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TOWARDS HUMAN-ORIENTED NORMS: INVESTIGATING THE EFFECTS OF NOISE EXPOSURE ON BOARD SHIPS

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Abstract: With current trends showing a decrease in crew numbers on board ships together with increased operational demands as well as increased paperwork, crew fatigue and comfort has become more critical and recently been given more importance. It is known that environmental factors have an effect on crew comfort and performance. The two outstanding environmental factors which exist in the shipboard environment are ship motions and noise, moreover, in these two areas the findings and lessons learnt from other industrial sectors are considered to be less relevant. Therefore, it was necessary to conduct research to understand the effects of these factors, so that, the lessons learnt can be integrated into design process in order to eliminate the adverse effects of the aforementioned two factors during operation. Due to having more obvious performance outcomes ship motions and motion sickness research attracted more interest where human response to noise have been neglected so far. Therefore, this paper reports the findings of research study which investigated the current levels of crew noise exposure through field studies. Furthermore, developed human response models to noise on board ships and SILENV green label noise standards will also be introduced in comparison with current normative framework.

Keywords: Noise on board ships, SILENV Project, shipping noise, noise exposure, seafarers, IMO noise code.

1 INTRODUCTION

Today, together with technological developments, ships are equipped with sophisticated system and automation. Hence the trend to decrease the number of crew members on board ships has been triggered. However, these automated systems still require human intervention, when interpreting the information or when tasks require decision making. Therefore, when 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 is becoming more important than before to achieve safe shipping operations. Investigations of the shipping accidents showed that human error is the major contributor of shipping accidents which in turn caused more and more research to be focused on human performance and wellbeing on board ships.

In terms of human factors on-board ships, a naval architect's primary role is to ensure designing ships considering the needs of crew. It is important to mention that the environment on ships which crew members spend their day-to-day life is unique (motions, noise, vibrations, heat, smell etc.) and can be considered as the most extreme when compared with many other industries. Moreover, when it is considered that crew members not only work but also required to live and rest in this same environment for months long, the matter becomes more complex. Therefore, environmental conditions of 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 conditions on ships is motion. Due to having obvious consequences and performance outcomes on crew, 'motion sickness' was studied in-dept, resulting in numerous human response models which can be utilised to estimate the levels of comfort even at the design stage. However, shipping industry failed to develop similar knowledge and even awareness on noise which is one of the most important environmental factors on board ships.

Therefore, in this paper, the research conducted under EU FP7 SILENV Project will be explained which produced a 'Green Label Standard' for noise levels on board ships.

2 LITERATURE REVIEW

The most obvious effect of noise on human is called Temporary Threshold Shift (TTS) which is an auditory fatigue resulting from being exposed to hazardous levels of noise. When TTS becomes repetitive or exposure to very hazardous levels of noise happens Permanent Threshold Shift (PTS) may occur (Alberti 2001) and it would not be wrong to say that current regulatory framework is designed to protect workers from these hazardous noise exposures.

At this point it is important to mention about the two relevant noise standards which are applicable to ships. International Maritime Organization (IMO) recently updated the old Code on Noise Levels on Board Ships (IMO 1981) with the new one (IMO 2012) which is enforced under the provisions of regulation II-1/3-12 of the SOLAS Convention. The code defines the minimum acceptable noise levels for ship compartments and

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considers that, when complied with, the equivalent continuous noise exposure of crew members will not exceed 80 dB(A). On the other hand EU Physical Agents Directive for Noise (EC 2003) aims to protect the workers' health from hazardous noise exposures by defining the daily noise exposure limits. This approach considers not only the noise emission levels that a worker is being exposed to, but also takes into account the time spent in that noisy environment. It can be said that the approach of EU Physical Agent Directive is more human focused when compared to the aforementioned IMO Noise Code. However, both regulations are not satisfactory enough when the effect of noise on crew performance and wellbeing is considered, furthermore, in this specific topic there is not enough research conducted in maritime domain. The aforementioned research gap and the need for diverting more research to this important area is also recognised by Martin and Kuo (1995).

Numerous research studies from other industrial sectors were 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 (Weston and Adams 1932, Broadbent 1954, Melamed and Froom 2002, Button, Behm et al. 2004, Melamed, Fried et al. 2004, Kurt, Turan et al. 2010). However, it is also possible to find examples of studies in the literature where researchers found positive relation or no relation between noise exposure and human performance (Jerison 1957, Harcum and Monti 1973, Harrison and Kelly 1989, White, Meeter et al. 2012)

The review of literature demonstrates conflicting findings amongst different studies 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. 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. The new noise limits were compared with the existing ones in Table 1.

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* 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

*The limits for ship size greater than 10000 GRT are shown after /.

As can be seen from this table, a number of noise limits were reduced considering the noise emissions only. Several classification societies and maritime authorities have already imposed more strict standards to control the ship noise (SMA 1973, ABS 2001, DMA 2002, GL 2003, LR 2004, MCA 2007). 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 were followed the same path by issuing physical agent directive to protect workers from risks arising from exposure to noise (EC 2003). The directive covers all workers who are exposed or potentially to be exposed to risk from noise. The main difference between the IMO resolution and the EU directive is that the EU directive pay more attention to the workers' exposure to the noise emission rather that the source of noise. In a

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sense, it is a much better approach to regulate the noise limits in a human centred way. The exposure action and limit values defined by EU physical agents directive is shown in Table 2.

Table 2: Exposure limit and action values defined by EU physical agents directive.

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

For both EU Physical Agents Directive and IMO Noise Code, the exposure levels can be calculated by the following equation.

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

In the above equation t_i is the duration in a noisy environment while T is 8 when calculating 8 hour equivalent exposure level and 24 when calculating 24 hour 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, Helvacioglu et al. 2010) which included the following;

- Noise levels of compartments were measured for six different ships during the 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 calculated.
- Results were comparatively analysed based on 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.

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

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

Results showed that although ships are easily fulfilling the requirements set by the IMO for compartment bases, they are failing to comply with the defined noise exposure criteria. Therefore, it is necessary to redesign the noise levels defined by IMO by considering the recent improvements, practical implementation, comfort and performance of crew members. It was also identified that crew members who are working close to machinery spaces are at high health risk because they exceed the safe exposure limits defined to protect health. Exposure levels for each rank was calculated through an exposure assessment tool as reported in Turan, Helvacioglu et al. (2010)

4 EU FP7 SILENV PROJECT'S GREEN LABEL PROPOSAL

EU FP7 SILENV Project (SILENV 2009) was funded in response to emerging need for reducing ship-generated noise and vibration pollution. SILENV Project dealt with the wide range of issues related to noise and vibration on and from ships. The project a thorough review of the previous literature, conducted field studies and measurements, developed models, and issued guidelines aiming to improve current situation. One of the main outputs of SILENV Project is the 'Green Label Proposal' which defines new innovative noise limits for ships. 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.

- Preliminary target levels for noise has been defined based on the extensive state-of-the-art review conducted in the project.
- Considering the resulting human response (comfort, wellbeing and performance) from the preliminary limits
- Feasibility of these preliminary limits has been assessed based on;
- Finalisation of Green Label Proposal

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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 refer-to document when dealing with noise on board ships. Therefore, it was considered that the development of preliminary noise limits for 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- is just as stringent as the existing norms.

The developed preliminary noise levels are shown in Table 4 and Table 5 in comparison with the existing norms.

Table 4: Proposed preliminary noise limits for crew spaces (in dB(A))

		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

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Table 5: Proposed preliminary noise limits for passenger compartments

	Noise level in dB(A)						
	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 (swimming pools, sport decks, promenade decks...)	65	65	65	64	67	65	64
Discothèque, Ballroom	60	65	55	52	55	55	52
Restaurant, Lounge	55	55	55	52	55	55	52
Librairies, 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

4.3 Human Response

It was important to assess the preliminary noise target levels and resulting human response. Hence, innovative human response models were developed in the SILENV Project (Houben, Kurt et al. 2012). In order to achieve this, noise measurements were conducted in various compartments on board of 15 different ships. Together with the noise measurements, questionnaires were also deployed to capture the resulting human response. Then, the human response models were developed describing the relationship between the levels of noise and subjective ratings of crew on performance and passengers on comfort. 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 visited and final models with good fitness were obtained.

In order to represent total human response, 2 comfort and 3 performance models were developed resulting in total of 5 different human response models focusing on different performance or comfort criteria. These models are shown in Table 6.

Table 6: Dependent variable in models

	Models & Dependent variables
Comfort	**N2c** - Annoyance **O1c** - Overall feeling of discomfort
Performance	**N2p** - Annoyance **N7p** - Quality impairment **O1p** - Overall feeling of wellbeing

As a result of discussions amongst SILENV partners, for comfort 'N2c - Noise Annoyance model' and for performance 'N7p - Quality impairment model' were selected to assess the preliminary target levels. These selected models 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.

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

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 is 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 current ships to comply?". In order to achieve that, only the most recent ships from the SILENV Noise Database was selected considering that the technology in older ships will not be comparable to the new buildings. Total of 64 different vessels were taken into consideration and following table shows the noise limits and corresponding percentage of vessels which can comply with those levels. Table 8 shows the percentages of vessels from SILENV database which comply with the noise levels.

Noise limits which will correspond to 20% of the vessels to comply, was considered reasonable and achievable by the SILENV Consortium.

4.5 Finalisation of Green Label Proposal.

The noise requirements defined in previous sections were combined together 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. 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 were defined. After consolidating all the criteria, through a workshop SILENV partners further discussed and finalised the green label proposal.

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Table 8: Percentages of vessels which comply with given noise levels (SILENV 2012)

	x=50%		x=40%		x=30%		x=20%		x=10%		x=5%	
Space type *	Noise limit (dBA)	Exact percent. (%)	Noise limit (dBA)	Exact percent. (%)	Noise limit (dBA)	Exact percent. (%)	Noise limit (dBA)	Exact percent. (%)	Noise limit (dBA)	Exact percent. (%)	Noise limit (dBA)	Exact percent. (%)
Type I	54	46	54	39	51	31	50	27	46	12	44	4
Type II	60	52	59	41	57	33	54	19	51	11	49	7
Type III	59	49	58	42	55	32	52	25	51	14	49	7
Type IV	60	52	59	44	57	32	56	24	55	12	52	4
Type V	66	49	65	42	63	34	60	20	53	10	50	4
Type VI	76	47	76	40	74	27	69	20	59	13	59	13
Type VII	62	54	61	42	58	31	57	23	55	12	54	5
Type VIII	83	53	82	40	79	31	76	18	73	10	69	6
Type IX	70	51	69	40	66	30	62	23	60	11	58	4
Type X	105	46	104	39	102	23	97	15	89	8	79	0
Type XI	108	50	107	40	106	27	105	21	102	10	101	8

*Space types are described in more detail in final green label noise limits (see Table 9)

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 which are similar to but not identical to IMO.

Table 9: Noise Limits in SILENV Green Label

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

* hearing protection mandatory

5 CONCLUSIONS

In the SILENV Project innovative human response models were developed. Furthermore, these models were utilised for developing the SILENV green label proposal. Therefore, it can be considered that the noise criteria proposed by SILENV is the first example of human oriented noise norm developed for shipping. The developed green label proposal does not only aim to protect the health of the crew but also aims to maintain a good level of comfort as well as performance on board ships. Analysis of current fleet showed that the new limits are realistic and achievable by the new ships. More information is available in SILENV Green label proposal (SILENV 2012).

Following can be observed from the defined noise limits:

- The difference between crew cabins and passenger cabins were removed.
- Noise levels in cabins were designed to ensure that less than 10% of people will get annoyed.
- Noise levels in wheelhouses were designed to ensure that less than 10% of people will get performance degraded.
- In high noise areas the hearing protection should be worn.
- 'Public Space A' complies with the targeted human annoyance (max. 10 %).
- However the levels defined for 'Public Space B' corresponds to 15% of human annoyance.

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