A presentation of

Human factors in ship design and operation:

Challenges related to digitalization and automation

based on

A PhD thesis

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@HFC – Human Factors in Control Meeting:
Digitalization and autonomy–
Challenges and opportunities related to human interactions
Trondheim, 17 – 18 Oct 2017

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Background of the presentation

- All materials in this presentation are based on a research contract conducted in 2008 – 2012.
- The title: **Human Factors in Ship Design and Operation:** *Experiential Learning*
- The research was fully financed by the **Department of Marine Technology, NTNU**
- The thesis was defended in Jan 2016.
- Full text is available at:
  - http://hdl.handle.net/11250/2382315
  - http://hdl.handle.net/11250/2382316

- Selected topics relevant to **digitalization & automation** are presented here.

Introduction

Background of the research

- **Fatal accidents** at sea
- Caused by **human errors** and/or human-related factors (mostly)
- **Human factors** were **barely a consideration** when designing a ship

How ships are designed and built

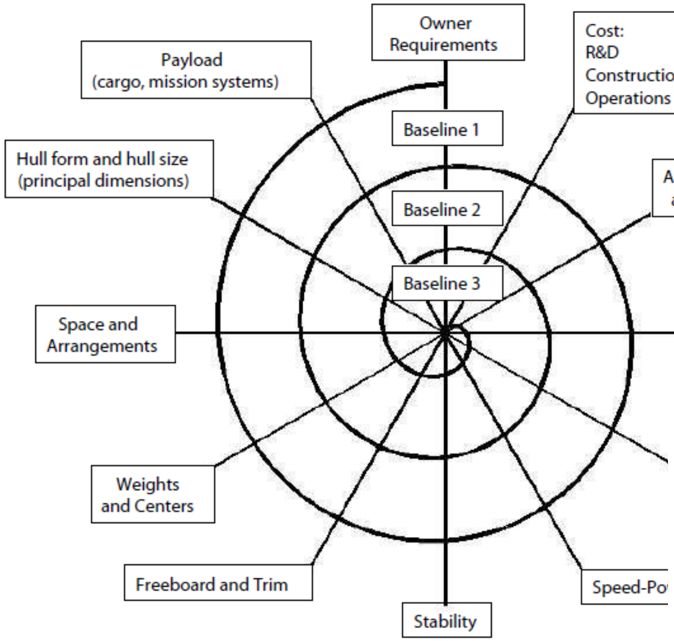


Figure 5.1 Design Spiral

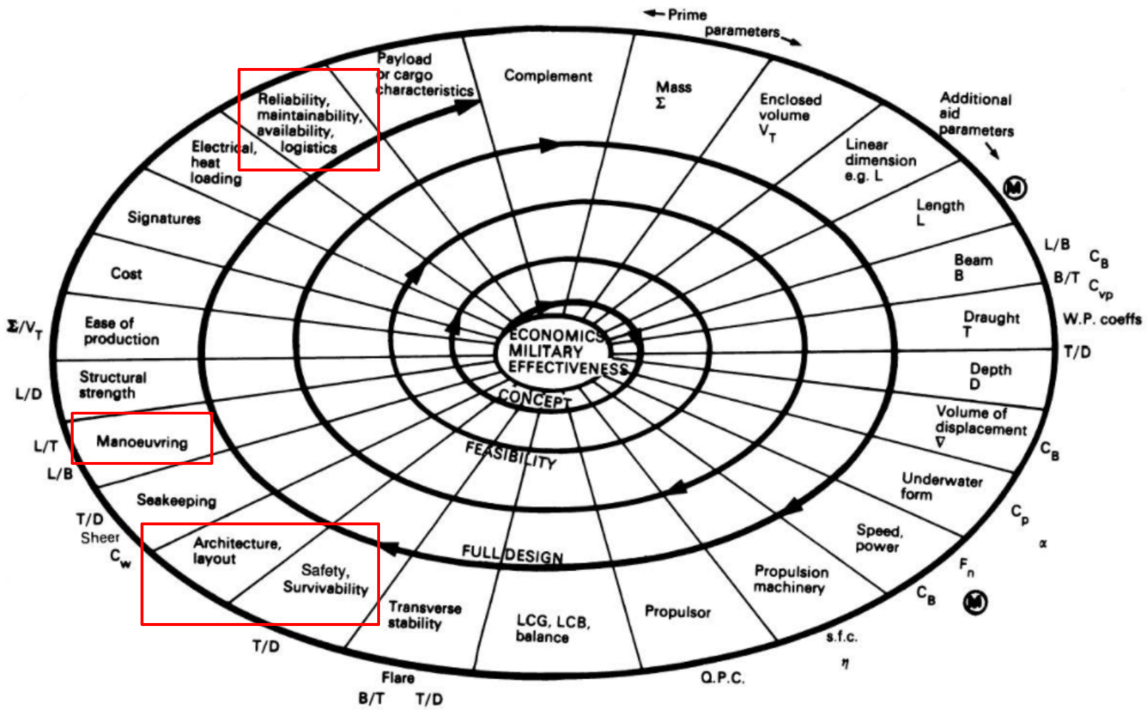
The Ship Design Process, Gale 2003 in Lamb (Ed)

The concept of **design spiral** represents the **sequential** and **iterative aspects** of the pro
that include:

- Conceptual design
- Preliminary design
- Contract design
- Detailed design

Ship design is a complex and multifaceted process, influenced by a number of actors. …

A successfully designed ship is the result of close and good cooperation between the designer, the customer, the yard and the equipment suppliers (Vossen et al 2013)

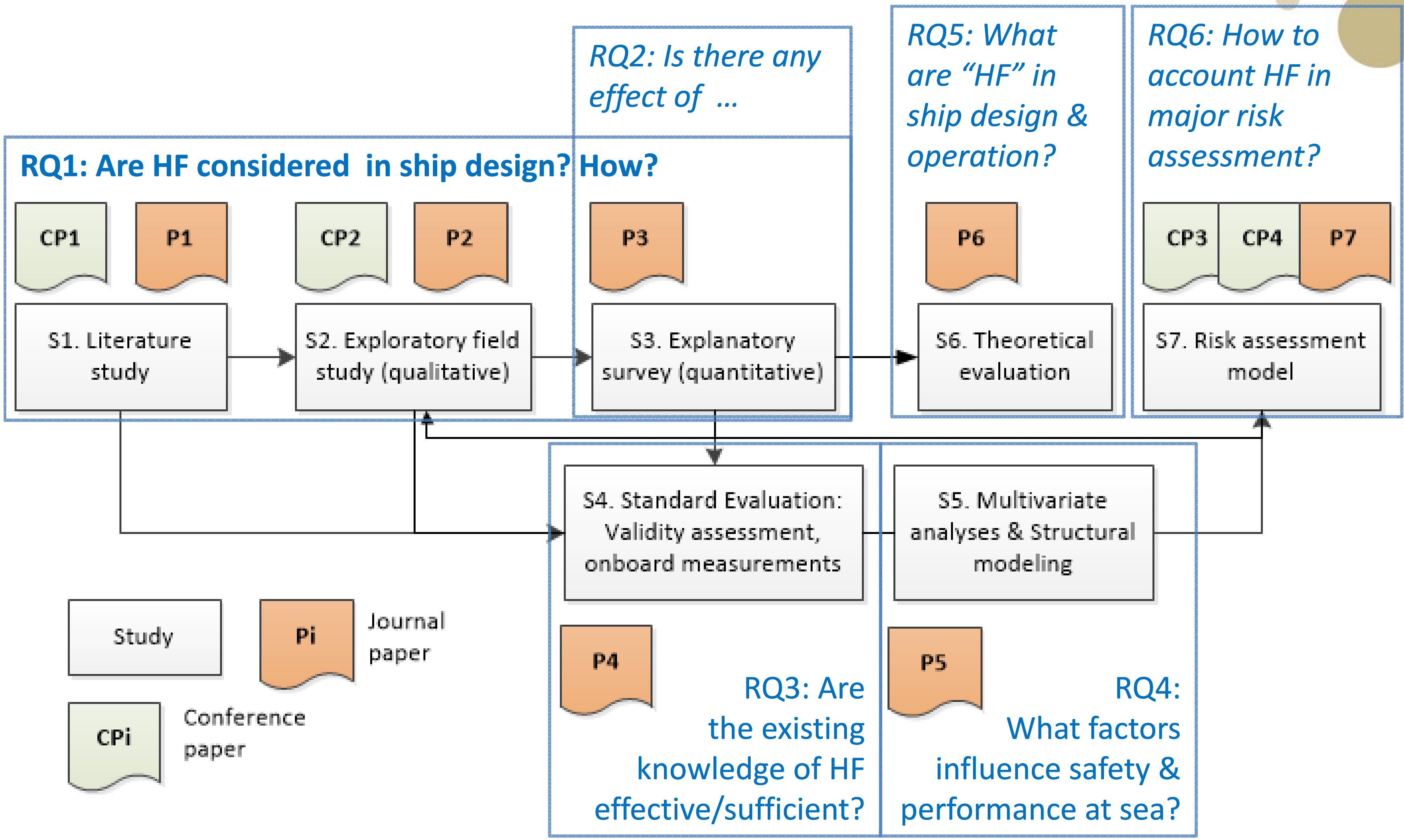


Basic Ship Theory, Rawson & Tupper 2001

Research questions

1. Are human factors considered in ship design? How … ?
2. Is there any effect of implementing HF?
   a. towards the crew
   b. towards incidences onboard
3. Are the existing knowledge of HF effective/sufficient?
4. What factors influence safety & crew performance at sea?
5. What are "HF" in ship design and operation?
6. How to take into account the "HF" in major risk assessment?

Research design and outline

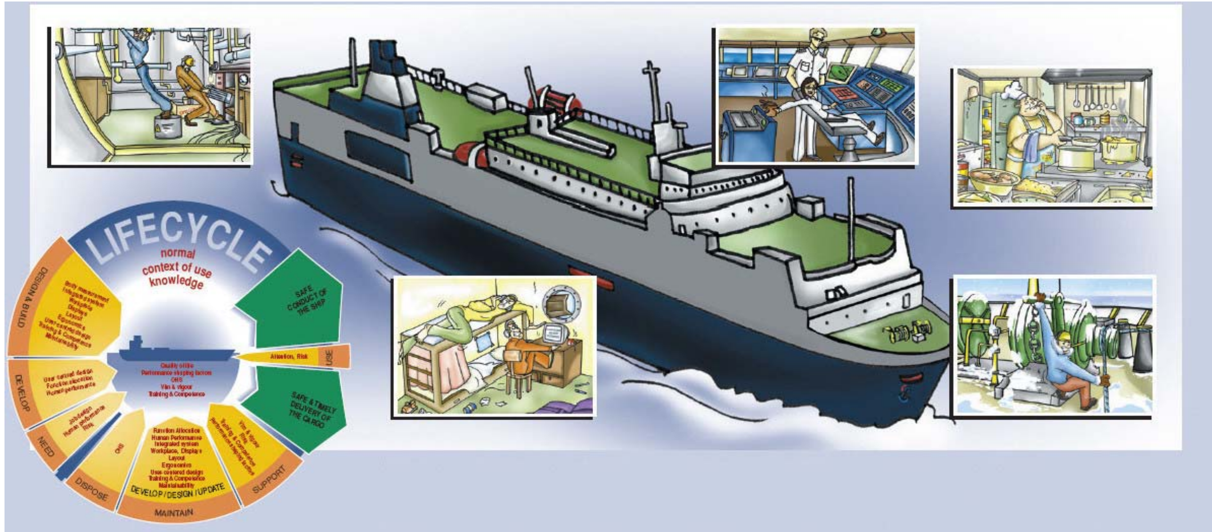


Some definitions

- **“human factors”**:
  - “Ergonomics (or human factors) is the scientific discipline concerned with the understanding of **<u>interactions</u>** 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” (IEA, 2012)
  - “human factors” is 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 eight considerations: habitability, maintainability, workability, controllability, manoeuvrability, survivability, occupational health and safety (OHS) and system safety (LR, 2008).

NB: “human factors” ≠ “human element” (physiological, psychological), “human error”, “human performance”, “HSE”, “human reliability”.

The research



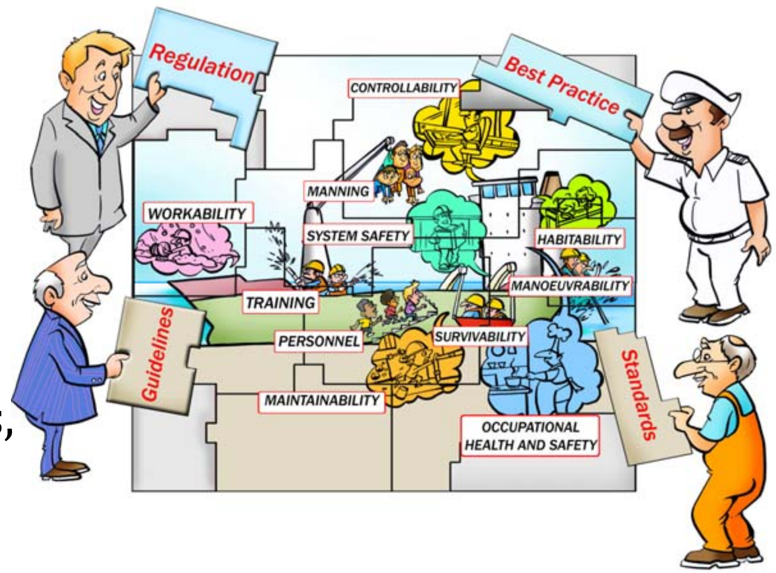
- RQ 1:

  Are HF considered in ship design? How?

☞ There are several ways to answer this:

- Ask the designer, the shipyard and/or the shipowner, or check the design specification/contract
- Check and review the ship itself (see Study 2)
- Ask the users (see Study 2 and Study 3)
- Consult the existing rules, regulations and standards available (Study 1)

Study 1. Literature study



- To check if human factors issues are taken into account in the existing standards, a survey of literature was performed.
- Two questions are to be answered:
  - What /which publications contain HF?
  - Which aspects of HF are addressed/considered?
- Results:
  - "A Content Analysis of Human Factors in the Design of Marine Systems". The International Conference on Ship and Offshore Technology, 11-12 Nov 2010, Surabaya
  - "A Content Analysis of Human Factors in Ships Design" The International Journal of Maritime Engineering, RINA Transactions Part A3, Vol 156, Jul – Sep 2014

Human factors framework

derived from:

Lloyd's Register, 2008, 2009 and developed in Rumawas & Asjbjørnslett 2010

RQ1. *Are HF considered in ship design? How?*

Study 1. ... Literature study

Results

- There are abundant documents cover HF
- HF issues have been sufficiently addressed.

- All HF DIMENSIONS are covered
- Most mentioned: SYSTEM SAFETY (highest freq)
- Most extensively: HABITABILITY (COMFORT)
  - Noise, vibration, indoor climate & lighting/illumination

- CONTROLLABILITY
  - Alarms, control centres, workstations, control & switches

- The least covered: MAINTAINABILITY

- HF issues is developing very fast

- The documents are *optional*.

Study 2. Exploratory field study

- To check if **the facts in reality** is *in accordance* with **the facts on paper**
  - Exploratory field surveys were performed using qualitative approach, incl:
    - Go on board
    - Join the trips
    - Observations
    - Do interviews
    - Discussions, focus group
  - NB:
    - Rapport is important
    - Action research, participatory, as a 'naïve observant'

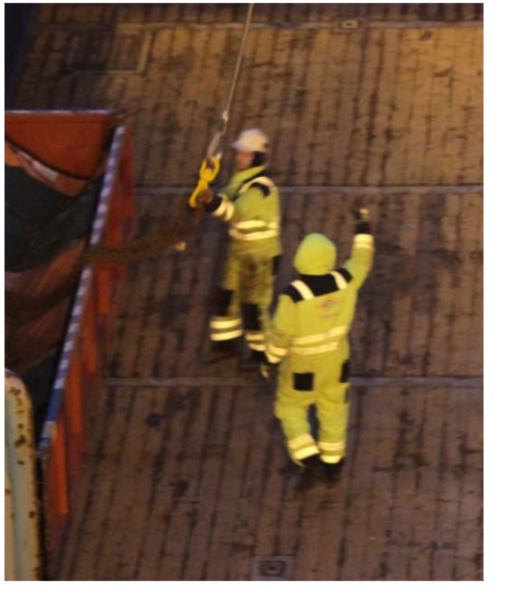
Study 2. Exploratory …

Before survey, some issues that were reported/found by other researchers on ship design were documented:

- Accommodation facilities, crew expect adequate levels of privacy (Strong 2000)
- Illumination problems on the bridge (Lutzhoft 2005)
- Ergonomic issues; no leg space, incorrect height/orientation, must-be-fixed equipment (Anderson & Lutzhoft 2007, Grundevik 2009)
- Problem with access & personnel movement, incorrect control panel, console problem (Dalpiaz et al 2005).

Incidences & accidents on OSV were also documented (Hansson 2006, PSA Norway 2011):

- Person squeezed between moving containers
- Person hit in the head by a moving hook
- Deckhand slip, fall, twisted a foot
- Poor autopilot interface system*)
- Collision with offshore installations*)



*) related to digitalization and autonomy

Collision cases related to automation

07.03 2004*)

Far Symphony had a course towards the facility West Venture. Entering the safety zone, the autopilot was engaged. The officer on the bridge did not realize that the autopilot was engaged and could not navigate the vessel. This ended in a collision.

18.07 2007*)

Grane was identified as a target for the autopilot on Bourbon Surf. The master misjudged the ship's speed and distance to the platform. He did not keep a proper lookout at the time. it was too late to stop the vessel, but they succeeded in reducing its speed from 3 m/s to 1 m/s before it hit Grane

06.06.2009*)

Well stimulation vessel Big Orange XVIII was approaching installation Ekofisk 2/4 X. The captain engaged the autopilot and forgot to switch it off. He could not control the vessel manually as he intended to do. Instead of slowing down, the vessel struck the installation at a speed of 9.5 knots.

Analysis: The crew failed to see that the autopilot was engaged and made a wrong decision in operating the vessel.

*)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

Offshore *supply vessels in Norwegian Continental Shelf*

- Carry goods to & from offshore platforms: containers, bulk, fluid (tanker), support platforms in various ways.
- Hi ***tech***
- *Developing very fast*
- 12 - 16 crew on board
- 2 - 3 trips per week
  serving 2 - 6 platforms per trip
- Crew rotation: 4 weeks on 4 weeks off

Issues found on board related to digitalization and automation

- The crew know less of their vessel, and more dependent of the manufacturers

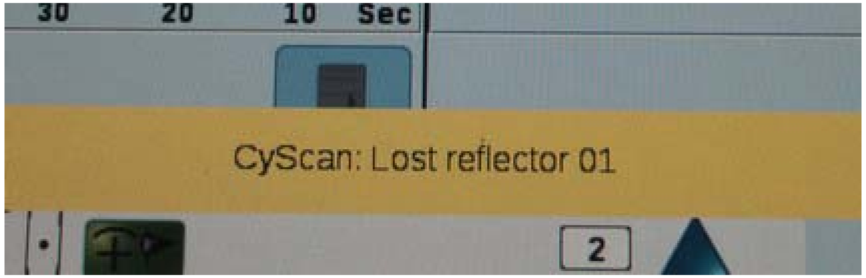
- No more 'wheel' and engine telegraph on the bridge

    - Most traditional controls are replaced by joystick, trackball, mouse, keyboard and touch screen
    - Given emergency situation, crew intervention becomes less straight forward and less intuitive

- Controll*ability*

Problems:

- Illumination
- System readiness, data validity
- Operating system related problems; updating, bugs
- Compatibility issues
- Software and data expiration date
- System overload, hang
- Unresponsive system
- A large number of alarms
- Limited internet bandwidth
- Variation in ‘electricity voltage’



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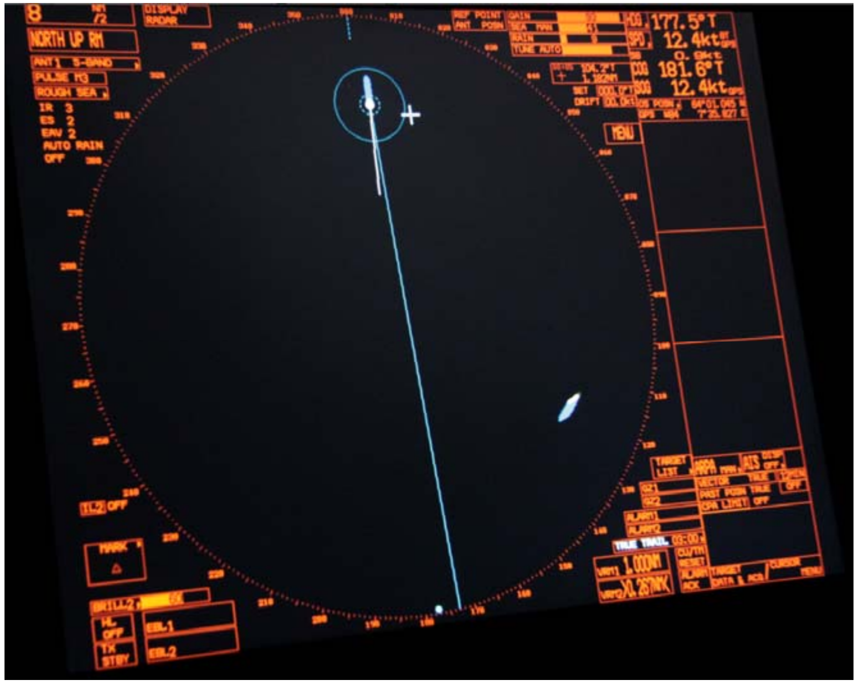
Issues related to digitalization and automation

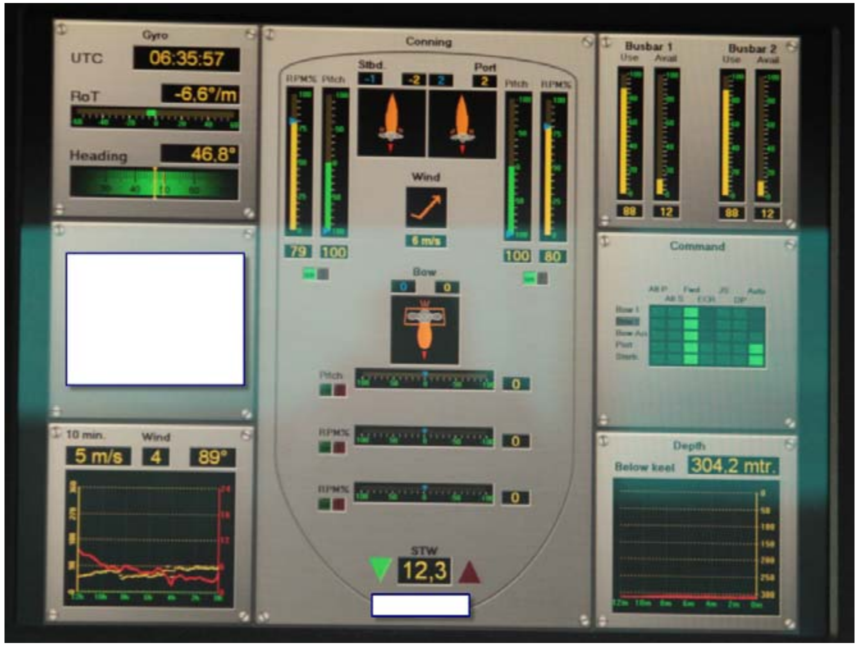
‘too much information on a screen’



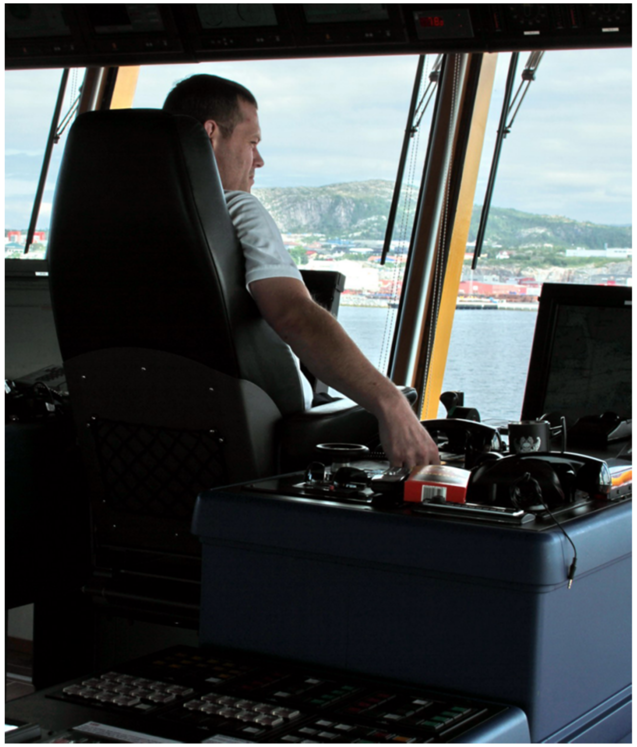
‘overabundant communication’

On a vessel, there are a number of conning displays installed in different locations. They should provide consistent information at all time.

These two pictures were taken almost at the same time on a vessel, showing two conning displays. Notice anything wrong?



Study 2. … Exploratory



- Ergonomics issue related to human interactions
- Discrepancy of knowledge:
    - special familiarization or training program

Critical incidents related to digitalization and autonomy

DP failure

One OSV 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.

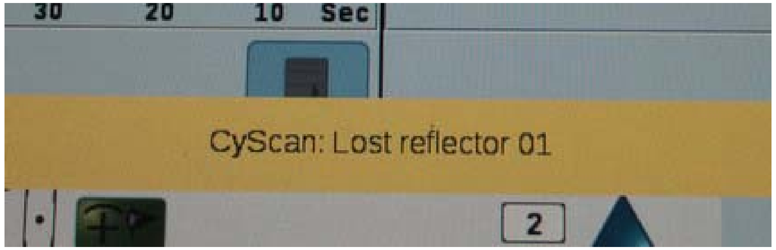
Explanation from the manufacturer:

" … We have found the root cause for this, and implemented a solution for it. This failure will not happen again."

☞ Interpreted as non-random, systematic error

☞ Overlooked scenario during design/development

Further exploration regarding the incident, according to the seafarers experience, "DP2 fails all the time"



Critical incidents affecting autonomy

Blackout

One OSV 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, and the system blackout.

Explanation:

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
- ☞ the designer and the manufacturer were not aware of this characteristic of LNG fuel.

13.11.2006 A collision caused by blackout: Navion Hispania (tanker) blacked out, due to polluted fuel and a system malfunction. Hit Njord B at 1.2 m/s. Collision energy > 60 MJ.

One unresolved issue related to digitalization and automation

On one OSV:

Releasing DP system from automatic mode to manual mode requires a specific response of time. Without full control, this delay can be critical, especially when the vessel is located close to an installation. Normally the operator will use the joystick to bring the vessel away from the installation before switching to manual mode.

On the other OSV

This does not occur because the transition occurs instantaneously.

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 vessel.

☞ The fact that the vessel is approved to operate and carry the associated notation causes confusion.

Study 2. Exploratory field study

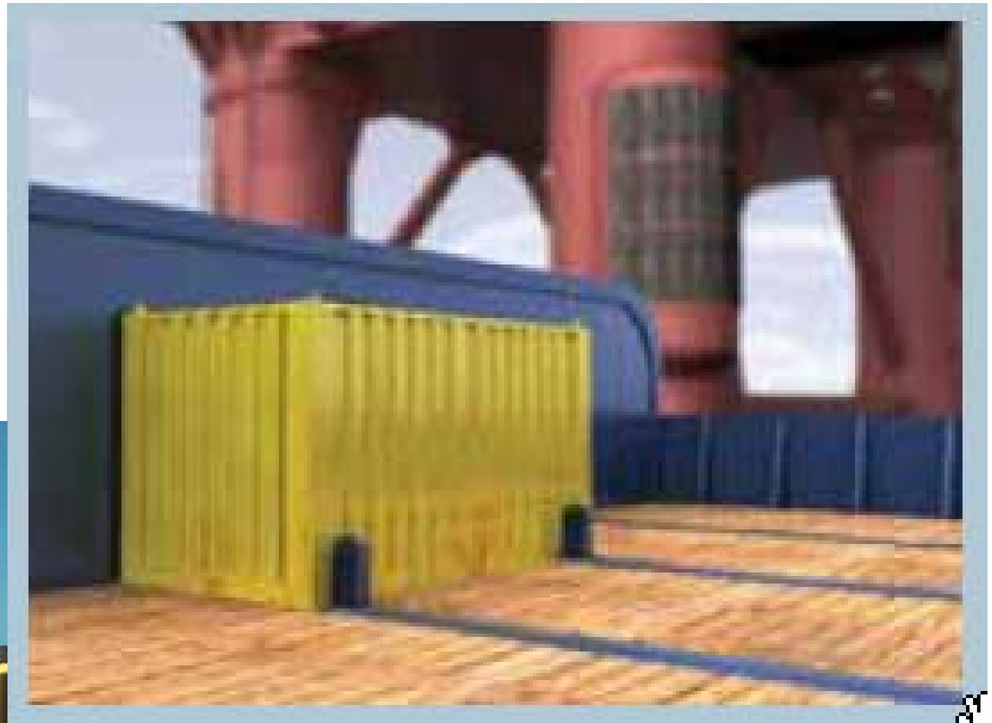
Lessons learned

- Modification of the autopilot system Currently, the autopilot will automatically deactivated when the crew operates the joystick (DNV NAUT OSV 2012).
- 500m safety zone is implemented. An installation can no longer be identified as a target for autopilot (NWEA 2006, updated 2009)

Potential contribution of automation on OSV operation:

- Smart lookout, enhanced autopilot
- 'Smart routing'
  ~ f(weather, fuel cons, t, etc.)
- Automatic positioning / 'parking'
- Maintenance: 'long distance setup, updates, or maintenance' by the manufacture
- Maintenance schedule, - can be performed when the vessel at port
- Automatic emergency stop
- e-(smart) check list

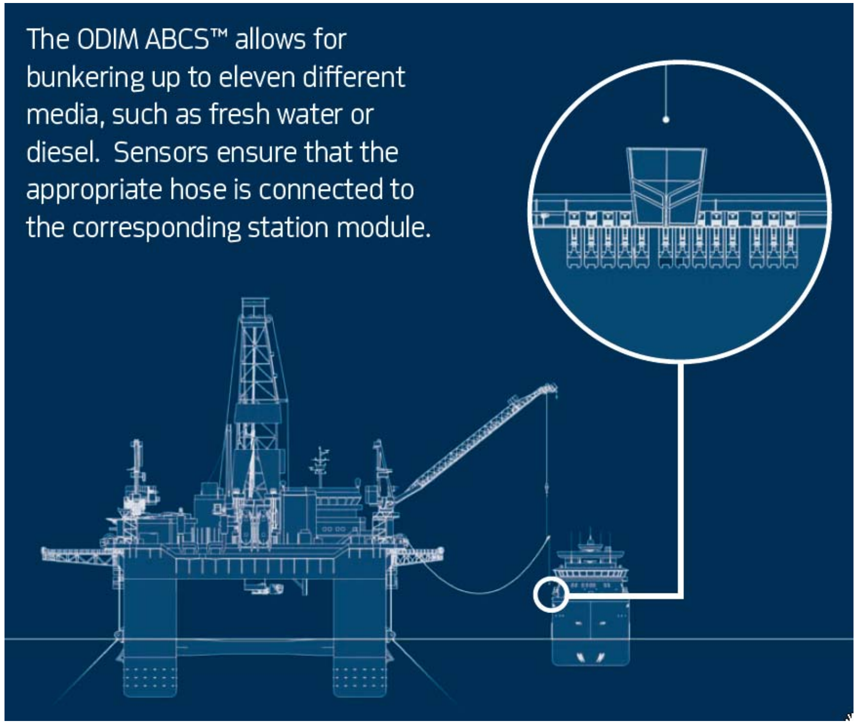
Lessons learned on deck



- Increase bulwark height to avoid green water

- To secure tubular cargoes on deck, **developed & installed:** portable, automatic, movable stanchions

Lessons (tried to be) learned, and fail



To help deckhands connect bulk hose at sea, an automatic bulk cargo securing & transfer system was developed & installed, but fail to work

Study 2. Qualitative study

Conclusions

- HF has been considered in OSVs design;
  - The crews in general are satisfied with their vessel
  - There is always room for improvement
  - HF considerations on OSVs were happening due to good communications between the crew, ship owners, cargo owners and different manufacturers, including the shipyards.
  - Financial incentives for research and development also plays an important role.

- Different problems are experienced by different vessels
  - HF problems are unique (noise, motion, controllability, etc.)
  - Some issues remain (illumination, layout, space, stairs, access)

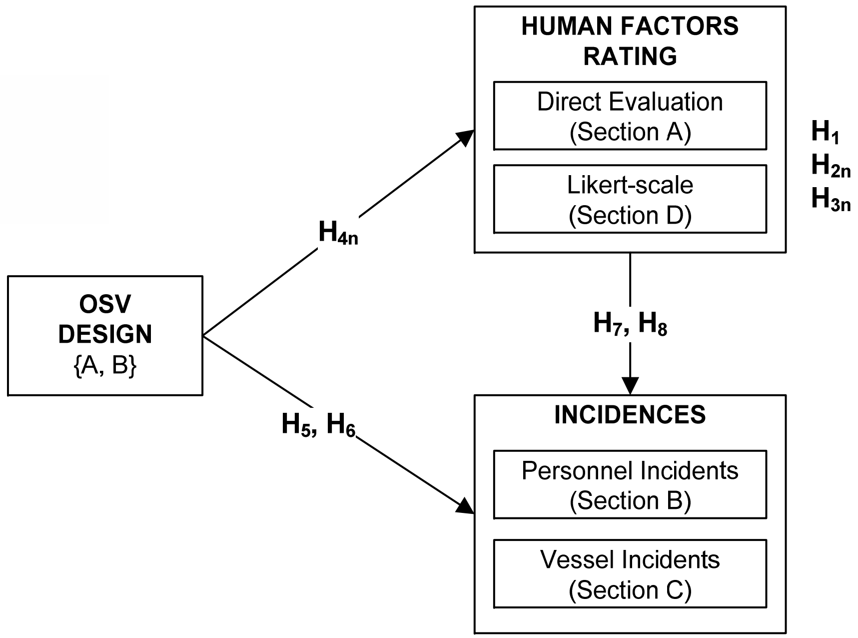
- Best satisfying: Habitability & Workability
- Lowest satisfying: Maintainability
- Fastest growing dimension: Controllability
- There is a potential of unknown risk in the development of new equipment/system.

RQ1. *How are HF taken into account in ship design?*
RQ2. *Is there any effect of HF consideration to incidences on board?*

Study 3. Quantitative study

To check if the qualitative findings are *valid*

- An **explanatory study** using **quantitative approach** was conducted

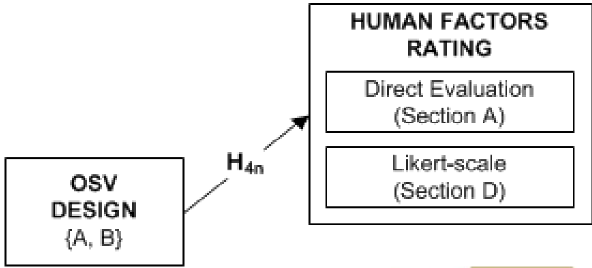


Results:

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

Trans RINA, Vol 158, Part A1, International Journal of Maritime Engineering, Jan-Mar 2016

RQ1. *How are HF taken into account in ship design?*



Study 3. … Quantitative

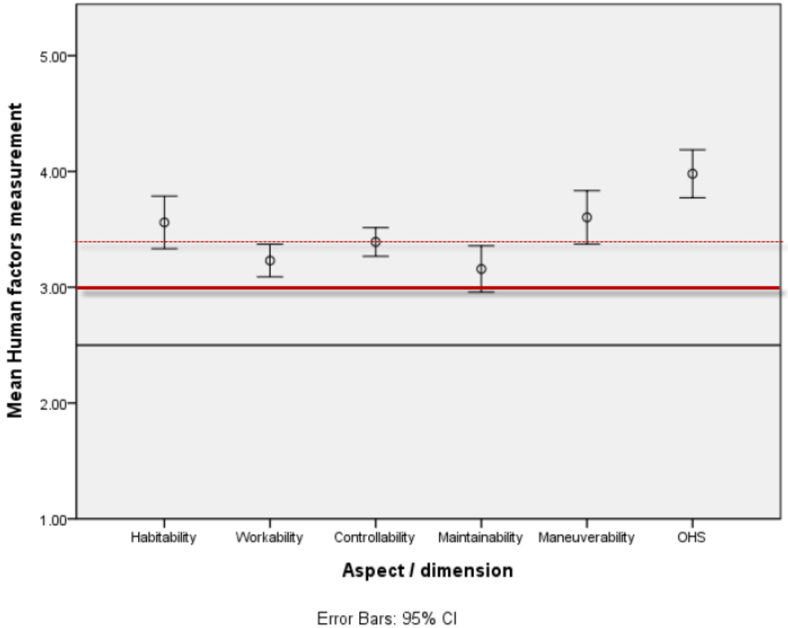
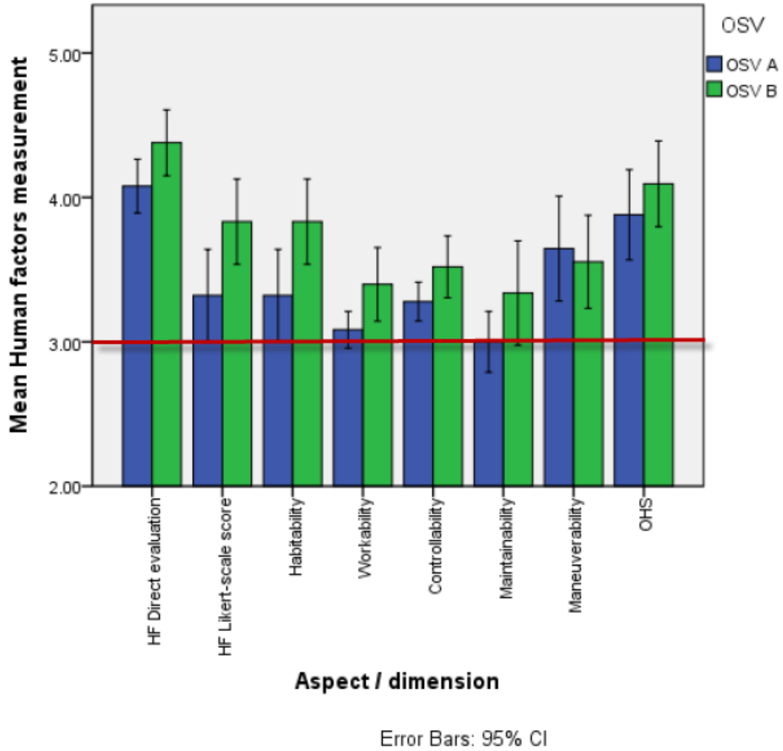


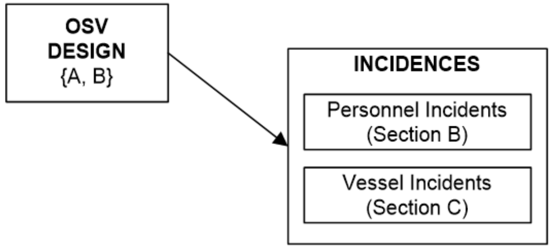
Figure 2 Human Factors Likert-scale Evaluation Result: Mean plot with error bar for each dimension



- Human factors are significantly addressed.
- Dimensions of human factors are not rated equally:
  - OHS is rated more highly
  - Maintainability is rated lower

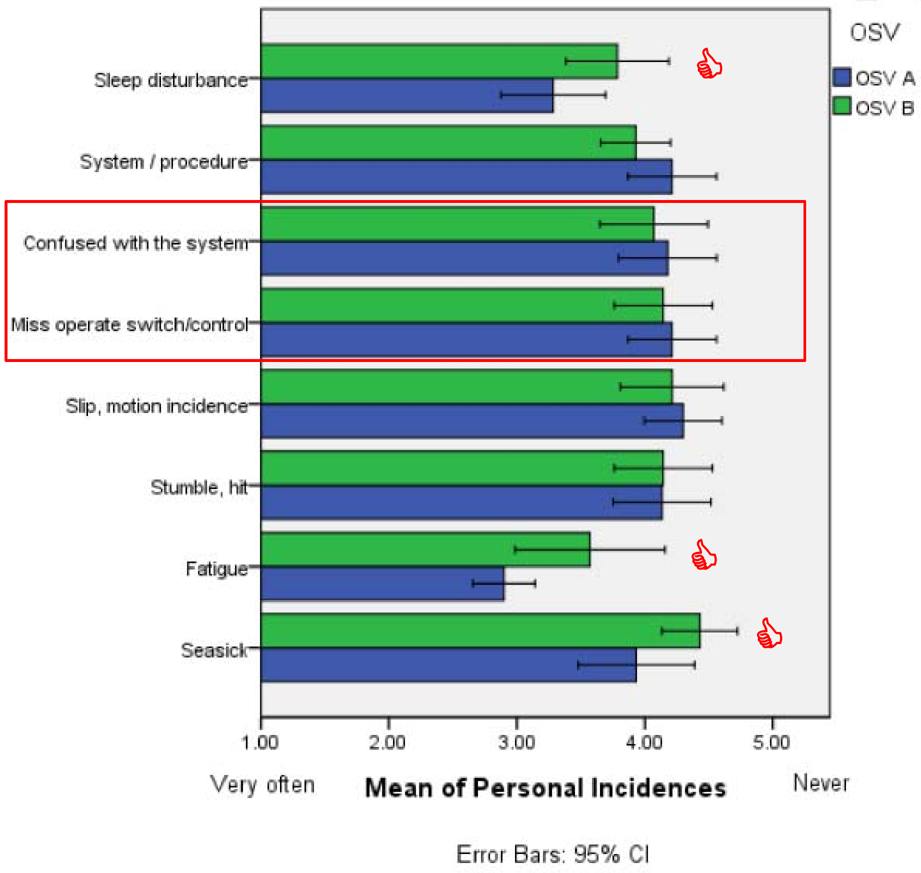
There is an indication that human factors rating varies as a result of OSV design, but the finding is inconclusive
(due to numerical correction)

RQ2a. *Is there any significant effect of ship design to incidences on board?*

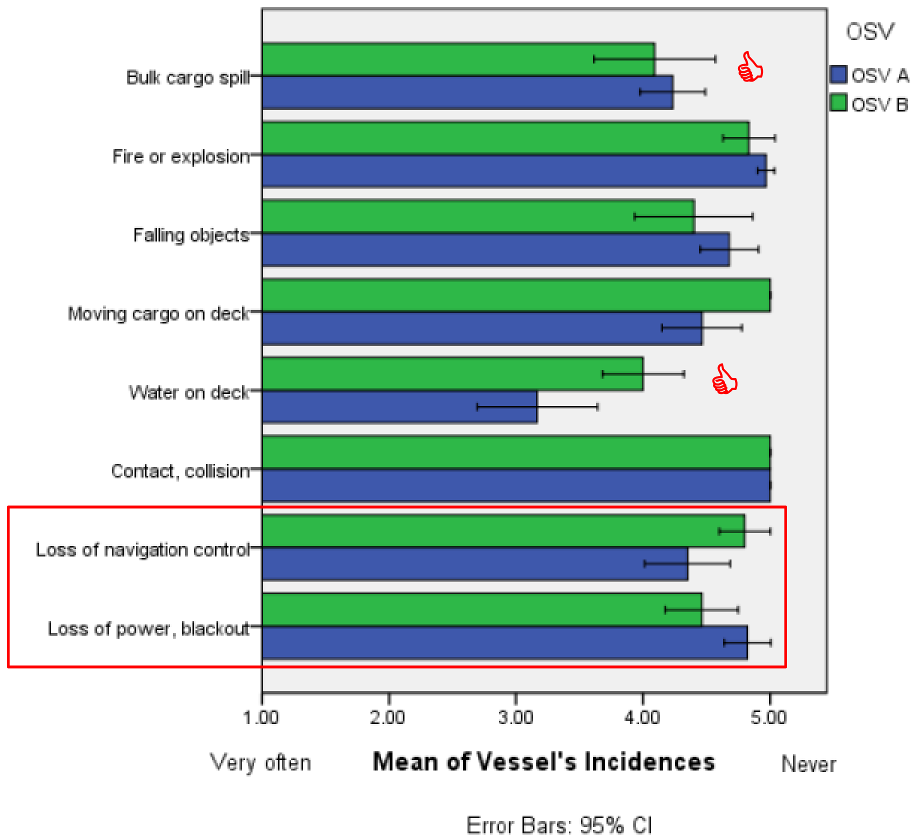


Study 3. … Quantitative

How often do the people on board experience the following:



How often does the vessel experience the following:



RQ2b. *Is there any significant effect of HF consideration to incidences on board?*

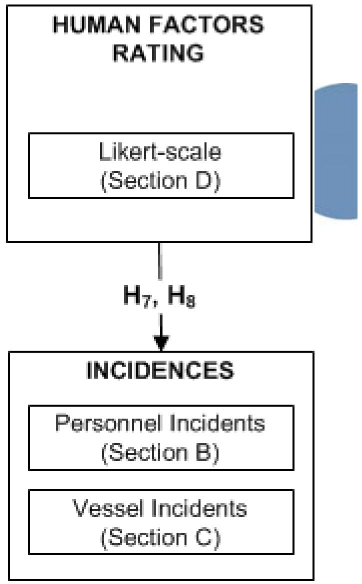
Study 3. Quantitative

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					

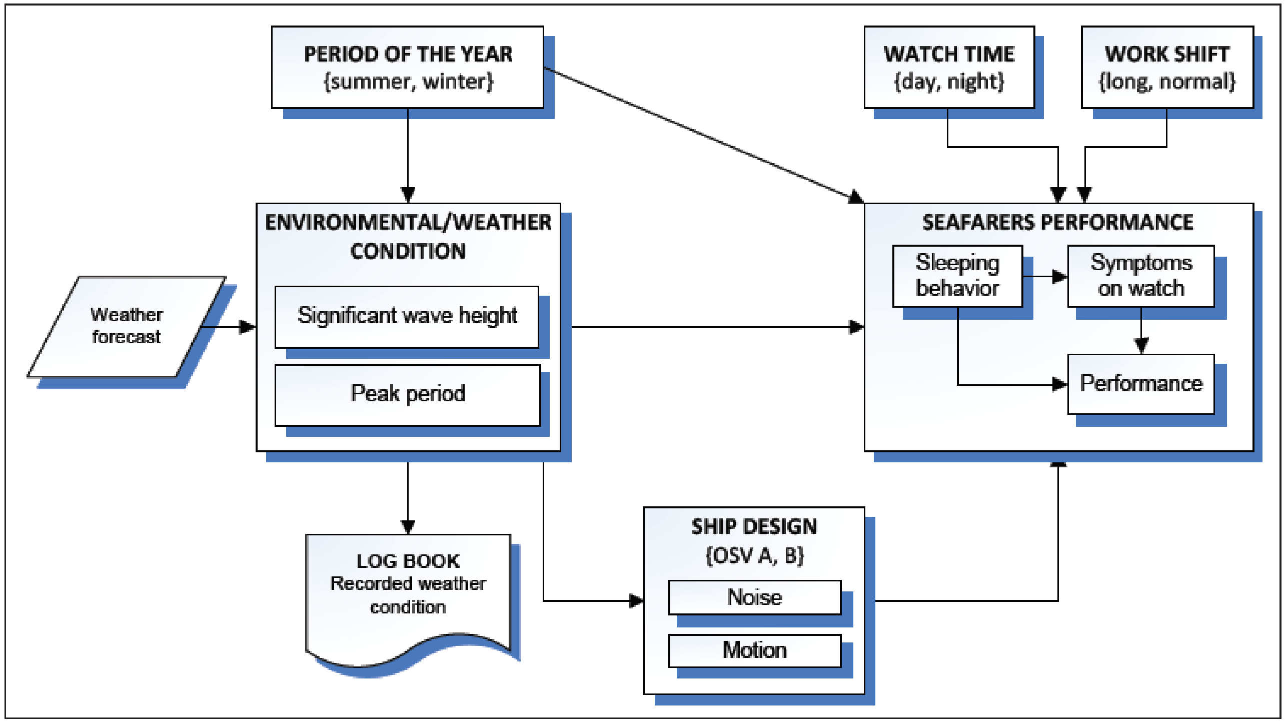


- **Habitability** has a positive effect on the frequency of personnel becoming **seasick, fatigue** and experiencing **sleep disturbance**.
- **Maintainability** has a negative effect on the frequency of **fire or explosion** on board.

Study 4. Evaluation study

To check if **the existing knowledge** of human factors in ship design and operation are effective

- An **evaluation study** was conducted, by **performing physical measurements** on board, combined with **some observations** and **daily diaries** filled in by the seafarers **after every watch**



Study 4. Evaluation study

- <u>**Conclusions:**</u>
  - The existing **noise criteria** do not reflect comfort
    - Disturbing noises [impulsive noise, high pitch noise, squeaking noise and hammering noise] are not covered nor captured
  - Motion criteria need to be revised for OSV operations
    - They are not realistic; the criteria are too high (too lenient), especially MII and roll motion.
  - The MSI (McCauley et al, 1976) is extremely conservative for seafarers population, needs to be adjusted

- **Recommendations:**
  - **Standards and criteria** be re-examined within **a reasonable period of time**, especially in case an incident occurs

RQ4. *What factors considerably influence crews' performance at sea?*

Study 5. Multivariate ...

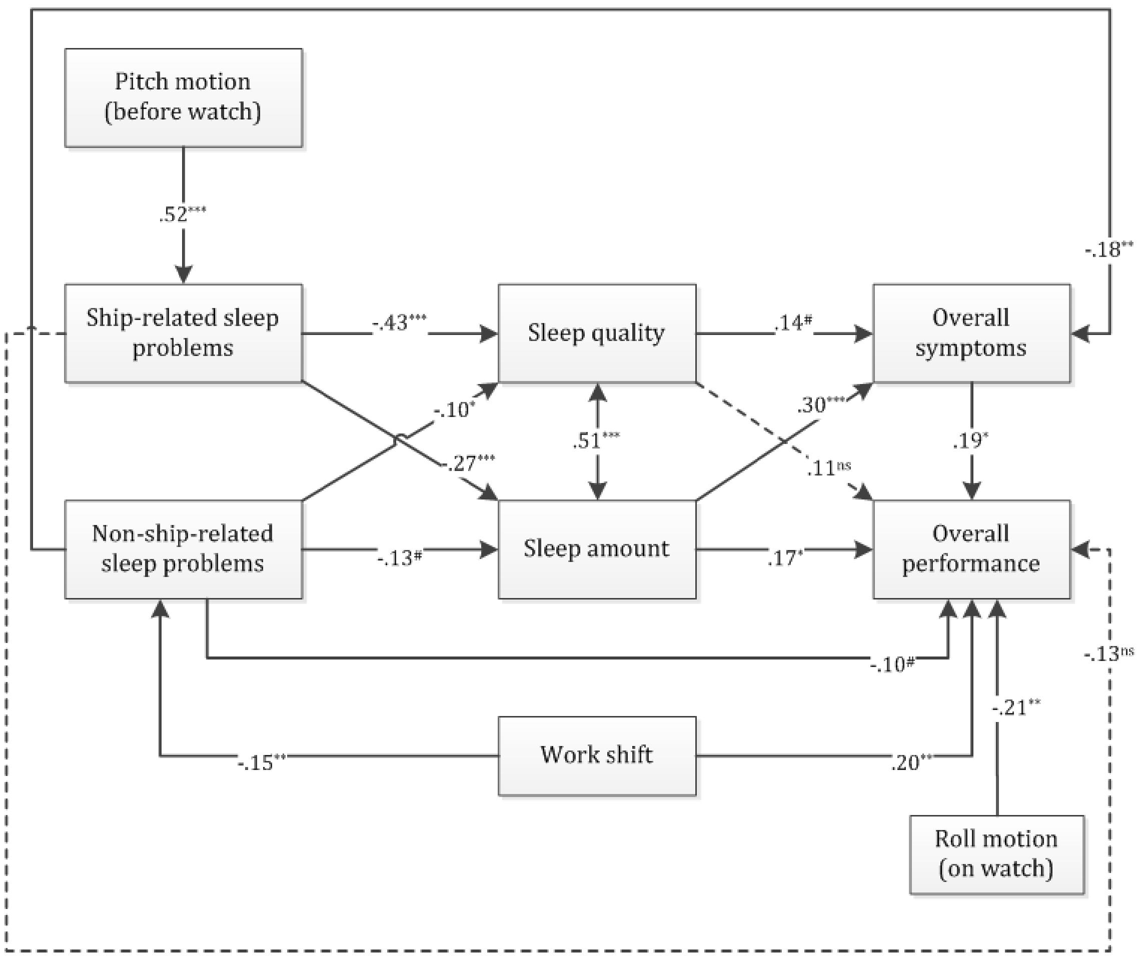


Figure 5 Path analysis on human factors of OSV operations (*** $p<.001$; ** $p<.01$; * $p<.05$; # $p<.10$; ns not significant)

Study 6. Theoretical evaluation

Some issues were found when developing HF check lists and questionnaires, indicating that the concept of HF is still developing

- A **theoretical evaluation** was performed **to evaluate** or **to confirm** the **concept of HF** in ship design & operation, using factor analysis

Report:

Human Factors in Ship Design and Operations: A Preliminary Survey of the Theoretical Construct
Trans RINA, Vol 158, Part A2, International Journal of Maritime Engineering, Apr-Jun 2016

RQ5. *What are HF in ship design (and operation)?*

Study 6. Theoretical evaluation

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

Controllability

Workability

Habitability

Cargo facilities

Reliability, Automation and Maintainability

RQ5. *What are HF in ship design (and operation)?*

Study 6. Theoretical evaluation

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							**Reliability, operability and maintainability**
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						**Interfacing complexity**
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					**Ship handling and manoeuvrability**
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				**System & procedure**
We have too many procedures to follow				0,77				
Some areas of the vessel are very noisy					-0,82			**Deck working condition**
The cargo deck is well designed					0,80			
The ECR is designed so it can be monitored and operated easily						0,81		**ER & ECR**
The ER can be maintained without any trouble						0,77		
Sometimes I can't sleep well on the vessel							-0,93	**Habitability**
Sometimes we can feel that the vessel is moving too much							-0,84	
Extraction Method: Principal Component Analysis Rotation Method: Oblimin with Kaiser Normalisation								

RQ5. *What are HF in ship design (and operation)?*

Study 6. Theoretical evaluation

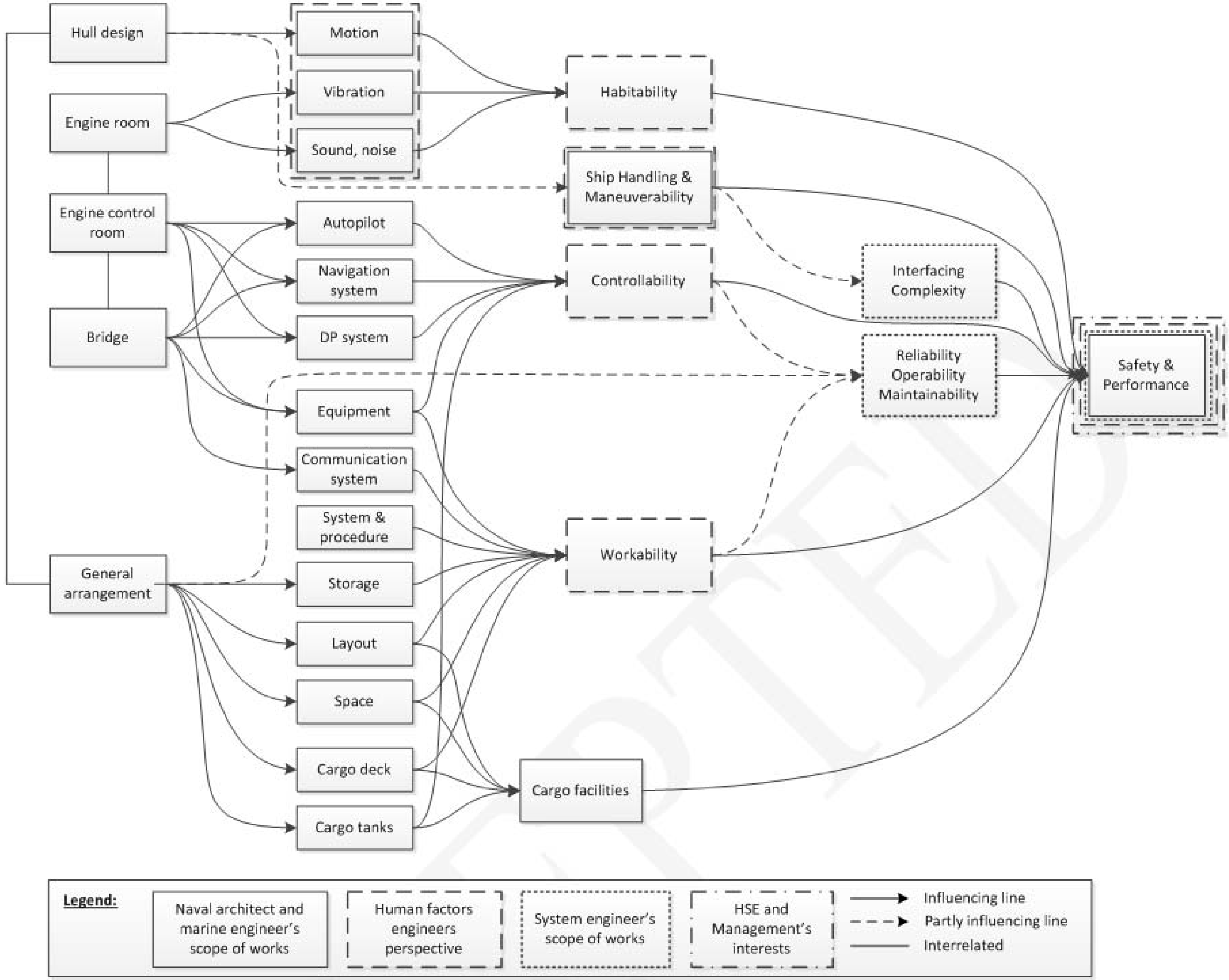


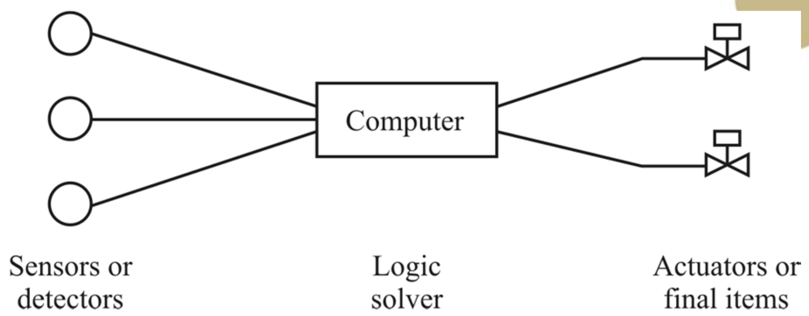
Figure 1 Inter-connectivity of human factors on ship design and operation

A model showing human factors considerations in ship design and operation is presented as a result of the theoretical study

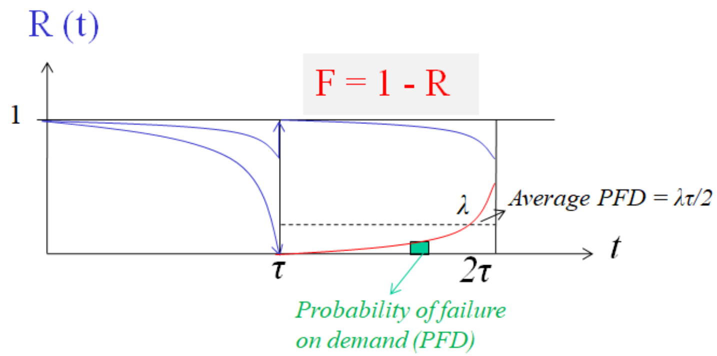
RQ6. *How to account HF in major risk assessment?*

Study 7. Risk assessment model

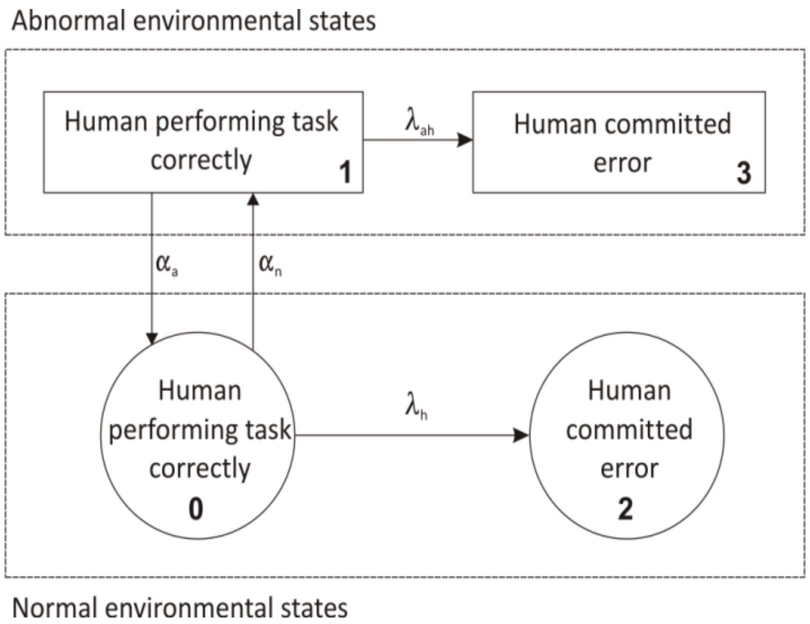
This research adopted the existing hardware reliability framework to develop a method for predicting the probability of accident by focusing on human factors



Safety instrumented system (Rausand & Høyland, 2004



$$PFD_{SYS} = PFD_S + PFD_L + PFD_{FE}$$



Markov model, adopted from Dhillon (2003)

- **Human reliability analysis**
- **Control theory, Cognitive approach**
- Implemented to several accident cases

The end of the presentation