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 have been 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 on board along the survey by means of sound level meter and accelerometer respectively. Data collections were conducted in two periods: summer and winter. Results of measurements were compared with the existing criteria and discrepancies are identified. It can be concluded that the existing human factors criteria are inadequate and less relevant to the actual experience on board and they are ineffective to induce comfort. 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 along the survey 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 crushed 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 et al. 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 et al. 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 et al. 2006; Alert! 2007). Motion and noise were also found as major causes of sleep interruptions (Haward, Lewis et al. 2009). Motion can cause operator performance to degrade, and thus safety (Ross 2009a). 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, Lewis et al. 2009).

Advice have been given by relevant organizations (Smith, Allen et al. 2006; Alert! 2007; ITF Seafarers 2012) how to mitigate and manage fatigue at sea during operation. 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 2001a; ABS 2001b). 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°		
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) have been 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 forms 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.

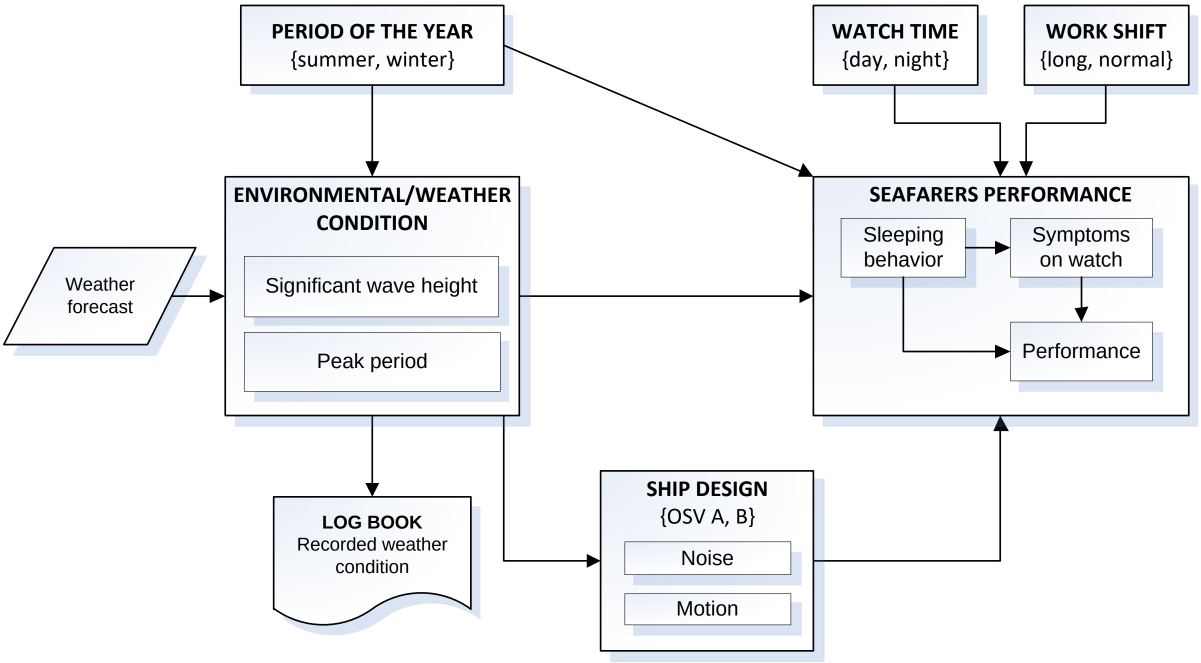

Figure 1 Research design

METHODOLOGY

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

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 operators also recorded the true wind speed and wave heights in terms of the sea state. 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 mounted on the cabin 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. 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 is the lowest frequency. Data was recorded in files, storing 300.000 samples per file for periods of 15 minutes.

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 et al. 1976) were also calculated by utilizing an existing in-house code.

QUESTIONNAIRES: DAILY DIARIES

An anonymous form was developed based on the NATO questionnaire (Colwell 2000; Haward, Lewis et al. 2009) and distributed among seafarers and to be completed after every watch. The questionnaire covered four different aspects of the conditions and activities on a watch: sleeping or resting before the watch, symptoms experienced during the watch, performance and problems encountered during the watch (see Appendix). Before sailing out, 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.

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 follows 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 is indicated that the vessel OSV B is more stable and quiet than OSV A. Both vessels comply with DNV COMF-V(3).

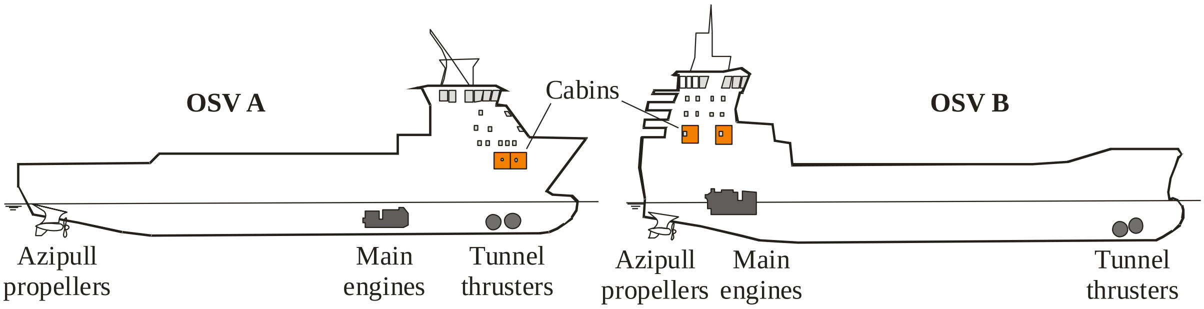

Figure 2 Two different OSV designs (Rumawas and Asbjørnslett 2013)

RESULTS

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

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.

WEATHER FORECASTS AND SHIPS' LOG

Figure 3 and Figure 4 show significant wave height (Hs) and peak period (Tp) predictions 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).

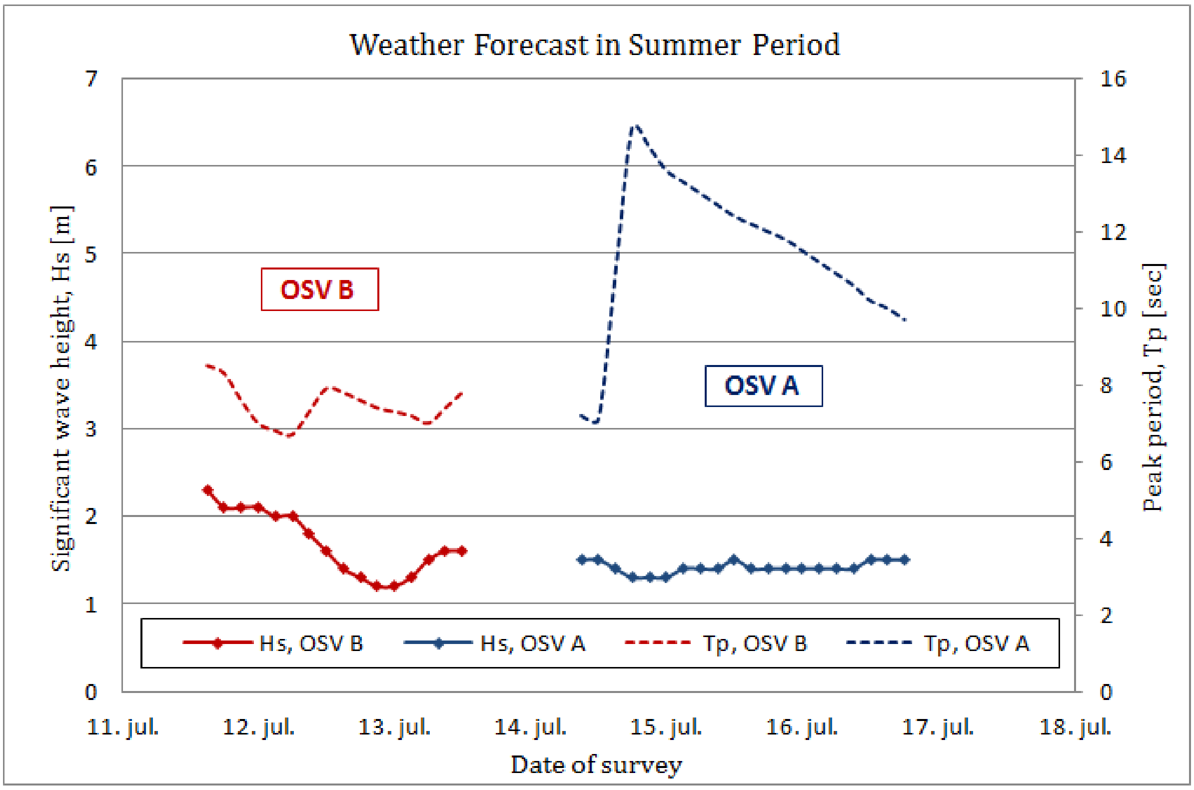

Figure 3 Weather forecasts during the survey in summer

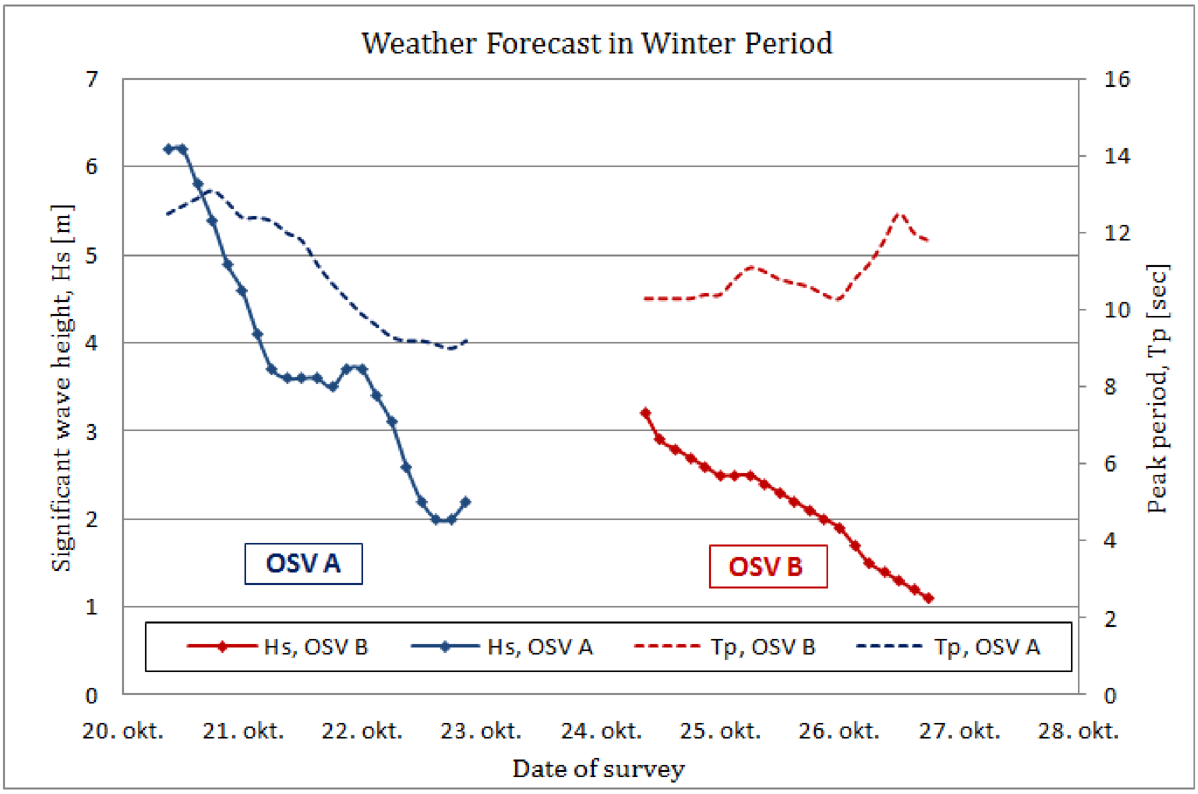

Figure 4 Weather forecasts during the survey in winter

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

Slamming and high pitch noise caused by tunnel thrusters when dynamic positioning (DP) system is in operation are mentioned as the problems on OSV A. Squeaking noise from the deck machineries and hammering noise from the people working on the deck are reported on OSV B. Obviously, all these noises are disturbing.

There is 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 are still lower than the maximum limit of 60 dB(A). The impulsive noise and the high pitch tone cannot be captured nor reflected by the outlined procedures in this study (ISO 1996; ISO 2008).

In summer, the cabin on OSV A is 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 is located closer to the engine room, giving more hissing noises. On OSV A, during normal condition the situation is quiet. But in high seas, the vessel struggles with the waves and winds, consequently generating more noise.

In some places, the noise level on OSV B is substantially higher than A, but there is no significant difference in the aggregate noise level on OSV A (M=70.39, SD=18.82) compare to OSV B (M= 71.99, SD=20.06), $F(1, 16)=.030$, $p>.10$.

MOTION MEASUREMENT

During the survey, 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 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. Examples of a 15-minute period of roll and pitch data processed using Matlab v 2012a are presented in Figure 5 (velocity) and Figure 6 (motion). Figure 7 shows an example of lateral acceleration (sideways in y-direction) and vertical acceleration which indicates local heave.

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

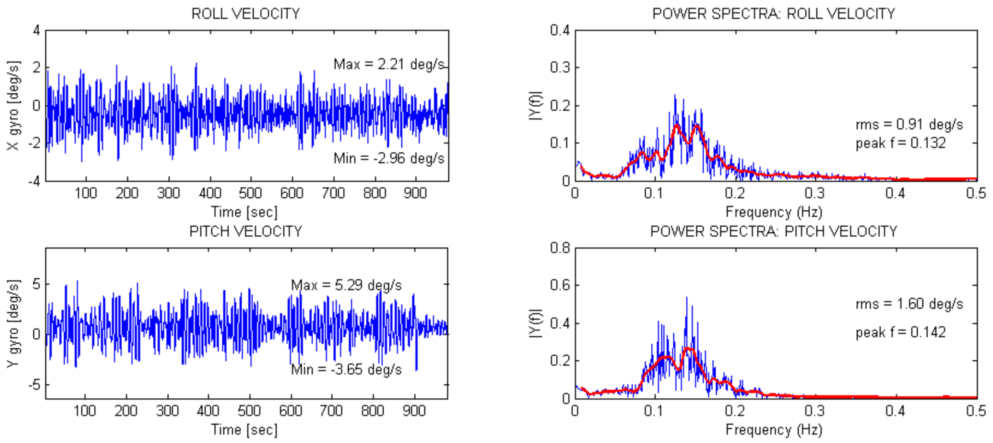

Figure 5 Roll and pitch velocity on OSV A in the winter

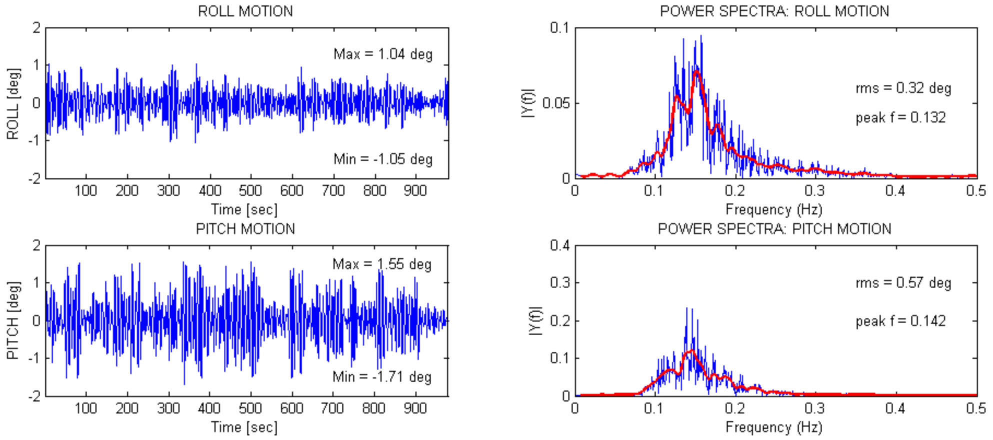

Figure 6 Roll and pitch motion on OSV A in the winter

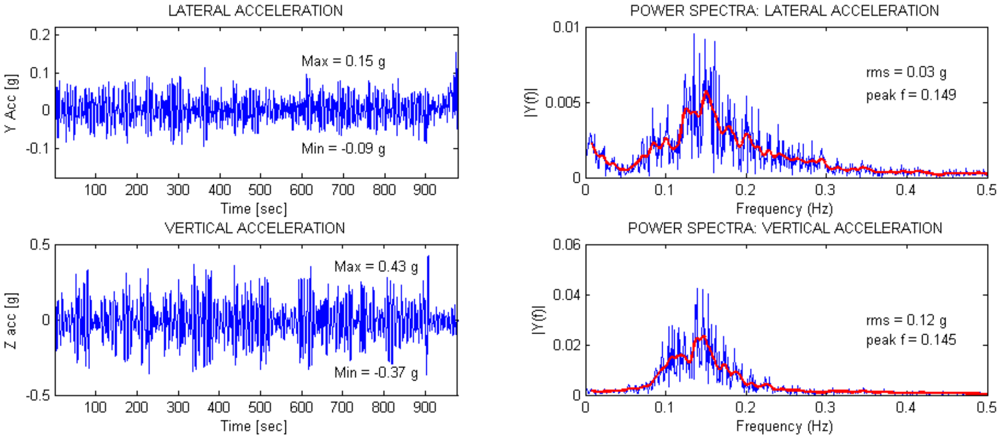

Figure 7 Lateral and vertical acceleration on OSV A in the winter

ROLL MOTION

The RMS of roll velocity on OSV A during summer is 0.390 deg/s, while in the winter it is 0.946 deg/s. The RMS of roll motion is 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 are 0.318 deg/s in the summer and 0.355 deg/s in the winter which leads to RMS of 0.124 deg and 0.127 motions respectively. Figure 8 shows maximum, minimum and RMS of roll motions during the whole survey for both OSVs. Rolling periods (in sec), derived from the motions are also calculated and presented in the figure. Rolling period OSV A (*M*=6.68, *SD*=0.521) is significantly lower than of OSV B (*M*=7.13, *SD*=0.856), *F*(1, 688)=70.357, *p*<.001. These findings support that OSV A is more sensitive to roll motion (Rumawas and Asbjørnslett 2013).

With respect to *comfort* evaluation, no condition is 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 is 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

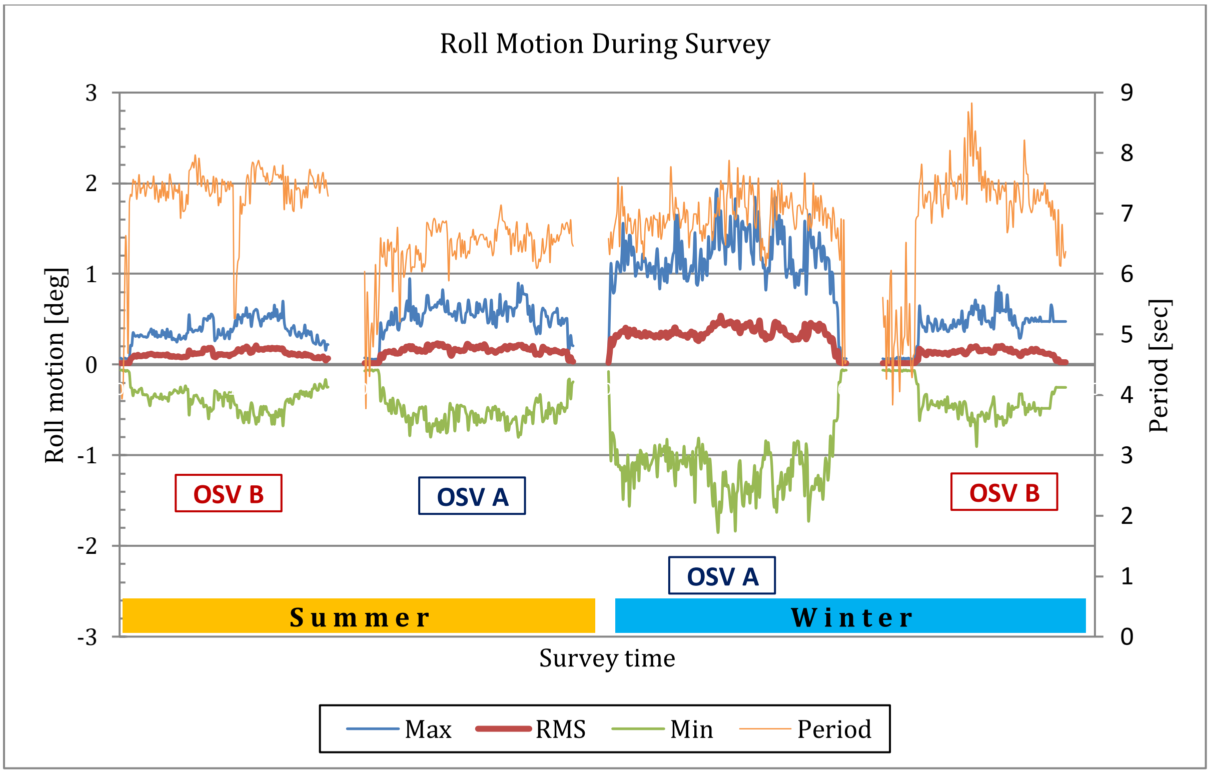

Figure 8 Calculated roll motions during the surveys for both OSVs

PITCH MOTION

In average, 1.233 deg/s (RMS) of pitch velocity is measured on OSV A in the winter, while in the summer it is 0.294 deg/s (RMS). This gives an average of 0.483 deg (RMS) pitch motion in winter and 0.127 deg (RMS) in the summer. On OSV B, higher pitch is found in the summer 0.605 deg/s (RMS) and winter 0.375 deg/s (RMS). This gives a 0.605 deg (RMS) and 0.375 deg (RMS) pitch motions respectively. These findings support the vomit incidence caused by pitch motion (Rumawas and Asbjørnslett 2013). 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 9 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) does not differ significantly compared to OSV A (*M*=6.519, *SD*=0.880), *F*=(1, 688)=1.012, *p*>.10.

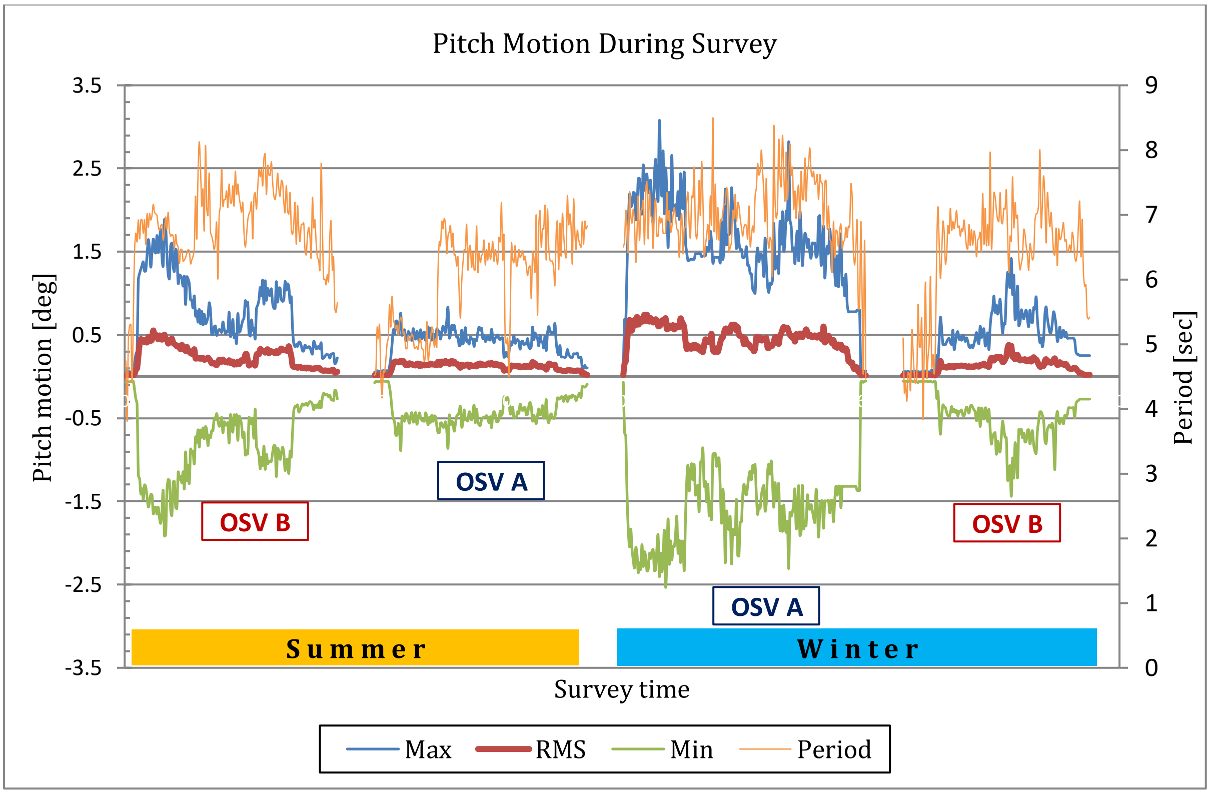

Figure 9 Calculated pitch motions during the surveys for both OSVs

TRANSLATIONAL ACCELERATIONS

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

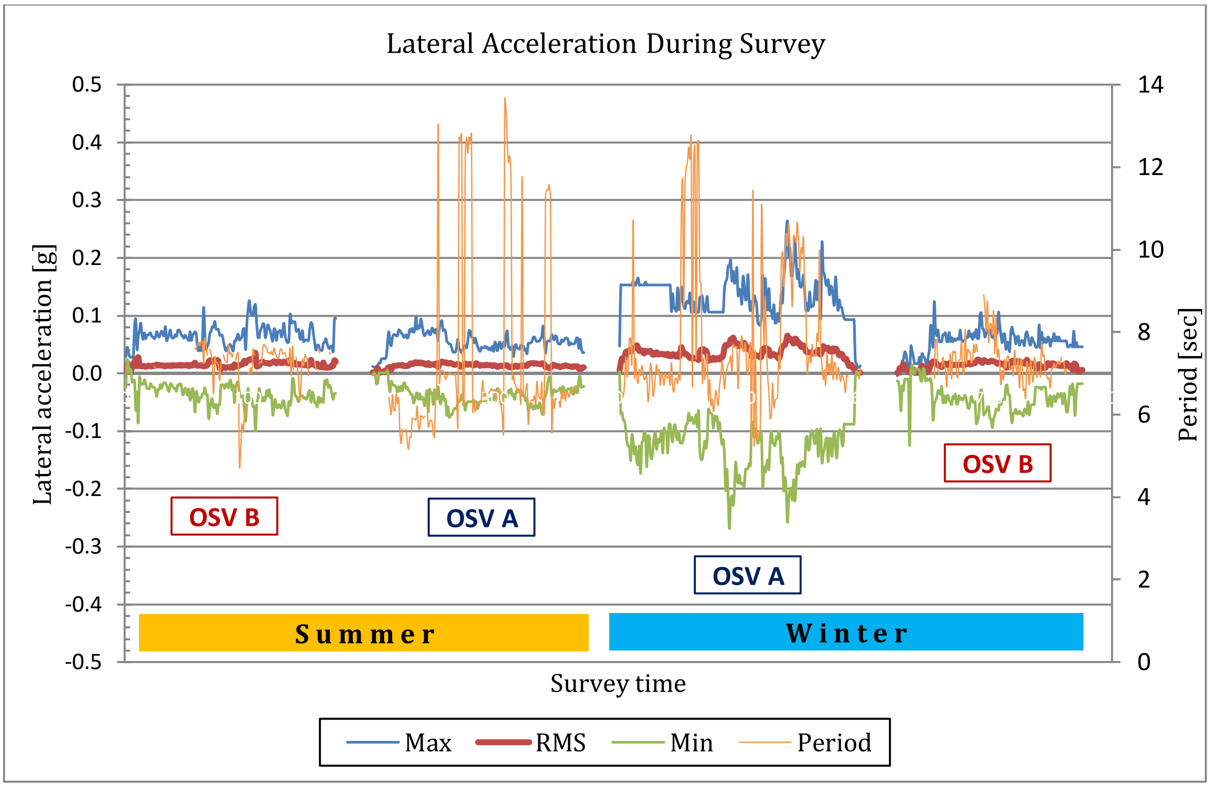

Figure 10 Lateral accelerations measured during the surveys on both OSVs

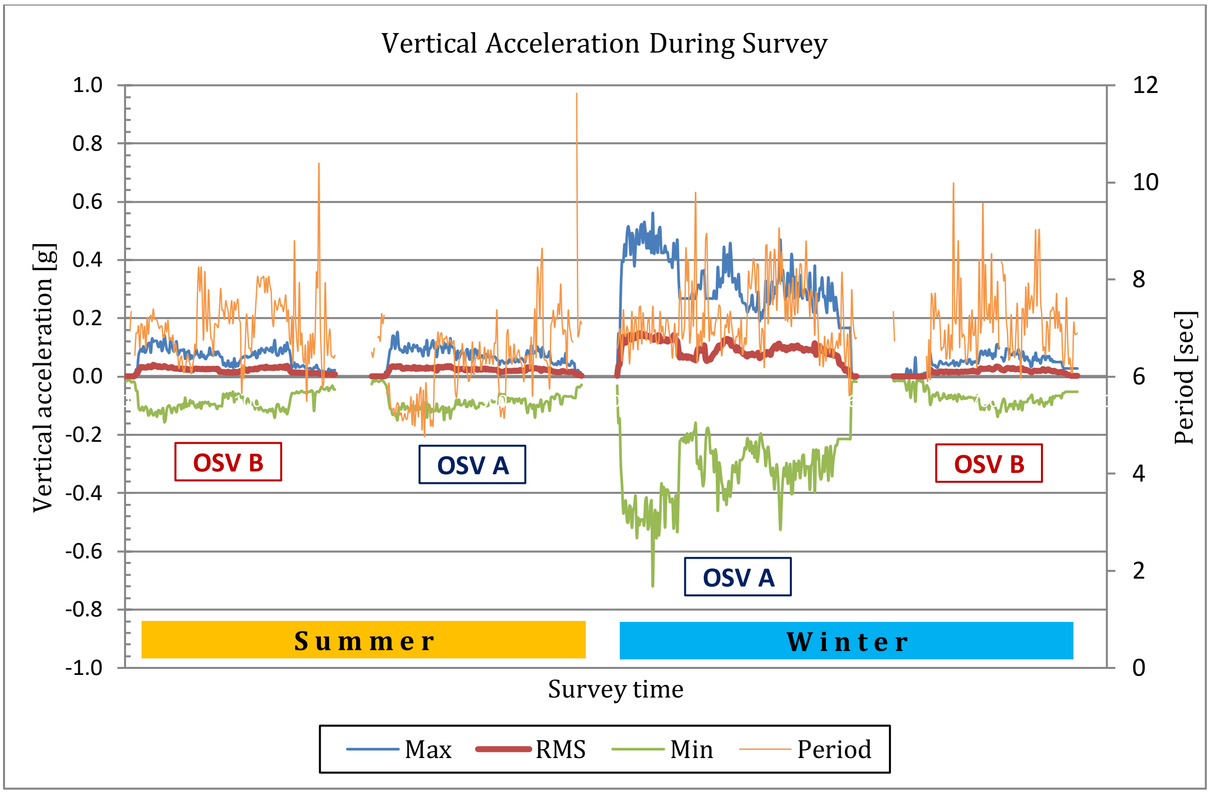

Figure 11 Vertical accelerations measured during the surveys on both OSVs

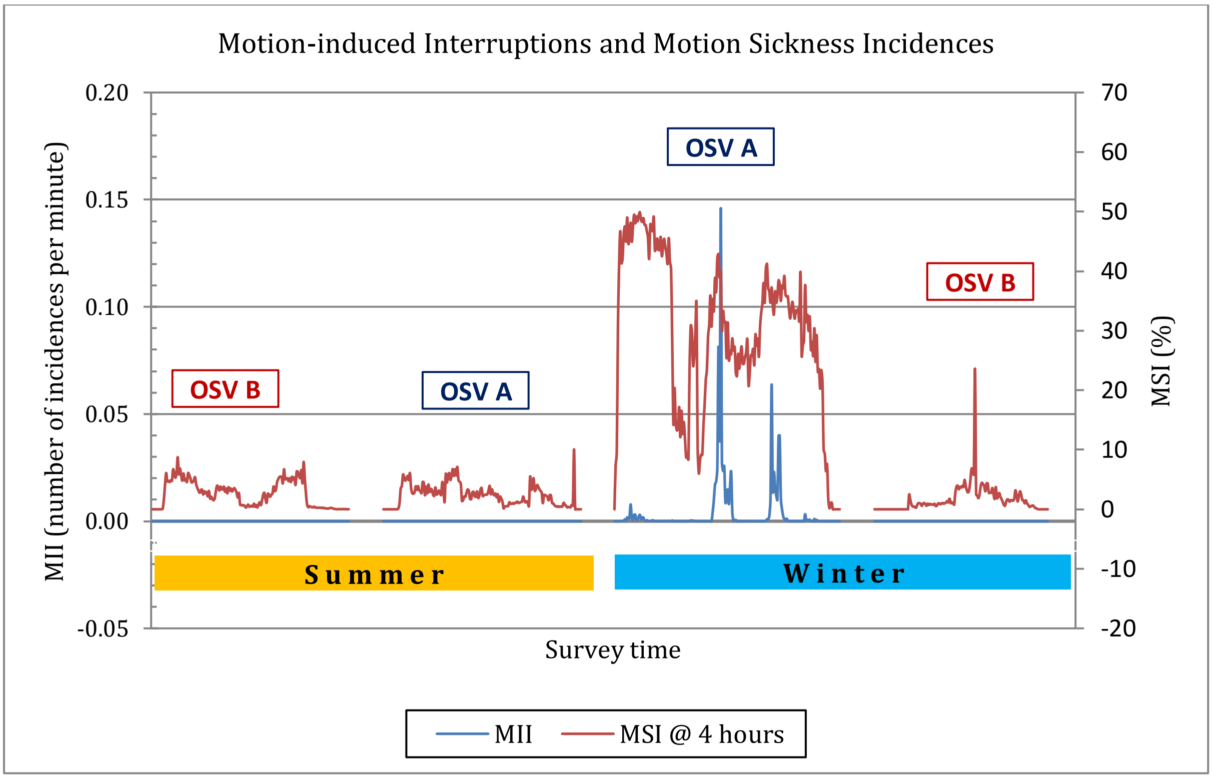

Figure 12 MII and MSI calculated during the surveys on both OSVs

MII AND MSI

The MII index calculated after Graham (1990) along the survey emerged only on OSV A during winter (Figure 12). A maximum of 0.14 MII per minute is obtained while criterion is set as 1 per minute (Table 3). The maximum risk level observed in the survey lies between "Possible" to "Probable" (Table 5). These results look 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 reaches 10 m, interruptions occurred all the time; the crews stop working and just sit tight or stand still by holding on to something to keep their balance.

The MSI index calculated for 4 hours period of exposure shows 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 is 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 become tired when the sea is harsh, but no longer nauseous. The majority are insusceptible to motion sickness.

DISCUSSIONS

NOISE

Both vessels fulfill the noise criteria set by IMO (1981) and DNV (2009), even if the vessels are 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, are 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.

The downside about this 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 insusceptible to MSI. On the other hand, we also notice that motions are possible to manipulate and its effect can be made more acceptable to human. 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*** and urgently need to be revised.

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 are 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 8 to Figure 11 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.

- 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).

- 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 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.

To sum up, it can be concluded that the existing criteria of human factors are not adequate and do not answer to the actual humans' issues effectively. The standards as they exist today are merely formality. Revisions are strongly recommended.

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