Ocean Engineering 120 (2016) 101–107

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Towards human-oriented norms: Considering the effects of noise exposure on board ships

Rafet Emek Kurt [a,*,1], Hassan Khalid [a], Osman Turan [a], Mark Houben [b], Jelte Bos [b,c], Ismail Hakki Helvacioglu [d]

[a] Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow, UK
[b] TNO, Soesterberg, The Netherlands
[c] Faculty of Behavioural and Movement Sciences, Vrije Universiteit, Amsterdam, The Netherlands
[d] Faculty of Naval Architecture and Ocean Engineering, Istanbul Technical University, Istanbul, Turkey

ARTICLE INFO

Article history:
Received 28 June 2015
Received in revised form
8 February 2016
Accepted 17 March 2016
Available online 11 April 2016

Keywords:
Noise
Comfort
Ship
Noise exposure
Crew
SILENV Project

ABSTRACT

With modern trends of decrease in crew numbers on board ships together with increased operational demands and paperwork, crew fatigue and comfort have become more critical and are being given more importance. It is well known that environmental factors affect crew comfort and performance. The two outstanding factors which exist in the shipboard environment are vessel motions and noise. As such, the findings and lessons learnt from other industrial sectors are considered to be less relevant for ships. Therefore, it is necessary to conduct focused research to understand the effects of these factors, so that the lessons learnt can be integrated into the ship design process so as to mitigate their adverse effects during vessel operations. Due to obvious performance issues, ship motions and motion sickness research has attracted far more interest than human response to noise. This paper reports the findings of a recent research study undertaken as part of an EU FP7 research project, namely SILENV, which investigated the current levels of crew noise exposure through field studies. Furthermore, developed models on human response to noise on board ships and SILENV Green Label noise standards are also introduced in comparison with the current normative framework.

1. Introduction

Today, as a result of technological developments, ships are equipped with sophisticated systems and automation. This has triggered a trend to decrease the number of crew members on board ships. Nevertheless, these automated systems still require human intervention for interpreting the information or when tasks require decision-making. Therefore, as compared to the past, even though the physical workload of the crew members on today's vessels decreased, the cognitive load is much higher than it used to be. As a result, maintaining the performance of the crew has become more important than before to achieve safe shipping operations. Investigations of the shipping accidents from US, UK, Canada, and Australia showed that human error is the major contributor of shipping accidents where 80% to 85% of all accidents were primarily caused by or associated with human error (Baker and Seah, 2004). As a result of this increased understanding on the importance of the human element, more research was focused on human factors on board ships.

In terms of human factors on-board ships, a naval architect's primary role is to design ships while considering the needs of crew in terms of health, wellbeing and performance. It is important to mention that the environment on ships in which crew members spend their day-to-day life is unique (motions, noise, vibrations, heat, cold, smell etc.) and can be considered as extreme when compared with many other industries. For example, one of the most challenging ship operations where human performance becomes critical is in arctic conditions, which is even compared by scientists to space operations (Sillitoe et al., 2010; Wickman, 2012). Moreover, as crew members not only work on board but are also required to live and rest in this same environment for months, crew performance and wellbeing become more complex. Therefore, environmental conditions on ships should be designed in a way to ensure not only the health but also the performance and wellbeing of crew members on board.

One of the most important environmental factors on ships is passive motions. Due to having obvious consequences and performance outcomes on crew, motion sickness has been studied

* Corresponding author.
E-mail address: rafet.kurt@strath.ac.uk (R.E. Kurt).
[1] Postal address: Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, 100 Montrose Street, Glasgow G4 0LZ, United Kingdom.

http://dx.doi.org/10.1016/j.oceaneng.2016.03.049
0029-8018/

in-depth, resulting in numerous human response models, which can be utilised to estimate the levels of comfort even at the design (McCauley et al., 1976; Bos et al., 2005; Khalid et al., 2011) shipping industry has failed to develop a similar knowledge base and even awareness on human response to noise, which are also very important environmental factors on board ships. Shipping industry focussed on complying with the limits set by IMO (International Maritime Organization), which were under scrutiny and forced to change recently.

This paper reports research conducted under the EU FP7 SILENV Project (Ships Oriented Innovative Solutions to Reduce Noise and Vibrations) which gave specific importance to human response to noise on board ships and produced a 'Green Label Standard' for noise levels on board ships.

2. Literature review

The most obvious effect of high exposure to noise on humans is called Temporary Threshold Shift (TTS) which is an auditory fatigue resulting from being exposed to hazardous levels of noise. Repeated exposure, not giving the affected person enough time to fully recover the TTS, or exposure to very hazardous levels of noise, progresses into a Permanent Threshold Shift (PTS) (Alberti, 2001). The current regulatory framework is only designed to protect workers from these hazardous noise exposures. However, effects of noise on crew is much wider than the health as it affects the crew wellbeing, comfort and performance considering that crew most of the time live and work in the same environment.

At this point it is important to mention two relevant noise standards which are applicable to ships. The IMO has recently updated the old Code on Noise Levels on Board Ships (IMO, 1981) with a new one (IMO, 2012) which is enforced under the provisions of regulation II-1/3-12 of the SOLAS Convention. The code defines the maximum acceptable noise levels for ship compartments and considers that, when complied with, the equivalent continuous noise exposure of crew members will not exceed 80 dB (A). On the other hand, the EU Physical Agents Directive for Noise (EC, 2003) aims to protect the workers' health from hazardous noise exposures by defining the daily noise exposure action and limit values. In EU's approach, human is at focus and the aim is to monitor and regulate the total amount of noise received by the crew. Therefore, exposure duration becomes more important since it directly affects the noise exposure levels. It may be inferred that the approach of EU Physical Agent Directive is more human oriented as compared to the aforementioned IMO Noise Code. However, both regulations are not strict enough when the effect of noise on crew performance and wellbeing is considered. Furthermore, the effect of noise on performance and wellbeing lacks research in the maritime domain. The aforementioned research gap and the need for diverting more research to this important area was also recognised by Martin and Kuo (1995).

Numerous research studies from other industrial sectors are focused on understanding the effect of noise exposure on worker performance and wellbeing. A review of the literature shows that exposure to noise has negative effects on human performance and wellbeing (Broadbent, 1954; Button et al., 2004; Kurt et al., 2010; Melamed et al., 2004; Melamed and Froom, 2002; Weston and Adams, 1932). However, it is also possible to find examples of studies in the literature where researchers found a positive relation or no relation between noise exposure and human performance (Harcum and Monti, 1973; Harrison and Kelly, 1989; Jerison, 1957; White et al., 2012).

The literature review thus demonstrates conflicting findings, which shows that the relationship between the noise exposure and human performance/wellbeing may change depending on the duration of noise exposure, type of noise, demography of the subjects, type and complexity of the task. Unfortunately, this situation makes the lessons-learnt from other industrial sectors to be less relevant and therefore less transferrable to the maritime domain. Therefore, effects of on-board noise levels on the human performance and wellbeing needs to be investigated and findings should be taken into account when defining new noise limits for ships.

3. Noise criteria

3.1. IMO Noise Code

The IMO Code on Noise Levels on Board Ships (resolution A.468 (XII)) has been in use for many years by regulatory bodies, ship owners and designers as permissible noise limits. Compliance with the limits defined by IMO Noise Code was voluntary, and therefore not every ship met the requirements of the code. Recently, some modifications were made to improve on the noise control/allowable exposure levels in the code (IMO, 2012), which came into force in January 2013, and is now mandatory to comply with. A comparison of the noise limits of the old and new code is given in Table 1 below.

It can be seen from the above table that for some of the compartments the noise limits were reduced while other compartments noise limits remained same. Several classification societies and maritime authorities have already imposed more strict standards to control the ship noise (ABS, 2001; DMA, 2002; GL, 2003;

Table 1
Noise level limits according to IMO Resolution A468 (XII) 1981 and IMO Resolution MSC.337 (91) 2012.

Locations		IMO (1981) dB(A)	IMO (2012)[a] dB(A)
Work spaces	Machinery spaces (continuously manned)	90	*removed*
	Machinery spaces (not continuously manned)	110	110
	Machinery control rooms	75	75
	Workshops	85	85
	Non-specified work spaces	90	85
Navigation spaces	Navigation bridge and chartroom	65	65
	Listening post, including navigation bridge wings and windows	70	70
	Radio room (with radio equipment operating but not producing audio signals)	60	60
	Radar rooms	65	65
Accommodation spaces	Cabins and hospitals	60	60/55
	Mess rooms	65	65/60
	Recreation rooms	65	65/60
	Open recreation areas	75	75
	Offices	65	65/60
Service spaces	Galleys, without food processing equipment operating	75	75
	Stores and pantries	75	75
Normally unoccupied spaces	Spaces not specified	90	90

[a] The limits for ship size greater than 10000 GRT are shown after /.

Table 2
Exposure limit and action values defined by EU Physical Agents Directive.

	Daily exposure levels, dB (A)	Peak levels, dB (C)
Exposure limit values (L_{EX},8h)	87	140
Upper exposure action values (L_{EX},8h)	85	137
Lower exposure action values (L_{EX},8h)	80	135

LR, 2004; MCA, 2007; SMA, 1973). It is stated in the code that, when ships comply with the noise limits defined in Table 1, the equivalent continuous noise exposure of crew members will not exceed 80 dB(A).

3.2. EU Physical Agents Directive

The European Parliament has followed a similar approach by issuing a physical agent directive to protect workers from risks arising from exposure to noise (EC, 2003). The directive covers all workers who are exposed or likely to be exposed to risk from noise. The main difference between the IMO resolution and the EU directive is that; the EU directive pays more attention to the workers' exposure to the noise and tries to limit hazardous exposures, while IMO aims to control noise at the design stage and enforce compartment-based noise limits for ships to ensure the protection of human health on board. In a sense, it is a better approach to regulate the noise limits in a human-centred way but since ships are remote and monitoring compliance is harder, defining compartment based limits at the design stage is also effective. The exposure action and limit values defined by the EU Physical Agents Directive are shown in Table 2.

For both EU Physical Agents Directive and IMO Noise Code, the exposure levels can be calculated using the following:

$$L_{EX,T}=10 \times \log \frac{1}{T} \sum_{i}^{n} t_i \times 10^{Li/10} \quad (1)$$

In the above equation t_i is the duration in a noisy environment while T is 8 when calculating 8 h equivalent exposure level and 24 when calculating 24 h equivalent levels.

3.3. Comparative study

In order to understand the current regulatory compliance, the authors conducted a comparative study on noise exposure on board ships (Turan et al., 2010) which included the following activities:

- Noise levels at various compartments were measured in six different Oil/Chemical Tankers during their sea trials.
- A questionnaire was designed and applied to capture the work patterns of the tanker crew.
- Based on the identified work patterns, noise exposure levels of all crew ranks were estimated.
- Results were comparatively analysed using the criteria defined by IMO and EU.

The main particulars of the six Oil/Chemical Tanker ships are given in Table 3. It can be seen that all tankers are of similar size, apart from the “Oil/Chemical Tanker no: 4” which is a larger vessel.

It is stated in the IMO Noise Code that if ships comply with the defined noise limits seafarers will not be exposed to an LEX(24) exceeding 80 dB(A). In order to investigate this, exposure levels for each rank were calculated through an exposure assessment tool reported in Turan et al. (2010). Results of this study showed that although ships are fulfilling the requirements set by the IMO on compartment bases, they are failing to comply with the defined noise exposure criteria. In the aforementioned study calculations were carried out for 4 different hearing protection levels; (1) no hearing protection used, (2) the IMO's estimated noise reduction levels are used, (3) a correction for using ‘A’ weighted TWA (time weighted average) is applied to the noise reduction rates of hearing protectors, and (4) OSHA's correction factor from lab-obtained NRR (Noise Reduction Rating) to a real work environment is applied. It was concluded in this study that when all corrections applied on hearing devices to estimate their effective protection, seafarers, especially those who working in or near machinery spaces, are at risk. As a result it can be said that even in terms of protecting human health on board, there are issues that need to be improved. Therefore, it is necessary to introduce new norms, which will ensure designing the noise levels on board ships by considering the recent improvements, practical implementation, health, comfort and performance of crew members.

Table 3
Main particulars of ships used in full scale measurements.

Type of Ship	DWT	$L_{Overall}$ (m)	Speed (knots)	Engine power (kW)
1. Oil/Chemical Tanker	7915	121	14	3840
2. Oil/Chemical Tanker	6000	107	13	2620
3. Oil/Chemical Tanker	8000	121	14	3840
4. Oil/Chemical Tanker	18000	148	14	5920
5. Oil/Chemical Tanker	4500	106	15.5	3250
6. Oil/Chemical Tanker	6100	123	13	2610

4. EU FP7 SILENV Project's Green Label Proposal

EU FP7 SILENV Project (SILENV, 2009) was funded in response to an emerging need for reducing ship-generated noise and vibration pollution. The SILENV Project dealt with a wide range of issues related to noise and vibration on and from ships which can be summarised in following three groups; (1) noise and vibration onboard, (2) underwater noise radiation, and (3) airborne noise emissions from ships. The project conducted a thorough review of the available published literature, carried out field studies and measurements, developed human response models, and issued guidelines aiming to improve the current situation (André et al., 2014; Badino et al., 2012a, 2012b, 2013; Borelli et al., 2015). One of the main deliverables of SILENV Project is the ‘Green Label Proposal’ (SILENV, 2012) which defines new improved noise limits for ships. The following sections will explain the development procedure as well as the final proposed green limits.

4.1. Methodology

In order to define the SILENV Green Label, the following methodology was adopted as demonstrated in Fig. 1 below.

First, the SILENV Consortium aimed to define preliminary target levels for noise on board ships. In order to achieve this, a comprehensive research was conducted to review all applicable noise standards and regulations.

In the next step, the SILENV Project investigated the resulting human response from preliminary noise levels as defined in the previous step. Specific human response models (comfort,

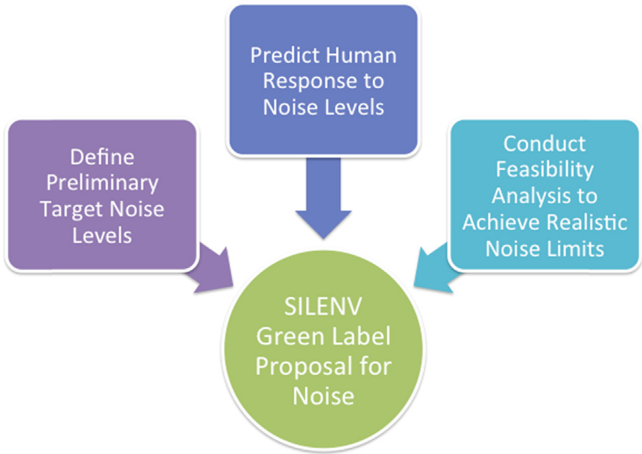

Fig. 1. SILENV Approach for defining noise limits.

wellbeing and performance) were developed to predict the human response. These models were then utilised to take human response into consideration.

It was also important to define noise limits which are achievable and which will be accepted by the industry. Therefore, in the SILENV Project a database of noise measurement levels from European ships was built, so that proposed levels could be assessed to see whether it is feasible for current fleet to comply with or not.

Finally, the SILENV Consortium finalised the Green Label Proposal through an expert workshop.

4.2. Preliminary targets and critical analysis

The IMO "Code on noise levels on board ships" is fully accepted by the maritime community as a reference document when dealing with noise on board ships. Therefore, it was considered that the development of preliminary noise limits for the SILENV 'Green Label Proposal' should use the IMO Noise Code as a base. Then, through conducting an extensive review on available noise norms, target noise levels were developed. It was thought that SILENV should consider all the limit levels defined by the various existing norms and define the preliminary target noise levels which – if not more stringent – are just as stringent as the existing norms to ensure compliance with the most demanding noise mitigation standards for comfort and work environment.

The proposed preliminary noise levels are shown in Tables 4 and 5 for crew and passengers respectively, in comparison with the existing norms. The proposed values are based on the minimum values taken from the various guidelines. Therefore, the proposed values are very stringent compared to the available guidelines.

4.3. Human response

As already highlighted in Section 3.3, the study on the compliance of existing vessels with IMO regulation and EU directive, revealed that in some cases the ships fulfilling limiting noise level criteria of IMO regulation were still failing to meet the noise exposure limits (see Turan et al., 2010). It was, therefore, considered important to assess the preliminary noise target levels against human subjective responses from on board comfort and work environment point of view. Hence, improved human response models were developed in the SILENV Project (see Houben et al., 2012 for further details). For the model development, noise measurements were conducted in various compartments on board 15 different ships. Together with the noise measurements, questionnaires were deployed to capture the human response. The human response models describe the relationship between the levels of noise and subjective ratings of crew on performance and of passengers on comfort. The number of various ordinal subjective ratings obtained were reduced through correlation, factor analyses and common sense. The relationship between dependent and independent variables appeared to be non-linear, hence logistic regressions were used and final models with good fitness were obtained.

In order to represent multidimensional nature of human responses, 2 comfort and 3 performance models were developed, resulting in a total of 5 human response models focusing on different performances and comfort criteria. These models are summarised in Table 6.

As a result of detailed discussions amongst SILENV partners, for comfort 'N2c-Noise Annoyance model' and for performance 'N7p-Quality impairment model' were selected out of a larger range of questionnaire items deployed by the SILENV Project to assess the preliminary target levels. These selected models were then used to calculate the percentage of human discomfort and performance impairment. Table 7 shows the limits corresponding to a specific percentage of people annoyed or impaired in their work by the noise. In the SILENV Green Label Proposal it was aimed to ensure at least 90% of passengers' and crews' satisfaction.

4.4. Feasibility of the preliminary target levels

It is important to define realistic noise limits which are achievable for new ships. Therefore, the aim of this analysis was to find an answer to the following question: "what noise criteria should be defined in order to make only 5%, 10%, 20%, 30%, 40%, and 50% of modern ships to comply?". In order to achieve that, only the most recent ships from the SILENV Noise Database were selected considering that the technology in older ships will not be comparable to the new buildings. A total of 64 different vessels were taken into consideration and Table 8 shows the percentages of vessels from the SILENV database that comply with the noise levels. Noise limits which will correspond to 20% of the vessels to comply, were considered reasonable and achievable by the SILENV Consortium. More details about the SILENV database can be found in a publication by Beltrán Palomo (2013).

4.5. Finalisation of Green Label Proposal

The noise requirements defined in previous sections were combined to obtain the SILENV Green Label Proposal. First, the preliminary noise limits (IMO limits as well as other standards) were taken as a starting point and compared to the human response criteria defined in the previous sections. As a result of this comparison and discussions, new noise limits were defined (see Houben et al., 2012 for details). Then, these noise limits were compared with the noise criteria based on 20% of current vessels compliance. Again, after these comparison and discussions within the SILENV Consortium, new noise limits have been defined. After consolidating all the criteria, through a workshop SILENV partners further discussed and finalised the Green Label Proposal. The final SILENV Green Label Proposal is shown in Table 9 below. As it can be seen from the table, SILENV introduced its own space groups, similar but not completely identical to the compartments specified by IMO (Table 1).

5. Conclusions

In the SILENV Project improved human response models have been developed (Kurt, 2014). Furthermore, these models were utilised for developing the SILENV Green Label Proposal. The noise

Table 4
Proposed preliminary noise limits for crew spaces in comparison with existing norms (in dB(A)) (SILENV, 2012).

	Locations	RINA	BV	GL	ABS	DNV	LR	IMO Code	IMO New	Proposed
Accomodation	Crew cabins	55	52	52	50	50	52	60	55	**50**
	Day cabins	–	–	–	–	–	55	–	–	**55**
	Officers cabins	52	–	50	–	–	–	–	–	**50**
	Hospital	50	55	54	50	55	–	60	60	**50**
	Offices	58	57	57	55	60	55	65	65	**55**
	Open deck recreation	70	70	68	65	70	–	75	70	**65**
	Closed public spaces	60	57	90	–	55	–	–	–	**55**
	Mess room	60	57	57	–	–	57	65	60	**57**
	Recreation	–	–	57	60	–	–	65	65	**57**
	Corridors	–	70	58	60	–	–	–	–	**58**
	Dining spaces	–	–	–	55	–	–	–	–	**55**
Navig.	Radio room	58	55	55	55	55	60	60	65	**55**
	Navigation spaces	58	–	55	–	–	–	65	–	**55**
	Chart rooms	–	–	–	55	–	–	–	–	**55**
	Radar room	–	–	–	55	–	–	65	–	**55**
Work	Engine control room	70	70	67	65	70	75	75	70	**65**
	Workshops	–	85	80	80	–	85	80	80	**80**
	Open deck working areas	70		75	–	–	63	–	–	**63**
	Laundries	–	–	–	75	–	–	–	–	**75**
	Continuously manned machinery spaces	–	–	–	85	–	90	90	–	**85**
	Not continuously manned machinery spaces	–	–	110	108	–	110	110	105	**105**
	Cargo handling spaces/Areas near cargo handling equipment	–	–	–	80	–	–	–	–	**80**
	Fan rooms	–	–	–	85	–	–	–	–	**85**
	Alleyways, changing rooms	–	–	–	–	–	70	–	–	**70**
	Listing posts, bridge wings	–	–	65	–	–	–	70	70	**65**
	Galleys	–	70	68	70	–	75	–	70	**68**
	Pantries	–	–	66	70	–	–	–	–	**66**
	Stores	–	–	80	70	–	–	–	–	**70**
	Wheelhouse	–	–	–	55	60	85	–	65	**55**

Table 5
Proposed preliminary noise limits for passenger compartments.

	Noise level, dB(A)						
Locations	ABS	BV	DNV	GL	LR	RINA	Proposed
Passenger top level cabins	45	45	44	44	45	45	**44**
Passenger standard cabins	45	49	49	46	49	50	**45**
Outside installation	65	65	65	64	67	65	**64**
Discotheque, ballroom	60	65	55	52	55	55	**52**
Restaurant, lounge	55	55	55	52	55	55	**52**
Libraries, theatre	55	53	55	52	50	52	**50**
Shops	55	60	55	52	60	55	**52**
Gymnasium	65	60	55	52	55	55	**52**
Corridors, staircase	60	60	55	54	55	60	**54**
Hospital	45	55	55	54	52	50	**45**

Table 6
Dependent variable in models. Numbers only refer to specific items used in the questionnaires deployed in the SILENV Project, and are of no particular value here.

	Models and dependent variables
Comfort	N2c-Annoyance O1c-Overall feeling of discomfort
Performance	N2p-Annoyance N7p-Quality impairment O1p-Overall feeling of wellbeing

Table 7
Noise limits per human response.

Extra probability relative to base line	Noise Annoyance, dB(A)	Noise Induced Work Quality impairment, dB(A)
5%	48	55
10%	55	64
15%	60	71
20%	65	77
25%	70	82
30%	75	86

criteria proposed by SILENV is the first example of a human oriented noise norm developed for the shipping industry. The developed Green Label Proposal not only aims to protect the health of the crew but also aims to maintain a good level of comfort as well as performance on board ships, also for passengers. Analysis of current fleet shows that, the new limits are realistic and achievable by the new ships. More information can be seen in the SILENV Green Label Proposal (SILENV, 2012).

The SILENV Green Label stands out by the following issues:

- The difference made by classification societies between crew cabins and passenger cabins is removed. The main reason for this is related to the minimum standards of wellbeing of human regardless of their role onboard ships. 50 dB(A) is an achievable noise level for both passenger and crew and provides a basic standard. Crew being able to sleep and rest is very critical since sleep deprivation is identified as one of the contributors to crew fatigue, which is leading to human errors and ship accidents/ incidents. In previous studies it was reported that noise induced sleep disturbance is likely to cause impaired mood and daytime sleepiness as well as reduced cognitive performance (Basner, 2008, Elmenhorst et al., 2010). For passenger ships, different classification societies offer various comfort class notations that differentiate in the level of quietness of the room. However, crew who live and work onboard ships do not have such choices

Table 8
Percentages of vessels which comply with given noise levels (SILENV, 2012) for the different locations and corresponding location types as defined in Table 9.

Locations	Corresponding location type	$x=50\%$		$x=40\%$		$x=30\%$		**$x=20\%$**		$x=10\%$		$x=5\%$	
		Noise limit dB(A)	Exact per-cent. %	Noise limit dB(A)	Exact per-cent. %	Noise limit dB(A)	Exact per-cent. %	**Noise limit dB(A)**	**Exact per-cent. %**	Noise limit dB(A)	Exact per-cent. %	Noise limit dB(A)	Exact per-cent. %
Passenger cabin	1	54	46	54	39	51	31	**50**	**27**	46	12	44	4
Crew cabin	1	60	52	59	41	57	33	**54**	**19**	51	11	49	7
Offices	2	59	49	58	42	55	32	**52**	**25**	51	14	49	7
Public spaces	3	60	52	59	44	57	32	**56**	**24**	55	12	52	4
Crew public spaces	4	66	49	65	42	63	34	**60**	**20**	53	10	50	4
Outdoor areas	6	76	47	76	40	74	27	**69**	**20**	59	13	59	13
Wheelhouse	7	62	54	61	42	58	31	**57**	**23**	55	12	54	5
Work spaces	9	83	53	82	40	79	31	**76**	**18**	73	10	69	6
Control room	8	70	51	69	40	66	30	**62**	**23**	60	11	58	4
Auxiliary en-gine room	11	105	46	104	39	102	23	**97**	**15**	89	8	79	0
Engine room	11	108	50	107	40	106	27	**105**	**21**	102	10	101	8

Table 9
Locations used for the SILENV Green Noise Label.

Location type	Group name	Location example	Noise limits, dB(A)
1	Cabins	Passenger cabins	50
		Crew cabins	50
		Hospital	50
2	Offices	Offices	53
3	Public spaces A	Libraries	55
		Calm public spaces	55
4	Public spaces B	Restaurant	60
		Lounge	60
		Mess room	60
		Shops	60
5	Public spaces C	Discotheque, dance floor	65
		Ball room	65
		Corridor	65
		Staircase	65
6	Outdoor areas	Open recreational areas	70
		Bridge wings/Open deck working areas	70
7	Wheelhouse	Wheelhouse	60
		Radio room	60
8	Work space A	Engine control room	65
		Galleys	65
9	Work space B	Pantries	75
		Stores	75
		Laundries	75
		Workshops	75
		Garage	75
10	Work space C	Continuously manned ma-chinery space	90
11	Work space D	Not Continuously manned machinery space	105

and it is very important that they at least receive the cabin equivalent to the minimum standard of a passenger cabin for a given ship. Therefore, 50 dB(A) is a desirable and technologically achievable minimum standard for crew cabins considering both crew wellbeing and safer ship operations.

- Another point is that even in the new IMO Noise Code, the noise limit defined for the hospital location is 60 dB(A), which is 10 dB (A) higher when compared to the SILENV proposed limit of 50 dB(A). The main reason for a more stringent SILENV limit is that any patient admitted to the hospital section of the ship, should have the ideal conditions for fast recovery and at least they should have the minimum cabin standards.
- Noise levels in cabins were specified to ensure that less than 10% of people will get annoyed. Tolerating a small percentage of people being annoyed is based on the fact that, even in the absence of any physical environmental habitat deficiencies, average complaints are around 10%, which is attributed mainly to the passenger expectations and personal or other factors such as price vs. service (Turan, 2006). Therefore achieving 90% satisfaction level was considered feasible and more realistic.
- Noise levels in wheelhouses have been specified to ensure that less than 10% of people will judge their performance degraded based on subjectively reported self-ratings. Again, considering safe operations, a lower noise limit in the wheel house (bridge) is necessary. Study carried out by Kurt et al. (2010) shows that increasing noise levels on the bridge influence the concentration of the officer and affect the passage performance significantly. Therefore, the limit set by IMO of 65 dB(A) should be further investigated.
- In high noise areas (Work space C and D) hearing protection has to be worn. Previous studies showed that noise exposure of crew mainly working in engine and related rooms exceeds the exposure limits defined by the EU Physical Agents Directive (Turan et al., 2010). It is clear that reducing the noise levels in engine rooms or similar compartments to a habitable level is not always possible. Therefore, Personal Protective Equipment (PPE) is essential to be worn by the crew who work in these spaces. There are various types of PPEs available providing different levels of protection against noise. Therefore, it is important to choose the correct type of hearing protection to reduce the hazardous noise exposure.
- When considering the public spaces, the proposed SILENV standards took into account the activities taking place in those spaces as well as human expectations. This resulted in the proposal of different limits. The noise level in public spaces such as libraries is expected to be low and therefore a lower noise limit, corresponding with a lower annoyance level (10%) is chosen. On the other hand, in public spaces like dining spaces or shops, noise levels are naturally higher due to the leisure activities and therefore noise limits are chosen to be less stringent, corresponding with 15% annoyance level.

Overall, the proposed SILENV Green Label Noise standards advocate to consider not only health but also wellbeing and performance of humans on board. It was also shown that these proposed standards can be achieved by the industry with currently available technologies and know-how.

Acknowledgement

Authors gratefully acknowledge that the research presented in this paper is generated as part of European Commission funded project SILENV (Ships Oriented Innovative Solutions to Reduce Noise and Vibrations), Seventh Framework Programme, Grant Agreement SCP8-GA-2009-234182.

References

ABS, 2001. Guide for Crew Habitability on Ships. American Bureau of Shipping.
Alberti, P.W., 2001. The pathophysiology of the ear. In: Goelzer, B., Hansen, C.H., Sehrndt, G.A. (Eds.), Occupational Exposure To Noise Evaluation, Prevention And Control. World Health Organisation (WHO), Geneva.
André, M., Baudin, E., Palomo, P.B., Dambra, R., Delente, M., Gaggero, T., Haimov, E., Hallander, J., Houben, M., Ianniello, S., 2014. Holistic noise and vibration abatement within the EU 7FP. The SILENV Project: Ship Innovative soLutions to rEduce Noise and Vibrations. Transport Research Arena.
Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., Schenone, C., 2012a. Control of airborne noise emissions from ships. In: Proceedings of the International Conference on Advances and Challenges in Marine Noise and Vibration, MARNAV2012. Glasgow, UK.
Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., Schenone, C., 2012b. Noise emitted from ships: impact inside and outside the vessels. Procedia – Soc. Behav. Sci. 48, 868–879.
Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., Schenone, C., 2013. The EU research effort towards the control of noise emissions from ships: the SILENV Project (7FP). In: Proceedings of the AIA-DAGA 2013 Conference on Acoustics. Merano, Italy.
Baker, C.C., Seah, A.K., 2004. Maritime accidents and human performance: the statistical trail. In: Proceedings of MarTech Conference. Singapore.
Basner, M., 2008. Nocturnal aircraft noise exposure increases objectively assessed daytime sleepiness. Somnol.-Schlafforsch. und Schlafmed. 12 (2), 110–117.
Beltrán Palomo, P., 2013. The most recent noise & vibration assessment of the European Fleet, within the framework of the SILENV Project. Ship Sci. Technol. 7 (14), 43–66.
Borelli, D., Gaggero, T., Rizzuto, E., Schenone, C., 2015. Measurments of airborne noise emitted by a ship at quay. In: Proceedings of the 22nd International Congress on Sound and Vibration Florence. Italy.
Bos, J.E., MacKinnon, S.N., Patterson, A., 2005. Motion sickness symptoms in a ship motion simulator: effects of inside, outside, and no view. Aviat. Space Environ. Med. 76 (12), 1111–1118.
Broadbent, D.E., 1954. Some effects of noise on visual performance. Q. J. Exp. Psychol. 6 (1), 1–5.
Button, D.C., Behm, D.G., Holmes, M., Mackinnon, S.N., 2004. Noise and muscle contraction affecting vigilance task performance. Occup. Ergon. 4 (3), 157–171.
DMA, 2002. Technical regulation on noise in ships, Technical regulation 4. Danish Maritime Authority.
EC, 2003. On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). Offi. J. Eur. Union.
Elmenhorst, E.-M., Elmenhorst, D., Wenzel, J., Quehl, J., Mueller, U., Maass, H., Vejvoda, M., Basner, M., 2010. Effects of nocturnal aircraft noise on cognitive performance in the following morning: dose–response relationships in laboratory and field. Int. Arch. Occup. Environ. Health 83 (7), 743–751.
GL, 2003. Rules for Classification and Construction, Chapter 16 Harmony Class-Rules on Rating. Germanischer Lloyd.
Harcum, E.R., Monti, P.M., 1973. Cognitions and placebos in behavioural research on ambient noise. Percept. Mot. Skills 37 (1), 75–99.
Harrison, D.W., Kelly, P.L., 1989. Age differences in cardiovascular and cognitive performance under noise conditions. Percept. Mot. Skills 69 (2), 547–554.
Houben, M., Kurt, R.E., Khalid, H., Zoet, P., Bos, J., Turan, O., 2012. Human response to noise and vibration aboard ships. In: Proceedings of International Conference on Advances and Challenges in Marine Noise and Vibration. 5–7 September, University of Strathclyde, Glasgow, UK.
IMO, 1981. Resolution A.468(XII): Code on Noise Levels on Board Ships. International Maritime Organization, London.
IMO, 2012. Resolution MSC.337(91): Adoptation of the Code on Noise Levels on Board Ships. International Maritime Organisation, London.
Jerison, H.J., 1957. Performance on a simple vigilance task in noise and quiet. J. Acoust. Soc. Am. 29 (11), 1163–1165.
Khalid, H., Turan, O., Bos, J.E., 2011. Theory of a subjective vertical–horizontal conflict physiological motion sickness model for contemporary ships. J. Mar. Sci. Technol. 16 (2), 214–225.
Kurt, R.E., 2014. Development of Human Response Models and Human Oriented Criteria for Noise on Board Ships. Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow, United Kingdom.
Kurt, R.E., Turan, O., Arslan, O., Khalid, H., Clelland, D., Gut, N., 2010. An Experimental Study to Investigate Effects of Noise on Human Performance Onboard Ships. In: Proceedings of Human Performance at Sea Conference. Glasgow, UK.
LR, 2004. Provisional Rules for Passenger and Crew Accommodation Comfort. Lloyd's Register.
Martin, A., Kuo, C., 1995. The effects of noise and vibration on crew performance. In: Proceedings of International Conference on Noise and Vibration in the Maritime Environment. The Royal Institution of Naval Architects Trinity House, London, UK.
MCA, 2007. Codes of Practice For Controlling Risks due to Noise and Vibration on Ships. Maritime and Coastguard Agency.
McCauley, M.E., Royal, J.W., Wylie, C.D., O'Hanlon, J.F., Mackie, R.R., 1976. Motion sickness incidence: Exploratory studies of habituation, pitch and roll, and the refinement of a mathematical model. DTIC Document.
Melamed, S., Fried, Y., Froom, P., 2004. The joint effect of noise exposure and job complexity on distress and injury risk among men and women: the cardiovascular occupational risk factors determination in Israel study. J. Occup. Environ. Med. 46 (10), 1023–1032.
Melamed, S., Froom, P., 2002. The joint effect of industrial noise exposure and job complexity on all-cause mortality – the CORDIS study. Noise Health 4 (16), 23.
SILENV, 2009. Ships oriented innovative solutions to reduce noise and vibrations. European Union, Framework Programme 7 Collaborative Project no. 234182.
SILENV, 2012. WP 5: Green Label Proposal – Subtask 5.2: Noise and Vibration label proposal.
Sillitoe, A., Upcraft, D., Rich, K., LaRoche, M., Røed, B., Huse, J., 2010. Supporting Human Performance in Ice and Cold Conditions. Lloyd's Register, London.
SMA, 1973. Sjöfartsverkets meddelanden Serie A. Swedish Maritime Authority.
Turan, O., 2006. COMPASS Final Publishable Report A rational approach for reduction of motion sickness & improvement of passenger comfort & safety in sea transportation.
Turan, O., Helvacioglu, I.H., Insel, M., Khalid, H., Kurt, R.E., 2010. Crew noise exposure on board ships and comparative study of applicable standards. Ships Offshore Struct. 6 (4), 323–338.
Weston, H.C., Adams, S., 1932. The effects of noise on the performance of weavers. Medical Research Council Industrial Health Research Board, pp. 38-62.
White, K., Meeter, M., Bronkhorst, A., 2012. Effects of transportation noise and attitudes on noise annoyance and task performance. In: Proceedings of INTER-NOISE and NOISE-CON Congress and Conference Proceedings. Institute of Noise Control Engineering, pp. 780–788.
Wickman, L.A., 2012. Comparing Crew Operations in Extreme Environments: Arctic Shipping vs. Outer Space, International Conference and Exhibition on Performance of Ships and Structures in Ice 2012 Canada.