickness on board occurs within a period of several days [24, 25], however, the fact that the crews on OSV B experienced less motion and slamming and heard fewer disturbing noises from the tunnel thrusters explains the difference in sleep disturbance incident.

OSV B is a stable vessel which reduces the movement of cargo on deck especially during high seas. This was verified by the survey. All the crews on OSV B responded “never” to the question: ‘how often does the vessel experience moving containers on deck’ It is the most positive rating in the scale. The same answer was given to the item contact/collision incident, which was also responded to with “never” by the crews on both OSVs. This shows how stable OSV B is, according to the crew assessment, based on their personal experience.

The finding regarding water on deck incidents was quite unexpected. Designed with superstructure at the fore, OSV A should have a deck relatively protected from green water compared to B. The result shows the opposite. Further investigation reveals that OSV B is higher than OSV A. There is an approximately one meter difference in the distance from the sea level to the cargo deck between OSV A and B. This could be why the crews notice less water on deck on OSV B. Another possible explanation could be the height of the freeboard and the shape of the bow, including the bulbous bow. The location of the longitudinal centre of gravity (COG) on OSV A is relatively forward. The vessel tends to experience trim by bow which lowers the freeboard and allows more water on deck. The COG on OSV B is instead to the aft. The vessel tends to trim by stern, leading to higher freeboard, and thus less water on deck. The detail bow design of OSV A differs from that of OSV B (Figure 2). The bow on OSV A was designed with a bigger rake angle and equipped with a bigger bulbous bow. OSV A was designed to operate at a slightly higher speed than OSV B. A detailed hydrodynamic analysis is required to explain the phenomena of water on deck on these two OSVs.

6.4. THE EFFECT OF HUMAN FACTORS ASSESSMENT ON INCIDENTS ON BOARD

The overall human factors rating had no significant effect on the overall incidents on board, but specific dimensions emerged and were confirmed to have a considerable effect on their corresponding incidents.

Habitability was revealed as one dimension that influenced personnel incidents on board. This could be a good argument for paying more attention improving habitability in order to reduce the probability of people getting seasick, to reduce sleep disturbance and to increase crew performance.

An appealing finding is the negative relationship found between maintainability in relation to fire and explosions. Such a phenomenon is not novel. Perrow mentions the case of 'radar assisted collisions' [6]. Norman argues that as automation rises in industry, it often increases the chance of human error when failures do occur [26]. Better facilities can increase a lack of awareness, such as automation in the early development and implementation phase, which often comes with unexpected adverse effects. The grounding of the *Royal Majesty* shows the role of automation leading to error in navigation [27]. It seems to be a similar mechanism here. The crew on OSV B valued maintainability relatively more highly than those on OSV A. On the other hand, on OSV B the incident of fire/explosions scored lower, meaning that the frequency of fire is higher.

OSV B is a gas fuelled vessel. This is a new technology that requires a certain level of safety and a different mode of preparedness. The designer had put a number of precautions and mitigating measures together with the system. A fire did break out, not on OSV B, but on an older sister vessel with almost the same specification. This could be an explanation of the negative trend in answers relating to maintainability and fire/explosions. Most of the crew on OSV B were aware of the fire, and thus responded to the questionnaire accordingly. These findings can also be interpreted conversely. Since the people on OSV B had experienced a fire on their vessel, they had learned the lesson, become more aware of maintainability on their vessels and made significant improvements. Further investigation of the data, by removing responses from OSV A showed that the result became weaker. This means that the argument that 'OSV B experienced fire, therefore increased maintainability' must be rejected, because the response from the crew on OSV A also counts. The probability of multi-collinearity occurring was also checked and it did not. Maintainability has a negative correlation with fire. This leaves us with the only possible explanation that *better facilities* (in this case: maintainability) in some instances *may lead to lack of awareness* (in this case: fire/explosion) incidents. Yerkes-Dodson law describes the relationship between arousal and performance as represented by an inverted U curve [28] where performance increases with arousal to a certain point, then decreases with higher levels of stress. In this case, better maintainability provides lower arousal, hence lower performance.

Examining the outcome of the regression analysis, it appears that personnel incidents are more sensitive to variation in human factors rating than vessel incidents. All the significant intercept coefficients in Section B are higher relative to those in Section C. The validity of the findings can therefore be concluded.

All the above incident analyses (in Subsections 6.3. and 6.4) were based on questionnaires that were administered once. Questionnaires are subjective and a single administration is slightly inaccurate for some of the measured qualities such as incidents which fluctuate over time. Although, the questionnaires used in this study were confirmed as valid, it would be beneficial to verify the findings with the existing incident/accident records as well as the performance records. More accurate methods can be used to measure fatigue, seasickness and sleep disturbances in real time. Combination with other measurements such as sea states, ship motion, noise levels and crew performance would be advantageous to evaluate the design in relation to human factors. The results of hydrodynamic tests can also be used to analyse the performance of a vessel including motion, deck movement, water on deck, and slamming.

With regard to the introductory part of the study, it has been confirmed that some errors were inherited from the design stage [5-8] such as dynamic positioning error and blackout that were reported previously [13, 14]. The relationships between design, human factors rating and incidents were also revealed in this study. Although incidents are not "errors" *per se,* the connections are undeniable. The study also provides an index that can be used as an indicator of how much variation in a human factors rating will affect the corresponding incident.

7. CONCLUSIONS

Surveys were conducted on two offshore supply vessels in the Norwegian Sea to reveal the application of human factors principles in ship design via questionnaires. Information regarding personnel incidents and vessel incidents was also gathered. As many as eighteen hypotheses were established. Statistical analyses were performed. A summary of all the hypotheses tested and the results can be found in the following list:

H_1 : Confirmed
Human factors are significantly addressed in the design of marine systems.

H_{2i} : Confirmed
Habitability is significantly addressed in the design of marine systems.

H_{2ii} : Confirmed
Workability is significantly addressed in the design of marine systems.

H_3 : Confirmed
Dimensions of human factors are not rated equally in the design of marine systems.

H_{3i} : Confirmed
OHS is rated more highly than workability and maintainability.

H_{3ii} : Confirmed
Maintainability is rated lower than habitability, workability and OHS.

H_4 : Inconclusive
There is indication that human factors rating varies as a result of OSV design, but the finding is inconclusive

H_{4i} : Inconclusive
There is indication that habitability rating varies as a result of OSV design, but the finding is inconclusive

H_{4ii} : Inconclusive
There is indication that workability rating varies as a result of OSV design, but the finding is inconclusive

H_5 : Rejected
There is no variation in personnel incidents as the result of OSV design

H_{5i} : Inconclusive
There is a slight variation in personnel being seasick as a result of OSV design, but the finding is inconclusive

H_{5ii} : Inconclusive
There is a slight variation in fatigue level of personnel as the result of OSV design, but the finding is inconclusive

H_{5iii} : Inconclusive
There is slight variation in personnel experiencing sleep disturbances as a result of OSV design, but the finding is inconclusive

H_6 : Rejected
There is no variation in vessel incidents as the result of OSV design

H_{6i} : Confirmed
There is a significant difference in water on deck incident as the result of OSV design

H_{6ii} : Confirmed
There is a significant difference in moving cargo on deck incident as the result of OSV design

H_7 : Mostly rejected, partly confirmed
Human factors rating has no significant effect on personnel related incidents, however, habitability is revealed to have a positive effect on the frequency of personnel becoming seasick, fatigued and experiencing sleep disturbance.

H_8 : Mostly rejected, partly confirmed
Human factors evaluation has no significant effect on vessel related incidents, however, maintainability is revealed to have a negative effect on the probability of fire or explosion.

Based on quantitative surveys performed on two OSVs in the Norwegian Sea, it can be concluded that human factors are far from being neglected. It has been addressed satisfactorily in the design of marine systems, not perfectly but adequately. Human factors is a broad subject with many dimensions. The level of knowledge and implementation of human factors varies from one dimension to another. The most satisfactory dimension is occupational health and safety. Maintainability is considered the least satisfactory, but still adequate.

Although all analyses regarding the effect of OSV design on human factors rating and incidents were inconclusive, the indication is promising. Conversely, the relationships between a certain human factor rating and particular incidents were revealed. A good human factors rating for habitability is revealed to have a positive effect on personnel incidents; sleep disturbances, fatigue and seasickness. At the same time, a good rating for maintainability was perceived to have a negative effect on the probability of fire or explosions on board.

This study makes a contribution by presenting a holistic picture of human factors in ship design, involving most human factors dimensions, evaluating the effect of the design on the human operators and trying to draw a link between application of human factors and the likelihood of incidents.

The study has identified limitations. The way human factors are considered in the process of design has not been examined. The sample size is small, obviously restricting generalisation of the results. The questionnaires that were developed in this research are unique; some of the questions are relevant for offshore supply vessel design and operation. Nonetheless, methods introduced here can potentially be applied to other vessels and the results can be analysed to give a meaningful picture regarding actual risk in reality. It is expected that this study provides evidence for those who still believe that "human factors" is a difficult entity to deal with. Human factors exist, its effects are real and measureable, and affect performance and safety on board a vessel. The relationship is also measureable.

Some recommendations based on this study are made:

- Publish more documents related to human factors implementation, especially in the area of habitability, controllability and workability.
- Increase the level of enforcement in human factors implementation, at least for the most fundamental issues, such as habitability and workability.

Some recommendations for further research are proposed as follows:

- To investigate the paradoxical relationship between maintainability and fire incident.
- To investigate more thoroughly the relationships between the designs, the human factors ratings and the effects of those variables on performance, mishaps, and incidents using more accurate data collection methods. Obviously, more data is required.
- To expand the study with more samples and larger populations, including other types of vessels and other areas of the world.[2]

ENDNOTE

The analysis performed in this study was continued to evaluate the theoretical construct of human factors in ship design and operations. The same data was used and the result is presented in a separate note in the same edition.

8. REFERENCES

1. BAKER, C.C. AND D.B. MCCAFFERTY. *Accident database review of human-element concerns: What do the results mean for classification?* International Conference on Human Factors in Ship Design, Safety and Operation, London: Royal Institution of Naval Architects, 2005.
2. WAGENAAR, W.A. and J. GROENEWEG, *Accidents at sea: multiple causes and impossible consequences*. International Journal of Man-Machine Studies, 27: p. 587-598, 1987.
3. MOORE, W.H. and R.G. BEA, *Management of Human Error in Operations of Marine Systems Final Joint Industry Project Report*. HOE-93-1. University of California at Berkeley, CA, 1993.
4. MCCAFFERTY, D.B. and C.C. BAKER. *Trending the Cause of Marine Incidents*. International Conference on Learning from Marine Incidents, London: The Royal Institution of Naval Architects, 2006.
5. REASON, J., *Human Error,* New York: Cambridge University Press, 1990.
6. PERROW, C., *Normal Accidents: Living with High-risk Technologies,* New Jersey: Princeton University Press, 1999.
7. CALHOUN, S.R. and S.C. STEVENS, Human Factors in Ship Design. *Ship Design and Construction*, Ed. T. Lamb. Vol. I. The Society of Naval Architects and Marine Engineers: Jersey City, NJ, 2003.
8. KINNERSLEY, S. and A. ROELEN, The contribution of design to accidents. *Safety Science,* 45(1-2): p. 31-60, 2007.
9. MILLER, G.E. *The Omission of Human Engineering in the Design of Offshore Equipment and Facilities: How Come?* Offshore Technology Conference (OTC), Houston, Texas, 1990.
10. GRAVESON, A. *Human Factors in Ship Design and Operation*. International Conference on Human Factors in Ship Design and Operation, London: The Royal Institution of Naval Architects, 2002.
11. RUMAWAS, V. and B.E. ASBJØRNSLETT. *A Content Analysis of Human Factors in the Design of Marine Systems*. International Conference on Ship and Offshore Technology (ICSOT) Surabaya: The Royal Institution of Naval Architects, 2010.
12. RUMAWAS, V. and B.E. ASBJØRNSLETT, A Content Analysis of Human Factors in Ship Design. *Trans RINA International Journal of Maritime Engineering,* 156 (Part A3), 2014.
13. RUMAWAS, V. and B.E. ASBJØRNSLETT. *Offshore supply vessels design and operation: A human factors exploration*. European Safety and Reliability Conference (ESREL), Troyes: European Safety and Reliability Association (ESRA), 2011.
14. RUMAWAS, V. and B.E. ASBJØRNSLETT, Exploratory Surveys of Human Factors on Offshore Supply Vessels in the Norwegian Sea. *Naval Engineers Journal*, 125(2), 2013.
15. LLOYD'S REGISTER, *The Human Element: An Introduction*, Lloyd's Register: London, 2008.
16. IMO, *Guidelines on Ergonomic Criteria for Bridge Equipment and Layout*, International Maritime Organization: London, 2000.
17. LLOYD'S REGISTER, *The Human Element Best Practice for Ship Operators*, Lloyd's Register: London, 2009.
18. ABS, *Guidance Notes for The Application of Ergonomics to Marine Systems*, American Bureau of Shipping: Houston, TX, 2003.
19. ABS, *Guide for Crew Habitability on Ships*, American Bureau of Shipping: Houston, TX, 2001.

[2] For this reason, the authors will share the questionnaires and methods of analysis with other researchers who are interested in performing similar investigations.

20. ABS, *Guide for Passenger Comfort on Ships*, American Bureau of Shipping: Houston, TX, 2001.
21. DNV, *Rules for Classification of Ships Comfort Class*, in *Special Service and Type Additional Class,* Det Norske Veritas: Høvik, Norway, 2009.
22. HORIZON, *Project Horizon - a wake-up call.* Seventh Framework Programme, FP7-234000, 2012.
23. KONGSVIK, T., K. STØRKERSEN, and J.H. HANSEN. *The possible impact of different watch keeping regimes at sea on sleep, fatigue, and safety*. European Safety and Reliability Conference (ESREL), Troyes, France: European Safety and Reliability Association (ESRA), 2011.
24. CALVERT, J.J., *Motion Sickness, Crew Performance, and Reduced Manning in High-Speed Vessel Operations*, Naval Postgraduate School: Monterey, CA, 2005.
25. MCCAULEY, M.E., J.W. ROYAL, C.D. WYLIE, J.F. O'HANLON, and R.R. MACKIE, *Motion Sickness Incidence: Exploratory Studies of Habituation, Pitch and Roll , and the Refinement of a Mathematical Model.* Human Factors Research, Inc., 1976.
26. NORMAN, D.A., *The* 'Problem' with Automation: Inappropriate Feedback and Interaction, not 'Over-Automation'. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, 327(1241): p. 585-593, 1990.
27. LÜTZHÖFT, M. and S.W.A. DEKKER, On your watch: Automation on the bridge. *Journal of Navigation*, 55(GEOBASE): p. 83-96, 2002.
28. YERKES, R.M. and J.D. DODSON, The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, 18(5): p. 459-482, 1908.

Appendix D: Criteria/Standard Evaluation

Human Factors Evaluation in Ship Design: A Case Study on Offshore Supply Vessels in the Norwegian Sea, Part I: Theoretical Background and Technical Constructs

Naval Engineers Journal (accepted)

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Human Factors Evaluation in Ship Design: A Case Study on Offshore Supply Vessels in the Norwegian Sea, Part I: Theoretical Background and Technical Constructs

Keywords: Human factors, Comfort, Noise, Motion, Slamming, MII, MSI, Offshore supply vessel, Human factors criteria

Abstract

Surveys were conducted in the Norwegian Sea to evaluate the existing human factors standards and their implementations on two different offshore supply vessels designs. The results are reported in two parts. This paper (Part I) covers the theoretical background and reports all the technical aspects of the research: noise, motion and slamming that includes measurements, analyses and evaluations. Noise level and motion were measured by means of sound level meter and accelerometer respectively. Data were collected in two periods: summer and winter. Results of measurements were compared with the existing criteria and discrepancies are identified. It can be concluded that some of the existing human factors criteria are inadequate and less relevant to the actual experience on board and they are ineffective to induce comfort on both supply vessels studied. Improvements and revisions are strongly recommended with respect to noise, motion and slamming criteria. An extended methodology to predict MII is also advised. The other paper (Part II) reports the human factors subjective evaluation performed by the seafarers where multivariate analyses were performed to reveal a human factors model in ship design and operations.

Introduction

Motivation

Working as seafarers is demanding. It is not only a job, but it is a way of living. They are isolated from the world, separated from their family and physically cramped with their shipmates. They have relatively long working hours, often with monotonous working and living conditions. Occasionally, the situation becomes harsh and risky (Alderton 2004; Oldenburg, Baur and Schlaich 2010).

Almost all accident investigation reports mention fatigue as a feature underlying accidental events (Alert! 2007). Human fatigue is confirmed to be closely related to failures of situation awareness and human errors which then leading to accidental events (Baker and McCafferty 2005). Unfortunately, fatigue has been under-researched in the maritime domain compared to other transport sectors (Allen, Wadsworth and Smith 2008).

Fatigue is caused by factors such as lack of sleep, poor quality of sleep, insufficient rest time, noise, vibration, ship movement, and excessive work load (Smith, Allen and Wadsworth 2006; Alert! 2007). Motion and noise were also found as major causes of sleep interruptions (Haward, Lewis and Griffin 2009). Motion can cause operator performance to degrade, and thus safety (Ross 2009). Motion of a vessel at sea may interfere with the crew members' balance, causing motion-induced interruptions (MII), increasing the energy expenditure and increasing the levels of fatigue, drowsiness and dizziness. Motion also creates stomach awareness, induces motion sickness incidences (MSI) and causes vomiting incidence (Stevens and Parsons 2002; Haward et al. 2009).

Advice has been given by relevant organizations (Smith et al. 2006; Alert! 2007; ITF Seafarers 2012) how to mitigate and manage fatigue at sea during operations. Measures proposed are sleeping pattern, watch schedule, environmental manipulation, workload management and dietary arrangement. Several measures have been addressed to the design of the vessel; including to provide comfortable accommodations, to minimize noise and vibration, to improve indoor climate and to provide better working facilities to reduce workload.

Prescriptive guides and voluntary standards on how to enhance vessels' design by improving habitability and comfort for the sake of the crew are available and ready to apply. Controlling the environment by design will increase the comfort level of the personnel, give them the opportunity for better sleep and rest, and increase their performance. For instance, Det Norske Veritas (DNV) publishes an additional comfort class which is divided in two groups: noise and vibration (COMF-V notation) and indoor climate (COMF-C notation) (DNV 2009). The noise and vibration criteria are distinguished into three levels of comfort: 1 (highest), 2 (medium) and 3 (acceptable). Table 1 shows examples of noise criteria on several different locations on the vessel. Measurements should be made according to the ISO 2923 standard.

Table 1 Crew Accommodation Noise levels in dB(A) (DNV 2009)

Locations	Comfort rating nr (*crn*)		
	1	***2***	***3***
Wheelhouse	60	60	65
Crew cabins	50	55	60
Crew public spaces	55	60	65
Engine control room	70	70	75
Open deck recreation	70	70	75

The American Bureau of Shipping (ABS) publishes several guides covering habitability and comfort (ABS 2001; ABS 2001). The guides cover five comfort aspects of vessel and layout: accommodations criteria, whole-body vibration, noise, indoor climate and lighting. ABS gives HAB notation for a vessel complying with the minimum criteria for those five aspects, and HAB+ notation for more stringent habitability criteria. In parallel with ABS' outline, the International Maritime Organization (IMO) publishes a framework to consider ergonomics and work environment to reduce accidents and human errors on ships (IMO 2006). In a separate document, IMO has developed and published a code on noise levels on board ships (IMO 1981). Table 2 shows examples of criteria for maximum noise level on ships.

Table 2 Noise levels on board ships (IMO 1981)

Noise level limits	**dB(A)**
Machinery spaces (continuously manned)	90
Machinery spaces (not continuously manned)	110
Machinery control rooms	75
Workshops	85
Non-specified work spaces	90
Normally unoccupied spaces	90

Apart from vibration, noise, and indoor climate, criteria for ship motion are not covered by the classification societies or other regulatory bodies like IMO. Two references often cited for ship motions criteria are North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 4154 (NATO 2000) and Nordic Co-operative Organization for Applied Research (NORDFORSK 1987), covering maximum roll amplitude, pitch amplitude, vertical and lateral acceleration. Table 3 and Table 4 show operability criteria set by the two references. Table 5 presents the MII risk levels used by Graham (1990).

Table 3 Personnel criteria limits (NATO 2000)

Recommended Criteria	**Limit**	**Location**
Motion Sickness Incidence (MSI)	20% of crew @ 4 hrs	Task location
Motion Induced Interruption (MII)	1/min	Task location
Default Criteria	Root mean square (RMS)	
Roll	4°	
Pitch	1.5°	
Vertical acceleration	0.2 g	Bridge
Lateral acceleration	0.1 g	Bridge

Table 4 Operability and criteria set for ships (NORDFORSK 1987)

General Operability Limiting Criteria for Ships	For merchant ships		
Vertical acceleration RMS, bridge	0.15 g		
Lateral acceleration RMS, bridge	0.12 g		
Roll (RMS)	6°		
Probability of slamming (for up 100 m long vessel)	0.03		
Criteria with regard to acceleration and roll	Vert acc	Lat acc	Roll
Light manual work (RMS)	0.20 g	0.10 g	6.0°
Heavy manual work (RMS)	0.15 g	0.07 g	4.0°
Intellectual work (RMS)	0.10 g	0.05 g	3.0°
Transit passengers (RMS)	0.05 g	0.04 g	2.5°
Cruise liner (RMS)	0.02 g	0.03 g	2.0°

Table 5 MII risk levels (Graham 1990)[*)]

Risk Level		MII's per minute
1.	Possible	0.1
2.	Probable	0.5
3.	Serious	1.5
4.	Severe	3.0
5.	Extreme	5.0
*) original source: Baitis, A.E., T.R. Applebee, and T.M. McNamara: "Human Factor Considerations Applied to Operations of the FFG-8 and LAMPS MK III," Naval Engineers Journal, Vol. 96, 1984, pp. 191-199.		

Preliminary surveys on offshore supply vessels (OSVs) were conducted prior to this research where two COMF class vessels were taken as the samples (Rumawas and Asbjørnslett 2013). The surveys identified issues such as high pitch disturbing noise in the cabin, noisy deck, excessive rolling motion and slamming and pitching. Occasionally, being on board one experiences stomach awareness, gets seasick and even vomits.

SCOPE OF WORK

The present research was conducted to answer two questions:

1. Are the existing criteria of human factors in ship design relevant and adequate?

2. What factors considerably influence seafarers' performance at sea?

Due to the extent of the present research, the report is divided into two parts. Part one covers the introduction, methodology and the technical aspects of the research that includes measurements of the environmental conditions, noise and motion combined with some relevant evaluations. Part two covers the multivariate analyses regarding the seafarers' condition and performance and the liable underlying factors.

RESEARCH DESIGN

The overall research design is presented in Figure 1. Before sailing, the vessels receive work orders containing information which offshore facilities they are about to visit and at approximate time. Then, weather forecasts will be provided with information about the wind speed and wave characteristics (significant wave height, *Hs* and peak period, *Tp*) in a particular area as a function of time. During the voyage, the crew registers the environmental conditions at least every four hours in their logbook. The ship responses to the environmental conditions in the form of their own motions are measured during this research together with the noise levels at several locations on the vessel. Surveys are conducted in summer and in winter, as each season has their own environmental characteristics. Direct effects of the environmental condition to seafarers' performance are investigated as well as how the effects are moderated by the different ship designs. Seafarer' performance is assessed in terms of sleeping behavior, symptoms on the watch and performance on watch. Sleeping behavior covers the quality and duration of the sleep and sleep related problems encountered by the seafarers before they go to watch. Symptoms on watch consist of ten aspects including fatigue, tiredness, sleepiness, motion-induced interruptions (MII) or loss of balance, and stomach awareness or motion-sickness incidence (MSI). Performance on the watch is evaluated in terms of cognitive activity, motoric activity and communication. Sleep problems are divided into two: ship-related and non-ship related problems. Watch time and work shift are also included in the model as they may influence performance.

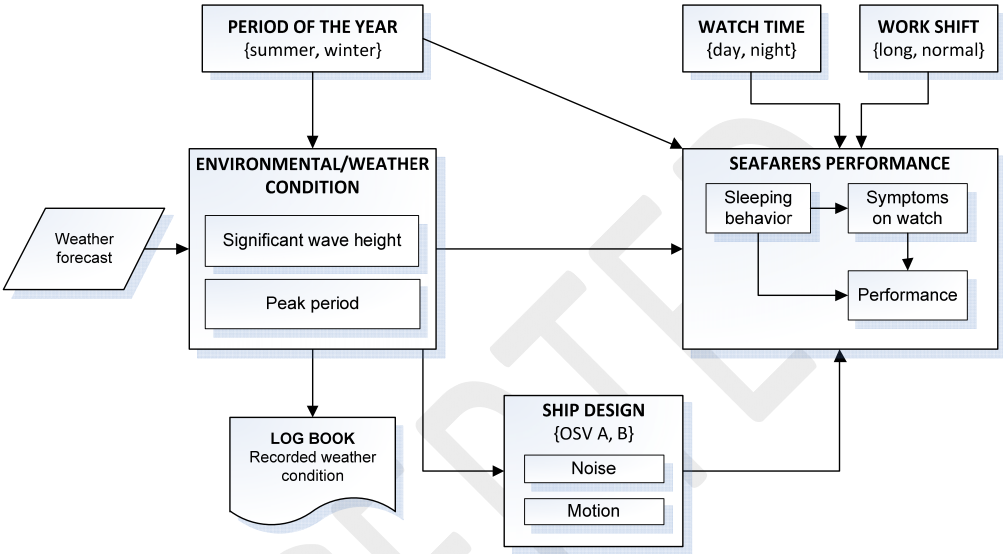

Figure 1 Research design

METHODOLOGY

The field surveys were conducted to collect different types of information simultaneously.

SAMPLES AND DATA COLLECTION

Two offshore supply vessels (OSVs) operating in the Norwegian Sea were chosen as the object for the study. Surveys were conducted in two periods: July 2011, representing summer period and October 2011, representing winter period. On each survey, due to limited resources, both vessels were visited alternately. OSV A followed the standard OSV design, built with the superstructure on the bow. On the other hand, OSV B was built with superstructure at the aft (Figure 2). From a previous study (Rumawas and Asbjørnslett 2013), it was indicated that the vessel OSV B was more stable and quiet than OSV A. Both vessels complied with DNV COMF-V(3).

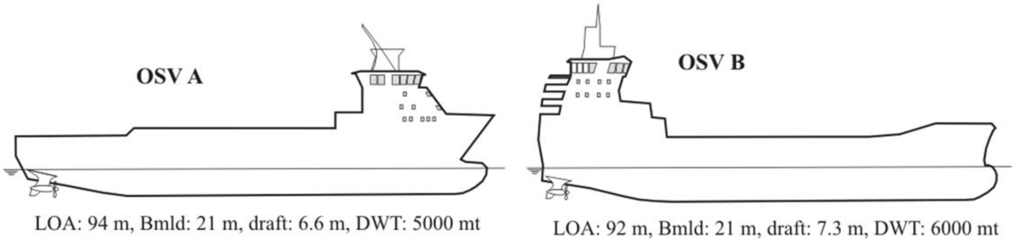

Figure 2 Two different OSV designs (Rumawas and Asbjørnslett 2013)

ENVIRONMENTAL CONDITIONS

Information regarding the upcoming environmental conditions was obtained from weather forecasts. The data was downloaded from the website for any particular location and time. During the voyage, the officers on the bridge also recorded the true wind speed and wave heights in terms of the sea state every four hours. Wind speed measurement was provided by an anemometer installed on the vessel, while the wave height was observed visually.

NOISE LEVEL MEASUREMENT

Noise measurements were performed in accordance with the procedures described in ISO 2923 (ISO 1996) and ISO 20283-2 (ISO 2008) with respect to covering the type and class of instrument, setting and position of the instrument, and length of each measurement. Class 2 sound level meter Bruel & Kjaer Type 2236 was used where A-frequency-weighting was applied. Several locations on the vessel were surveyed: cabin, bridge, engine room (next to the main engines and in the bow thrusters' area), engine control room, cargo deck and dirty mess. Several measurements were conducted on each location for the different modes of operation (working, non-working, etc.). Average equivalent continuous sound levels (L_{eq}) results in decibel (dB) are presented.

SHIP MOTION MEASUREMENT

Motion was measured by using a high-precision tri-axis inertial sensor, ADIS16364, a product of Analog Devices. The sensor can measure tri-axis angular velocities (roll, pitch and yaw) as well as tri-axis translational accelerations (surge, sway and heave) at the same time. The sensor was placed in the cabin, mounted on the floor facing forward parallel to the ship's longitudinal axis and connected to a personal computer by means of a universal serial bus (USB) cable. Figure 3 shows the distance of the sensor relative to the centerline, the midship line and the waterline. Due to some limitations in the study, the location of the sensor could not be kept at the exact same spot.

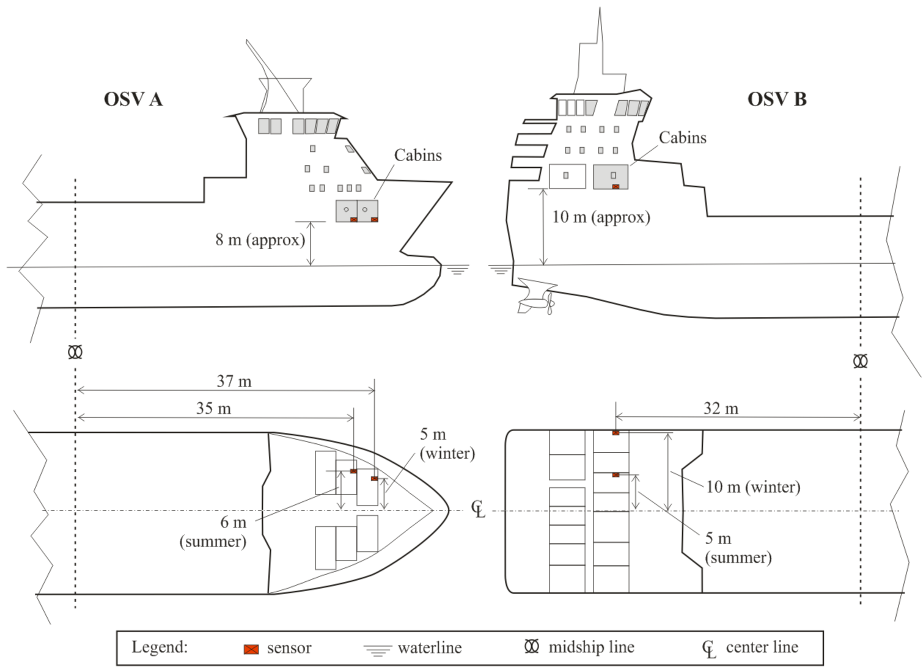

Figure 3 Location of the motion sensor during the survey

Measurements were performed during the whole trip, from the time when the vessel was berthing and loading at the base, sailing, completing the offshore mission, until she returned back to the base. The sampling rate was set to 204 samples per second, which was the lowest frequency. Data was recorded in files, storing 300.000 samples per file. All three rotational velocities and three translational accelerations were recorded simultaneously with time, however only roll (x_gyro), pitch (y_gyro), lateral acceleration (y_acc) and vertical acceleration (z_acc) were further processed and reported. In total 690 files were collected in the period of 283 hours for both OSVs in summer and winter. Recorded data were downsized and a low pass filter was applied to reduce noise and other irrelevant high frequency signals. Rotational velocities were recorded in degrees per second [deg/s] while translational accelerations were in g-force [g]. For further analyses, rotational velocities were integrated to motions and were presented in degrees [deg]. Irregular extreme values were checked and peculiarities caused by errors in measurement were removed.

Results for each 15-minute record were presented in the form time series and spectrum diagram, utilizing a Fast Fourier Transform (FFT) algorithm. Statistical values of the results for each OSV on each trip were calculated and summarized. MII index (Graham 1990) and MSI index (McCauley, Royal, Wylie, O'Hanlon and Mackie 1976) were also calculated by utilizing an existing in-house code. Examples of a 15-minute period of roll and pitch data processed using Matlab v 2012a are presented in Figure 4 (velocity) and Figure 5 (motion). Figure 6 shows an example of lateral acceleration (sideways in y-direction) and vertical acceleration which indicates local heave.

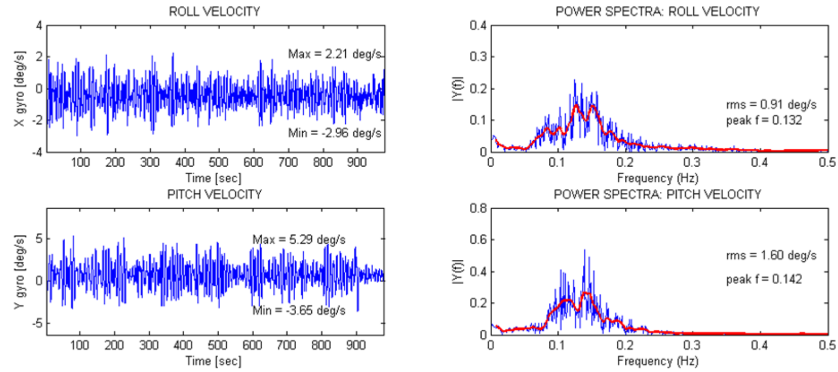

Figure 4 Roll and pitch velocity on OSV A in the winter

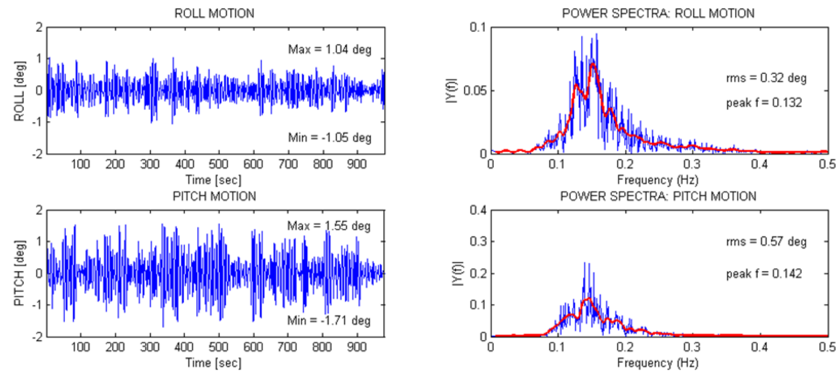

Figure 5 Roll and pitch motion on OSV A in the winter

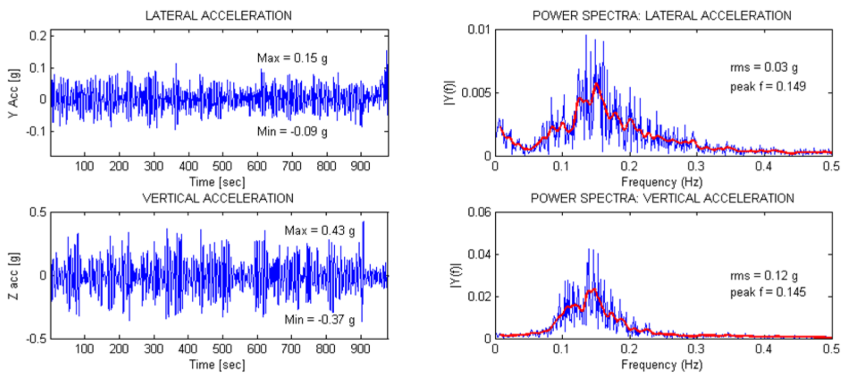

Figure 6 Lateral and vertical acceleration on OSV A in the winter

QUESTIONNAIRES: DAILY DIARIES

An anonymous form was developed based on the NATO questionnaire (Colwell 2000; Haward et al. 2009) and distributed among seafarers to be completed after every watch. A detail description regarding the questionnaire is presented in Part II (Rumawas, Asbjørnslett and Klöckner 2016).

RESULTS

In the summer, the weather was typically calm with light winds and the sea relatively flat. On the contrary, during winter, the weather tended to be harsh, characterized by strong wind and high seas. Sometimes, the vessels were not even allowed to sail and most of the vessels in the area were called in.

Each vessel was visited two times for this study; first in the summer and second in the winter. Each visit took approximately three days which correspond to the length of each mission of the vessel. Results presented in this research cover the environmental conditions or the sea state during the survey (predicted and recorded in the log book), the noise and motion measurements, and the onboard questionnaires filled in by the seafarers after every watch.

ESTIMATED SEA CONDITIONS AND SHIPS' LOG

Figure 7 and Figure 8 show the estimated significant wave height (Hs) and peak period (Tp) along the trip during the survey. During the voyage in summer, the seafarers on OSV B assessed the sea as moderate (sea state 4), while on OSV A they measured the sea as being smooth (sea state 2). In the winter, OSV A mostly logged sea state 5 to 6 (rough to very rough) along the survey, while on OSV B was recorded as 4 (moderate).

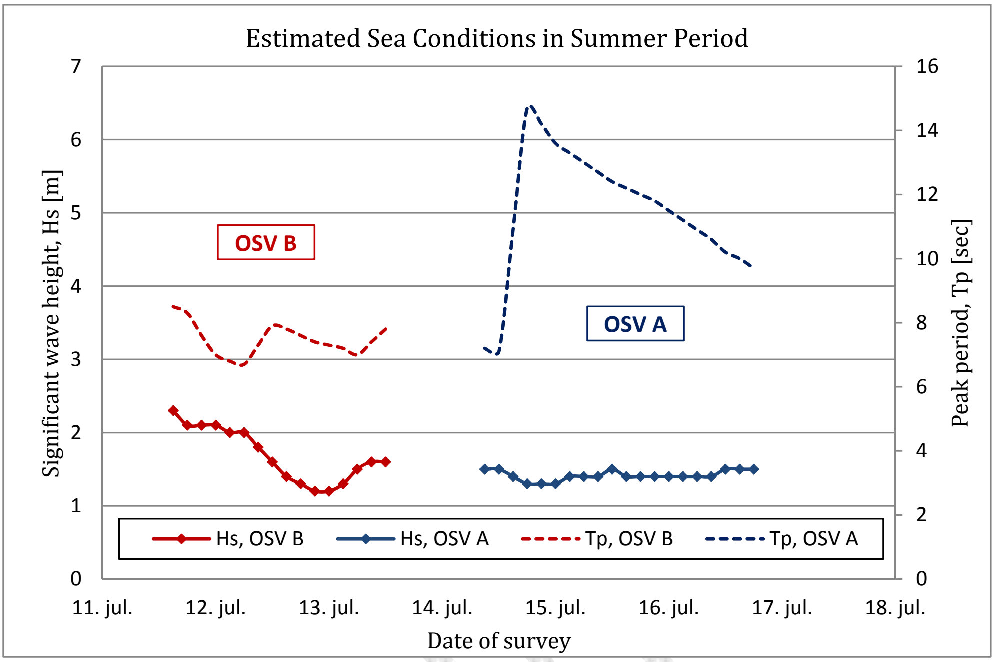

Figure 7 Estimated sea conditions during the survey in summer

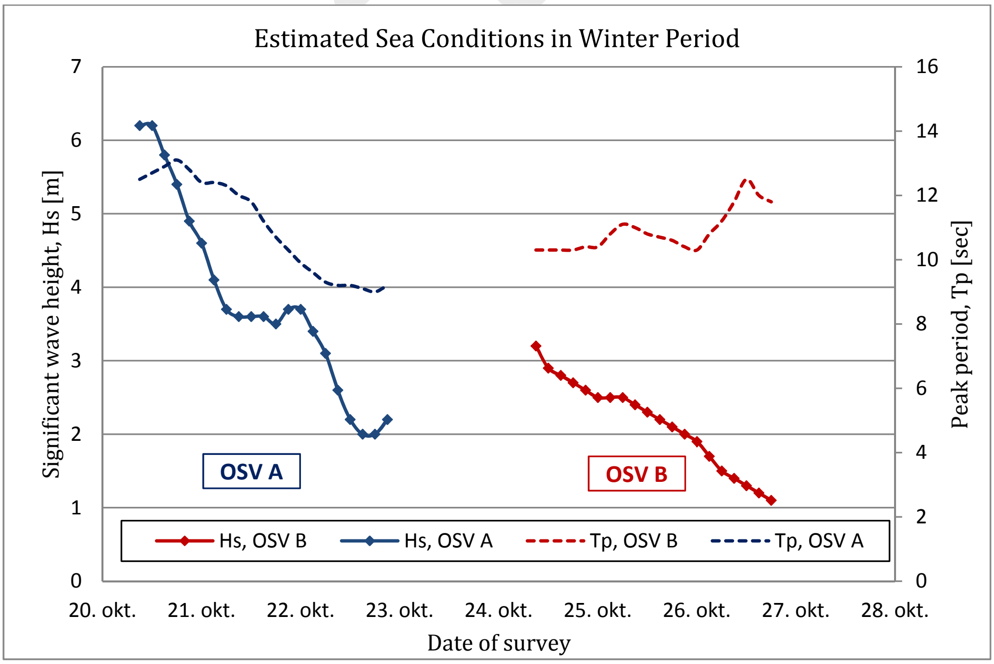

Figure 8 Estimated sea conditions during the survey in winter

NOISE LEVEL MEASUREMENT

Results of noise measurement in different spots on the two OSVs are presented in Table 6. Most of the measurements were conducted more than once in different operational mode. However, the observations did not vary much (+/- 2 dB). All observations did satisfy the criteria set by DNV (Table 1) as well as by IMO (Table 2).

Table 6 Noise level measurement result

Location on the vessel	Summer		Winter	
	OSV A	**OSV B**	**OSV A**	**OSV B**
Bridge		59.7	59.4	57.5
Bridge (with moderate music)	63.2	61.4		
Cabin (normal)	40.9	45.4	42.4	41.8
Cabin (on DP)	49.7		56.7	
Cabin (deck machineries. windlass operating)			49.5	
Cabin (sailing in high seas with slamming)			54.1	
Engine control room (normal)	57.9	66.7	58.9	57.7
Engine control room (with additional noises; music, and people chatting)	71.2			61.7
Engine room (main engines)	104.6	105.9	103.8	104.9
Engine room (bow thrusters)	96.5	101.7	102.3	91.4
Engine room (bow thrusters. non-working)	93.1	73.2	91.7	70.0
Cargo deck (muster station)	71.0	85.9	68.5	83.9
Dirty mess, workshop	67.9	77.7	64.6	78.8

Noise problems caused by air intake to the engine room was reported on the muster station of OSV B (Rumawas and Asbjørnslett 2013). Measurement on the location shows that the noise level was below the limit of 90 dB(A); 85.9 dB(A) in summer and 83.9 dB (A) in winter.

Slamming was reported to be disturbing by the crew on OSV A and high pitch noise caused by tunnel thrusters was reported to interrupt sleep (Rumawas and Asbjørnslett 2013), while on OSV B it was the squeaking noise from the deck machineries, hammering noise from the people working on the deck and creaking noise in the cabin that were found to be disturbing. The measurement performed in this study showed that there was a substantial difference, $F(1, 10)=37.458$, $p<.001$, in the cabin's noise level between normal operation and on DP on OSV A in summer. Yet, the highest level of noise recorded on DP and sailing in high seas with slamming were still lower than the maximum limit of 60 dB(A). The impulsive noise and the high pitch tone could not be captured nor reflected by the outlined procedures in this study (ISO 1996; ISO 2008).

In summer, the cabin on OSV A was quieter than the one on OSV B, i.e., 40.9 dB(A) on OSV A and 45.4 dB(A) on OSV B. Cabins on OSV B was located closer to the engine room, giving more hissing noises. On OSV A, during normal condition the situation was quiet. But in high seas, the vessel struggled with the waves and winds, consequently generating more noise.

In some places, the noise level on OSV B was substantially higher than A, but there was no significant difference in the aggregate noise level on OSV A (M=70.39, SD=18.82) compared to OSV B (M= 71.99, SD=20.06), $F(1, 16)=.030$, $p>.10$. Due to the heat in summer, the crew tends to left the doors in the accommodation open, to let the air circulates. This condition also allowed the noise from outside to propagate in. On OSV B, it explains why the average noise levels in the bridge and in the cabin were slightly higher during summer. However, the noise level differences between summer and winter in the engine room and engine control room on OSV B are worth noted and should be explored further. There was no detail observation performed during the survey that can be used to explain the phenomena.

MOTION MEASUREMENT

Summary of statistical analyses on motion measurements are presented in Table 7 (roll), Table 8 (pitch) and Table 9 (translational accelerations). The average magnitude of the motion during each watch period was calculated, covering roll motion RMS [deg], pitch RMS [deg], lateral acceleration RMS [g] and vertical acceleration RMS [g].

ROLL MOTION

The RMS of roll velocity on OSV A during summer was 0.390 deg/s, while in the winter it was 0.946 deg/s. The RMS of roll motion was 0.163 deg in summer and 0.355 deg in winter, maximum 0.948 deg in summer and 1.934 deg in winter. On OSV B, RMS roll velocities were 0.318 deg/s in the summer and 0.355 deg/s in the winter which leaded to RMS of 0.124 deg and 0.127 motions respectively. Figure 9 shows maximum, minimum and RMS of roll motions during the whole survey for both OSVs. Rolling periods (in sec), derived from the motions were also calculated and presented in the figure. Rolling period OSV A (M=6.68, SD=0.521) was significantly lower than of OSV B (M=7.13, SD=0.856), $F(1, 688)=70.357$, $p<.001$. These findings supported that OSV A was more sensitive to roll motion (Rumawas and Asbjørnslett 2013).

With respect to *comfort* evaluation, no condition was found beyond any of the criteria presented in Table 3 and Table 4, even if these vessels were considered as cruise liners. The highest RMS roll motion measured in our survey was 0.54 deg, while the criterion for cruise liners is 2 deg.

Table 7 Summary of statistical analyses for roll velocity and roll motion

OSV	Season	Roll Velocity [deg/s]				Roll Motion [deg]			
		Min	Mean	Max	RMS	Min	Mean	Max	RMS
A	Summer	-2.463	-0.391	1.688	0.390	-0.801	0.000	0.948	0.163
	Winter	-7.150	-0.400	5.763	0.946	-1.846	0.000	1.934	0.355
B	Summer	-2.288	-0.430	1.400	0.318	-0.677	0.000	0.701	0.124
	Winter	-2.600	-0.376	1.788	0.355	-0.903	0.000	0.870	0.127

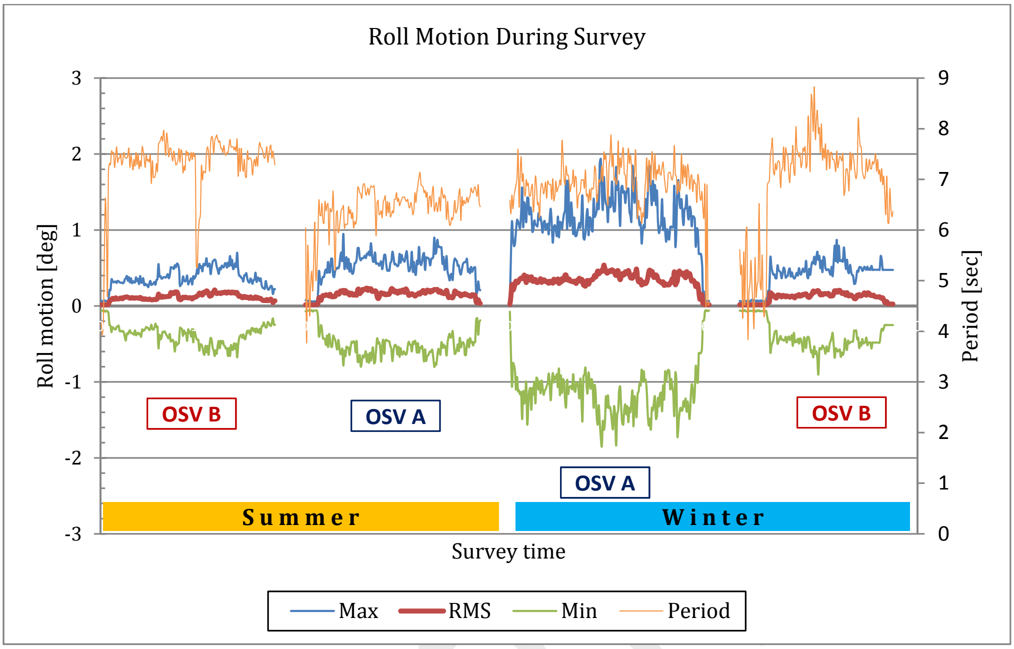

Figure 9 Calculated roll motions during the surveys for both OSVs

Pitch motion

On average, 1.233 deg/s (RMS) of pitch velocity was measured on OSV A in the winter, while in the summer it was 0.294 deg/s (RMS). This gave an average of 0.483 deg (RMS) pitch motion in winter and 0.127 deg (RMS) in the summer. On OSV B, higher pitch was found in the summer 0.605 deg/s (RMS) and winter 0.375 deg/s (RMS). This gave a 0.605 deg (RMS) and 0.375 deg (RMS) pitch motions respectively. Table 8 presents a detailed summary of pitch velocity and pitch motion measured during the survey.

Table 8 Summary of statistical analyses for pitch velocity and pitch motion

OSV	Season	Pitch Velocity [deg/s]				Pitch Motion [deg]			
		Min	Mean	Max	RMS	Min	Mean	Max	RMS
A	Summer	-1.325	0.644	2.313	0.294	-0.888	0.000	0.828	0.127
	Winter	-6.800	0.698	8.163	1.233	-2.525	0.000	3.073	0.483
B	Summer	-3.475	0.639	4.713	0.605	-1.915	0.000	1.882	0.269
	Winter	-2.325	0.708	3.600	0.375	-1.440	0.000	1.419	0.151

Figure 10 shows that pitch RMS never reached 1.5 deg as stated by the NATO criterion in Table 3, but a maximum of 0.74 deg (RMS, OSV A, winter). The maximum pitch motion at that particular time reached a little above 3 degrees. Unlike the roll, the pitch period of OSV B (*M*=6.586, *SD*=0.860) did not differ significantly compared to OSV A (*M*=6.519, *SD*=0.880), *F*=(1, 688)=1.012, *p*>.10.

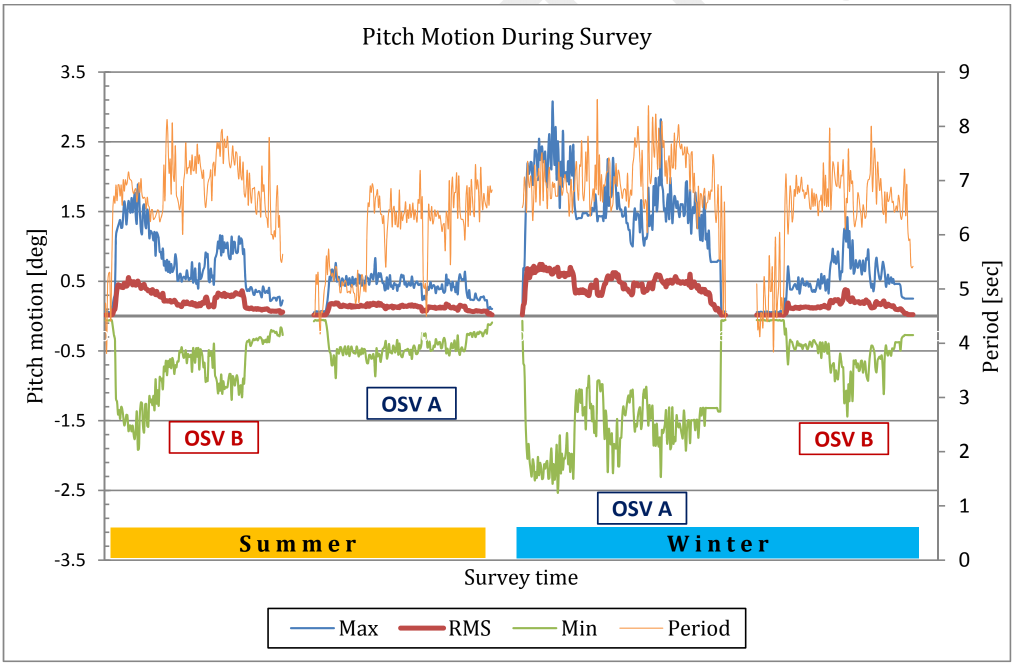

Figure 10 Calculated pitch motions during the surveys for both OSVs

TRANSLATIONAL ACCELERATIONS

Table 9 shows the summary of the statistical values for both lateral and vertical accelerations, while Figure 11 and Figure 12 show the whole range of the data recorded during the surveys. The highest RMS accelerations measured was 0.065 g (lateral) and 0.149 g (vertical). The NATO criteria (Table 3) and NORDFORSK operability criteria (Table 4, for light manual work) were set to 0.10 g and 0.20 g for lateral and vertical accelerations respectively. The criteria were perfectly met at all time during our survey, including in sea state 5 to 6, where the wave heights reached more than 10 m.

Table 9 Summary of statistical analyses for lateral and vertical accelerations

OSV	Season	Lateral Acceleration [g]				Vertical Acceleration [g]			
		Min	Mean	Max	RMS	Min	Mean	Max	RMS
A	Summer	-0.076	0.010	0.098	0.014	-0.149	-0.011	0.153	0.026
	Winter	-0.269	0.002	0.263	0.038	-0.720	-0.012	0.562	0.097
B	Summer	-0.100	0.015	0.126	0.016	-0.156	-0.010	0.142	0.024
	Winter	-0.125	0.007	0.124	0.015	-0.138	-0.011	0.111	0.020

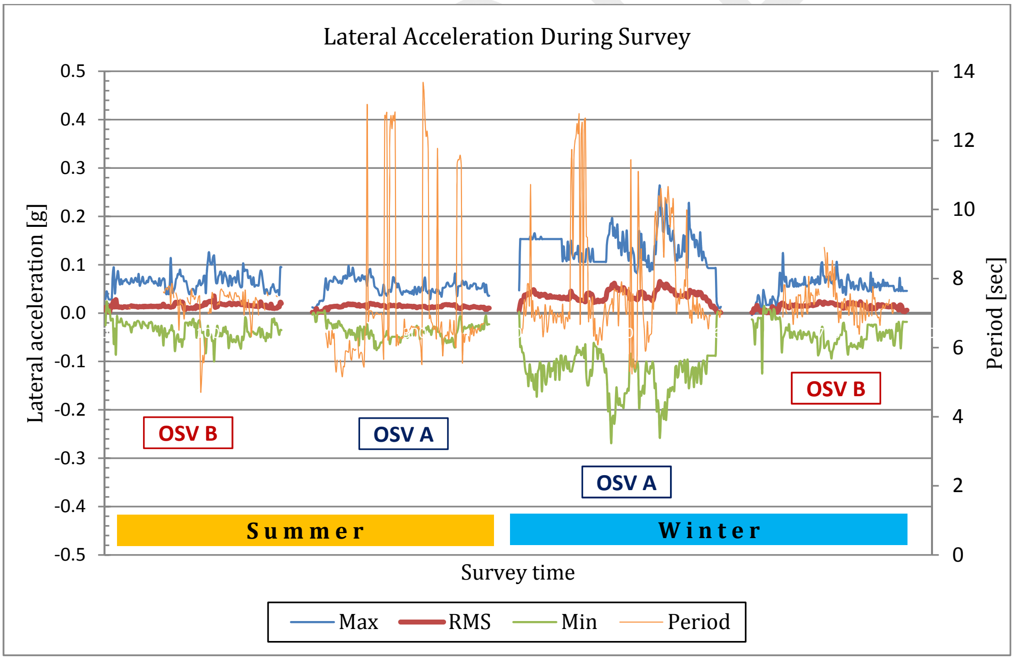

Figure 11 Lateral accelerations measured during the surveys on both OSVs

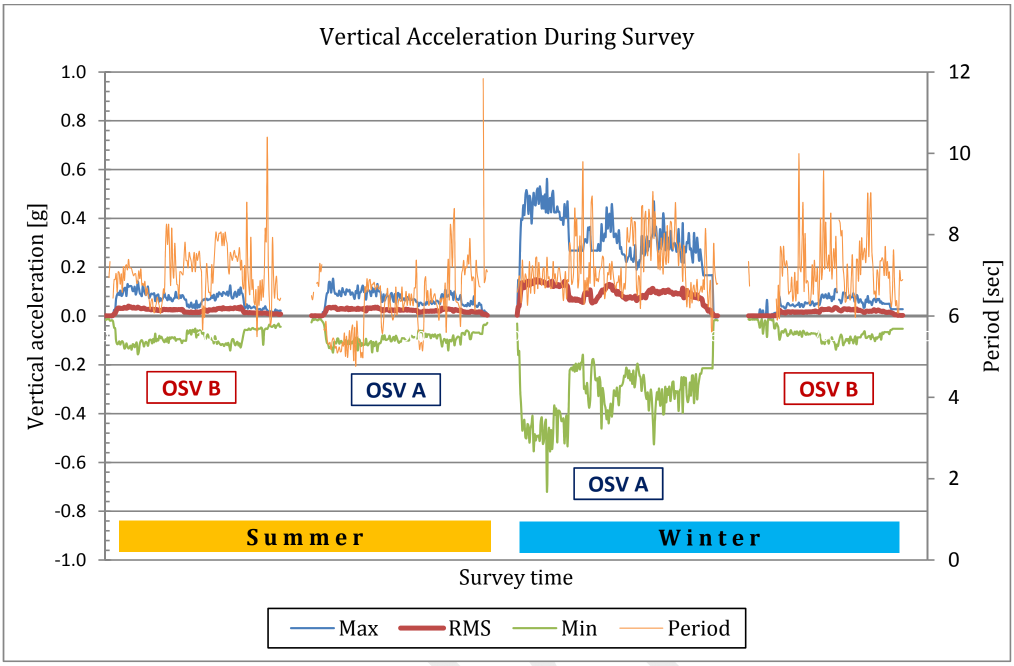

Figure 12 Vertical accelerations measured during the surveys on both OSVs

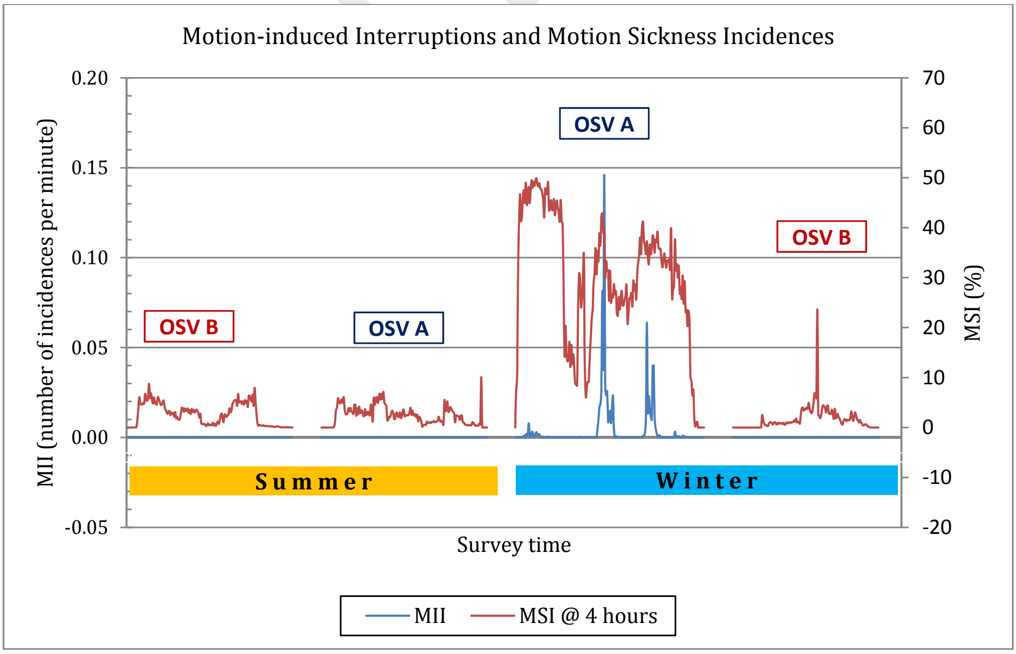

Figure 13 MII and MSI calculated during the surveys on both OSVs

MII AND MSI

The MII index calculated after Graham (1990) during the survey emerged only on OSV A during winter (Figure 13). A maximum of 0.14 MII per minute was obtained while criterion was set as 1 per minute (Table 3). The maximum risk level observed in the survey laid between "Possible" to "Probable" (Table 5). These results looked extremely low compared to the experience on board. "0.14" is equivalent to one MII in 7 minutes, while in high seas, interruptions occurred more than once per minute. As a matter of fact, when the wave height reached 10 m, interruptions occurred all the time; the crews stopped working and just sat tight or stood still by holding on to something to keep their balance.

The MSI index calculated for 4 hours period of exposure showed the average of less than 5% in summer on both OSVs. An average of 29% MSI was calculated on OSV A during winter while a maximum of 50% was indicated. The MSI criterion was set to be 20% (Table 3). On OSV B, a maximum of 23% MSI was acquired only once, in one spike, during winter, while most of the time it was below 5%. According to observations on board during the survey, only a few of the crew actually experienced MSI on either of the OSVs. The majority of the seafarers state that they became tired when the sea was harsh, but no longer nauseous. The majority were adapted to motion sickness.

DISCUSSIONS

NOISE

Both vessels fulfilled the noise criteria set by IMO (1981) and DNV (2009), even if the vessels were rated in with a higher comfort rate. However, it is clear that the current noise standards and measurements do not represent the real comfort level perceived by personnel on board, especially for sleeping. The existing noise level standards, which specify continuous noise-level measurements, were developed on the basis of a health perspective. The disturbing noises: short term impulsive noise (slamming), high pitch noise (tunnel thrusters and deck machineries) and squeaking noise are not yet covered nor reflected in the standard. Therefore, a noise measure based only on the equivalent continuous sound pressure level, expressed as dB(A) is not sufficient to reflect comfort of personnel on board. The World Health Organization (WHO) published a document on community noise (Berglund, Lindvall and Schwela 2009) and specifies that measures of individual events such as the maximum noise level (L_{Amax}), or the weighted sound exposure level (SEL) should also be acquired in addition to the A-weighted equivalent sound level pressure (L_{Aeq}) when there are distinct events. Two sets of criteria are therefore presented: for continuous noise (L_{Aeq} in dB(A)) and for single sound events (L_{Amax} in dB). For example, the guideline values for bedrooms are 30 dB L_{Aeq} for continuous noise and 45 dB L_{Amax} for individual noise event. These numbers appear to be more realistic to induce comfort and to prevent sleep disturbances. In addition a frequency analysis should be performed when the difference between dB(C) and dB (A) measurements is more than 10 dB. This can be done by octave band analysis, 1/3 -octave band analysis or narrow-band analysis (FFT). A spectral analysis may be utilized to assess annoyance (Brüel & Kjær Sound & Vibration Measurement 2000). ISO 1996-1 (ISO 2003) specifies a Rating Level (L_r) parameter which is defined as a numerical value to quantify a level of annoyance of a noise in relation to the people. The parameter uses the adjusted A-weighted equivalent continuous measure (L_{Aeq}) and takes into account other factors such as impulsiveness, tonality, and time of day. There is no criterion set in ISO 1996-1 standard regarding the maximum Rating Level that cannot be exceeded. These are regulated separately by other authorities such as national or local authority.

The downside about noise problem on OSVs is that it occurs intermittently, in parallel with activities positioned near an offshore installation on DP. The people who are supposed to rest during that period cannot have a good and sufficient sleep because of the disruption. For OSVs, operating on DP is one of the main operational modes. The positive side regarding noise is that it is not considered disturbing while on watch.

The crew on OSV B claim that their vessel is quiet (Rumawas and Asbjørnslett 2013). In this study we found that the noise level on OSV B is slightly higher than OSV A, although not being statistically significant. At the same time, there are substantially more complaints on OSV A regarding sleep-disturbing noise and watch-disturbing noise compared to OSV B. Noise level is set and measured at specified locations. However comfort level perceived by the crew is determined by the location where they are. For instance, the noise level produced by the tunnel thrusters when operating on OSV A and OSV B do not differ at all for both OSVs use the same equipment. But, the distance from the tunnel thrusters to the location of the people differ considerably. Similar explanations are found for the deck machinery noise and slamming.

MOTION

The motion studies show that all the criteria set by NORDFORSK (1987) and NATO STANAG (2000) are completely met in all conditions on both OSVs. The vessels have very small roll motions compared to the standards. It becomes evident that the criterion set for the roll motion is too high, at least for OSVs, as they never are exceeded. The criteria set for pitch seems to be more reasonable compared to the observed motion on the vessels. A similar conclusion is found for vertical and lateral accelerations as the results from the survey came near the criteria. However, referring to our experience on board during the most extreme condition, when the RMS of the roll was 0.54 deg, the pitch was 0.74 deg, vertical acceleration was 0.149 g and lateral acceleration was 0.065 g, it was difficult to stand still on the vessel. The criteria still allow heavy manual work to be performed in conditions up to 4 deg of roll, 0.15 g of vertical acceleration and 0.07 g of lateral acceleration. We strongly argue that it is impossible to conduct safe heavy manual work under such conditions.

With respect to comfort, motion is identified as one of the most disturbing factors. When the weather is extreme, it is not uncommon that someone finds themselves thrown out of their bed while sleeping. In contrast to noise which occurs continuously, motion takes effect in periods with bad weather and extreme sea states. Some people argue that motion is part of the risk of going to sea and cannot be avoided. We did witness that most people working on both OSVs are adapted to MSI. On the other hand, we also notice that motions are possible to manipulate and its effect can be made more acceptable to humans. OSV B can be seen as an evidence of this.

NORDFORSK (1987) seems to be quite an outdated standard. When it was developed, the main focus was on seakeeping and operability with respect to safety and not comfort. Some of the criteria were determined based on expert judgment, specifically by captains on merchant vessels. NATO STANAG (2000) was developed primarily for military purposes where well-trained navy personnel were taken as the reference population. Most operability criteria: MII, roll, pitch, vertical acceleration, lateral acceleration and slamming are unrealistic for the vessels studied. They need to be revised to not only to induce comfort but also to ensure safety.

SLAMMING

Seakeeping criteria state that a maximum of three slamming occurrences is allowed for 100 pitch motions (.03). In reality, it is required that people can have a continuous sleep, uninterrupted for six hours. The standard implies roughly three slamming per hour. Three slamming is more than enough to interrupt sleep. One may argue that the crew could do voluntary speed reduction once they feel that the vessel is going through harsh conditions. In reality, vessels operate on tight schedules. Voluntary speed reduction may be effective to a certain degree, but efforts to reduce slamming should also be taken already in the design stage. According to our experience, 1 slamming per hour is the maximum that one can tolerate when sleeping. Fortunately, particularly for working vessels, slamming only takes place when the vessel is cruising. Another advantage is that a lot of efforts have been performed in the industry to reduce slamming i.e. by designing the optimum hull form.

MOTION-INDUCED INTERRUPTIONS

Graham (1990) applies a statics theoretical approach to describe MII where the person is modeled as a rigid body. It was derived as a function of roll and heave components. In the present study, we see that the pitch component is more dominant. A considerably low MII was acquired compare to the actual MII experienced on board (see Part II for more detail information). The MII index after Graham (1990) needs to be extended to cover more forces motion, especially pitch. It also needs to be calibrated for non-military personnel doing non-military activities. In parallel, the MII risk levels (Table 5) are overly optimistic. They are not applicable for non-military population and need to be amended.

MOTION SICKNESS INCIDENCE

The MSI index calculated after McCauley et al (1976) is too conservative for the population taken as the sample in this survey (see Part II for more detail information), but shows good agreement with the new trainees on board. This finding is very sensible, considering that the reference subjects involved in McCauley's study were students. Improving the model for a broader population and applying the appropriate reference for a particular type of vessel will be issues for improvement. Figure 9 to Figure 12 present the motions periods along the survey and they are close to the most critical frequency for motion sickness of 0.167 Hz and equivalent to 6 seconds period. This is a tough challenge for ships designed to operate in the Norwegian Sea where the sea conditions often get near to the critical frequency. Moving the superstructure to the aft is one alternative that works and already recognized by the crew on OSV B. Modifying hull design is another approach that is currently developed: the X-bow and the wave-piercing hull designs are examples.

CONCLUSION

A comprehensive study to evaluate human factors in ship design has been completed. Two comfort class offshore supply vessels were taken as samples of the study. In this first part, human factors related criteria were referred and summarized. Field surveys with direct measurements and observations on board were reported, analyzed and concluded. Comparison between the existing criteria and the observations on board has been performed. The results show that the standards are inadequate and less effective for the vessels studied therefore they should be revised and improved for better relevance.

- Noise criteria set by IMO (1981) and DNV (2009) do not reflect comfort but health. Disturbing noises such as impulsive noise, high pitch noise, squeaking noise and hammering noise are not covered by the standard. The maximum values of the noise, the number of the noise events combined with the frequency analysis should also be measured to ensure comfort, especially for those vessels which missions may take weeks of operation at sea.

- Motions criteria: roll, pitch and accelerations set by NATO (2000) and NORDFORSK (1987) are not realistic as they are lenient for the vessels surveyed in this study. For instance, the maximum allowable roll motion is 4 deg (NATO 2000) and 6 deg (NORDFORSK 1987) while the highest roll motion recorded in more than 10 m wave height was *only* 0.54 deg (RMS). The criteria need to be adjusted, especially for those working vessels that are represented by this study.

- Slamming is important for comfort as it interrupts sleep and makes it difficult for people to fall asleep. The existing criterion for slamming of 0.03, i.e. 3 slamming per 100 pitch motions is too moderate and it does not facilitate people to have adequate sleep on board. One slamming per hour or at least a 0.01 criterion is proposed.

- The MII index calculated after Graham (1990) is relatively low compared to the observations on board. It needs to be extended and adjusted for better validity.

- The MSI index developed by McCauley et al (1976) shows rather elevated figures compared to the crews experience on-board. The predictions are rather low for a population that has adapted to live at sea for periods of time. It should be adjusted with an adaptation factor.

To sum up, it can be concluded that the existing criteria of human factors do not ensure comfort of personnel on offshore supply vessels operating in Norwegian Sea. The standards that were followed appear like a formality for the type of vessels represented in this study. Further studies that include more vessels are recommended.

ACKNOWLEDGEMENT

We are especially grateful for the opportunity given by the companies involved giving us access to their fleets and to the crews onboard OSV A and OSV B for opening their doors for this study. We also would like to address our gratitude to Mr. Frode Gran (NTNU) for helping us preparing the instrument used in this study, to Mr. Geir Spachmo (MARINTEK, AS) and Abdillah Suyuthi MSc (NTNU) for helping us processing the motion data, and to Prof. Sverre Steen, Prof (Em). Anders Endal (NTNU), Dr. Egil Jullumstrø and Darius Fathi, PhD. (MARINTEK, AS) for fruitful discussions.

References

ABS (2001). Guide for Crew Habitability on Ships. Houston, TX, American Bureau of Shipping.

ABS (2001). Guide for Passenger Comfort on Ships. Houston, TX, American Bureau of Shipping.

Alderton, T. (2004). The Global Seafarer: Living and Working Conditions in a Globalized Industry. Geneva, International Labour Office.

Alert! (2007). Time to wake up to the consequences of Fatigue. Alert! The International Maritime Human Element Bulletin, The Nautical Institute.

Allen, P., E. Wadsworth and A. Smith (2008). "Seafarers' fatigue: a review of the recent literature." International Maritime Health **59**(1-4): 11.

Baker, C. C. and D. B. McCafferty (2005). Accident Database Review of Human-element Concerns: What Do the Results Mean for Classification? International Conference on Human Factors in Ship Design, Safety and Operation. London, Royal Institution of Naval Architects**:** 65-71.

Berglund, B., T. Lindvall and D. Schwela (2009). Guidelines for Community Noise. W. H. Organization. Geneva.

Brüel & Kjær Sound & Vibration Measurement (2000). Environmental Noise. Nærum, DK-2850, Brüel & Kjær Sound & Vibration Measurement A/S.

Colwell, J. L. (2000). NATO Questionnaire: Correlation Between Ship Motions, Fatigue, Seasickness and Naval Task Performance. International Conference Human Factors in Ship Design and Operation. London, The Royal Institution of Naval Architects.

DNV (2009). Rules for Classification of Ships Comfort Class. Special Service and Type Additional Class Høvik, Norway, Det Norske Veritas. **Part 5 Chapter 12**.

Graham, R. (1990). "Motion-Induced Interruptions as Ship Operability Criteria." Naval Engineers Journal **102**(2): 65-71.

Haward, B. M., C. H. Lewis and M. J. Griffin (2009). "Motions and crew responses on an offshore oil production and storage vessel." Applied Ergonomics **40**(5): 904-914.

IMO (1981). Code on Noise Levels On Board Ships. Resolution A.468(XII). IMO. **Res A.468(XII)**.

IMO (2006). Framework for Consideration of Ergonomics and Work Environment. MSC-MEPC.7/Circ.3. I. M. Organization. London. **MSC-MEPC.7/Circ.3**.

ISO (1996). Acoustics - Measurement of Noise On Board Vessels. Geneva, Switzerland, The International Organization for Standardization. **2923**.

ISO (2003). Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessement procedures. Geneva, Switzerland, The International Organization for Standardization. **1996-1**.

ISO (2008). Mechanical Vibration - Measurement of Vibration on Ships - Part 2: Measurement of Structural Vibration. Geneva, Switzerland, The International Organization for Standardization. **20283-2:2008**.

ITF Seafarers. (2012). "Fatigue." Retrieved 29.01.2015, from http://www.itfseafarers.org/ITI-fatigue.cfm.

McCauley, M. E., J. W. Royal, C. D. Wylie, J. F. O'Hanlon and R. R. Mackie (1976). Motion Sickness Incidence: Exploratory Studies of Habituation, Pitch and Roll, and the Refinement of a Mathematical Model. Santa Barbara, California, Human Factors Research, Inc.

NATO (2000). Standardization Agreement (STANAG): Subject: Common Procedures for Seakeeping in the Ship Design Process, NATO, Military Agency for Standardization.

NORDFORSK (1987). Assessment of Ship Performance in a Seaway. Copenhagen, Nordforsk.

Oldenburg, M., X. Baur and C. Schlaich (2010). "Occupational risks and challenges of seafaring." Journal of Occupational Health **52**(5): 6.

Ross, J. M. (2009). Human Factors Considerations for Marine Vehicle Design. International Conference on Human Factors in Ship Design, Safety and Operation. London, Royal Institution of Naval Architects**:** 29-37.

Rumawas, V. and B. E. Asbjørnslett (2013). "Exploratory Surveys of Human Factors on Offshore Supply Vessels in the Norwegian Sea." Naval Engineers Journal **125**(2).

Rumawas, V., B. E. Asbjørnslett and C. A. Klöckner (2016). "Human Factors Evaluation in Ship Design: A Case Study on Offshore Supply Vessels in the Norwegian Sea, Part II: Multivariate Analyses and Structural Modelling." Naval Engineers Journal **xxx**(xx): pp.
Smith, A., P. Allen and E. Wadsworth (2006). Seafarer Fatigue: The Cardiff Research Programme. Cardiff, UK, Centre for Occupational and Health Psychology, Cardiff University.
Stevens, S. C. and M. G. Parsons (2002). "Effects of Motion at Sea on Crew Performance: A Survey." Marine Technology **39**: 29-47.

Appendix E: Multivariate Analyses

Human Factors Evaluation in Ship Design: A Case Study on Offshore Supply Vessels in the Norwegian Sea, Part II: Multivariate Analyses and Structural Modelling

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HUMAN FACTORS EVALUATION IN SHIP DESIGN: A CASE STUDY ON OFFSHORE SUPPLY VESSELS IN THE NORWEGIAN SEA, PART II: MULTIVARIATE ANALYSES AND STRUCTURAL MODELLING

Keywords: Human factors, Noise, Motion, Slamming, Daily diary, Sleep, Sleep problem, MII, MSI, Performance, Multivariate analysis, Structural Equation Modelling

ABSTRACT

Surveys were conducted in the Norwegian Sea to evaluate the adequacy of human factors criteria in ship design by taking two offshore supply vessels as the samples. Two reports are being published to present the results. Part I covers the theoretical background and reports the technical aspects of the research that include noise, motion and slamming. It is concluded that the existing human factors criteria are unjustifiable and need to be adjusted for the vessels studied. This paper aims to discover important factors that are relevant to seafarers' conditions and performance at sea. Physical measurements were performed together with crew member's subjective evaluation of ship board conditions. Surveys were conducted in two periods: summer and winter. The environmental conditions such as significant wave height (*Hs*) and peak period (*Tp*) were recorded during the survey. Noise and motion were measured on the vessel. Sleep, sleep problems, seafarers' conditions and performance were evaluated by means of self-administered questionnaires. Interconnectivities between variables of interest were investigated using multivariate analysis and a structural model was developed.

INTRODUCTION

A comprehensive study to evaluate the implementation of human factors (HF) in ship design was conducted. Due to the extent of the study, the results are reported in two parts. Part I (Rumawas, Asbjørnslett and Klöckner 2016) covers the background of the study, the relevant standards, the scope of work and the research design. It also reports the technical aspects of the study that include noise, motion, slamming, motion-induced interruptions (MII) and motion-sickness incidence (MSI). Results of on board measurements were compared to the standards. It is concluded that the existing criteria of human factors are neither realistic nor effective, for the vessels studied.

This paper (Part II) covers the seafarers' evaluations along the survey and reports their conditions and performance and is complementary to the Part I study. The aim of this part is to verify factors that considerably influence seafarers' performance at sea. The greater objective of the study is to lower the probability of accidents at sea.

METHODOLOGY

Most of the method of measurements performed in this study was covered in Part I. Information regarding the environmental conditions was obtained from weather forecasts, visual observations and onboard measurements. Noise level was measured by means of class 2 sound level meter Bruel & Kjaer Type 2236. Motion was measured with a high-precision sensor, ADIS16364 from Analog Device. To measure what happened on the humans' side, a questionnaire was constructed.

QUESTIONNAIRES: DAILY DIARIES

A questionnaire was developed based on the NATO questionnaire (Colwell 2000; Haward, Lewis and Griffin 2009) (see Appendix). Some adjustments were made based on preliminary observations on board (Rumawas and Asbjørnslett 2013), to fit offshore supply vessel's operation. Four aspects were measured by the questionnaire: sleeping condition, symptoms on watch, performance on watch and problems on watch. "Sleeping condition" probed whether the respondents sleep before they went to watch, how good and how long their sleeps were. It also checked if the respondent experienced sleeping problems. "Symptoms on watch" covered the respondent's conditions or wellbeing during their watch, checking if they were tired (physically), fatigue (mentally), sleepy, etc. Questions regarding MII and MSI were also included in this section. "Performance on watch" assessed how the crews rated their own performance during the watch they just completed; including the amount of tasks completed, the speed to complete the tasks, and the other qualities related to performance. "Problems on watch" were divided into two: ship-related and non-ship-related problems.

The surveys were conducted on two different OSV designs and performed in summer and in winter. Other possible influencing factors such as watch time (day time or night time) and type of shifts (long shift or normal shift) are also recorded and further analyzed.

The questionnaire was distributed among seafarers and to be completed after every watch. We explained the nature of the study, the purpose of the questionnaires and we asked the crews to participate in the survey, voluntarily. It was totally anonymous and confidential.

Before sailing, every seafarer received a number of forms sufficient for the voyage, in order to cover the watches that they were going to make. A box was provided in the mess room for submitting the forms after being completed after each watch.

DATA ANALYSIS

The answers were coded before they were analyzed. Table 1 shows how the "Yes or No" questions and the "Likert-scale" questions were coded. Checklists were tallied and summarized.

Table 1 Coding table for responses

Question	Coding and response				
Yes or No questions	**0**	**0.5**	**1**		
Did you sleep before this watch?	No	A little	Yes		
Did you experience sleeping problems?	No	A little	Yes		
Likert-type	**1**	**2**	**3**	**4**	**5**
Quality of your sleep	Very poor	Poor	Fair	Good	Very good
Amount of time of your sleep/rest	Too little	A little	Fair	Enough	More than enough
Symptoms	Severe	Consider-able	Somewhat	A little	Not at all
Performance	Very bad	Bad	Fair	Good	Very good

Quantitative inferential statistical analyses were applied to draw conclusions. Multivariate analyses were performed to evaluate factors that influence seafarers' conditions and performance at sea. Structural equation model (SEM) was applied to present a model that shows the relationships between variables of interest in this study.

STRUCTURE

The rest of the paper is presented as follows:

- Results; where summaries of observations are presented they are followed by simple comparisons
- Analysis; where relationships between measured variables (including Part I) are examined by means of multivariate analysis
- Discussions
- Conclusions

RESULTS

Data regarding the environmental conditions, noise level measurement and motion measurement (pitch, roll and translational accelerations) are presented in Part I (Rumawas et al. 2016). This paper presents the results of the seafarers' subjective evaluations on board regarding: sleeping or resting condition before the watch, symptoms experienced during the watch, performance and problems encountered during the watch.

AFTER-WATCH QUESTIONNAIRES

In total, 188 forms were filled in and returned (Table 2). It was the same group of seafarers surveyed in the summer as in the winter time. There were 17-18 members on each OSV on each visit. The crew in general can be divided into three groups according to their watch schedule; two groups work alternately in normal shift and one group works long shift. The former filled in around five to six questionnaires, while the latter handed in three. OSV A follows the 6/6 watch system where the crew watch for 6 hours and then off for the next 6 hours. OSV B follows 4/8 system. It was a modification of the 6/6 system by extending one shift for the crew to be able to get one long sleep. Long shift started at 07:00 or 08:00 and ended at 19:00 or 21:00. Each group consisted of 5 to 7 people, including some trainees, most of which worked long shift.

Table 2 Total number of responses collected

Survey period	OSV A	OSV B	Total
Summer (July 2011)	49	53	102
Winter (October 2011)	52	34	86
Total	101	87	188

SLEEPING CONDITION

Sleeping behavior

Only 25.8% of those who were going on watch during the night actually slept before they went on duty (Table 3). More than 80% of those who were going on watch during the day had slept before their watch. The difference between the two watch groups on their sleeping behavior was highly significant, χ^2 (2, N=185)=53.73, p=<.001.

Table 3 Sleep before watch

Question:	*Did you sleep before this watch?*			
Time of Watch	*"No"*	*"A little"*	*"Yes"*	Total
Day	3.0 %	15.8 %	81.2 %	100 %
Night	40.9 %	33.3 %	25.8 %	100 %
Total	18.4 %	20.5 %	61.1 %	100 %

Sleeping problems

Variation of sleeping problems was found significant across OSVs, χ^2 (2, N=164)=8.033, p<.05 and across seasons, χ^2 (2, N=164)=8.194, p<.05, but not across watch time, χ^2 (2, N=164)=0.312, p>.10 or across shifts χ^2 (2, N=164)=4.588, p>.10. Table 4 shows the proportion of respondents having sleeping problems on both OSVs in summer and in winter. There was only one respondent (2.4%) that experienced sleeping problems on OSV A in summer and none on OSV B. There was only one respondent (3.6%) on OSV B that reported sleeping problems in winter, while on OSV A there were eight (16.7%). These results supported the previous findings reported by the crews on the exploratory surveys (Rumawas and Asbjørnslett 2013). The two OSVs showed different characteristics in terms of motion, vibration, and noise.

Table 4 Sleeping problems

	Question:	*Did you experience sleeping problems?*			
OSV	***Periode***	*"No"*	*"A little"*	*"Yes"*	**Total**
A	Summer	73.2 %	24.4 %	2.4 %	100 %
	Winter	54.2 %	29.2 %	16.7 %	100 %
	Sub Total	62.9 %	27.0 %	10.1 %	100 %
B	Summer	76.6 %	23.4 %	0.0 %	100 %
	Winter	85.7 %	10.7 %	3.6 %	100 %
	Sub Total	80.0 %	18.7 %	1.3 %	100 %
Aggregate	Summer	75.0 %	23.9 %	1.1 %	100 %
	Winter	65.8 %	22.4 %	11.8 %	100 %
	Grand Total	70.7 %	23.2 %	6.1 %	100 %

Seasonal changes contributed to a substantial difference for people on board to fall asleep, χ^2 (2, N=140)=7.951, p<.05 (see Table 5). However, there was no difference found across OSVs, χ^2 (2, N=140)=2.211, p>.10, across watch time, χ^2 (2, N=140)=3.306, p>.10, and across work shifts, χ^2 (2, N=140)=1.092, p>.10.

Both watch time and work shift had an insignificant influence to sleep interruption problems on board (p>.10, see Table 6). Comparing sleep interruption problems reported by the crew on two OSVs only in summer showed no significant difference, χ^2 (2, N=71)=.152, p>.10, while in winter the difference was obviously very significant, χ^2 (2, N=57)=9.662, p<.01.

Table 5 Difficult to fall asleep

	Question:	***Did you experience: Difficult to fall asleep?***			
OSV	***Periode***	***"No"***	***"A little"***	***"Yes"***	**Total**
A	Summer	72.2 %	11.1 %	16.7 %	100 %
	Winter	40.0 %	35.0 %	25.0 %	100 %
	Sub Total	55.3 %	23.7 %	21.1 %	100 %
B	Summer	69.0 %	14.3 %	16.7 %	100 %
	Winter	63.6 %	18.2 %	18.2 %	100 %
	Sub Total	67.2 %	15.6 %	17.2 %	100 %
Aggregate	Summer	70.5 %	12.8 %	16.7 %	100 %
	Winter	48.4 %	29.0 %	22.6 %	100 %
	Grand Total	60.7 %	20.0 %	19.3 %	100 %

Table 6 Sleep interrupted

	Question:	***Did you experience: Sleep interrupted?***			
OSV	***Periode***	***"No"***	***"A little"***	***"Yes"***	**Total**
A	Summer	75.8 %	15.2 %	9.1 %	100 %
	Winter	38.9 %	36.1 %	25.0 %	100 %
	Sub Total	56.5 %	26.1 %	17.4 %	100 %
B	Summer	73.7 %	18.4 %	7.9 %	100 %
	Winter	81.0 %	14.3 %	4.8 %	100 %
	Sub Total	76.3 %	16.9 %	6.8 %	100 %
Aggregate	Summer	74.6 %	16.9 %	8.5 %	100 %
	Winter	54.4 %	28.1 %	17.5 %	100 %
	Grand Total	65.6 %	21.9 %	12.5 %	100 %

The questionnaire did further ask for the causes of sleep problems experienced. Table 7 shows the proportion of respondents mentioning ship-related sleep problems on both OSVs during summer and winter surveys. Table 8 shows the non-ship sleep related problems. It can be seen that more ship-related problems were reported by the crew during the survey. Slamming was the most frequently mentioned problem (13.8%), noise was in the second (10.6%) and ship motion was in the third highest (9.6%). The forth most frequent mentioned was temperature or indoor climate (8.5%), still a ship related problem. The fifth in the rank was toilet visit (7.4%) which was the most reported among the non-ship-related sleep causal problems. Habit (6.4%) and time schedule (5.9%) were the second and third stated in the corresponding category.

Ship motion, noise and vibration were reported to disturb sleep on OSV A mostly in winter while on OSV B was in summer. Slamming was only seen as a problem on OSV A in winter. Indoor climate was reported constant on OSV A in summer and winter, while on OSV B only in summer. Not a single ship-related sleep disturbing problem was actually mentioned on OSV B in the winter. However, the “Other” factor only mentioned on OSV B (3.7%) and it consisted of training (2), phone call (1), first night onboard (1) and not specified (3).

Table 7 Ship-related sleep causal problems

	Ship Motions	Noise	Vibration	Slamming	Temperature, indoor climate	Sun light	Mattress, accomodation facility
OSV A	**12.9 %**	**16.8 %**	**13.9 %**	**25.7 %**	**13.9 %**	**0.0 %**	**2.0 %**
Summer	2.0 %	12.2 %	6.1 %	0.0 %	14.3 %	0.0 %	4.1 %
Winter	23.1 %	21.2 %	21.2 %	50.0 %	13.5 %	0.0 %	0.0 %
OSV B	**5.7 %**	**3.4 %**	**3.4 %**	**0.0 %**	**2.3 %**	**0.0 %**	**1.1 %**
Summer	9.4 %	5.7 %	5.7 %	0.0 %	3.8 %	0.0 %	1.9 %
Winter	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Total	**9.6 %**	**10.6 %**	**9.0 %**	**13.8 %**	**8.5 %**	**0.0 %**	**1.6 %**

Table 8 Non-ship-related sleep causal problems

	Job-related	Time, schedule	Habit	Health condition	Personal problem	Coffee, tea, smokingg	Entertainment	Social	Night mares	Toilet visit	Other
OSV A	**2.0 %**	**3.0 %**	**5.0 %**	**1.0 %**	**2.0 %**	**2.0 %**	**1.0 %**	**3.0 %**	**0.0 %**	**5.0 %**	**0.0 %**
Summer	0.0 %	6.1 %	6.1 %	2.0 %	2.0 %	2.0 %	0.0 %	2.0 %	0.0 %	6.1 %	0.0 %
Winter	3.8 %	0.0 %	3.8 %	0.0 %	1.9 %	1.9 %	1.9 %	3.8 %	0.0 %	3.8 %	0.0 %
OSV B	**0.0 %**	**9.2 %**	**8.0 %**	**2.3 %**	**0.0 %**	**3.4 %**	**6.9 %**	**4.6 %**	**0.0 %**	**10.3 %**	**8.0 %**
Summer	0.0 %	11.3 %	9.4 %	0.0 %	0.0 %	5.7 %	3.8 %	5.7 %	0.0 %	11.3 %	5.7 %
Winter	0.0 %	5.9 %	5.9 %	5.9 %	0.0 %	0.0 %	11.8 %	2.9 %	0.0 %	8.8 %	11.8 %
Total	**1.1 %**	**5.9 %**	**6.4 %**	**1.6 %**	**1.1 %**	**2.7 %**	**3.7 %**	**3.7 %**	**0.0 %**	**7.4 %**	**3.7 %**

SEAFARERS' CONDITION: SYMPTOMS ON WATCH

Results of seafarers' conditions, measured by a number of symptoms experienced during their watch are presented in Table 9. The higher the numbers indicate the less severe the symptoms experienced by the crews (see Table 1 for descriptions). General trend shows that the crew experienced worse symptoms in the winter: significantly more physically tired, $F(1, 170)=3.931$, $p<.05$, experienced more motion-induced interruptions, $F(1, 165)=5.620$, $p<.05$ and experienced more stomach awareness, nausea, leading to vomiting, $F(1, 164)=3.649$, $p<.10$. However, the overall symptoms of the crew between summer and winter did not differ statistically, $F(1, 186)=.752$, $p>.10$.

There was a highly significant difference on the overall symptoms across OSVs, $F(1, 186)=6.871$, $p<.001$. The results showed no significant difference on the tiredness reported across OSVs, $F(1, 170)=2.638$, $p>0.10$. However, a highly significant difference on motion-induced interruptions was found, $F(1, 165)=8.346$, $p<0.01$ and a marginally significant difference on motion-sickness incidence was reported, $F(1, 164)=3.008$, $p<0.10$ across OSVs.

Analyses of variance showed that there was no significant effect of watch time to the symptoms reported by the crew ($p>.10$). But, different work shifts brought a significant effect to the overall symptoms of the seafarers, $F(1,186)=5.196$, $p<0.05$. Those who worked long shift showed a higher motivation ($M=4.78$, $SD=.420$) compared to those who worked normal shift ($M=4.53$, $SD=.741$), $F(1, 165)=3.318$, $p<.10$. At the same time, they also admitted more severe seasickness ($M=4.66$, $SD=1.004$) compared to those in normal shift ($M=4.91$, $SD=.450$), $F(1, 164)=4.708$, $p<.05$. As described in the earlier part of this section regarding the questionnaires respondents, most new trainees worked long shift.

Table 9 Symptoms reported by the crew during watch

	Summer			Winter			
Symptoms	**OSV A**	**OSV B**	**Subtotal**	**OSV A**	**OSV B**	**Subtotal**	**Total**
Tired (physical)	4.33	4.42	4.38	4.04	4.30	4.15	4.27
Fatigue (mental)	4.40	4.56	4.48	4.39	4.50	4.44	4.46
Sleepy	4.24	4.28	4.26	3.88	4.30	4.05	4.16
Headache, dizzy	4.84	4.73	4.79	4.64	4.94	4.77	4.78
Low motivation	4.82	4.49	4.65	4.48	4.53	4.50	4.58
Tension, anxiety, stress	4.75	4.80	4.78	4.67	4.85	4.75	4.76
MII, loss of balance	4.91	4.91	4.91	4.47	5.00	4.69	4.81
Stomach awareness, nausea, vomit	4.98	4.91	4.94	4.60	5.00	4.77	4.86
Ill, sick	5.00	5.00	5.00	4.62*)	5.00	4.78	4.90
Other	5.00	5.00	5.00	5.00	4.90**)	4.95	4.98
Overall	**4.49**	**4.64**	**4.56**	**4.32**	**4.71**	**4.47**	**4.52**

*) cold
**) back pain

Above all, sleepiness and tiredness were the two most severe symptoms reported by the crew on both OSVs in both periods of survey, $F(9, 1577)=27.915$, $p<0.001$. Sleepiness occurred when a person experienced sleep deprivations, sleep interruptions, difficulties to fall asleep and therefore he or she needed to sleep. Tiredness occurred because the high amount of energy expenditures, usually due to the ship's motion, more works, and the need to rest.

PERFORMANCE ON WATCH

Both crew on OSV A and OSV B reported lower performance in winter compare to the survey in summer (see Table 10 for detail results), $F(1, 186)=12.844$, $p<.001$. All the differences reported by the crew on OSV A were statistically confirmed ($p<.05$), however on OSV B the differences were insignificant ($p>.10$). There was a marginally significant difference on the overall performance across OSVs, $F(1, 186)=3.90$, $p<.10$. No difference in performance was found across watch time and across work shifts ($p>.10$). However, seafarers who worked in long shift reported better reaction time ($M=4.30$, $SD=.637$) compared to those who worked in normal shift ($M=4.09$, $SD=.638$), $F(1, 172)=3.123$, $p<.10$.

There was no difference in seafarers' performance across OSVs, across watch time, nor work shifts in summer (p>.10). In winter, the difference across OSVs was highly significant in motoric activities, $F(1, 80)=8.513$, $p<.01$ and *thus* in amount of tasks completed, $F(1, 80)=8.457$, $p<.01$. Results also indicated a significant difference in communication, $F(1, 80)=6.832$, $p<.05$, and concentration $F(1, 81)=5.204$, $p<.05$. A marginal difference was identified in decision making, $F(1, 80)=3.099$, $p<.10$. There was no difference in seafarers performance across watch time and work shifts in winter, $p>.10$.

Table 10 Performance on watch

Performance	Summer			Winter			
	OSV A	**OSV B**	**Subtotal**	**OSV A**	**OSV B**	**Subtotal**	**Total**
Concentration	4.20	4.33	4.27	3.88	4.18	4.00	4.14
Decision making	4.31	4.28	4.29	3.90	4.15	4.00	4.16
Communication	4.34	4.30	4.32	3.88	4.25	4.02	4.18
Motoric	4.26	4.34	4.30	3.76	4.22	3.94	4.13
Accuracy	4.32	4.31	4.31	3.86	4.13	3.96	4.15
Reaction time	4.24	4.19	4.22	3.94	4.16	4.02	4.13
Speed	4.27	4.15	4.21	3.86	4.09	3.95	4.09
Amount of task	4.14	4.17	4.16	3.68	4.09	3.84	4.01
Overall	**4.26**	**4.24**	**4.25**	**3.84**	**4.15**	**3.97**	**4.12**

Problems on Watch

Problems identified during the watch were summarized and grouped into ship-related and operational-related problems. The former consisted of ship motion, noise, slamming, vibration, bad smell and indoor climate. The latter covered bad weather, bad visibility, technical problems and operational problems (see Table 11). Ship motion and slamming were reported as the most frequent problems encountered during watch. Bad weather and indoor climate were being the third and forth in the rank, before vibration and bad smell. Operational problems were those problems experienced by the offshore platforms such as crane problems, space limited problems and offshore personnel problems that affected activities of the OSVs.

There was a highly significant difference on ship motions, $\chi^2(1, N=188)=13.858$, $p<.001$, slamming, $\chi^2(1, N=188)=17.453$, $p<.001$, and vibration, $\chi^2(1, N=188)=8.142$, $p<.01$ reported by the crew across OSVs. A significant difference was discovered in noise level, $\chi^2(1, N=188)=4.425$, $p<.05$ and indoor climate, $\chi^2(1, N=188)=6.227$, $p<.05$ across OSVs.

In parallel, highly significant differences were also found on ship motion, $\chi^2(1, N=188)=20.478$, $p<.001$, slamming, $\chi^2(1, N=188)=24.807$, $p<.001$ and vibration, $\chi^2(1, N=188)=11.211$, $p<.01$ across seasons. But, no significant difference on noise as well as indoor climate reported by the crew in across seasons, $p>.10$.

No difference was reported by the crew who were on watch during the day compared to those who worked during the night with respect to the problems encountered on their watch, $p>.10$.

Table 11 Problems encountered on watch

	Ship-related problems						Operational-related problems			
	Ship motion	Noise	Slamm ing	Vibration	Bad smell	Temperature, indoor climate	Bad weather	Bad visibility	Technical problems	Operational problems
OSV A	**19.8 %**	**5.0 %**	**20.8 %**	**8.9 %**	**5.9 %**	**11.9 %**	**18.8 %**	**3.0 %**	**5.0 %**	**1.0 %**
Summer	0.0 %	8.2 %	0.0 %	0.0 %	2.0 %	12.2 %	0.0 %	0.0 %	2.0 %	0.0 %
Winter	38.5 %	1.9 %	40.4 %	17.3 %	9.6 %	11.5 %	36.5 %	5.8 %	7.7 %	1.9 %
OSV B	**2.3 %**	**0.0 %**	**1.1 %**	**1.1 %**	**3.4 %**	**2.3 %**	**2.3 %**	**0.0 %**	**1.1 %**	**0.0 %**
Summer	3.8 %	0.0 %	1.9 %	1.9 %	5.7 %	3.8 %	3.8 %	0.0 %	0.0 %	0.0 %
Winter	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	2.9 %	0.0 %
Total	**11.7 %**	**2.7 %**	**11.7 %**	**4.8 %**	**4.8 %**	**7.4 %**	**11.2 %**	**1.6 %**	**3.2 %**	**0.5 %**

ANALYSIS

Inferential statistics was applied to test the relationships between variables of interest in the study. Multivariate approach was applied where correlation analysis was performed as the preliminary stage of the investigation. Stepwise regression analysis was utilized to confirm causal relationships between the variables. Finally, the structural equation modelling was used to describe the overall construction of the researched topic.

WEATHER FORECAST AND SHIP MOTION

Correlations between the estimated significant wave height and the motion data measured during the survey were calculated. Data was converted into watch group time scales (N=32) where long shifts were removed from the analysis to avoid duplication. The results are presented in Table 12. All correlation indices were highly significant. It can be inferred from the table that 47% variance of roll motions, 59% of pitch, 53% of lateral accelerations and 69% of vertical accelerations along the trip can be explained by variance in the estimated significant wave height. Vertical acceleration had the highest correlation index with the predicted significant wave height. Roll had a very strong correlation with lateral acceleration while pitch with vertical acceleration.

Table 12 Correlation between estimated wave height and ship motions

Pearson Correlation *)	Hs	Roll	Pitch	Y_acc	Z_acc
Hs	1.000	0.683	0.768	0.728	0.829
Roll		1.000	0.783	0.927	0.892
Pitch			1.000	0.830	0.922
Y_acc				1.000	0.913
Z_acc					1.000

*) All Sig. (2-tailed) = 0.000; N = 32

Ship motions and Sleep

Correlations between ship motions and sleep problems, sleep quality and sleep amount are presented in Table 13. Highly significant relationships between all motion components to ship-related sleep problems were identified. On the other hand, insignificant correlations were found between non-ship related problems and motions. Further investigation using stepwise regression method showed that vertical acceleration and pitch were the motion components that truly predict ship-related sleep problems (see Figure 1; Adjusted R square = .237; $F_{2,185}$ = 30.040 and p=.000) while lateral acceleration and roll motion were excluded.

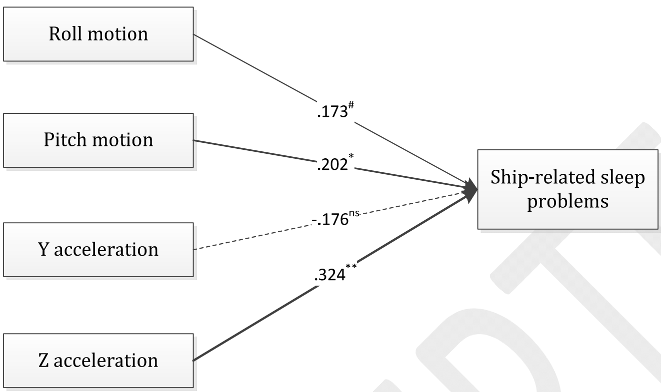

Figure 1 Results of stepwise regression analysis on ship-related sleep problems reported by the crew as a function of ship motions (index shows β and significant level: ** p < .01; * p < .05; $^{\#}$ p < .10; ^{ns} not significant)

Highly significant correlations were revealed between ship motions and sleep quality. Vertical acceleration was found to be the strongest element for sleep problems (r=0.477) as well as sleep quality (r=-0.349). A stepwise regression was conducted on sleep quality with respect to all four ship-motion components. The result confirmed the above findings and confirmed vertical acceleration as the only factor to remain in the equation while the others were excluded (*Adjusted* R^2 = .117; $F_{1,177}$ = 24.478, p=.000, see Figure 2).

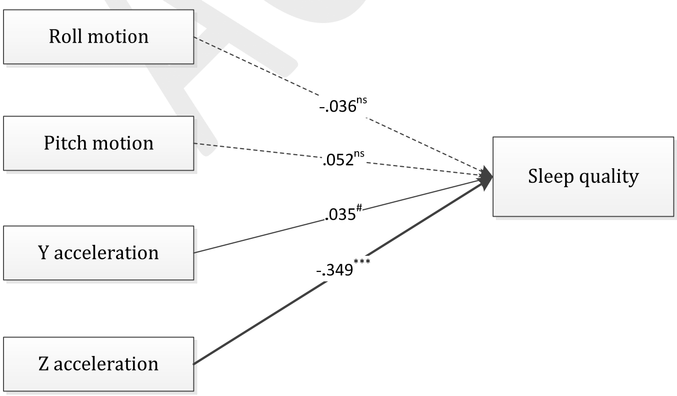

Figure 2 Results of stepwise regression analysis on sleep quality reported by the crew as a function of ship motions (index shows β and significant level: *** p < .001; $^{\#}$ p < .10; ^{ns} not significant)

The effects of survey period and OSV design on sleep quality were investigated by controlling the significant wave height. Analysis of covariance (Ancova) was performed. The result confirmed that the effect of OSVs on sleep quality was highly significant when wave height was controlled, $F(1, 175)=11.372$, $p<.01$. On the contrary, there was no significant effect caused by survey period on sleep quality, $F(1, 175)=.0534$, $p>.10$, if wave height was controlled. There was no significant interaction between survey period and different type of OSVs to sleep quality, $F(1, 175)=0.902$, $p>.10$.

Table 13 Correlations between ship motions and sleeping behavior

		Ship-related Sleep Problems	Non-ship related Sleep Problems	Sleep quality	Sleep amount
Roll	Pearson Correlation	0.427***	-0.105	-0.268***	-0.099
	N	188	188	179	176
Pitch	Pearson Correlation	0.448***	-0.075	-0.241**	-0.075
	N	188	188	179	176
Y_acc	Pearson Correlation	0.395***	-0.128$^{\#}$	-0.309***	-0.152*
	N	188	188	179	176
Z_acc	Pearson Correlation	0.477***	-0.139$^{\#}$	-0.349***	-0.200**
	N	188	188	179	176

*** $p < .001$; ** $p < .01$; * $p < .05$; $^{\#}$ $p < .10$

Sleep amount correlated highly significant with vertical acceleration and significantly with lateral acceleration. No significant effect was found for rotational motions, $p>.10$. Ancova was conducted to further examine the effect of OSVs sleep amount by controlling the environmental condition, i.e., significant wave heights. The results were similar to sleep quality: OSV design had a significant effect on sleep amount, given significant wave height was controlled, $F(1, 172)=5.836$, $p<.05$), but no significant effect caused by seasons and no significant interaction effect between OSVs and survey periods, $p>.10$.

Table 14 Correlation between sleep causal problems, sleep quality and sleep amount

		Ship-related Sleep Problems	Non-ship-related Sleep Problems	Sleep quality	Sleep amount
Ship-related Sleep Problems	Pearson Correlation	1.000	-0.184*	-0.462***	-0.260**
	N	188	188	179	176
Non-ship-related Sleep Problems	Pearson Correlation		1.000	-0.034	-0.088
	N		188	179	176
Sleep quality	Pearson Correlation			1.000	0.608***
	N			179	174
Sleep amount	Pearson Correlation				1.000
	N				176

*** $p < .001$; ** $p < .01$; * $p < .05$

Ship-related sleep problems had a very significant correlation with sleep quality, but non-ship related sleep problems did not (see Table 14). A similar tendency was found in the relationship of sleep causal problems to sleep amount. Obviously, sleep quality had a strong relationship with sleep amount.

SHIP MOTIONS, SLEEP AND OVERALL SYMPTOMS (SYMPTOMS DURING WATCH)

Stepwise regression analysis was conducted on the overall symptoms (symptoms reported during watch). Motion components (before watch), sleep causal problems, sleep quality and sleep amount were treated as independent variables (see Figure 3). Ship-related sleep problems, sleep amount and non-ship related sleep problems were revealed as significant influencing factors for the overall symptoms (*Adjusted* R^2 = .297; $F_{3,170}$ = 25.386, p=.000), while the others were excluded (see Figure 3).

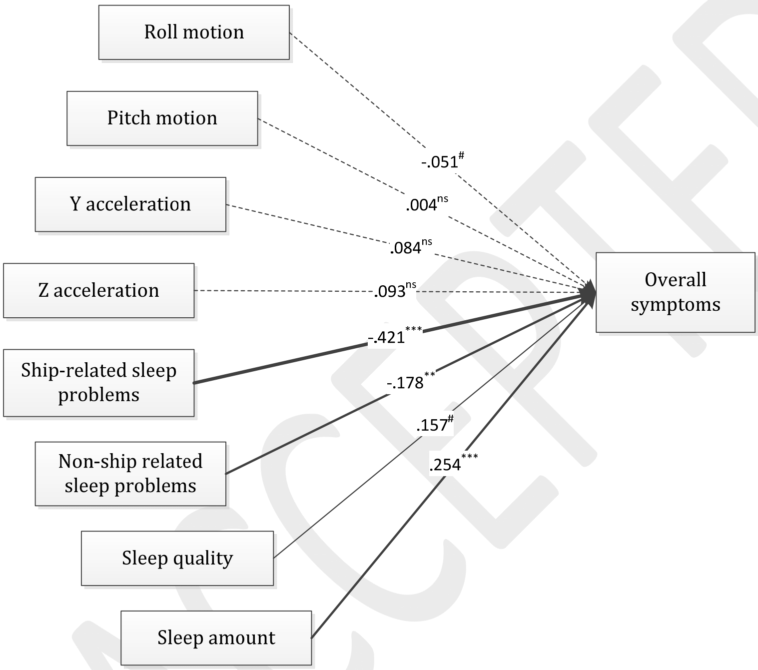

Figure 3 Results of stepwise regression analysis on the overall conditions (β *** p < .001; ** p < .01; * p < .05; $^{\#}$ p < .10; ^{ns} not significant)

Several symptoms of interest were analyzed separately: tiredness, motion-induced interruptions (MII), and motion-sickness incidence (MSI). Similar procedures and independent variables were entered. The results showed that tiredness was significantly influenced by sleep quality, sleep amount, ship-related sleep problems and non-ship related sleep problems while all motions were excluded from the equation. Vertical acceleration during watch was found by stepwise regression analysis significantly to affect MII (*Adjusted* R^2 = .110; $F_{1,165}$=21.499, β=-.340, p=.000,). The other motions showed little influence on MII, therefore excluded. A rather low correlation index was found between MII reported by the crew in this survey and the index calculated using the existing code (Graham 1990), r=-0.184[1], p=.018.

[1] Note that the negative sign is caused by the reverse scaling system used in the questionnaire.

Table 15 Results of stepwise regression method: Significant variables to tiredness

Variable of interest	Predictor variable	β	*p*
Tiredness	Sleep quality	.290	.001
Adjusted R Square = .344; $F_{4,155}$ = 21.808, p=.000	Sleep amount	.226	.006
	Ship-related sleep problems	-.197	.003
	Non-ship related sleep problems	-.187	.012

Motion sickness correlated with pitch, r=-0.405, p<.001 and roll motion, r=-0.400, p<.001. Stepwise regression with the four motions during watch as the independent variables indicated that pitch motion was the one significantly influencing stomach awareness, nausea leading to vomiting (*Adjusted* R^2 = .159; $F_{1,164}$=32.189, β=-.405, p=.000). There was a very significant but rather low correlation between the stomach awareness reported by the crew in this research and the predicted MSI index calculated for 8-hour exposure (McCauley, Royal, Wylie, O'Hanlon and Mackie 1976; Griffin 1990) r=-0.261, p=.001. The fact that pitch element was the one that was domineering instead of the vertical acceleration as modeled by McCauley et al. (1976) should be investigated further.

SHIP MOTIONS, SLEEP, OVERALL SYMPTOMS AND PERFORMANCE

Correlation analysis showed that the crew member's overall performance had a highly significant relationship with sleep amount, r=0.423, p<.001 and sleep quality, r=0.379, p<.001. Stepwise regression analysis on overall performance was conducted with ship motion, sleep quality, sleep amount, and watch problems where they were defined as predictors. The output suggested that performance can be predicted by sleep amount, vertical acceleration, overall symptoms and operational related problems (see Figure 4, *Adjusted* R^2 = .260; $F_{4,169}$ = 16.195, p=.000).

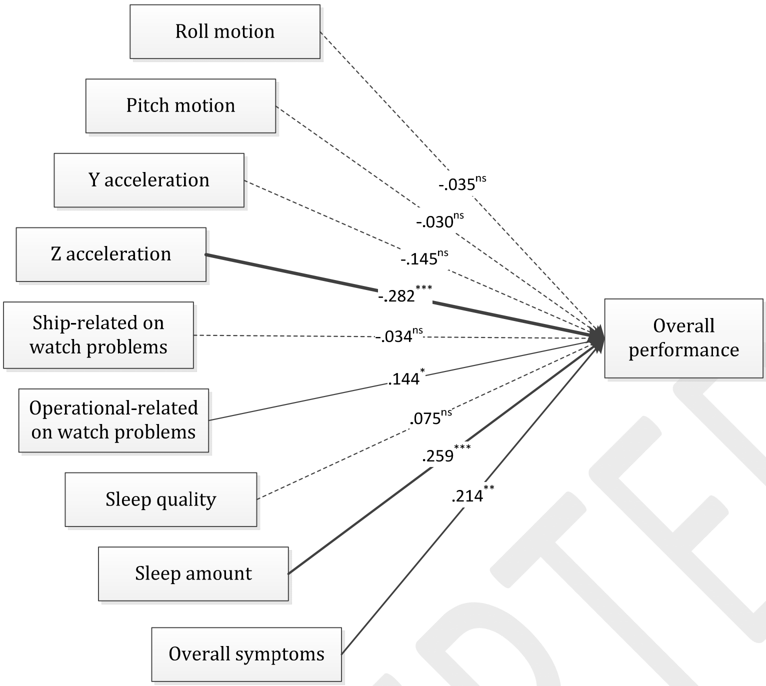

Figure 4 Results of stepwise regression analysis on the overall performance (β *** $p < .001$; ** $p < .01$; * $p < .05$; ns not significant)

STRUCTURAL MODEL

A more thorough and comprehensive model was then developed to demonstrate the relationships between variables of interest in this research. Structural equation modeling (SEM) was utilized. Path analysis was chosen as one specific method due to a limited number of respondents. The analysis was run in Mplus 6.1 software. The final model is presented in Figure 5. From the output, it can be inferred that the model fit is acceptable, χ^2=27.284, df=15, p=.027, CFI=.963, TLI=.919, RMSEA=.066[.022 .105], SRMR=.044).

Slightly different but still in line with the result from the stepwise regression model, the SEM showed that ship-related sleep problem was highly affected by pitch motion. Ship-related sleep problems such as motion, noise, vibration, slamming and indoor climate very significantly influenced sleep quality as well as sleep amount. Non-ship related problems had also an effect on sleep quality and sleep amount, but to a smaller degree. Subsequently, sleep amount showed a very significant effect to the personnel's overall conditions and also to their overall performance at the same time. People with sufficient amount of sleep tended to be fit and in shape with fewer symptoms, hence better performance. On the other hand, sleep quality did not have any significant effect to overall performance, but a marginally significant influence to overall symptoms. Work shift had significant impact to non-ship related sleep problems and to overall performance. People who worked in long shifts tended to have less non-ship related sleep problems and better performance than those who worked in normal shifts. Performance was also negatively affected by RMS roll motion during watch.

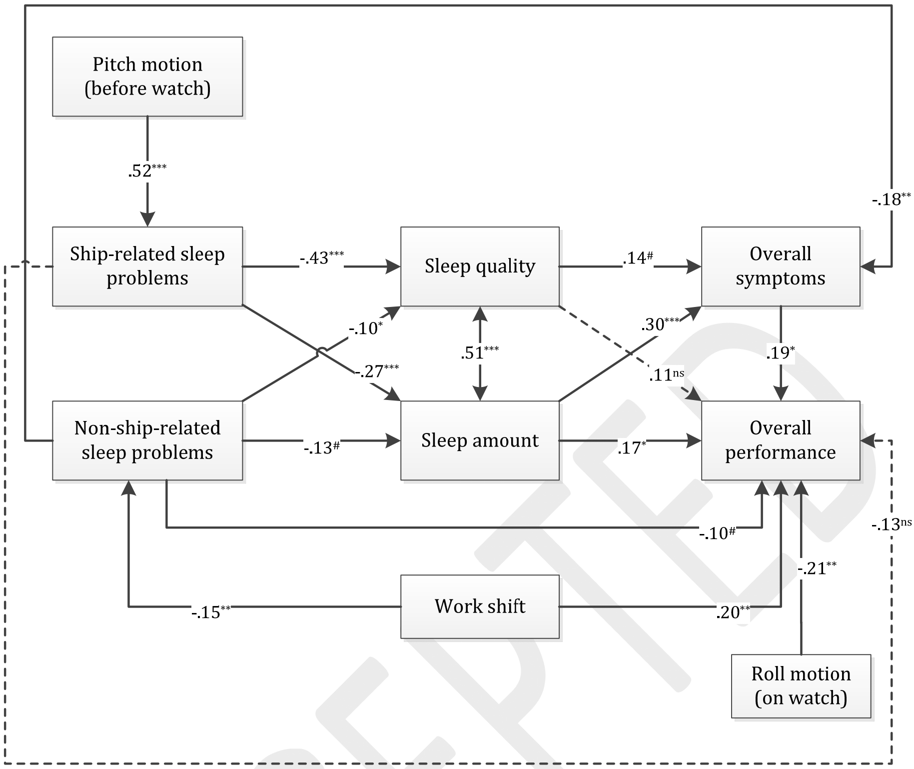

Figure 5 Path analysis on human factors of OSV operations (*** p<.001; ** p<.01; * p<.05; $^{\#}$ p<.10; ^{ns} not significant)

Other variables of interests: watch time, OSV design and season were eliminated from the model. Watch time showed no significant effect for the whole model, while different OSV designs and seasons were basically inclusive in the motions (pitch and roll) as initial predictors.

DISCUSSIONS

Working at sea is tiring. Surveys were conducted to investigate factors that influence seafarers' condition and performance on OSVs. Most of our findings are in parallel with previous studies and publications (Stevens and Parsons 2002; Smith, Allen and Wadsworth 2006; Haward et al. 2009). Seafarers' wellbeing was influenced by sleep amount, sleep quality, noise, vibration and motion. In this study, the precise interconnectivity between these factors was revealed and a model was established. Ship design, sleep quantity and sleep quality were identified as important moderating variables between environmental exposures and the personnel on board.

In reality, working at sea is a dynamic endeavor. The environmental condition fluctuates, the operations vary, the ship may deviate and the crews must adapt all the time. According to the survey, seafarers reported more technical and operational problems in the winter. The following cases may illustrate the risk situation: one vessel had a problem with the azipull propeller that could not be aligned properly under harsh winter conditions. We observed an officer on the bridge burnout[2] during an ambiguous loading/unloading operation beside an offshore installation. In the same trip, we also witnessed an officer outraged because all the deckhands were still asleep when loading and unloading was about to start.

From the results, strong and highly significant correlations between estimated weather and ship motions were confirmed. It means that the behavior of the vessel can be estimated prior to departure. Then, the subsequent variables: ship-related sleep problem, sleep quality, sleep amount, seafarers' conditions and performance can also be predicted. This information is valuable and has been considered in voyage planning to minimize risk and to ensure safety. The next conceivable step should be to use the information to maximize comfort. In practice, the crews sometimes chose an alternative route to reach the area of destination during heavy seas. This route was a little bit further but more protected from the exposure of strong wind and high waves.

It was confirmed that performance was significantly influenced by sleep amount, overall symptoms and ship motions during the watch. In winter one became even more vulnerable to the worse environmental conditions, greater motions, less sleep and poorer conditions in general. Under such conditions, operational problems may be a triggering factor that leads to a serious incident. At the same time, when awareness was declining and response time was decreasing, the chance for the crew to anticipate a hazard became lower, hence the risk became higher.

Some seafarers did exercise in the gym on the vessel and some of them went jogging whenever the vessel was in port, to keep them fit. However, when the seafarers were exhausted at sea, they took the initiative asking their colleague(s) to replace them on their watch while they took a rest. As illustrated above, when the deckhands were all tired, they went to sleep until the time to perform their job. The seafarers who work on OSVs during normal operations are more fortunate because the nature of the work gives them the opportunity to plan and run their activities according to their judgment. There is always room to postpone or even cancel a job that they consider unsafe, therefore disaster can be avoided. Nevertheless, fewer activities with more relax schedules are recommended to be planned in the winter.

LIMITATIONS OF THE STUDY

Only two offshore supply vessels were observed in this study and the length of the observation time on the vessels were relatively short. Unlike experiments in the lab or computer simulations, we could not control the environmental conditions. The data collected on both OSVs were not directly comparable. It was therefore not possible to draw general conclusions although the main findings indicate important lessons. However we should also bear in mind that both vessels were relatively new and among the top of the line in their fleet. Ship-related problems identified on these vessels most likely will be found on other older vessels and less likely in the older vessels have a better condition.

Accommodation facilities, indoor climate and high frequency vibration were not covered in this research due to satisfactory conditions were found on the previous survey (Rumawas and Asbjørnslett 2013).

[2] Fatigue, frustration or apathy resulting from prolonged stress, overwork, or intense activity

CONCLUSIONS

Field surveys of human factors in ship design were performed where collected data from physical measurements were associated with the crews' evaluations and reports. Descriptive statistics and multivariate quantitative analyses were applied. A structural model describing the relationship of relevant variables relative to human factors was developed and numerically estimated. These figures can be utilized to estimate how much a variable of interest can be influenced by manipulating other variables.

Some of the results worth highlighted and some conclusions can be derived as follows:

- A strong correlation index between estimated weather and ship motions is confirmed. From 49% to 69% of the motions variance can be explained by the predicted significant wave height.
- Most of the crews who watch during the night do not sleep before duty.
- Slamming, noise and ship motion are the most named problems disturbing sleep. On the other hand, ship motion, slamming and bad weather are the most frequently reported problems disturbing watch.
- OSV design[3] and season are significant predictors for sleeping problems.
- OSV design[3] has a significant effect on sleep quality as well as sleep quantity.
- Seasonal changes contribute to a substantial difference for the people on board to fall asleep. At the same time, the season also brings a significant influence on sleep-interrupted problems experienced by the crews. In winter, people experience more difficult to fall asleep and experience sleep interruption more often. Some measures to minimize these problems are recommended: always consult the weather forecast for the most recent update, check an alternative route for better riding comfort and spare more relax schedule in the winter.
- The crews reported more ship-related problems compared to non-ship related problems disturbing sleep. To increase sleep quality and sleep quantity, efforts must be performed definitely from the design stage.
- The MII reported by the crews is more sensitive compared to the calculated MII (Graham 1990). The MII index reported by the crew is significantly affected by vertical acceleration. The MII operability criteria must be adjusted before they can be utilized in the design stage.
- The MSI index developed by McCauley et al (1976) shows a rather low correlation but high significance with the stomach awareness reported by the crew. The MSI index reported by the crew has strong correlation with pitch and roll motion.

[3] In this case, different locations of the accommodations (at the bow vs at the aft)

- In general OSV operations, pitch motion is the significant predictor for ship-related sleeps problems while roll motion is more important for people performance during watch.

- Ship design does affect comfort. It has the potential to reduce noise, motion and slamming, hence sleep disruptions, MII and MSI. Good design will increase comfort and thus seafarers' condition and performance. Having the accommodations at the aft is one example that has been evidenced as a good design for the crews.

- Relationships between variables involved in this study: ship motions, sleep problems, sleep quality, sleep amount, overall symptoms of the seafarers' and performance were evaluated using path analysis and a robust model was presented.

References

Colwell, J. L. (2000). NATO Questionnaire: Correlation Between Ship Motions, Fatigue, Seasickness and Naval Task Performance. International Conference Human Factors in Ship Design and Operation. London, The Royal Institution of Naval Architects.

Graham, R. (1990). "Motion-Induced Interruptions as Ship Operability Criteria." Naval Engineers Journal **102**(2): 65-71.

Griffin, M. J. (1990). Handbook of human vibration. London, Academic Press.

Haward, B. M., C. H. Lewis and M. J. Griffin (2009). "Motions and crew responses on an offshore oil production and storage vessel." Applied Ergonomics **40**(5): 904-914.

McCauley, M. E., J. W. Royal, C. D. Wylie, J. F. O'Hanlon and R. R. Mackie (1976). Motion Sickness Incidence: Exploratory Studies of Habituation, Pitch and Roll, and the Refinement of a Mathematical Model. Santa Barbara, California, Human Factors Research, Inc.

Rumawas, V. and B. E. Asbjørnslett (2013). "Exploratory Surveys of Human Factors on Offshore Supply Vessels in the Norwegian Sea." Naval Engineers Journal **125**(2).

Rumawas, V., B. E. Asbjørnslett and C. A. Klöckner (2016). "Human Factors Evaluation in Ship Design: A Case Study on Offshore Supply Vessels in the Norwegian Sea, Part I: Theoretical Background and Technical Constructs." Naval Engineers Journal **xxx**(xx): pp.

Smith, A., P. Allen and E. Wadsworth (2006). Seafarer Fatigue: The Cardiff Research Programme. Cardiff, UK, Centre for Occupational and Health Psychology, Cardiff University.

Stevens, S. C. and M. G. Parsons (2002). "Effects of Motion at Sea on Crew Performance: A Survey." Marine Technology **39**: 29-47.

NTNU
Norwegian University of Science and Technology

Date ______ / ______ / ______

Watch time ________ to ________

After-watch Questionnaires

Dear Sir / Madame,

Please, fill in this questionnaire after every watch.

You can **tick (v)** or **cross (x)** the box that corresponds to your answer.

☐	[v]	☐
[x]	☐	☐

The questionnaire is fully **anonymous.**
We guarantee the **confidentiality** of the responds and the **privacy** of the respondents.

Please, **insert** the questionnaire that has been completed **into the box** that is available in the mess room.

You are free to give additional comments or explanation when necessary.

Your participation is highly appreciated and hopefully will benefit to improve working and living conditions at sea. Thank you very much.

Sincerely,

Vincentius Rumawas
Researcher/PhD student
Department of Marine Technology, NTNU
NO-7491 Trondheim

Visiting address: **Otto Nielsen v. 10, Trondheim**
Phone: **+ 47 73595589, 41455268**
email: vincentius.rumawas@ntnu.no

Please, answer the following questions:

1. SLEEPING / RESTING CONDITION BEFORE THIS WATCH

	NO	a little	YES
a. Did you sleep before this watch?	☐	☐	☐

How do you rate your sleeping / resting condition before this watch:

	very poor	poor	fair	good	very good
b. Quality of your sleep / rest	☐	☐	☐	☐	☐
	too little	a little	fair	enough	more than enough
c. Amount of time of your sleep / rest	☐	☐	☐	☐	☐

	YES	a little	NO
d. If you slept, did you experience sleeping problems?	☐	☐	☐
e. If you tried to sleep, did you experience:			
Difficult to fall asleep	☐	☐	☐
Sleep interrupted	☐	☐	☐
Other:	☐	☐	☐

f. Sleep / rest problem(s) caused by (you can tick more than one):

- ☐ Ship motions
- ☐ Noise, caused by ....
- ☐ Wave impact, slamming
- ☐ Vibration
- ☐ Job-related problems
- ☐ Sun light, too bright (light)
- ☐ Time or schedule related
- ☐ Mattress, bedroom/accommodation facility
- ☐ Temperature, indoor climate
- ☐ Just habitual
- ☐ Personal conditions (health related)
- ☐ Personal problems (family related, etc.)
- ☐ Too much coffee / tea / smoking
- ☐ Entertainment, games, music, movies
- ☐ Friends, colleagues (social activities)
- ☐ Nightmares
- ☐ Toilet visit(s)
- ☐ Other: ....

2. SYMPTOMS EXPERIENCED DURING THIS WATCH

	severe	considerable	somewhat	a little	not at all
a. Tired (physical)	☐	☐	☐	☐	☐
b. Fatigue (mental)	☐	☐	☐	☐	☐
c. Sleepy	☐	☐	☐	☐	☐
d. Headache, dizzy	☐	☐	☐	☐	☐
e. Low motivation	☐	☐	☐	☐	☐
f. Tension, anxiety, stress	☐	☐	☐	☐	☐
g. Motion-induced interruption, loss of balance	☐	☐	☐	☐	☐
h. Stomach awareness, nausea, vomit	☐	☐	☐	☐	☐
i. Ill, sick (describe: ....)	☐	☐	☐	☐	☐
j. Other:	☐	☐	☐	☐	☐

	very bad	bad	fair	good	very good
k. How do you feel during this watch?	☐	☐	☐	☐	☐

3. PERFORMANCE DURING THIS WATCH

	very bad	bad	fair	good	very good	not apply
a. How do you rate your performance on this watch	☐	☐	☐	☐	☐	
b. Concentration, awareness	☐	☐	☐	☐	☐	☐
c. Decision making	☐	☐	☐	☐	☐	☐
d. Communication	☐	☐	☐	☐	☐	☐
e. Motoric activities	☐	☐	☐	☐	☐	☐
f. Accuracy	☐	☐	☐	☐	☐	☐
g. Reaction time	☐	☐	☐	☐	☐	☐
h. Speed to complete the tasks	☐	☐	☐	☐	☐	☐
i. Amount of tasks completed	☐	☐	☐	☐	☐	☐

4. PROBLEMS ENCOUNTERED DURING THIS WATCH

- ☐ Ship motions (substanstial)
- ☐ Disturbing noise, caused by ....
- ☐ Significant wave impact, slamming
- ☐ Disturbing vibration
- ☐ Bad weather: ....
- ☐ Bad / distracted visibility
- ☐ Bad smell
- ☐ Inconvenient temperature , indoor climate
- ☐ Technical (hardware) problem
- ☐ Operational problem
- ☐ Other: ....

Additional comments / notes (for this shift):

Thank you very much for your kind participation

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Appendix F: The Underlying Factors

Human Factors in Ship Design and Operations: A Preliminary Survey of the Theoretical Construct

The International Journal of Maritime Engineering,
RINA Transactions (accepted)

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HUMAN FACTORS IN SHIP DESIGN AND OPERATION: A PRELIMINARY SURVEY OF THE THEORETICAL CONSTRUCT

(DOI No: 10.3940/rina.ijme.20xx.a?.???)

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SUMMARY

This technical note presents an analysis of the underlying factors of human factors in ship design based on questionnaires distributed on two offshore supply vessels operating in the Norwegian Sea. The concept of human factors in ship design is still evolving. The purpose of this paper is to present a preliminary model of the human factors construct by using a factor analysis method. The results confirm the existence of controllability, workability and habitability as the principal factors of human factors in ship design. Three other factors that emerged are cargo facilities, reliability, automation and maintainability (RAM) and interfacing complexity. Bridging variables found between these factors include elements such as safety, manoeuvring, engine room and bridge design. A preliminary model of how the components or parts relate to human factors in ship design and operation is developed. The model also indicates the parties who are responsible for the various aspects of ship design from a human factors perspective.

NOMENCLATURE

Abbreviations

DP	Dynamic positioning
ECR	Engine control room
ER	Engine room
HF	Human factors
HSE	Health, Safety and Environment
KMO	Kaiser-Meyer-Olkin
LR	Lloyd's Register
MECE	Mutually exclusive and collectively exhaustive
OHS	Occupational health and safety
OSV	Offshore supply vessel
PAF	Principal axis factoring
RAM	Reliability, automation and maintainability
SPSS	Statistical Package for the Social Sciences

1. INTRODUCTION

A quantitative survey using questionnaires to examine the implementation of human factors (HF) in ship design was conducted [1], using the Lloyd's Register's (LR) [2, 3] eight dimensions HF framework.

The framework did not perfectly satisfy the mutually exclusive and collectively exhaustive (MECE) principle. This principle is essential for developing a good theoretical construct[1] such as human factors in ship design. The MECE principle states that a list, such as HF framework should have no overlaps and no gaps or holes. Some problems of overlap were found in the development of the coding sheet for the literature study [4, 5] and questionnaires [1], therefore, a theoretical examination of the human factors concept was undertaken.

This paper presents a preliminary verification of the human factors concept using factor analysis. This is the logical continuation of a quantitative survey of human factors which was conducted on two offshore supply vessels in summer 2011 and also reported in this publication [1]. The same questionnaires and data are used in this paper.

2. FACTOR ANALYSIS

Factor analysis has been applied in psychological research for more than 100 years, since it was developed by Spearman [6]. It is a statistical approach used to reveal relationships between a number of observable variables and looking for common unobservable (latent) factors that can explain variations measurements; in this case, in human factors implementation, which are measured by items in questionnaires. It is customary to use factor analysis for data reduction or structure detection and to identify collinearity of variables.

Factor analysis was used in this study to:

- Identify the underlying factors of human factors implementation in marine design.
- Verify the existing human factors framework.
- Reduce the number of human factors dimensions to manage.
- Provide a firm theoretical construct of human factors in marine design.

42 respondents completed the questionnaires [1]. This number of respondents is too low for a proper factor analysis, but the investigation was performed with caution and the assumptions required for the analysis were always checked. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy examines whether the partial correlations among items are small. If the variables share common factor(s) the partial correlations will be small and the KMO will be close to 1.0. The KMO is expected to be higher than 0.5 to be

[1] A construct can be defined as a complex idea or a conceptual theory

"acceptable". Bartlett's test of sphericity determines whether the correlation matrix is an identity matrix. The test should be significant (<.05).

The questionnaire consisted of 107 valid items, in four sections, to which the factor analysis was applied:

- A: Human factors direct evaluation (26 items)
- B: Personal symptoms and person-related incidents (8 items)
- C: Vessel-related incidents (8 items)
- D: Human factors Likert-scale questionnaires (65 items).

A detail description of the questionnaires is presented in the first paper [1].

2.1. HUMAN FACTORS DIRECT EVALUATION

A KMO measure of sampling adequacy and Bartlett's test of sphericity confirm that the twenty-six-items in Section A are suitable for factor analysis. The Statistical Package for the Social Sciences (SPSS) software version 14.1 [7] was used to perform factor analysis. The principal axis factoring (PAF) extraction method was utilized. The programme first explored the strongest correlation between the items and a latent factor, called Factor 1, then, continued to look for the second latent factor, Factor 2 and so forth. Finally, five factors were revealed. Rotational methods were explored to clear the results. Table 1 shows the results of the factors after being rotated using the Oblimin rotation method with Kaiser normalisation. Each row of the table shows a regression equation where the item is expressed as a function of the factors. Coefficients smaller than 0.3 were suppressed because they are negligible. Several bridging variables were identified: "overall safety", "manoeuvring", "accommodation", "engine room" "bridge design" and "alarm". Bridging variables are items which contain more than one dominant coefficient or contain several less dominant coefficients, showing overlap. Typically in factor analysis this type of variable will be omitted, however, in this research, bridging variables seem to have a different and meaningful interpretation. They are discussed in Section 3.

The results presented in Table 1 are not completely clean because some variables still contain loadings in more than one factor, namely: "DP system", "general arrangement/layout", "equipment", "overall working condition", "space" and "ECR". The first rotated factor, Factor 1 was most highly correlated with "autopilot", "navigation system" and "DP system". The second factor was most highly correlated with "system procedure", "general arrangement and layout", "storage", "equipment", "overall working condition" and "space". The third factor was closely linked with "vibration", "sound/noise", "motion", and "ECR". The fourth factor was associated with "cargo deck" and "cargo tanks". The fifth factor was highly correlated with "overall reliability", "control & maintenance" and "automation".

According to LR's HF framework, Factor 1 can be identified as "Controllability", Factor 2 as "Workability", and Factor 3 as "Habitability". Factor 4 "Cargo Facilities" and Factor 5 "Reliability, Automation and Maintainability" are not specifically contained in the framework, but are common terms found in the industry.

Table 1 Pattern Matrix of Human Factors Direct Evaluation Scale (Section A)

Item	Factor				
	1	2	3	4	5
Autopilot	0.873				
Navigation system	0.767				
DP system	0.482				0.301
System procedure		0.771			
General arrangement/ layout		0.724		0.332	
Storage		0.671			
Equipment	0.337	0.604			
Overall working condition		0.573		0.386	
Space		0.508		0.305	
Communication system and equipment		0.364			
Vibration			0.826		
Sound, noise			0.786		
Motion			0.696		
ECR	-0.306		0.664		0.358
Overall comfort			0.440		
Accommodation			0.359		
Cargo deck				0.926	
Cargo tanks				0.711	
Overall reliability					0.777
Control & maintenance					0.713
Automation					0.671

Extraction Method: Principal Axis Factoring
Rotation Method: Oblimin with Kaiser Normalisation

2.2. PERSONNEL INCIDENTS

The KMO test shows a sampling adequacy of 0.574 and Bartlett's test of sphericity shows significance of 0.000, confirming that Section B is suitable for factor analysis. Three components were extracted from the eight-item personnel incidents data in Section B using principal component analysis (PCA). The Oblimin rotation method with Kaiser normalisation was applied. Table 2 shows that the first factor has an essential correlation with the following items: "confused by the system", "misoperate a switch or control" and "fail to follow the system/procedure". The factor can be labeled as "Operational Incidents". The second factor covers: "sleep disturbance and sleep interruption", "seasickness" and "fatigue/tiredness". These are related to "Discomfort" on the vessel. The third factor is most highly correlated to following items: "stumble or hit an object by accident" and "slip, fall or loss of balance". The third factor can be labeled "Occupational Incidents". It can be seen that "fatigue and tiredness", even though it lies under "Discomfort" (Factor 2), also correlates with "Occupational Incidents" (Factor 3). This is quite reasonable, as it involves the logic that people get tired because of being uncomfortable on board ship which then leads to incidents while working.

Table 2 Pattern Matrix of Personnel Incidents (Section B)

Item	Factor		
	1	2	3
Confused by the system	0.88		
Misoperate a switch/control	0.77		
Failed to follow the system / procedure	0.73		
Sleep disturbance or sleep interrupted		0.89	
Seasickness		0.78	
Fatigue/tired		0.71	0.48
Stumble or hit an object			0.85
Slip, fall or loss of balance			0.77
Extraction Method: Principal Component Analysis Rotation Method: Oblimin with Kaiser Normalisation			

Table 3 Pattern Matrix on Vessel's Incidents (Section C)

	Factor			
	1	2	3	4
Contact/collision	0.87			
Fire or explosions	0.84			
Water on deck		0.77		
Moving cargo on deck		0.72		
Loss of power/blackout			0.80	
Loss of navigation/control			0.74	
Falling objects				0.90
Bulk cargo spill				0.79
Extraction Method: Principal Component Analysis Rotation Method: Oblimin with Kaiser Normalisation				

2.3. VESSEL INCIDENTS

Assumption testing is not completely fulfilled for the eight-item vessel incidence data in Table 3. The KMO measure of sampling adequacy is lower than 0.5, at 0.460, but the Bartlett's test of sphericity reaches a significant level of 0.000. Factor analysis was thus performed with extra caution. Four components are extracted from the eight-item vessel's incidence data in Section C using the PCA extraction method. The Oblimin rotation method with Kaiser normalisation was also applied. The first factor covers these items: "contact/collision" and "fire/explosions" (see Table 3). This factor can be categorised as "Major Incident". The second factor has high correlation with the following items: "water on deck", "moving cargo on deck". It can be called "Deck Incidents". The third factor consists of two items: "loss of power/black out" and "loss of navigation/control". This factor can be labeled as "Ship Operation Incidents". The fourth factor have high relationships with: "falling objects" and "bulk cargo spill". This factor can be named "Cargo Operation Incidents".

2.4. HUMAN FACTORS LIKERT-SCALE

Section D, which consists of sixty-five items, is obviously not suitable for factor analysis given "only" the forty-two responses available, however, an experimental attempt to pursue the analysis was performed. As many as eighteen factors were extracted when factor analysis was run the first time using the principal component extraction method. The eigenvalue criterion of greater than 1 was used. An eigenvalue shows how much a factor explains the variance of the items. Vague items, items with no significant loadings, and items with several cross-loadings were eliminated. After several iterations, seven components were found (see Pattern Matrix in Table 4). The Oblimin rotation method with Kaiser normalisation was applied.

The first factor consists of items related to maintenance, equipment, bridge design, layout of the vessel and systems reliability. It is quite similar to Factor 5 in the human factors direct evaluation (Section 2.1.) "Reliability, Automation and Maintainability", but here it is broader. The factor revealed here can be called "Reliability, Operability and Maintainability". The second factor consists of items reflecting difficulties and problems encountered by the crews on board, such as too many alarms, too much automation and overly complicated systems. This factor is therefore called "Interfacing Complexity". The third factor consists of items involved with manoeuvring, the DP system and autopilot. It can be called "Ship Handling and Manoeuvrability". The fourth factor consists of forms, checklists and procedures. It is then labelled "Systems and Procedures". The fifth factor is related to noise and cargo deck, and thus, it is referred to as "Deck Working Condition". The sixth factor consists of items related to the engine control room and engine room; therefore it is named "ER and ECR". The seventh factor is related to sleep and ship motion. It is identified as "Habitability".

The factors revealed from the human factors Likert-scale questionnaires can be summarised:

1. Reliability, operability and maintainability
2. Interfacing complexity
3. Ship handling and manoeuvrability
4. Systems and procedures
5. Deck working condition
6. Engine room and engine control room
7. Habitability

Table 4 Pattern Matrix on Human Factors Likert-scale (Section D).

	Factor						
	1	2	3	4	5	6	7
It is easy to do maintenance of the vessel	0,91						
It is easy to operate the equipment on board	0,76						
The system on the bridge is quite informative	0,73						
The vessel has a good layout	0,71						
Most systems have good reliability	0,69						
We have too many alarms on board		0,92	0,31				
We have too much automation on board		0,79					
The computer menu system is too complicated		0,77					
Sometimes the alarm system is confusing		0,71					
It's not easy to manoeuvre the vessel			-0,91				
The vessel has a good manoeuvring capability			-0,85				
The vessel has a good and reliable DP system			-0,79				
It is easy to manoeuvre the vessel			-0,74				
Sometimes we cannot rely on the autopilot			-0,65				
There are so many forms & checklists to fill in				0,89			
We have too many procedures to follow				0,77			
Some areas of the vessel are very noisy					-0,82		
The cargo deck is well designed					0,80		
The ECR is designed so it can be monitored and operated easily						0,81	
The ER can be maintained without any trouble						0,77	
Sometimes I can't sleep well on the vessel							-0,93
Sometimes we can feel that the vessel is moving too much							-0,84
Extraction Method: Principal Component Analysis Rotation Method: Oblimin with Kaiser Normalisation							

3. DISCUSSION

Factor analysis was performed to examine human factors construct in ship design. Some factors defined in the framework remain and some dissipate during the process. The two different human factors scales that were analysed, Section A (direct evaluation) and Section D (Likert-scale), provide similar results. Both outcomes look reasonable and valid. The grouping presented in Table 1 (from Section A) involves similar components or parts of the ship approach with each other that eventually merge into one factor. These terms are familiar to naval architects and marine engineers, and thus obviously in the scope of the work of designers and engineers. The grouping presented in Table 4 shows more complex constructs. They represent the characteristics or traits of the components presented in Table 1, and are consequently following the components being positioned or applied on board. These complex constructs were revealed as bridging components such as manoeuvrability, accommodation, general arrangement, overall working conditions and safety. They disappeared during factor analysis in Section A. These types of constructs then appeared in Section D and called “Reliability, Operability and Maintainability”, “Interfacing Complexity”, and “Deck Working Conditions”. Those terms are slightly distant from the perspective of designers and engineers but are the realities of daily life for the seafarers.

An attempt to establish a theoretical construct of the human factors was performed based on results of the factor analyses of Section A and Section D. A model was developed (Figure 1) to describe the relationships between components or parts the ship and the factors of interest. The basic components from Table 1 were positioned and connected to the corresponding HF dimensions such as autopilot, navigation system and DP system related to controllability. Parts of the ship design, related to the components, were then identified, such as hull, bridge, engine room and engine control room. The complex factors obtained in Table 2 were inserted into the model by considering their relationships with other factors. Obviously, those bridging variables came later in the model, on the right hand side of the model in Figure 1 - which also represents the consequence or the product of the proceeding factors and processes. Hull design affects a ship’s motion which in turn will influence the habitability of the vessel. Habitability is also affected by noise and vibration, which originate from the engine room. In the end, habitability will have an impact on safety and performance.

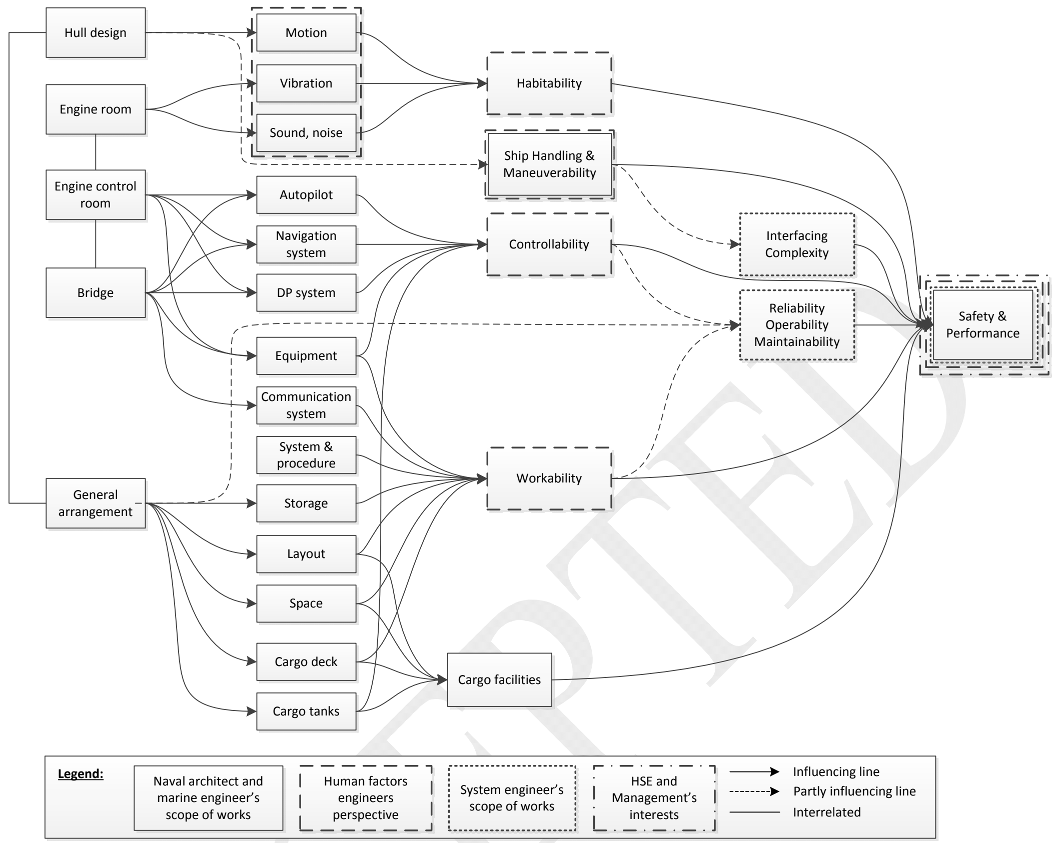

Figure 1 Inter-connectivity of human factors on ship design and operation

Hull design also makes a significant contribution to ship handling and the manoeuvrability of the vessel. It can be seen that the model is not yet complete. Ship handling and manoeuvrability are influenced by thrusters (and the rudder), which however were excluded from this process of data analysis. The items related to manoeuvrability were eliminated in the process due to weak loadings.

The model is still at its preliminary stage. The number of respondents was too small for anything except a tentative analysis. More data is obviously required. However, at this point it is safe to show that the ultimate objectives of the model are "Safety and Performance". Some of the factors may change their attributes (names) should more data and respondents be involved. Some relationships between parts and factors may also alter. It seems that some relationships still need to be explored, such as "Controllability and "Interfacing Complexity", hypothetically should be related.

An effort was made to identify the parties responsible for the different aspects. Naval architects and marine engineers are responsible for hull design, the engine room, engine control room and general arrangement of the vessel. They are familiar with the terms of motion, vibration, noise, autopilot, navigation system, etc. The human factors engineers are acquainted with terms such as habitability, controllability and workability, while the HSE personnel is familiar with safety.

We can confidently argue that safety is inherent in all other components, parts, dimensions or constructs. Figure 1 shows a preliminary model of how these components, parts, and dimensions are connected to safety. Addressing safety as a separate entity, whether at the last stage of designing a ship or even only at the operational stage is therefore considered insufficient.

4. CONCLUSIONS

Factor analysis was used to analyse the human factors framework. The dominance of some factors is similar to the dimensions defined by the theoretical construct [2, 3]: (1) controllability, (2) workability and (3) habitability. Ship handling and manoeuvrability emerged as one factor, and three "new" factors appeared: (4) cargo facilities, (5) reliability, operability and maintainability and then (6) interfacing complexity. Several dimensions such as OHS and maintainability faded and merged into the other factors. Survivability and system safety were too weak to emerge, however, it was discovered that weak factors should not be excluded from the analysis. They should be re-arranged and have the potential to show interconnectivity between components, parts, dimensions and constructs of human factors on ship design and operation. It is expected that this can help us address human factors issues effectively, including who should consider what issue and when.

A preliminary model of human factors considerations in ship design and operations has been presented.

Personnel incidents onboard are summarised into three factors: (1) operational incidents, (2) discomfort, and (3) occupational incidents. Vessel incidents are divided into: (1) major incidents, (2) deck incidents, (3) ship operation incidents and (4) cargo incidents. More data is required for this effort to be meaningful, and therefore, it is recommended that the study be expanded to include more respondents.

5. REFERENCES

1. RUMAWAS, V. and B.E. ASBJØRNSLETT, Human Factors on Offshore Supply Vessels in the Norwegian Sea – An Explanatory Survey. *Trans RINA International Journal of Maritime Engineering*, 20XX. XXX (Part XX).
2. LLOYD'S REGISTER, *The Human Element: An Introduction,* Lloyd's Register: London, 2008.
3. LLOYD'S REGISTER, *The Human Element Best Practice for Ship Operators*, Lloyd's Register: London, 2009.
4. RUMAWAS, V. and B.E. ASBJØRNSLETT, A Content Analysis of Human Factors in Ship Design. *Trans RINA International Journal of Maritime Engineering*, Vol 156 (Part A3), 2014.
5. RUMAWAS, V. and B.E. ASBJØRNSLETT, *A Content Analysis of Human Factors in the Design of Marine Systems*, International Conference on Ship and Offshore Technology (ICSOT), The Royal Institution of Naval Architects: Surabaya, Indonesia, 11-12 Nov 2010.
6. SPEARMAN, C., "General Intelligence," Objectively Determined and Measured. *The American Journal of Psychology*, 15(2): p. 201-292, 1904.
7. SPSS INC. *SPSS for Windows*, Version 14.1. Chicago, SPSS Inc., 2010.

Appendix G: Questionnaires

A Survey of Human Factors on Ships

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A Survey of Human Factors on Ships

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The Department of Marine Technology
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2 0 1 1

A Survey of Human Factors on Ships

Introduction

This is a survey on ship design with respect to human considerations.

We would like to find out if the existing ship design has sufficiently considered human factors. By considering human factors, we can hopefully increase performance and assure safety.

We need your feedback, based on your subjective opinion and experience regarding the vessel's conditions. We need to know the problems that occur during the operations, so that they can be evaluated and therefore improved.

All given information and data are treated anonymously and with high confidentiality.

Regards,

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NO-7491

Instructions

We realize that the scope of this research is quite broad. Some questions may not be relevant to you. Therefore you are free to skip any question that is irrelevant.

- Tick (✔) or cross (✗) one of the cell that represents your answer.
- Tick (✔) or cross (✗) "no answer" if you don't know the answer or you cannot answer the question.
- You can elaborate your answer by adding more information in the blank page overleaf**.**

Your input is very valuable and may affect improvements in ship design in the future.

Should there any questions regarding this questionnaire, you can contact us directly, or via:

email vincentius.rumawas@ntnu.no
phone +47 735 95589; +47 414 55268

A	How would you rate the following characteristics of the vessel:	very poor	poor	neither	good	very good	no answer
1	The overall comfort						
2	Accommodation facilities						
3	Bridge design						
4	Vessel's motion						
5	Vessel's vibration						
6	Sound, noise, acoustic						
7	Equipment on board (in general)						
8	System and procedure						
9	Available space and room size						
10	Overall working conditions						
11	Vessel's general arrangement and layout						
12	Cargo deck design and arrangement						
13	Cargo tanks design and arrangement						
14	Communication system and equipment						
15	The overall safety						
16	Alarm system and monitoring						
17	Dynamic positioning (DP) system						
18	Navigation system						
19	Autopilot system						
20	Engine room design and arrangement						
21	Engine control room design						
22	Control and maintenance system						
23	System's automation						
24	Overall system reliability						
25	Available space for storage						
26	Vessel's manoeuvring capability						

B	How often do the people on board experience the following:	very often	quite often	some times	seldom	never	no answer
27	Get seasick						
28	Fatigue, tired						
29	Stumble, hit an object by accident, hit by an object						
30	Slip, motion-induced interrupted, loss of balance, fall						
31	Miss operate the switch or control						
32	Confused with the system						
33	Fail to follow the system / procedure						
34	Sleep disturbance, sleep interrupted						

C	How often does the vessel experience the following:	very often	quite often	some times	seldom	never	no answer
35	Loss of power, black out						
36	Loss of navigation control						
37	Contact, collide, collision with platform or other objects						
38	Water on deck						
39	Moving containers on deck, loosing pipes, etc						
40	Falling objects						
41	Fire or explosion						
42	Bulk cargo spill, pollution						

D	Please indicate whether you agree with the following statements:	strongly disagree	disagree	neutral	agree	strongly agree
43	The vessel is comfortable					
44	The vessel is quite stable					
45	It is easy to operate the equipment on board					
46	The vessel has a good layout					
47	Most systems on board have good reliability					
48	The vessel is quiet					
49	The system on the bridge is quite informative. The crew can detect any deviation during operations					
50	It is easy to do maintenance of the vessel					
51	The vessel is a good place to work					
52	It is safe to work on this vessel					
53	The vessel is designed by considering the human operator's perspective					
54	It is not comfortable to live on this vessel					
55	Most systems on board are ready for use from day 1.					
56	There are so many forms and checklists to fill in					
57	The cargo deck is well designed, the crane operator has a clear visibility through the whole area					
58	Some switches / controls are not easy to operate					
59	The vessel has good and reliable DP system					
60	It is easy to operate the vessel using this computerized system					
61	Some equipment is located hard to reach areas					
62	It is easy to control and maneuver the vessel					
63	We need a system that can automatically prevent vessel to collide with platforms or other objects					
64	I am proud to be a part of this ship					
65	Sometimes I cannot sleep well on the vessel					
66	Sometimes we can feel that the vessel is moving too much					
67	We have too many procedures to follow					
68	I think they need to improve the general arrangement of the vessel					
69	We have too many communication channels to monitor					
70	We have too much information presented on the screen					
71	We have too many alarms on board					
72	The engine control room has been designed so it can be monitored and operated easily					
73	The automation on board can be a trouble					

D	Please indicate whether you agree with the following statements:	strongly disagree	disagree	neutral	agree	strongly agree
74	Sometimes it is hard to do maintenance because of limited space					
75	We need a faster ship					
76	I like to work on this ship					
77	The color of the vessel is sometimes disturbing					
78	Sometimes I am disturbed by the vessel's slamming					
79	Some procedures are too complicated to follow					
80	I don't like the layout of the vessel					
81	We need a better system for transferring bulk cargoes					
82	Sometimes the crew is annoyed by the alarm					
83	This computer menu system is too complicated					
84	We need more space to put supplies, parts and tools					
85	Working in a vessel like this, is not good for our health					
86	Sometimes I feel that the crew is less considered in the vessel design					
87	The vessel is noisy					
88	It is not easy to find crew for this type of vessel					
89	Some people have very limited space for working					
90	Working on deck at sea is quite dangerous					
91	Sometimes the crew are confused with all the communication systems on board					
92	Sometimes it is hard to operate the vessel due to limited view					
93	Some displays cannot be dimmed, and it disturbs our visibility at night					
94	Sometimes the alarm system is confusing					
95	Sometimes we cannot rely on the autopilot					
96	Most systems on board are user-friendly					
97	The vessel is too complicated to maintain					
98	Some doors are difficult to open					
99	The vessel has a good maneuvering capability					
100	The vessel is designed by considering that something might go wrong					
101	Some areas of the vessel are very noisy					
102	The process of loading unloading cargo can be done without any significant problems					
103	Connecting hose at sea is not a difficult task					
104	The displays are visible in all conditions					
105	Sometimes it is hard to read the displays due to glare					
106	Some alarms are irrelevant					
107	We never have any problem with the DP system					
108	The engine room can be maintained without any trouble					
119	We have too much automation on board					
110	Some ladders / stairs are too steep					
111	It is not easy to maneuver the vessel, especially in restricted waters					
112	It is 'safe' to make mistakes because the system has been design with sufficient redundancies					

Thank you for your kind participation!

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