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

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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 factors are implemented, and to assess the role of human factors on design and operation and the degree to which a

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

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.

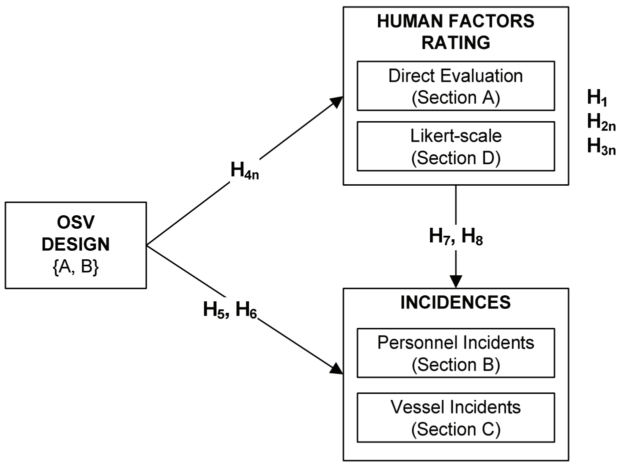

Figure 1. Research design and defined hypotheses

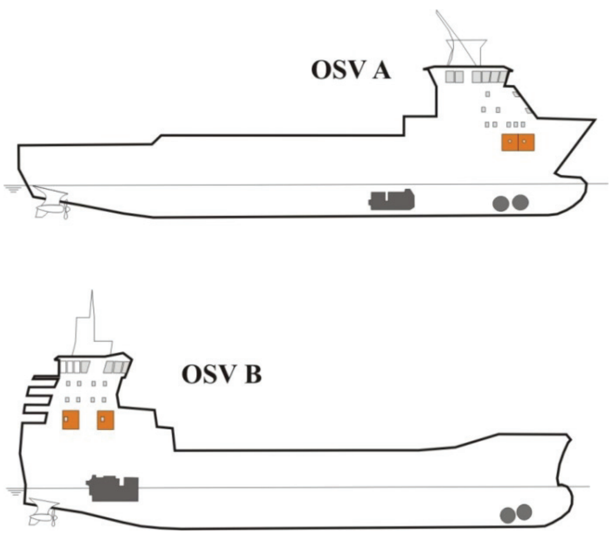

Figure 2. Offshore supply vessels [14]

Table 1 Human factors considerations

Habitability	**Maintainability**	**Survivability**
Accommodation	Accessibility	Firefighting
Washing	Tools provision & location	Damage control
Bathroom	On board expertise	Lifesaving & security facilities
Toilet	Disposal of parts & equipment	Security arrangements
Galleys	Through-life support	Ship layout
Messroom	Location of heavy spare-parts	Equipment fit
Exercise area	Maintenance tasks	Manpower availability
Recreation & personal study facilities	Manuals	Emergency response system & procedure
Personal storage	Diagnostics	**Occupational Health and Safety**
Workability	Schematics	Effect of work
Users	Bench space	Working environment
Equipment & software	Noise protected communications	Living conditions
Materials	Policy for on board spares	OHS policy
Procedures	Storage of spare parts and supplies	Safe working practices
Physical environment	Handling of heavy parts	Development of safety culture
Social environment	**Manoeuvrability**	Permit to work
Accessibility	Propulsion systems	Health awareness
Information, handbooks	Steering system	Medical screening
Communications	Thrusters	Medical support
Signage	Potential weather conditions	Balanced diet
Protective equipment	Communications	Drug and alcohol policy
Controllability	Min & max manoeuvring speed	Provision, maintenance, access & use of PPE
Ship control centres	Critical system redundancy	**System Safety**
Machinery control rooms	Through-life costs	Hazard identification
Cargo control rooms	Protection of the environment	Potential for human error
Equipment	Fuel economy	Risk analysis
Systems		Management of risks
Interfaces		Operating instructions & procedures
Communication facilities		Communication/working language
Control & switches		Business imperative
Displays		Training & familiarisation
Alarms		Potential for environmental damage & pollution
Video-display units		Recording, reporting & feedback procedures
Computer workstations		

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.

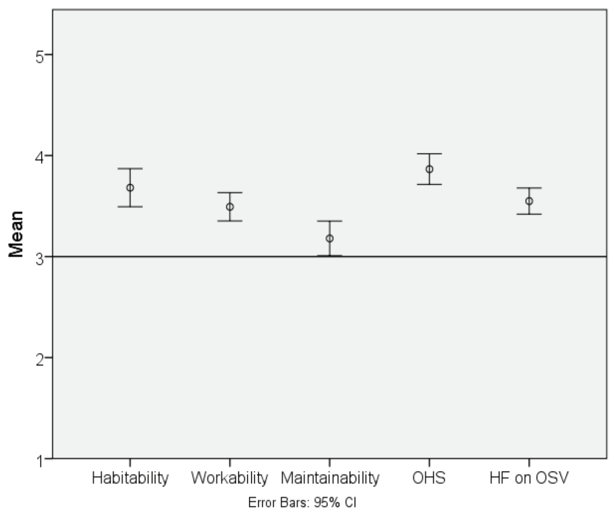

Figure 3. Human Factors Likert-Scale Evaluation Result: Mean plot with error bar for each dimension ($N = 42$)

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 Likert-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

*) Bonferonni 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

*) Bonferonni 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.

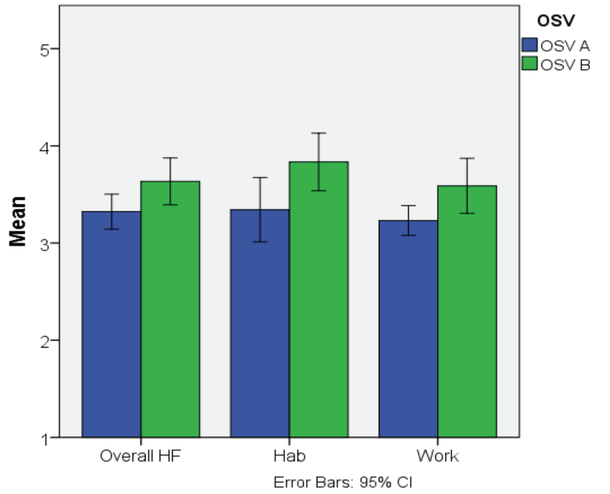

Figure 4. Human factors assessment on two different OSV designs in the Norwegian Sea

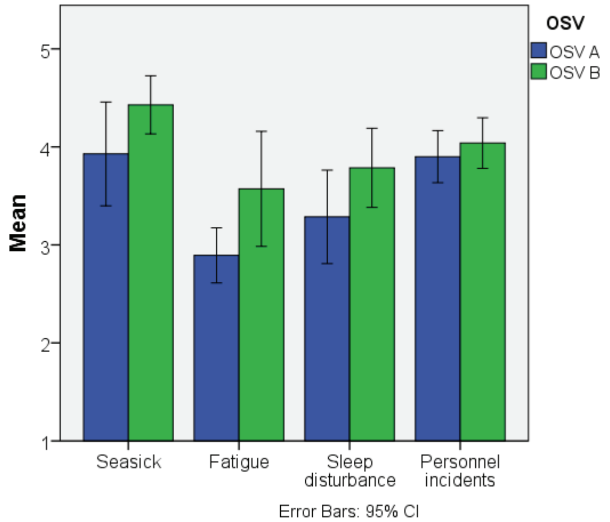

Figure 5. Mean frequencies of personal incidents perceived by the crew

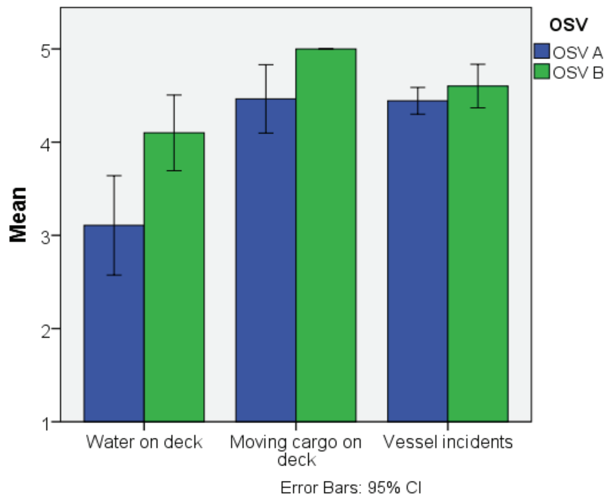

Figure 6. Mean frequencies of related incidents on vessels, as perceived by the crew of two OSVs

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	Standard 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	Standard Dev	Standard 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.

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]

8. ENDNOTE

The complete version of the questionnaires can be found in [29].

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

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