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Development of Human Response Models and Human Oriented Criteria for Noise on Board Ships

by

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Signed: Rafet Emek Kurt *Date: 10 December 2014*

This thesis is dedicated to the memory of my father, Hasan Basri Kurt, who sadly lost his fight with lung cancer on the 20th of January 2014.

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ABSTRACT

Working at sea has traditionally been perceived by society as an arduous but rewarding occupation. Competitive markets, minimal manning and an increase in the prevalence of technology have led to the profession of a seafarer evolving from being focused on skills of a physical nature to those requiring an increased cognitive approach. This has resulted in human performance and wellbeing becoming more significant in securing the health and safety of the individual, and the safety and efficiency of the system. The impact of noise on human performance and wellbeing is an area which has not been appropriately addressed in the maritime domain but has been attributed in literature to hearing loss, fatigue, performance reduction, stress and ultimately accidents.

In this thesis, through a review of literature, an assessment of noise exposure levels of crew on board ships, an experimental study measuring performance in relation to noise and the collection and analysis of real human response data from ships; statistical models for predicting human response to noise on board ships have been developed. Then, through utilisation of the human response models a new human oriented noise criteria and design methodology is proposed.

In this body of research the main findings include: the strong suggestion that health is at risk due to noise on board ships; evidence that human performance is being affected by background noise levels and; the establishment of a statistically significant relationship which predicts noise in relation to performance. It is envisaged that this research will be utilised by ship designers in estimating the human response to noise at the design stage.

Overall, this research has made a significant contribution in addressing the effects of noise on human performance and wellbeing in the maritime domain. In future research it is anticipated that the findings of this research can be combined with the other factors affecting human response on board ships.

Chapter 1. INTRODUCTION

1.1 Chapter Overview

This chapter briefly explains the background reasoning for pursuing the study of the human response to noise in the marine domain

1.2 General Perspectives

Ninety percent of the world's commercial cargo is transported by sea (Glass, 2014) and this is a trend which is likely to increase further with the continued globalisation of developing and emerging economies. Accordingly the total size of world merchant fleet is also increasing as shown in Figure 1-1.

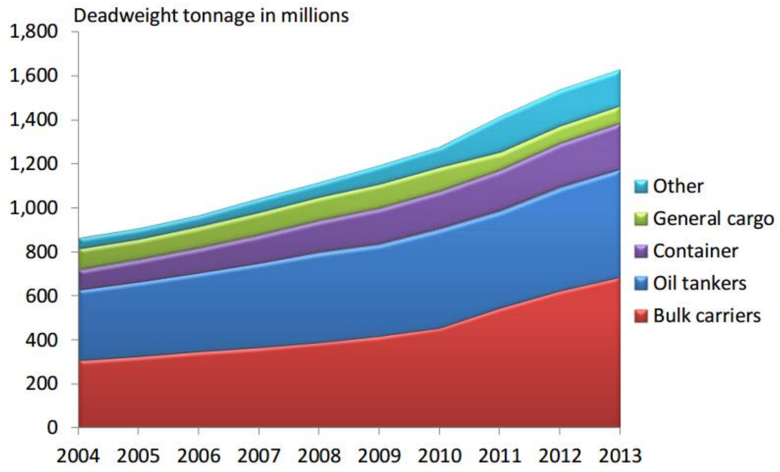


Figure 1-1: World merchant fleet by type of ship, 2004 to 2013 (Economics, 2014)

In comparison, if one charts the increase of globalisation to a current industry overview of shipping, a picture of excessively competitive market conditions are described (Walters, 2005, Glass, 2014). However, increased competitiveness and today's tougher market conditions comes with some consequences. According to Smith *et al.* (2006) through the introduction of flags of convenience, increased reliance on technology, reduced crewing and internationally sourced labour, the feedback from many industry observers and academics is that, profits are increased at the expense of welfare concern (Bloor *et al.*, 2000). In the drive for lower costs and increased efficiencies, there are accusations that crews are now 'being paid less for doing more' and suffering the consequences ranging from catastrophic accidents to long term effects on health (Cockroft, 2003).

At the very centre of seafarer welfare, in the context explained above, is the problem of human fatigue. According to the international convention on Standards of Training, Certification and Watchkeeping (STCW), a seafarer can work up to 98 hours a week which is allowed for two weeks in 'exceptional' circumstances. When compared to European Working time directive which allows maximum of 48 hours per week, one can easily understand the excessive workload that seafarers face. Even the most basic of literature review reveals the global concern for seafarer fatigue and the associated potential costs. All stakeholders including the maritime regulators, ship owners, trade unions and P & I clubs are aware of the dangerous combination of minimal manning, sequences of rapid port turnarounds, adverse weather conditions and high levels of traffic leading to seafarers working long hours with insufficient recuperative rest (Smith *et al.*, 2006). In these circumstances, fatigue and reduced performance have the potential to contribute to conditions which may lead to environmental damage, ill-health and reduced life-span amongst seafarers.

One of the main concerns related to seafarer fatigue is accidents and casualties. It was reported by Alert (2007) that almost every accident investigation report includes 'fatigue' as one of the contributing factors and most of these reports are related to the grounding or collusions which are caused by inattention of the fatigued officer of the watch. Furthermore, a comprehensive study on seafarer fatigue was conducted (Smith *et al.*, 2006, ITF, 2014). The findings shown in bullet points below are based on the feedback of seafarers who took part in this study and they are good demonstrations of the dangers of fatigue.

- One out of four seafarers has fallen asleep on watch
- 50% of seafarers reported working weeks of 85+hours
- Half of seafarers think that working hours had increased over the past 10 years.

- Almost 50% of seafarers reported their working hours as causing a danger to their personal safety
- 37% of seafarers think that their working hours are likely to danger to the safety of the shipping operations.

There is extensive evidence from both laboratory and field studies showing that acute fatigue and impaired performance are strongly associated. Fatigue is recognised as one of the most important safety hazards in marine transportation. It decreases the cognitive function of ship officers, impairs task performance and thus decreases their ability to operate the ship adequately (Juned and Utne, Jones *et al.*, 2005)

The organisational factors together with the environmental conditions on board ships can contribute to the increased fatigue levels of seafarers which in turn can affect their performance. According to Perrotis (2014) following are the common factors that contribute to seafarers' fatigue;

- Excessive workload and long working hours
- Insufficient rest between work periods
- Sleep deprivation or poor quality sleep
- Motion
- Vibration
- Noise

As seen above, the seafarer is exposed to a unique combination of factors which can be considered extreme when compared to other industries. While excessive workload and insufficient rest can be attributed to organizational factors, the remaining can be influenced through the physical design of the vessel. The main focus of this thesis is noise.

1.3 Specific Issue of Noise

Noise on board ships has been a major concern for a long time. On board a ship the noise generated from different sources and vibrations can range from 50 dB(A) to

120 dB(A) while instantaneous peak values can reach a lot higher levels. As a member of crew on a vessel, one is expected to work and rest in these conditions. However, what impact the exposure to the noise on board ships has on the crew in terms of their wellbeing and performance is not very well defined.

Experience from other industries show that noise exposure can have the following effects on human wellbeing and performance; (1) Hearing Loss, (2) Sleep deprivation, (3) Annoyance, (4) Speech interference, (5) Stress, (6) Reduced cognitive performance, (7) Lower vigilance, (8) Accidents and injuries (refer to Chapter 4). However, the aforementioned factors have not been specifically investigated in the maritime domain.

Environmental conditions of ships and their effects on a human have not been specifically studied in depth especially with regards to performance. The only environmental condition considered in this context is ‘ship’s motion’ because it has obvious consequences and performance issues for the crew (i.e. motion sickness). However, the shipping industry has failed to develop similar knowledge and even awareness of noise which is one of the most important physical stressors on board ships (Rengamani and Murugan, 2012).

It is obvious that a ship designer needs valid and reliable methods to estimate human responses resulting from an environment which includes background noise and having the tools to determine the required trade-offs between human acceptance and the levels of noise present. Even though naval architects are criticized for not considering human limitations and needs when designing ships, the aforementioned tools and criteria are not currently available for them to refer to.

Therefore, within this research the factors discussed above will be investigated in a systematic manner in order to develop human response to noise models which are required by ship designers.

1.4 Layout of the Thesis

This chapter has presented some background to the issue addressed in this PhD study. The specific issue of 'human response to noise on board ships' is addressed in this thesis, through following the structure shown in Figure 1-2.

As shown in Figure 1-2, Chapter 1 outlines the background information and need for conducting this research study. In Chapter 2, an introduction is made to human factors in the maritime domain which lead to the identification of the research gap and defining of the main aims and objectives in Chapter 3.

In Chapter 4, a comprehensive literature review is conducted with the aim of identifying current developments in the area of human response to noise. Relevant regulatory framework was also reviewed. In Chapter 5 an approach and methodology is proposed for this PhD study.

In Chapter 6, the noise exposure levels of crew working on six chemical tanker ships were assessed with the main focus on health. In the same chapter, noise related regulatory compliance of the aforementioned vessels is also investigated.

In Chapter 7, an investigation of the effects of noise exposure on crew performance through conducting an experimental study in a ship bridge simulator is conducted. In this chapter a Peripheral Detection Task (PDT) is used to assess crew vigilance performance under different background noise levels. Findings of this experiment are presented which show exposure to noise has a significant relationship with crew performance.

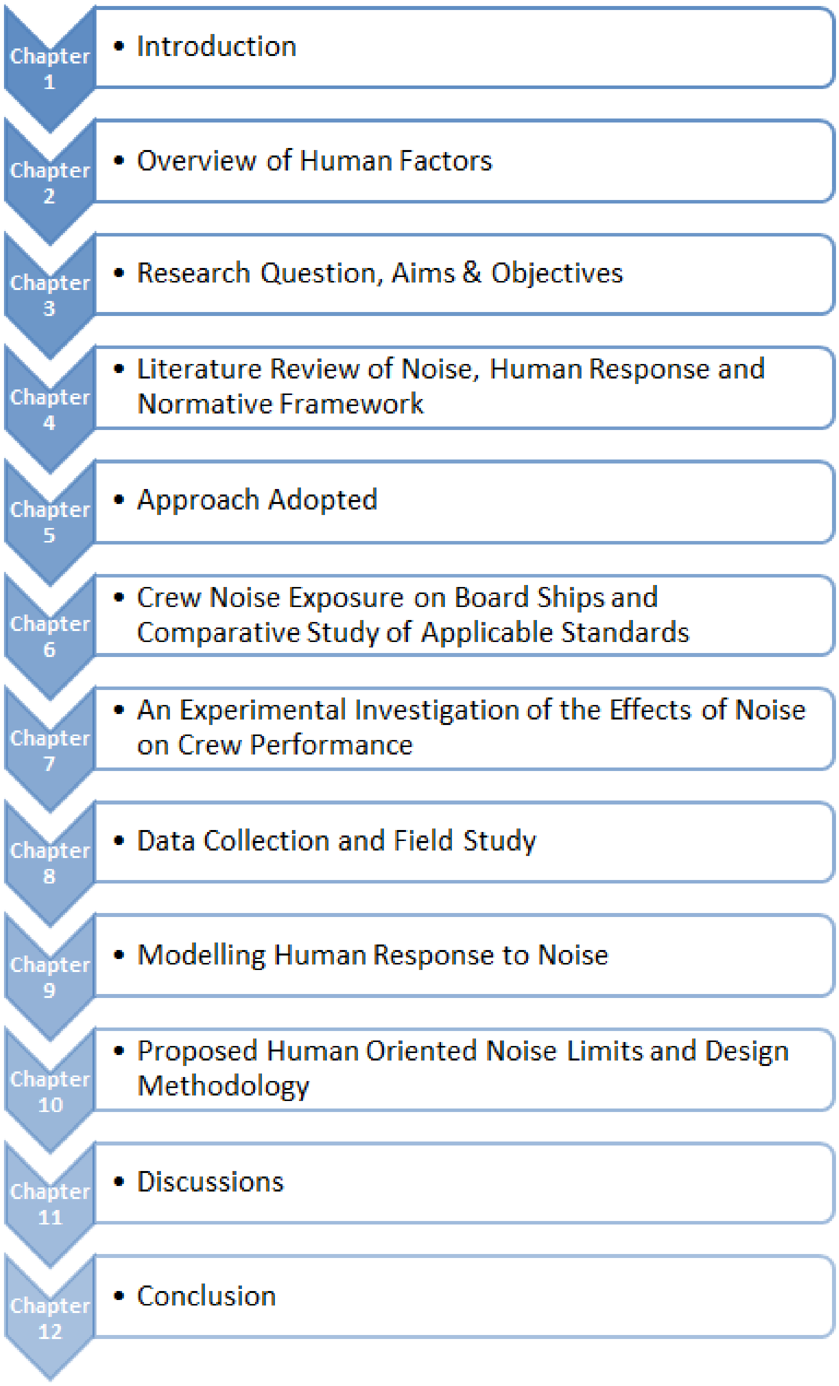


Figure 1-2: Layout of the thesis

In Chapter 8, a measurement campaign from ships and collected human response data is explained and reported. In Chapter 9, the outputs of Chapters 6 and 7, and the data from Chapter 8 is utilised in the creation of human response models. In Chapter 10, the models are utilised to create a new human oriented noise criteria for ships as well as in the development of a design methodology. In Chapters 11 and

12, the main findings of this research are summarised, the limitations of this PhD study are discussed along with potential recommendations for future research.

1.5 Chapter Summary

This chapter summarised the need for conducting this PhD research

Chapter 2. OVERVIEW OF HUMAN FACTORS & IDENTIFICATION OF THE RESEARCH GAP

2.1 Chapter Overview

The initial motivation for committing to this PhD research study was recognising the increasing need to conduct human factors related research in maritime domain, so that, the new ships could be designed and equipped in a human oriented manner. Therefore, through considering the limitations and needs of human on board ships, it was considered that, safer and more efficient maritime operations could be achieved. As a result, at first a review of generic human factor concepts was conducted, which then lead to the focussed topic of this PhD study; 'Human Response to Noise'. Therefore, this chapter reports the findings of initial research conducted in the area of human factors.

2.2 Concept of human factor

Advances in technology have resulted in systems which have increased intelligence and reliability. However, this has resulted in the complexity of the systems also increasing. This dilemma initiated scientists to concentrate on human factor science which is also referred to as ergonomics. The word ergonomics is derived from the Greek words 'ergo' (work) and 'nomos' (laws). It was used for the first time by Wojciech Jastrzebowski in a Polish newspaper in 1857 (Karwowski, 1991). This was recorded as the very first usage of the term ergonomics (human factors). The terms 'ergonomics' and 'human factors' are sometimes used in an interchangeable manner. For example, the term 'human factors' is generally used in the United States where the term 'ergonomics' is used in the Europe. Alternatively, the term 'human element' is also used in the same meaning. For the purpose of the clarity in this thesis the term human factor will be used, which is further defined and discussed below.

Through the evolution of human factor science, the human factor has been researched in a variety of industries which have different needs. Therefore, numerous definitions have been given by various organisations and academics. These definitions are generally centred on the particular industry/problem they are addressing. Some of these definitions are shared below;

- Human factors refer to the environmental, organisational and job factors, and individual characteristics, which influence behaviour at work in a way which can affect health and safety (HSE, 1999).
- Human factors is a broad-based discipline, addressing not only naval marine vehicles , but any situation in which a human comes into contact with a machine, whether that machine is a car, a spacecraft or a mobile phone (Ross, 2009).
- Ergonomics is the application of scientific information concerning humans to the design of objects, systems and environment for human use (IEHF, 2010)
- Human factors are those elements which influence the efficiency with which people can use equipment to accomplish the functions of that equipment (Meister, 1971).
- Human factors is a scientific, theoretical, and applied discipline dealing with psychological, physical, and organizational aspects of the interaction between humans and systems (e.g., technology) primarily in occupational contexts (Grech *et al.*, 2008).
- The study of factors and development of tools that facilitate the achievement of the goals of reducing error, increasing productivity, enhancing safety and enhancing comfort for the human interacting with the systems. (Wickens, 2004).
- Human factors discovers and applies information about human behaviour, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use (Sanders and McCormick, 1993).

- Ergonomics advocates systematic use of the knowledge concerning relevant human characteristics in order to achieve compatibility in the design of interactive systems of people, machines, environments, and devices of all kinds to ensure specific goals (HFES, 2003).

As it seems from the definitions given above, human factor science aims to achieve the better performing and more reliable systems by considering the human integrated in to that system. Despite the fact that, state-of-the-art technology is being used on ships which is more reliable and more automated, errors and accident still cannot be prevented. Therefore, considering human as part of the system and understanding the fact that improving the reliability or the performance of that system can only be achieved by improving the performance of the human operator in that system, lead human factors science to be more noticed.

Human factor is a very broad subject and the problems associated with it can only be addressed by adopting a multidisciplinary approach. Moreton (2000) also confirms that a multi-disciplinary approach to human factors' research should be adopted, drawing interests from interrelated subject areas such as psychology, physiology, computer science and engineering.

The wide scope of human factors often divided into subgroups. For example, Karwowski (2001) described the ergonomics as a holistic approach which considers following groups; physical, cognitive, social, organizational, environmental and other relevant factors.

However, it is possible to find different categorisation used by different scientists. Table 2-1 presents a wide range of issues addressed in Human Factors Engineering discipline. This categorisation is useful in understanding human factor problems from different perspectives.

Table 2-1: Classification Scheme for Human Factors/Ergonomics (EIAC, 2001)

Classification Scheme for Human Factors/Ergonomics
1. General
Human Characteristics
2. Psychological aspects
3. Physiological and anatomical aspects
4. Group factors
5. Individual differences
6. Psychophysiological state variables
7. Task-related factors
Information Presentation and Communication
8. Visual communication
9. Auditory and other communication modalities
10. Choice of communication media
11. Person–machine dialog mode
12. System feedback
13. Error prevention and recovery
14. Design of documents and procedures
15. User control features
16. Language design
17. Database organization and data retrieval
18. Programming, debugging, editing, and programming aids
19. Software performance and evaluation
20. Software design, maintenance, and reliability
Display and Control Design
21. Input devices and control
22. Visual displays
23. Auditory displays
24. Other modality displays
25. Display and control characteristics
Workplace and Equipment Design
26. General workplace design and buildings
27. Workstation design
28. Equipment design environment
29. Illumination
30. Noise
31. Vibration
32. Whole body movement
33. Climate
34. Atmosphere
35. Altitude, depth, and space
36. Other environmental issues

Classification Scheme for Human Factors/Ergonomics
System Characteristics
37. General system features
38. Total system design and evaluation
39. Hours of work
40. Job attitudes and job satisfaction
41. Job design
42. Payment systems
43. Selection and screening
44. Training
45. Supervision
46. Use of support
47. Technological and ergonomic change
48. General health and safety
49. Etiology
50. Injuries and illnesses
51. Prevention
Social and Economic Impact of the System
52. Trade unions
53. Employment, job security, and job sharing
54. Productivity
55. Women and work
56. Organizational design
57. Education
58. Law
59. Privacy
60. Family and home life
61. Quality of working life
62. Political comment and ethical
63. Approaches and methods

As it was discussed above, it is possible to approach human factor from many different perspectives and it is not possible to deal with all human factor problems without involving a multidisciplinary approach. Therefore, the 'human factors' in the context of this PhD is defined as;

"A discipline which aims to maximise safety, reliability, performance and comfort by improving the environmental factors to be compatible with the physical and cognitive aspects of the human in a system."

2.3 Human factor– Historical Perspectives

From even the prehistoric era, with the invention of simple equipment, human factors were always considered in the simple design procedures. For example, when ancient hunting equipment is investigated, it can be seen that the ergonomics have been taken into consideration when designing the handle. In middle ages, similar considerations can be found in the design of swords to match the physical needs of the soldiers.

Furthermore, the relationship between the military and human factor research cannot be neglected. This relationship is very well presented in the work conducted by Meister (1999) describing the formal Human Factors history in following 5 groups; Pre-modern Period, Between the Wars, World War II, Post World War II (Modern) and 1965 to the Present (Postmodernism). Following paragraphs will summarise the work conducted by Meister.

One of the earliest approaches of human factors was concentrated on fitting the man to the machine. There were very limited efforts to design the machine to match with the needs of human operator. Many examples can be given from military where operators of military vehicles were chosen to fit the space limitations of that vehicle.

Meister (1999) states that another sign of human factor was the work conducted by the American inventor Simon Lake who studied the various parameters in order to investigate the ability of submarine operators to resist the unfavourable environmental conditions like seasickness. This approach considers the human as a weak point of the system as a potential risk factor and still being frequently mentioned by human factors experts in their concerns about human error and human performance requirements.

The study of Taylor (1911), which aimed to increase the efficiency of workers in the workplace, was another important milestone for human factors. Taylor (1911) investigated the training, work-rest patterns as well as conducted time motion studies which constructed the base for today’s methods.

As mentioned before, many of the human factors and ergonomic advances originated from military necessity. Start of 'World War I' triggered development of more sophisticated equipment and human operator has become a very important topic for the reliability of the system. In order to employ the newly invented airplane in the war, it was necessary to select and train pilots rapidly which was resulted the development of aviation psychology and the beginning of aeromedical research.

It was noted that there was a reduction in research during the time between 'World War I' and 'World War II', although some achievements were made.

Aeronautical research on human factors continued through the establishment of laboratories and simulators. The basics of anthropometry were applied to include the study of human body measurements into the design of airplanes in this time period. Another notable research in this period was the behavioural research on automobile drivers, perceptual aspects of driving as well as studies of accidents (Forbes, 1939).

According to Meister (1999), the outbreak of World War II boosted research activities in the human factors. There was a need of employing vast numbers of man and women but it was not practical to apply Taylor's principles to select individuals for specific jobs. Therefore, the efforts have been put together to design and improve equipment to eliminate the effects of human limitations which can be described as designing for human. The research conducted by Fitts (1947) aimed to identify the most effective configuration of control knobs for aircraft cockpit design can be noted as a good example related to the aforementioned concept.

After the World War II, military continued to sponsor the human factor research. Moreover, universities utilised the government funding in order to establish their research laboratories. Furthermore, private sector established their human factors and ergonomics groups as well which created a major change in human factors because it was no longer a research oriented topic, rather it became part of design procedure (Meister, 1999). Human factors Society was established in 1957 which now has more than 4500 members.

From 1965 until today, the human factor discipline kept on expanding, the profession became widely recognised and today universities offer human factor programs. The developments in technology and increased level of sophistication in the equipment and systems as well as introduction of safety critical industries (such as nuclear plants) increased the importance of the human factors discipline in order to deal with the new challenges. Today, 'human factors' is a multidisciplinary profession which requires cooperation of experts from different domains who aim to deal with the complex problems of different industrial needs.

2.4 Human factors in maritime industry

In every occasion where human and technology interact, human factor issues will exist. Human factor concerns are more critical on board ships due to the couple of other factors. First of all, a ship is a complex system equipped with sophisticated software, technology and equipment and this complexity increases the cognitive demands on the crew. Besides, the complexity of ship systems, factors like; being isolated from community, environmental conditions (e.g. ship motions, heat, noise and vibration), work rest patterns and demanding tasks of ship maintenance and operation add additional physical and psychological demands on ships' crew.

The attempt to study human factors on board ships has mainly been triggered by the maritime accidents. In 1971, due to high accident rates at sea, Maritime Transportation Research Board of US started a study to investigate the problem of human error in maritime safety (Margetts, 1976). The research study utilised a review of literature, data base evaluations, survey, casualty flow diagrams and job descriptions to come up with recommendations on measures to prevent casualties. These recommendations are listed in order of priority as follows; (1) Vigilance, (2) Pilot-master relationship, (3) Bridge design, (4) Operating standards, (5) Physical qualifications, (6) Vessel familiarization, (7) Boredom and job satisfaction, (8) Fatigue, (9) Calculated risk, (10) Alcohol use, (11) Radar, (12) Sound signals, (13) Lights and markers, (14) Rules of the road. However, these recommendations were mainly focused on the final human error and were lacking deeper investigation of the human factor problems.

Similarly, shipping rules also generally developed in reaction to the bad experiences at sea and generally after major shipping accidents. For example, Titanic disaster triggered the development of Safety of Life at Sea (SOLAS) convention (IMO, 1974).

Major maritime accidents and human factor contribution to these accidents influenced IMO to recognise the need for incorporating the human factors in to its rules. As a result, in order to promote better management practice for shipping, International Safety Management (ISM) Code was adopted into SOLAS in 1994. Moreover, STCW Convention gone through a major amendment in 1995 in order to address the modern shipping operations as well as the recognised problem of human error which was further amended in 2010 (IMO, 2010).

Through this reactive approach, introduction of new rules and safety equipment on ships resulted in safer shipping with fewer accidents when compared to early times. Today, systems on board ships are technologically advanced and reliable. However, it is evident from the accident investigations that 75 to 96% of maritime accidents are still caused by or related to human error (A. Rothblum, 2002). Therefore, further reduction in the accident rates can only be achieved through addressing the ‘human factor’ related issues in maritime operations. It is important to mention that, despite very beneficial, current human factor research in maritime domain is falling too short to address all wide range of human factor issues in the maritime operations or lacking to conduct in-depth proactive research to uncover the unknown factors affecting human performance.

If ships, with its management systems, equipment and human on board are considered as a whole, then addressing human factor issues in this system will vary depending which part of the system is being dealt with. Therefore, human factors on board ships, in its simplest form, can be classified under 3 groups as shown in Figure 2-1;

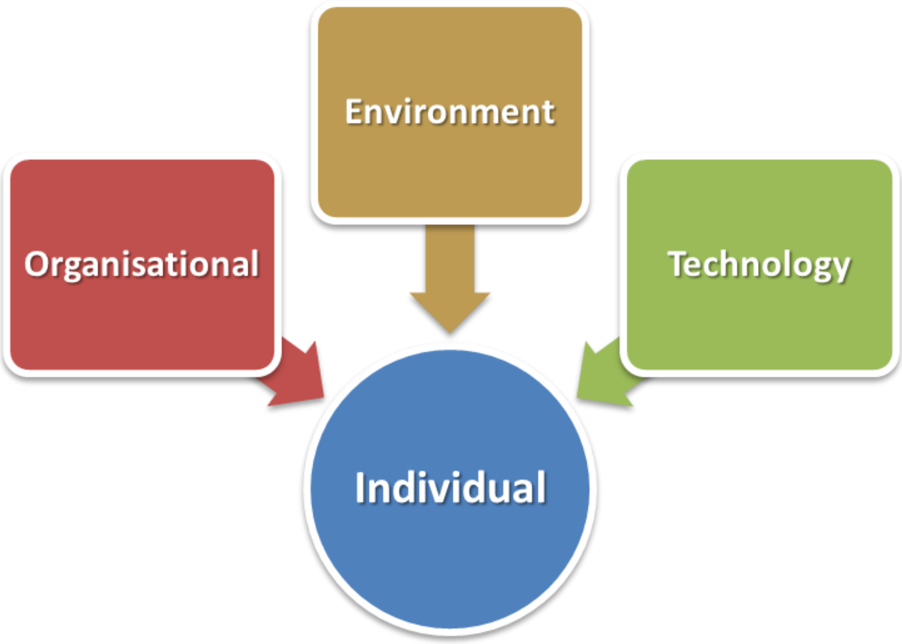


Figure 2-1: Human factors in maritime domain

Without a doubt, the performance of crew is highly related to the individuals own characteristics. However, the overall performance of crew cannot be explained solely by their individual character since the performance of crew also gets affected by;

- the organisational factors that they are involved in,
- the environmental conditions that they work in, and
- the technology that they interact with on board ships.

2.4.1 Individual

In shipping operations, performance of the crew plays a key role. Hence, individual factors easily influence a crew member’s performance, which in turn will have an effect on the overall system. Some of these individual factors may be specific to a person while others may be generic. In either case special attention should be given to fit the task to the capabilities and limitations of crew members.

Each individual crew member on board a ship will have different personal attitudes, skills, habits and personalities which can have positive or negative effect on performing different tasks. Some of these negative factors can be eliminated through designing jobs to fit the needs of the individuals. However, not all the negative effects can be mitigated through job design. In that case, careful selection of right person for the specific job becomes necessary. For example, according to Health and Safety Executive (HSE) (1999) some of the factors like personality cannot be changed while skills and attitudes may be enhanced.

Moreover, working on board a ship can have different psychological effects on individuals such as depression, stress etc. Iversen (2011) researched different factors which has an effect on the mental health of seafarers and reported that there is no doubt that loneliness and social isolation has bad effects on seafarers. However, it is also necessary to mention that this effect can vary from one individual to another depending on many factors such as marital status, personality as well as culture etc.

On the other hand, some of the individual factors can be considered to be generic such as human senses. Crew on board ships will widely use their senses in order to perform their tasks on board. Human senses such as hearing and vision have great importance on the performance of the crew and safety of overall system because crew members rely on their senses for receiving most of the information. A good example can be given that human eye is not able to sense the variations higher than 60Hz, therefore, in order to avoid flicker which can affect the performance of the crew, visual displays are generally designed to refresh at 60Hz (Watson, 2009). This clearly shows that the human capabilities and limitations are taken into account in order to achieve better human performance. Similarly, other human senses such as hearing, tactile or vestibular senses create limitations for the crew on board when they are performing their tasks. These limitations need to be taken into account at the design stage of ships.

Undoubtedly, each member of crew on board ships form an important part of the system and performance of these crew members will have an effect on the safety of the ship. Therefore, special attention should be given to increase the awareness on considering these human limitations and needs at design stage.

2.4.2 Technology

On board today’s vessels, crew members interact with technology (including machinery computers, equipment and systems) in order to perform their duties. The interaction of human with technology, introduces additional cognitive and physical demands on crew who has certain capabilities and limitations (Figure 2-2 illustrates this interaction). Moreover, increased use of technology and automation on board ships resulted in decreased number of crew members operating on each vessel which increased the importance of ‘fitting the machine to human’ for the operational safety of vessels.

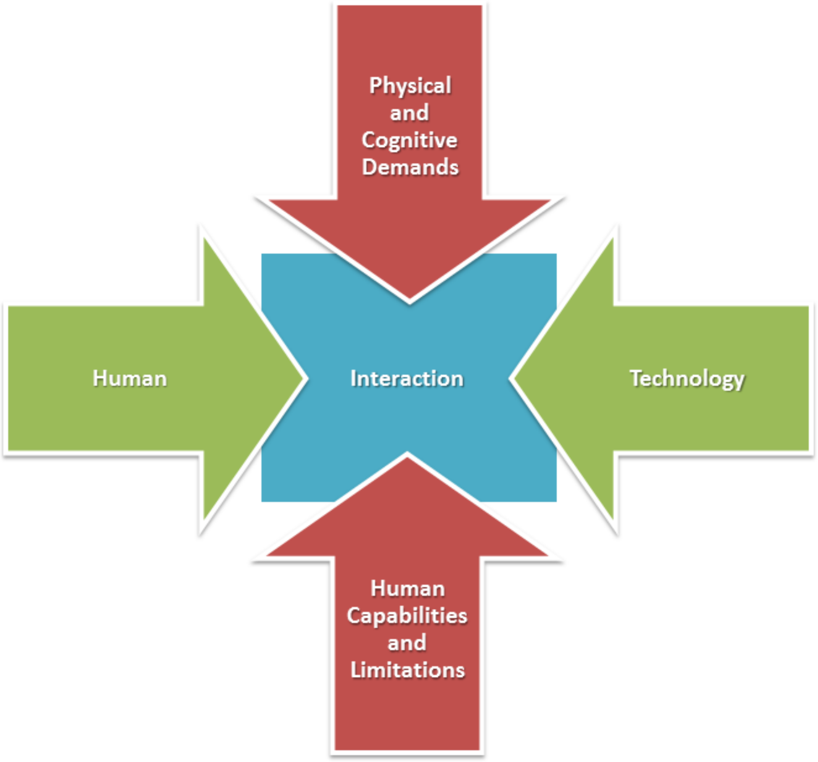


Figure 2-2: Interaction of Technology and Human

One of the branches of science which focuses to tackle the problems associated with this interaction is anthropometry which can be defined as the study of human body dimensions and capabilities in order to be utilised at the design of equipment and systems that human will interact with (Dorf, 2004). According to Ross (2011), it will not be realistic to estimate that same size of design would fit everyone. Therefore a naval designer should benefit from anthropometrics to ensure the good ergonomic design for the crew on that specific vessel. Design of equipment in this respect will ensure the performance of human operator will be maximised. For example, a seated operator on a desk will have a maximum reach limited with the length of his arm, therefore when equipping this desk with controls it is logical to consider this range. Moreover, functional grouping or placing commonly used controls closer to the operator will definitely increase performance of the operator. In order to achieve better ergonomics guidelines are published by ABS to aid in ergonomic design of maritime systems. (ABS, 2003b, ABS, 2003a)

On the other hand, as mentioned before the role of seafarers on board ships tends to change with the increasing technology levels. As a result, they are required to process and interpret the information provided by various systems of the ship and take action. The matter was also recognised by Sarter and Woods (1995) who mentioned that automation may result in additional demands on the operator who is required to monitor the numerous systems continuously. Consequently, the role that crew play in order to achieve safe and efficient shipping operations is becoming more important. Therefore, the design of human machine interface (screens, alarms etc.) should take into account the functional requirements for the crew to perform the task.

2.4.3 Organisational

In almost every industry, it is commonly accepted that organisational factors have a direct effect on the human performance. Similarly, in shipping the policies adopted by the company, the safety culture enforced by the management, level of communication in the team and the way crew and their work is organised can definitely influence the human performance on board.

It is quite common that human is the first one generally to be blamed for causing an accident. However, shipping accidents are the result of error chains rather than single events (Swift, 2004) and when a deeper investigation is conducted, it can be seen that resulting human error is generally caused by combination of other factors such as in appropriate technology, environmental conditions, organisational factors along with the individuals own limitations. Swiss cheese model of accidents (Reason, 2000) is often used to demonstrate the process of accidents and how different layers of defence can fail when not designed properly. It is evident from this model that an active failure (committed by people) can be result of latent conditions which may be caused by designers, builders or management. Figure 2-3 demonstrates an accident caused by the failure of several defensive layers.

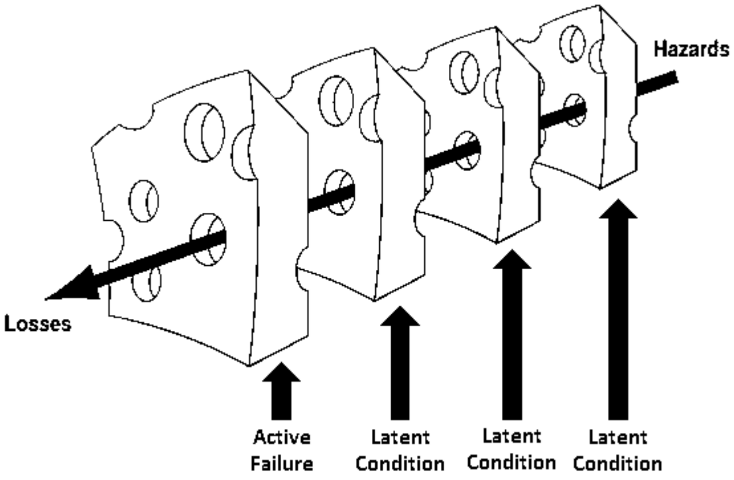


Figure 2-3: The Swiss cheese model of system accidents (adopted from Reason (2000))

Moreover, human and organisational factors have also been recognised by the IMO through the International Safety Management (ISM) Code. However, compliance with ISM is criticized for not being sufficient to ensure safety, but it is minimum level of organisational arrangement of an organisation (Schröder-Hinrichs, 2010). Crew fatigue is one of the major factors on board ships which has been a concern for some time and has adverse effects on crew performance and overall safety of operation. On this matter, IMO has developed and published 'Guidelines on Fatigue' (IMO, 2002) which aims to increase the awareness on fatigue by focusing manning levels and training. However, it is necessary to mention that not many practical solutions are given in these guidelines. Fatigue, as being a major problem in maritime industry has been also addressed by collaborative projects supported by the EU. One recent example is EU FP7 HORIZON Project which is aiming to research fatigue and its effects on cognitive performance and decision making. Some of the initial findings of HORIZON Project indicated that ‘6 hours on 6 hours off’ watch regime has significant impact on fatigue and performance of seafarers (P. Maurier, 2011)

Improving organisational issues is one of the key points for ensuring operational safety. In respect to this, one of the fairly new approaches is ‘resilience engineering’ concept which can be defined as the ability of a system to adjust its functioning prior to, during or following changes and disturbances, so that it can sustain required operations even after a major mishap. (Christopher Nemeth, 2008) Maritime industry is also adopting resilience engineering concepts and integrating it into their safety management systems on board which can improve the operational safety on ships.

Organisational factors have a direct effect on human performance on board ships and the matter is well recognised by the maritime sector. As a result, efforts have been put into place to research the associated maritime problems and develop systems which in turn will lead to better organisational practices and improve safety of shipping operations.

2.4.4 Environment

Effects of environmental factors on human performance and wellbeing cannot be neglected. Especially, the unique environment of ships puts additional demands on seafarers. For example, some of environmental factors demonstrated in Figure 2-4 exist in land base jobs as well and regulatory frameworks are developed considering the person will have a rest period at their homes which will be almost free from these factors. However, on board ships, seafarers do not have the same chance to recover from the effects of being exposed to these agents since their rest place is in the same structure. Knowing that physical work environment directly affects the human performance (A. Rothblum, 2002), it is not difficult for one to guess that this situation is more critical for seafarers.

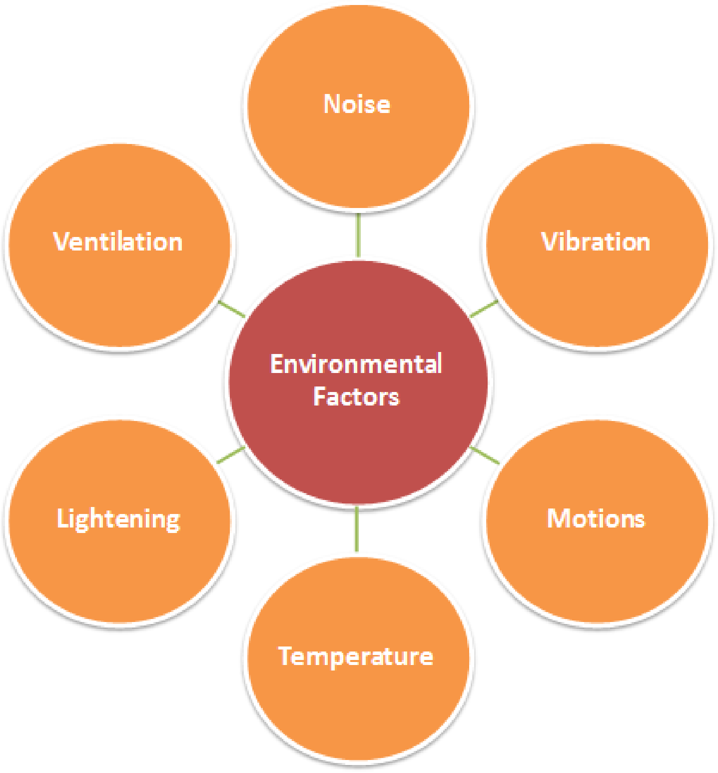


Figure 2-4: Environmental factors

It is important to mention that, the combined effect of these factors has still not been uncovered yet due to the high level of interdependencies. Therefore, the aim of researchers has been, first, to tackle the problem at individual factor level. As a result, following paragraphs will explain each environmental factor and their effects on human.

2.4.4.1 Motions

Due to the trend of decreasing crew members the importance of human factors in regards to safe and efficient shipping operations became more obvious. One of the unique environmental factors that seafaring occupation has to deal with is the motions. In severe sea conditions motions play a key role in limiting the ability of seafarers to perform their tasks (Dobie, 2003). This problem is very well recognised by the maritime industry since the resulting effects of being exposed to severe motion is obvious. Immediate effect of being exposed to ship motions is on the balance of the crew standing on board the vessels subjected to such movements. This will directly affect the ability of the crew not only to stand, walk but also interact with the tasks of crew such as maintenance and computer operations (Dobie, 2003). Another effect of the ship motions is on the fatigue which can be divided in to two: first one is directly related to the energy expenditure to maintain the balance where second one is an indirect one which is sleep deprivation due to the motions (Colwell, 2000). Moreover another effect of being exposed to motion is seasickness which is the most common form of motion sickness and has adverse effects on human performance. There has been a lot of effort put into the research of motion sickness. Researchers have taken either of the two common routes of focusing on descriptive approach or physiological reasoning of the phenomenon (H. Khalid, 2010). Results of the aforementioned research efforts on modelling has been taken into account by the marine standards on comfort (ISO, 1997b).

2.4.4.2 Temperature

Temperature is another issue; ships operate in conditions which can be ice cold or very hot and humid. This situation will be more critical if the heat caused by the ships own machinery systems also taken into account. It is obvious that human body performs best in between certain range of temperatures and if this range is exceeded the performance of the crew will be affected or fail totally if the temperature reaches extreme levels (A. Rothblum, 2002). Results of research conducted by Seppanen *et al.* (2006) shows that performance in the office increases up when the office temperature is around 21-22 ^{o}C and decreases above 23-24 ^{o}C whilst the highest productivity is observed at 22 ^{o}C. Same study further reports that performance at 30 ^{o}C compared to the maximum at 22 ^{o}C shows 8.9 % decrease. One of the other important conclusions of this study is that the effect of temperature on human performance is stronger in actual work environment than the ones observed in short term experimental studies.

Another effect of temperature is on the sleep quality which may cause fatigue on seafarers and indirectly affect their performance. Experimental study conducted by Libert *et al.* (1988) shows that participants' sleep got affected adversely in terms of total sleep broken, sleep patterns and wakefulness in 35 °C when compared to a baseline at 20 °C. Moreover, Johnson and Kobrick (2001) reported that the effect of heat on the quality of sleep does not change with allowing time for adaptation.

On the other hand it is quite common for ships to operate in conditions both humid and warm. People are less tolerable to humid at high temperatures. This statement is supported by the results of research study conducted by Okamoto-Mizuno and Tsuzuki et al. (2005) concluding that the combination of humid and high temperatures have adverse effects on the sleep and it generally affects the beginning of the sleep cycle more adversely.

2.4.4.3 Lightening

Lightening is another important issue which will affect the performance of the crew in many ways. Lightening levels can affect the alertness and sleepiness of people.

Van Bommel and Van den Beld (2004) state that benefits of good lightening in workplace is not limited to better health and wellbeing but it also leads to better performance, less errors, less accidents and therefore better safety. In another study they also concluded that improving lightening levels from 300 to 500 lux and from 300 to 2000 lux increased the productivity respectively 8% and 20% (Van Bommel *et al.*, 2002)

Küller and Wetterberg (1993) investigated the brain wave patterns of people in a laboratory under different illumination levels and they have concluded that bright light has an alerting effect on the central nervous system which decrease the sleepiness.

Together with the direct sun light, reflections from sea surface may cause glare effect which may be undesirable for crew members to perform their tasks. Bülow-Hübe (2008) concluded that designing large windows does not always make lightening better. Especially for the spaces in which people perform computer based work it may become difficult to avoid glare on surfaces which may decrease the performance.

2.4.4.4 Ventilation

Without any doubt clean air is a basic requirement not only for human health but also comfort and productivity. According to Occupational Safety & Health Organisation (OHSA), the term ‘indoor air quality’ (IAQ) describes how inside air can affect a person's health, comfort, and ability to work (OSHA, 2013). Indoor air quality in a workplace becomes a problem when the air inside includes dust, contaminants dampness or odour. Common factors which may result in poor IAQ are; (a) smoking, (b) radon, (c) molds and other allergens (d) carbon monoxide (e) volatile organic compounds (f) bacterium, (g)asbestos, (h)carbon dioxide and (i)ozone.

With regards to maintaining the indoor air quality ventilation plays a key role by supplying fresh air. A Study by Turiel *et al.* (1983) showed that when ventilation rate was decreased the concentrations of carbon dioxide and other pollutants were increased in the air together with the odour perceptibility. Moreover, the HVAC (heating, ventilating, and air conditioning) systems are in use not only for controlling the contaminants but also for maintaining a comfortable environment by reducing the most common complaints related to air quality (i.e. temperature, air movement and humidity).

In a relevant study, a ‘task ambient conditioning system’ which increase comfort by providing air flow to certain parts of body was tested on subjects. And results showed that whenever an air motion was provided, perceived air quality was of the subjects were improved (Zhang *et al.*, 2010).

Poor air quality can also affect human health especially when contaminants exist in the air. However, according to Daisey *et al.* (2003) there is a scarcity of studies which focus on IAQ related health symptoms. It is also noted that IAQ related serious health problems are considered to be rare, however the perception of endangered health is becoming more common (AIHA, 2012).

Relevant international and national guidelines also exist about the air quality. For example World Health Organisation (WHO) published guidelines which aim to protect public health from hazardous effects of known air pollutants by eliminating the contaminants and reducing exposure to them (WHO, 2000). US-EPA (1995) also published guidance for inside air quality (The Inside Story - A Guide to Indoor Air Quality).

On ships, maintaining an acceptable level of air quality is very important because various machinery and electronic equipment are installed in a relatively small volume when compared to land base applications. Considering that the ship's crew work, live and rest in those spaces, it is a must for ships to have a proper ventilation system. For example it is estimated that an operator on a ship requires about 30 cubic meters of fresh air per hour (Grech *et al.*, 2008). Therefore, today modern ships are designed with enhanced HVAC systems.

Fortunately, it is reported that air quality problems on ships are not severe when compared to land base applications (Webster and Reynolds, 2005). In terms of air quality concerns, machinery spaces can be considered as the most critical compartment in ships due to containing main propulsion engines, auxiliary engines and many other equipment as well as odour from fuel. Mohd Nasruddin *et al.* (2012) investigated engine room air quality status in an engine room of a vessel during normal operation. Results show that that the 3-h average concentrations of CO_2 did not exceed the recommended limits.

Moreover, maritime sector also developed design guidelines and rules for required ventilation to maintain the air quality at good levels (Command, 1995, ABS, 2001, HSE, 2002, ILO, 2006).

The review of the literature shows that air quality on ships is well recognised and relevant industry guidelines exist. Moreover, in terms of air quality, the lessons learnt from other sectors are considered to be transferrable.

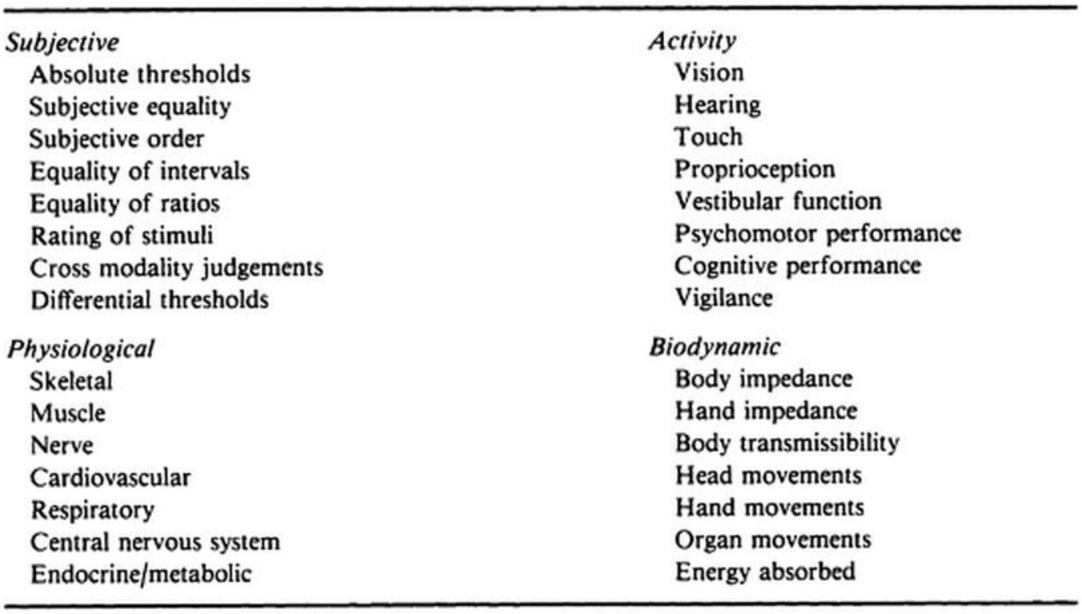
2.4.4.5 Vibration

Obviously one of the main characteristic physical factors exist on ships is vibration. Similar to other transportation vehicles propulsive machinery and auxiliary machineries are the main sources of vibration on ships. Moreover, these excitations are also increased by the contributions of ship’s slamming movement, bad weather conditions, interaction of ship’s hull with water, propeller cavitation and other internal sources of vibration etc. Furthermore, todays operational demands sometimes force shipping companies to deliver of cargo quicker, as a result of this, increased ship speed may also have an adverse effect on the resulting vibration levels especially if the ship is not designed to operate in that condition. When it is also considered that most commercial ships have steel structures, vibration propagation becomes easier when compared to land base concrete structures; therefore, vibration becomes a more serious problem on-board ships.

Effects of shipboard vibration are various; which can result in fatigue failure of structural members of the ship or components of the machinery. Vibrations can interact with cause a negative effect on the performance of shipboard equipment so it can result in increased maintenance costs (Edu, 2012). More importantly vibrations can cause a great increase in human discomfort and wellbeing.

It will not be wrong to say that, due to having major commercial consequences vibration research in maritime is mainly focussed on structural vibration propagation modelling, prediction of vibration levels and preventing fatigue related structural failure. However, exposure to excessive vibration may have very important health, wellbeing and performance outcomes on crew resulting in a threat not only for individuals but also overall safety and efficiency of operations. Experimental studies show that human are more sensitive to vibration frequencies below 1Hz and less sensitive to frequencies above 5Hz (Demić *et al.*, 2002).

Griffin (1990) investigated the human response to vibration extensively and generic findings of this study can be adopted for shipping use. Figure 2-5 shows some of the parameters which are studied in the area of human response to vibration.



Subjective
- Absolute thresholds
- Subjective equality
- Subjective order
- Equality of intervals
- Equality of ratios
- Rating of stimuli
- Cross modality judgements
- Differential thresholds

Physiological
- Skeletal
- Muscle
- Nerve
- Cardiovascular
- Respiratory
- Central nervous system
- Endocrine/metabolic

Activity
- Vision
- Hearing
- Touch
- Proprioception
- Vestibular function
- Psychomotor performance
- Cognitive performance
- Vigilance

Biodynamic
- Body impedance
- Hand impedance
- Body transmissibility
- Head movements
- Hand movements
- Organ movements
- Energy absorbed

Figure 2-5: Parameters studied in the research of human response to vibration (Griffin, 1990)

When human response is considered, vibrations can be investigated in the following two areas; (1) hand arm vibration and (2) whole body vibration. Ship vibrations are transmitted to crew through the floor that they stand on; therefore, the main concern for crew members is the whole body vibration and potential consequences. It is reported that on ships, whole body vibration can be related to chronic health problems such as back pain, musculoskeletal disorders (Grech *et al.*, 2008).

One of the major effects of whole body vibration is considered to be on visual performance especially on reading tasks. Moseley and Greffin (1986) report that the vibration affects the reading tasks adversely. According to another study by Ljungberg *et al.* (2004) reaction times of human did not get effected by combined by vibration however subjects reported that the conducting tasks under combined noise and vibration was more annoying and more difficult. Moreover, comfort is another issue and it is shown that vibrations affect passenger comfort. Extensive research in this area resulted in development of prediction models for passenger comfort under different vibration levels (Dempsey and Leatherwood, 1976). However, McLeod and Griffin (1989) in their behavioural model shows the adaptive ability of human to vibration so in long term the adverse effects of the vibration may decrease.

Maritime community reacted to the developments in the area of human response to vibration and developed norms and standards to ensure the level of comfort and protect health (Buchmann, 1962, Noonan *et al.*, 1984, Command, 1995, ABS, 2001, ILO, 2006, Lamb, 2006, MCA, 2014). However, more research can be conducted to explore the effects of shipboard vibration on performance.

2.4.4.6 Noise

Even though noise and vibration are two different physical factors on ships, origin of the both is same (machinery, propeller, ships movements etc.) as explained in the previous section in detail. One of the most unique environmental factors that seafarers are needed to operate under is noise. Hence the noise levels in ships are a major concern for the health and wellbeing of seafarers. The health effects due to noise exposure, especially long term noise exposure, has been recognised worldwide and exposure – response relationships have been generated. As a result, national and international norms were developed with the particular attention to protect human health from hazardous noise exposure. An example is EU Physical Agents Directive which is enforced throughout EU and aims to protect workers from risks of noise. In this directive workers' daily 8 hour equivalent noise exposures are calculated and compared with the defined exposure action and limit values. As it can be seen EU defines exposure limits based on 8 hours working day considering that the rest of the day will allow workers to recover from the effects of exposure. However, on ships often crew work longer than 8 hours a day. Moreover, they are also required to rest in ship compartments which are not as comfortable as their homes. When it is considered that environmental noise is causing discomfort, annoyance, day time sleepiness, tiredness and stress even in rural areas (Archibald, 2005, Muzet, 2007, Basner, 2008, Basner *et al.*, 2010, Fyhri and Aasvang, 2010, Basner *et al.*, 2011), it will not be hard to come to conclusion that the same situation for seafarers may be worse.

Similarly, IMO developed the ‘Code on Noise Levels on Board’ (IMO, 2012a) for ships, to protect the health of crew from hazardous noise exposures. IMO’s noise code sets compartment based noise limits which ships need to comply. These noise limits are considered to ensure crew working on those ships will be protected. However, IMO’s noise requirements are often criticized and overrun by the requirements of ship-owners and classification societies (Insel *et al.*, 2009).

On the other hand, effects of noise on human cannot be limited to hearing. The Joint ILO/WHO Committee on the Health of Seafarers reports that seafarers’ hearing, alertness and mental health can get affected by the noise levels on ships which can easily exceed 100 dB in engine rooms and 60dB in crew cabins (ILO/WHO, 1993).

However, attaining dose response relationships in non-auditory effects of noise is more complicated and there is no global agreement on it (e.g. performance, sleep deprivation). Therefore, the effects of noise on human performance, efficiency, comfort and wellbeing has been a key area of concern for researchers for a very long time. Research in this area started in early the 1900s (Weston and Adams, 1932) where noise effects on employee efficiency was investigated. Afterwards non-auditory effects of noise attracted more attention. Researchers from almost every sector studied the human response to noise in many different contexts. Review of available literature in this area shows that human response to noise is a complicated issue and there are other factors effecting resulting response (Smith *et al.*, 1992). For example resulting human response to same noise level may differ depending on the nature of the task, type of the noise and individual psychological factors. For this reason, results of different studies often contradict with each other hence the findings of each study is only applicable to the scenarios which replicate the same conditions with the original study. This makes findings of noise related human response studies not easily transferable to different contexts. As a result, in order to make suggestions for ships it becomes necessary to investigate the effects of noise exposure in shipboard environment. Unfortunately, maritime sector failed to respond this research topic and very little is known today about human response to noise, in particular, crew response to noise on board ships.

2.5 Research Gap

With regards to the achieving good human factor practices on-board ships, a naval architect's main responsibility is to design ships considering the needs and limitations of crew during the operational life of the ship. While other factors such as individual and organisational factors can be improved even when the ship is in operation, it is not cost effective to improve environmental conditions after the ship is built. As explained before, 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 (i.e. motion sickness) and performance outcomes on crew, ship motions were 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, development of human response models to noise on board ships will provide a tool for the ship designers to predict the human responses at the design stage which is the most cost effective time to apply measures to decrease the noise levels.

2.6 Chapter Summary

In this chapter the human factors in the context of this PhD study was defined. The concept of human factor and its application areas were demonstrated. Moreover, the importance of human element in the maritime domain was also discussed. From the wide range of areas that was covered under the topic ‘human factors’ environmental influencers of human element was selected to be focussed in this research study. Because the main role of a naval architect was identified as designing the right environment for the crew for conducting safer and more efficient shipping operations. A research gap was identified in as there is not enough understanding on the relationship between noise exposure and resulting human response including performance on board ships. Therefore, after defining the approach (Chapter 3) for this PhD study, further review of the literature was conducted (Chapter 4) with specific focus to noise and human response.

Chapter 3. RESEARCH QUESTION, AIMS & OBJECTIVES

3.1 Chapter Overview

For the success of this PhD study it was important to define the problem which will be tackled along with the clear and achievable objectives that could be used as milestones towards the completion of this PhD study. Therefore, this chapter presents the research question together with the aims and objectives of this PhD study.

3.2 Research Question

The research question which will be addressed in the research study can be put together as;

“Is there a relationship between the noise exposure and human performance/wellbeing on board ships and can we study this relationship to uncover the unknown human response to noise on board ships by developing specific models which can be used at design stage?”

3.3 Aims & Objectives

The main aim of this research is to study and identify the link between shipboard noise and human performance and wellbeing on board ships. This is to be carried out by careful investigation of the noise levels on-board ships and conduct studies to identify the consequences of being exposed to these noise levels especially in the areas of health, safety and efficiency.

Achieving the aim of this study is expected to contribute significantly to maritime research by developing a set of tools, models and criteria which will be utilised at the design stage of the ships aiming to prevent hazardous exposures of people on-board and therefore resulting in an improved wellbeing or comfort on board ships as well as improved human performance and safety.

The aforementioned aim is expected to be achieved through the following specific objectives;

- To critically review the literature in order to identify the noise studies carried out focusing on the human and identify the shortcomings of the current research and available models.
- To study the current regulatory framework and challenges being faced for compliance.
- Develop a framework which will be utilised to ensure the prevention of human being exposed to hazardous noise levels on board ships and therefore, allow the duration of crew's shift in certain spaces of the ship to be formulated to eliminate any adverse effect on their health.
- Design and conduct experiments to research the link between the noise exposure and crew performance/human response
- Conduct field studies to collect noise data as well as the human response to these levels on board ships.
- Analyse the collected human response ratings (both performance and comfort related ratings) from ships to identify the statistically and logically strong factors that can represent the overall human response to noise on board ships.
- Develop human response models from selected human response ratings to depict the resulting human performance and comfort (wellbeing) when noise levels and demography of the population are known.
- Compare the model results with the current noise regulations applicable to ships.
- Propose new human oriented noise criteria for ships.

3.4 Chapter Summary

In this chapter the research question along with the aims and objectives of this PhD study was identified.

Chapter 4. LITERATURE REVIEW OF NOISE, HUMAN RESPONSE AND NORMATIVE FRAMEWORK

4.1 Chapter Overview

The research gap identified in Chapter 2 of this thesis required more focussed review on human response to noise and available standards. Therefore, in this Chapter a detailed review of the literature was conducted with the focus of human response to noise. After general introduction of the noise and its physics, the way humans receive and respond to noise was described. Then, the effects of noise on humans were reported together with the different prediction models developed in other industrial sectors. Finally, the current applicable norms were reviewed in detail.

4.2 Physics of noise

Before detailing the available literature on human response to noise, it was considered useful to briefly introduce the physics of sound. Sound can be described as a travelling wave generated by pressure oscillations in a medium. However, since the focus of this PhD study is human response to sound then it can be said that the aforementioned medium within the scope of this PhD study is atmosphere. Figure 4-1 shows the representation of a sound wave.

A pure tone is the simplest form of a sound, which is a sin wave moving in a direction without expanding. In Figure 4-1 (a) a snapshot of the moving sound wave in one direction is shown, while Figure 4-1 (b) shows the pressure fluctuations around the atmospheric pressure.

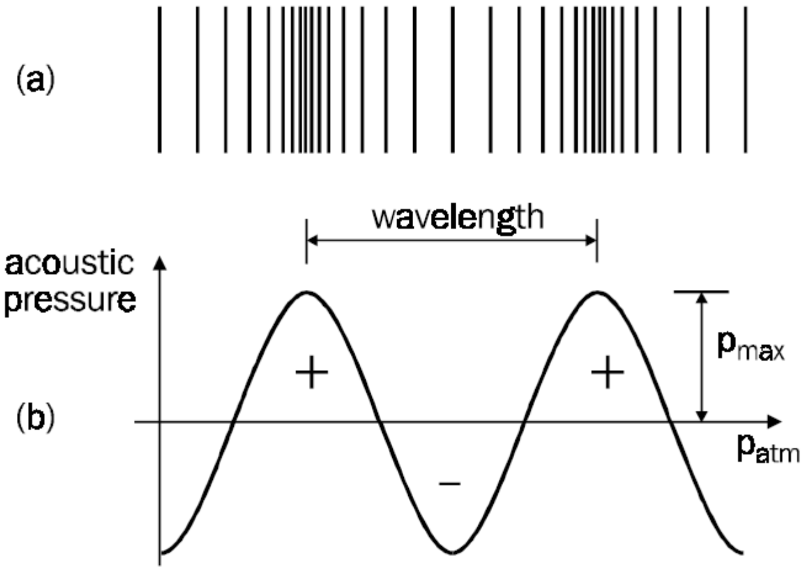


Figure 4-1: Representation of a sound wave (Hansen, 2001)

A sound wave will also have a frequency (f) which is a number of cycles that a sound wave completes in a second. The unit of the frequency is Hertz. Wave length shown in Figure 4-1 (b) is the distance travelled by the wave to complete one cycle. Period (T) is the time required for one cycle of a wave to pass through a point. Also the amplitude of the sound can be described by the amplitude of pressure changes. Average of these changes will be zero since pressure fluctuates around the atmospheric pressure. Therefore, root mean square (RMS) is used which means each pressure is squared, averaged and the square root of this average is reported. RMS is popular because it directly represents the energy of the sound wave. Since the unit of pressure is the Pascal (Pa), sound pressure can be measured in Pascals. However, it is more common to use the decibel scale. The decibel scale is a logarithmic scale meaning the measurement range is narrower which makes it more practical and logical to understand. In a decibel scale 0.00002 Pa is represented by 0 decibels while 2.0 Pa is represented by 100 decibels. In Figure 4-2 sound pressures produced by different noise sources are shown in both the decibel scale as well as in Pascals. Sound pressure measured in Pascals can be converted to decibels by using following equation:

$$L_p = 20\ x\ log_{10}\left(\frac{p}{p_0}\right)$$

Equation 4-1

In Equation 4-1, L_p represents the noise pressure in decibels where p represents the rms noise pressure in pascals. p_0 is the reference pressure level (0.00002 Pa)

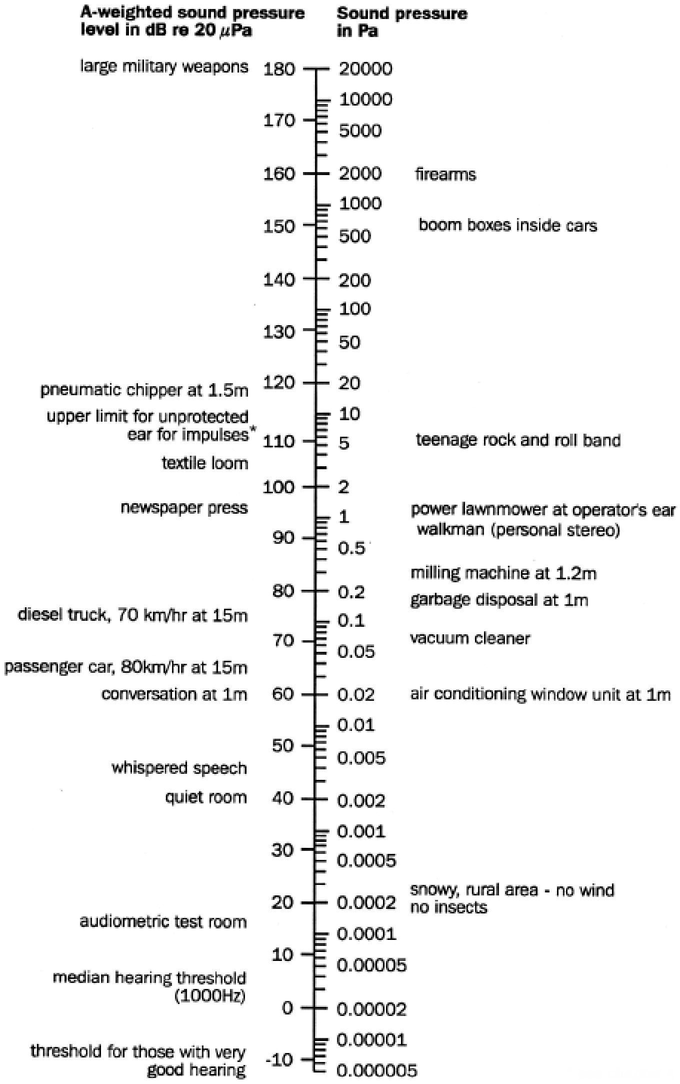


Figure 4-2: Sound levels produced by different sources (Hansen, 2001)

4.3 Human response to noise

Hearing is one of the major human senses which is important for communication and situational awareness. Hearing is very important for shipping operations where effective communication is paramount. As well as being important to have proper hearing on board, it is also important to protect hearing organs due to existence of high level of noise in various locations of the ship. First, it is important to explain how hearing happens. The human ear can be divided into three parts: outer ear; middle ear; and inner ear. Figure 4-3 demonstrates each section of the ear.

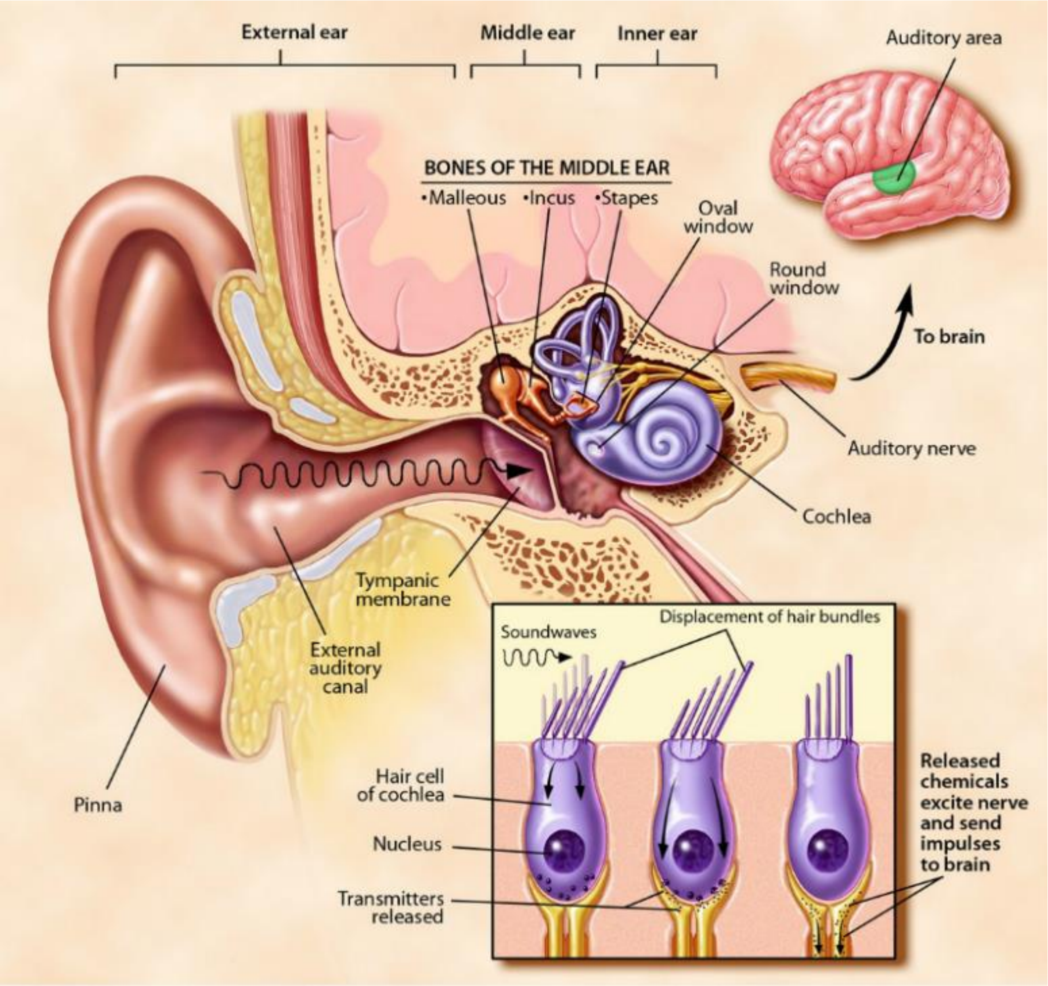


Figure 4-3: The Ear and Hearing cells (SFN, 2012)

In the human ear, pinna catches the sound and diverts it to the ear canal which is 3-4 cm long in an adult. The middle ear is filled with air and hosts the three small bones (ossicles) hammer, anvil and stirrup (in latin; malleus, incus and stapes). The middle ear is connected to the throat with the Eustachian tube which allows pressure on both sides of the ear drum to be equal. The ear drum is the boundary of the outer ear and the middle ear which moves with the sound. These movements are then transmitted to the hammer which is attached to the ear drum. Then through the anvil and the stirrup the sound is transmitted to oval window which forms the boundary between the middle ear and the inner ear. The inner ear is filled with fluid; vibrations are transferred through oval window into the snail shape cochlea of the inner ear in the form of pressure waves. Since different parts of cochlea are sensitive to different frequencies, frequencies are separated here. There are around 30,000 hair cells through which the vibrations are detected, and transduced into nervous impulses which are transferred to the brain via the auditory nerve. Aforementioned hearing mechanism is in fact very delicate and therefore requires protection.

Noise is described as unwanted sound, by the description noise perception is a subjective reaction to physical phenomenon. Hence, what is noise for some people may not disturb another person, who is exposed to the same source. When dealing with occupational noise exposure, along with the physical quantity of the noise, the way humans respond to this noise also becomes important. Two characteristics are important while dealing with human response to noise: the amplitude; and the frequency of the sound.

One of the limitations with regards to the frequency content of the noise is that the human ear is sensitive to frequencies between 20 Hz and 20 kHz and is less sensitive to low frequencies than high frequencies. Hence, humans react differently to the same amplitude of noise in different frequencies. Moreover, this human response also differs from one person to another. With regards to this issue, previous studies resulted in the establishment of equal loudness curves. An Equal loudness curve is a measure of noise pressure over the frequency spectrum which when played to a human receives a constant loudness. For each frequency, these curves explain how loud the sound should be in order to make a human understand it as loud as given reference tone in 1 kHz (Fletcher and Munson, 1933). Loudness is measured in phons which explain how the actual pressure of the sound (measured in decibels) is heard by human ears. In brief, a decibel is an objective measure and phon is subjective. International Standardisation Organisation (ISO 226:2003) utilised the research conducted by researchers, revised and standardised the equal loudness contours (ISO, 2003c). Figure 4-4 shows the equal loudness curves from ISO 226. It can be seen that, for example, a 50-Hz tone at 75 dB sounds as loud as a 1000-Hz tone at 40 dB. However, equal loudness curves show that as sound levels increase, the ear becomes more uniformly sensitive to all sounds.

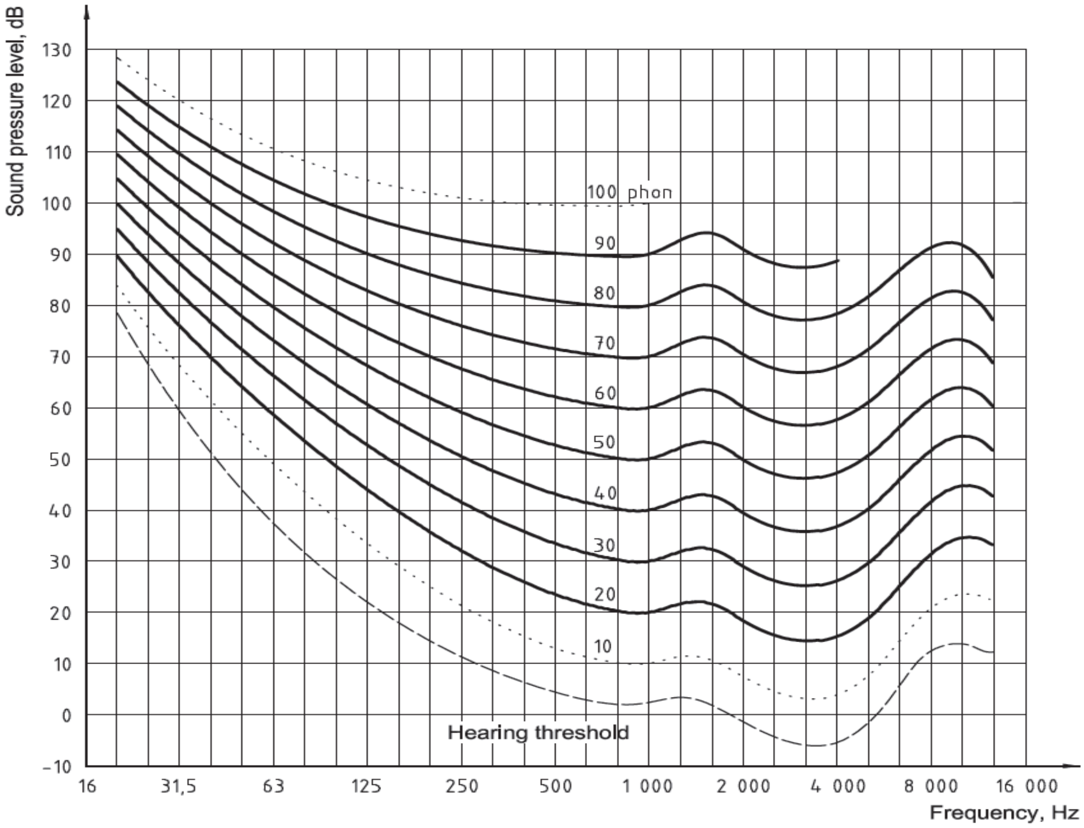


Figure 4-4: Equal loudness curves (ISO, 2003c)

On the other hand, noise is not a pure tone but it is a mixture of different frequencies; moreover, considering that the human ear has different levels of sensitivity to different frequencies, after much scientific research made on the subject, it was considered as necessary to use a frequency weighting to address the need for clarifying the influence of each frequency on a human ear when defining the amplitude of noise. There are a number of different weightings which are defined in the international standard IEC 61672 (IEC, 2003a). However, ‘A’ weighting of sound was found to be the most adequate weighting to represent a wide range of human responses, while other weightings have lost their usage. However, ‘C’ weighting is still important when assessing noise peaks because when dealing with peaks frequency of the sound it becomes less important and the human ear reacts more uniformly. Consequently, all noise measurement devices use ‘A’ weighting when assessing noise measurements and ‘C’ weighting for assessing peak noise levels.

Figure 4-5 shows the A, B, C and D weightings. The type of weightings for the measurements is commonly presented by an abbreviation after ‘dB’. For example, ‘80 dB(A)’ shows that measurements are in ‘A’ weighting.

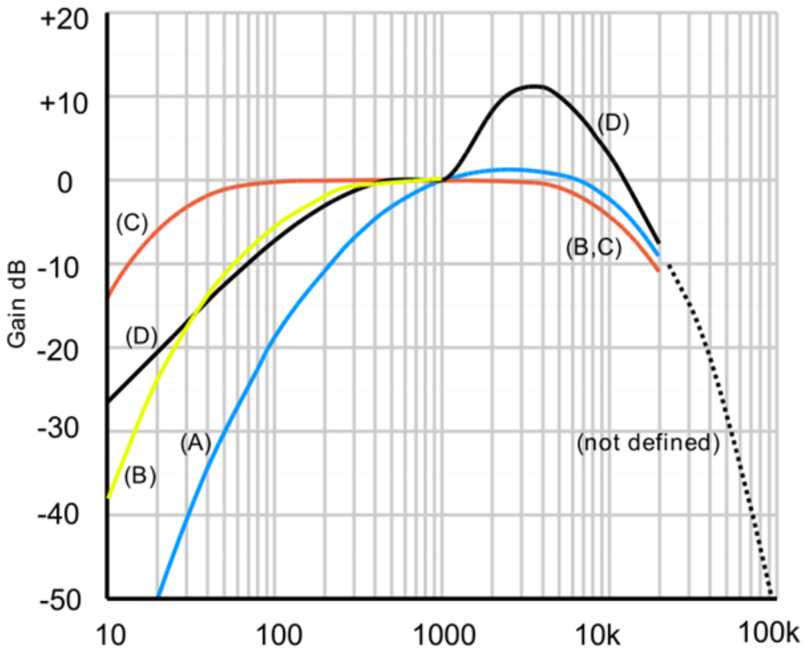


Figure 4-5: Graph of A, B, C, D weightings (Wikipedia, 2014b)

4.4 Sources of noise on ships

Noise on board ships has been a major concern for a long time. On board a ship the noise generated from different sources and vibrations from moving parts merge together and generate a constant background noise. However, crew members are required to both work and sleep on board. This makes the background noise more critical since it directly affects the wellbeing of the crew on board and causes performance and health issues. There are various noise sources on board ships which, when combined, result in a complex noise spectrum. Figure 4-6 was taken from the report MEPC 59/19 of IMO which demonstrates various noise sources on a ship with their corresponding frequency ranges. A propeller is one of the noise sources on board and noise emitted from propellers are generally linked with cavitation. However, the main contributor of noise inside the ship is the engine. Most ships are equipped with diesel engines as the primary propulsion unit. Slow speed diesel engines are lower in noise emissions when compared to medium and high speed diesel engines. Noise emitted from engines is directly related to the rotation speed and combustion characteristics of the engine. Moreover, reduction gears also generate additional noise. Apart from the main engine, auxiliary engines and generators are also important source of noise. It is not only the noise emitted from these engines that are important but also, it is of key importance to ensure appropriate mounting of these engines to prevent propagation of the noise.

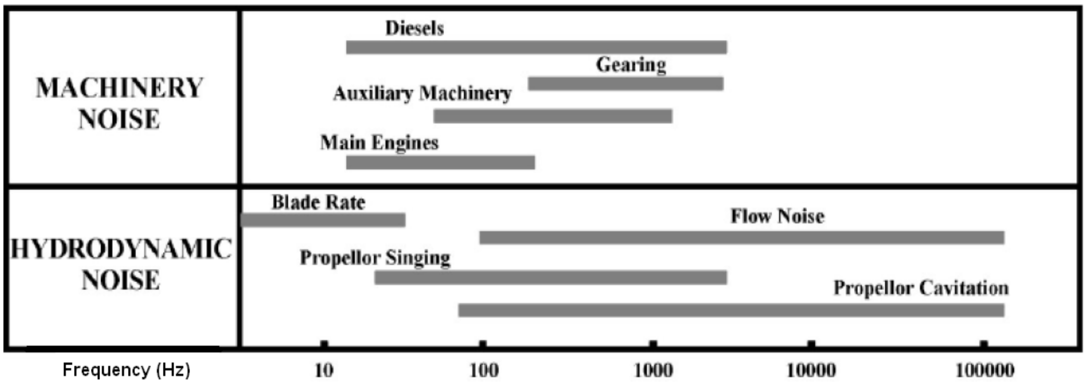


Figure 4-6: Sources of Noise on board ships (IMO, 2009)

Other sources of the noise on board ships include the following:

- Ventilation noise
- Unbalanced rotating shafts
- Cavitation and turbulence in fluid flowing in pipes
- Mechanical friction

- Interaction of water with ship hull and appendixes
- Slamming of ship into water

As mentioned before, the main source of noise on board is caused by the machinery and propulsion mechanism therefore the noise levels measured in engine rooms is almost always measured over 100 dB(A). Table 4-1 is taken from the book "Textbook of Maritime Medicine" (Jegaden, 2013) and shows the average noise levels from various noise sources in a ship's engine room.

Table 4-1: Mean noise levels in various types of engine room (Jegaden, 2013)

Location	dB(A)
Low-speed diesel engine	100-105
Medium-speed diesel engine	105
Electricity generator	95-105
Turbo generator	90-95
Steam turbine	85-95
Main boiler	90-95
Reducer	80-90
Auxiliary boiler	95
Compressor	85-100
Water pump	80

Maintaining noise levels within the acceptable limits gets more difficult when dealing with smaller ships. For example it is likely to see more noise discomfort in fishing vessels then the noise on board big merchant vessels.

4.5 Noise induced hearing loss

For the purpose of occupational noise exposure both the noise level and exposure duration is important and these two are well integrated into the regulatory framework in protecting humans from the bad effects of noise exposure. When talking about the health effects of noise exposure, one of the main consequences of exposure is hearing loss. Many studies have been carried out over the years to understand noise-induced damage to the ear and its pathophysiology. Consequently, it is now established that excessive noise damages the ear (Alberti, 2001). On exposure to a typical hazardous industrial sound, the ear may fatigue and a temporary threshold shift (TTS) may take place. This happens because the sensory hair cells become exhausted from excessive metabolic stress. For example, workers typically notice this phenomenon when they leave work and listen to music on their radio and find the next morning the volume setting has become too loud to comfortably listen to it. This is due to the ability of the hair cells to recover from a TTS over a period of time when not exposed to excessive noise. If TTS occurs frequently, the ability of the hair cells to recover reduces and a permanent threshold shift (PTS) occurs. PTS can also occur when the hair cells are exposed to a one off instance of very high level of noise.

In order to demonstrate the occurrence of TTS and PTS after hazardous noise exposure findings of the research conducted by Gao *et al.* (1992) are shown in Figure 4-7. The study, using guinea pigs as a substitute to humans, was aimed to investigate the changes in stereocilia (haircells in inner ear) before and after temporary and permanent hearing losses.

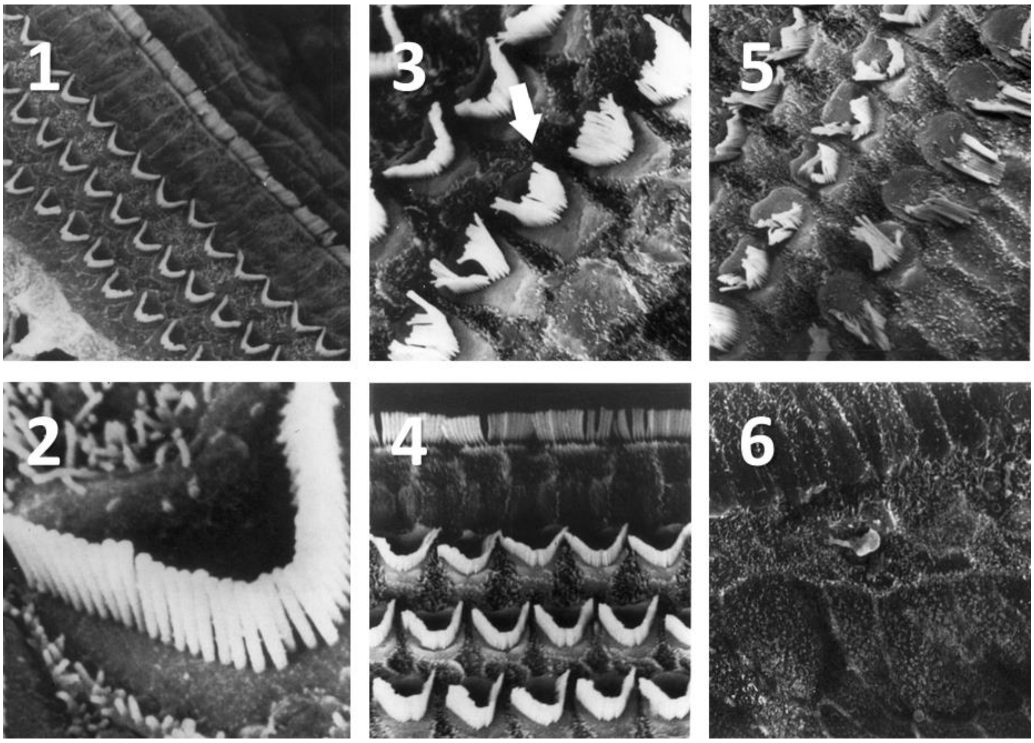


Figure 4-7: Comparison of changes in the stereocilia between temporary and permanent hearing losses in acoustic trauma (Gao *et al.*, 1992)

In Figure 4-7, picture 1 shows the normal organ of corti which is part of the cohlea of the inner ear which has hair cells while picture 2 is closer view of stereocilia. Picture 3 shows the status of the Stereocilia after being exposed to 110 dB noise for 30 minutes and as a result the ear had a TTS while picture 4 shows the status of the ear after 80 days. Similarly picture 5 shows the changes in the stereocilia after exposure to 120 dB noise for 30 minutes, it can be noted that the bases of stereocilia is collapsed completely. Picture 6 show the condition of the same ear in picture 5 after 80 days. It can be seen that the surface is completely free from stereocilia and hair cells.

It is well known that when the intensity of noise or the duration of noise exposure is increased the hearing loss becomes worse. International standard ISO 1999 (ISO, 2013) aims to present the link between the noise exposure and the noise induced hearing loss for people of various ages. Therefore, it is useful to refer to when dealing with the risk of noise induced hearing loss.

In terms of noise induced hearing loss of seafarers, there are a few studies available which show evidence of seafarers being exposed to noise levels above the allowed levels, and audiometric examinations showing statistically significant results supporting the existence of temporary threshold shift in engine room crew (Pośpiech and Zalesska-Krecicka, 1981, Radzievskiĭ *et al.*, 1983, Volkov and Markarian, 1985, Szczepański and Otto, 1994). This problem was also highlighted by Kaerlev *et al.* (2008) who found that engine room personnel on ships where 2.39 times more likely to suffer from hearing problems compared to other crew members crew. In another study, results showed that 26.8% of engineers, 16% of deck crew members and 9.9% of supervisors had noise induced hearing loss (Parker *et al.*, 1997). It has also been reported that fisherman are at a greater risk of noise induced hearing loss when compared to other seafarers due to the fact that they work longer periods and they are exposed to high noise levels as well as being less aware of hearing protection (Hansen, 2013). Moreover, Trécan (2006) adds that the seafarers of oil tankers and cargo ships are also at greater risk in terms of hearing loss.

4.6 Non-auditory effects of Noise

In the previous section, the effects of hazardous noise exposure on human hearing have been described. From literature, a clear consensus related to the hypothesis that exposure to excessive noise leads to hearing loss and damage has been formed and as a result noise has been recognised as a potential workplace hazard. However, a similar understanding and agreement on the non-auditory effects of noise exposure is yet to be agreed by academics and industry professionals.

Before explaining the details of non-auditory effects of noise it is important to briefly explain the term “noise annoyance” which is defined in the ISO 15666 regulation as “a person’s individual adverse reaction to noise” (ISO, 2003b). However, this reaction may be referred to in many different ways, for example; disturbance, dissatisfaction, sleep-interference, annoyance or bother. In order to determine the community noise annoyance, these individual reactions are collected analysed and explained in statistical terms. Stallen (1999), in his research paper, mentions that the determinants of annoyance are not clearly understood. Moreover, in the same article, the author defines noise annoyance as phenomenon of 'mind and mood'. By its definition noise annoyance brings subjectivity with it, in other words, what is annoying for one person may be an informative or pleasuring sound for others. Hence, noise annoyance can be partially due to acoustic factors and partially due to personal/social aspects where attitudes and expectations also come into account. The effect of acoustic factors is well accepted to contribute to the noise annoyance. For example, research studies show that noise levels with tonal components were causing more noise annoyance in working environments (Landström *et al.*, 1990, Landström *et al.*, 1995). However, Guski (1999) states that; “*at best, about one third of the variance of annoyance reactions can be explained by the variance of acoustical features*”. Therefore, if one wants to explain noise annoyance should consider acoustic factors of noise along with the personal characteristics of the individual. Furthermore, in another study Guski *et al.* (1999) explains even the term annoyance is not perceived in the same way by the experts from different domains, nationalities or locations that can lead to further complexity.

Due to the aforementioned disagreements and social and personal factors that affect the noise annoyance it is not easy to directly compare the findings of research conducted in different areas. As a result of this, it becomes more pertinent to study noise annoyance in the maritime context. Regrettably, to date in the maritime domain there has not been enough attention or research focusing on the non-auditory effects of noise exposure. Dobie (2003) explains the critical importance of human factors in ship design and states that the non-auditory (stressor) effects of noise are not well-defined when compared to those that affect hearing. Martin and Kuo (1995) highlight a scarcity of research relating to shipboard noise, mentioning that no experiments which replicated the auditory conditions of the bridge or engine room where currently available. This situation to date remains unchanged. The non-auditory effects of noise exposure will further be detailed in the forthcoming subsections.

4.6.1 Effects of noise on communication

One of the most obvious effects of noise is on communication. Noise in an environment can get loud enough to affect people's ability to understand spoken words and hence impair successful communication. This issue is addressed under the topic; 'speech intelligibility' which is defined as *"a measure of effectiveness of understanding speech"* by ISO 9921 (Steeneken, 2001, ISO, 2005) and includes both face to face communications and other communications (such as conversations over the phone or radio). These communication methods are integral instruments utilised everyday by the ships' crew and the effectiveness of these communication channels are critical in ensuring shipping safety. The importance of crew communication in maritime domain was extensively reviewed and demonstrated by

Pyne and Koester (2005) who concluded that it was possible to minimise the amount of accidents by achieving effective maritime communications.

As discussed before, background noise can affect speech intelligibility and according to Moore (2012) for accurate communication to be achieved, the average speech noise levels should exceed that of the noise by 6dB. On ships, due to moving parts, there are locations where this condition can never be achieved. Even though it is shown that speech may be understood at even negative speech to noise (S/N) ratios where the noise level is higher than the speech level (Plomp and Mimpen, 1979), it requires a greater effort to maintain meaningful communication. Moreover, successful communication at negative S/N ratios may require one or more conditions below;

- listener to be familiar with the matter
- speech and noise coming from different directions
- listener being able to see the speaker's face

Helpful guidance is given in the Aviation Noise Effects report of the Federal Aviation Administration, which determined the acceptable distance between the speaker and listener for different ambient noise and voice levels as shown in Figure 4-8 (Newman and Beattie, 1985).

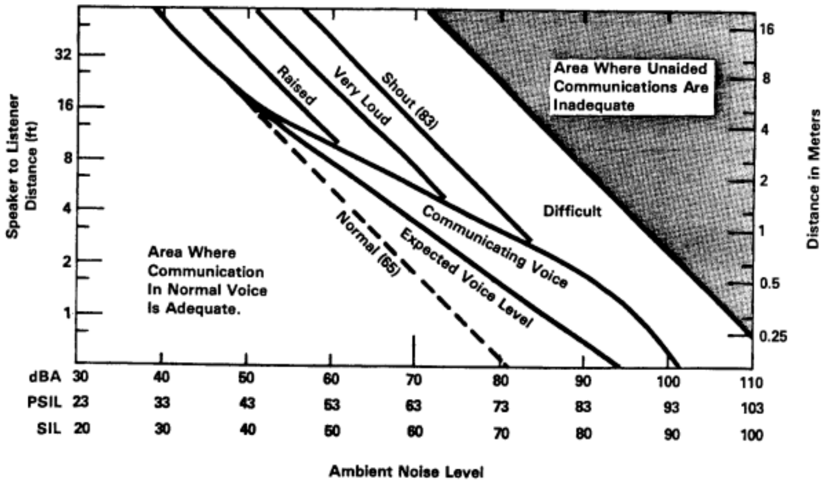


Figure 4-8: Acceptable distance between a speaker and listener for specific voice and ambient noise levels. (Newman and Beattie, 1985)

Another useful guideline was shared by Harris (1979) in his book "Handbook of Noise Control" where he described speech communication capability under different background noise levels (as shown in Table 4-2).

When both aforementioned guidelines are compared to the noise levels which can be typically found in engine rooms (see Table 4-1) and neighbouring locations, it is shown that it will be hard to achieve effective communications in these locations without taking extra measures. This is also the case for other locations in addition to the engine room areas where noise levels likely to cause difficult communications according to the scheme shown in Table 4-2.

Table 4-2: Speech Communication Capability vs Level of Background Noise (Harris, 1979)

Communication	Below 50 dB(A)	50-70 dB(A)	70-90 dB(A)	90-100 dB(A)	110-130 dB(A)
Face-to-face (unamplified speech)	Normal voice at distances up to 6 m	Raised voice level at distances up to 2 m	Very loud or shouted voice level at distances up to 50 cm	Maximum voice level at distances up to 25 cm	Very difficult to impossible, even at a distance of 1 cm
Telephone	Good	Satisfactory to slightly difficult	Difficult to unsatisfactory	Use press-to-talk switch and an acoustically treated booth	Use special equipment
Intercom system	Good	Satisfactory	Unsatisfactory using loudspeaker	Impossible using loudspeaker	Impossible using loudspeaker
Type of earphone to supplement loudspeaker	None	Any	Use any earphone	Use any in muff or helmet except bone conduction type	Use insert type or over-ear earphones in helmet or in muffs; good to 120 dB(A) on short-term basis
Public Address System	Good	Satisfactory	Satisfactory to difficult	Difficult	Very difficult
Type of microphone required	Any	Any	Any	Any noise-canceling microphone	Good noise-canceling microphone

Finally, it needs to be remembered that communication is a critical part of the shipping operation and used by crew members as an instrument for achieving their tasks. Therefore, working spaces in ships should have their noise levels carefully considered and regulated as far as practicable to facilitate clear communication.

4.6.2 Effects of noise on sleep

Sleep disturbance can be considered as one of the most disturbing non-auditory effects of noise. Humans need enough comfortable and undisturbed sleep not only to maintain a healthy life and recover from the effects of the previous working day but also to maintain alertness and good performance for the next day (Muzet, 2007). According to the World Health Organisation (Fritschi *et al.*, 2011), sleep disturbance is shown as most deleterious non-auditory effect of noise exposure as shown in Figure 4-9.

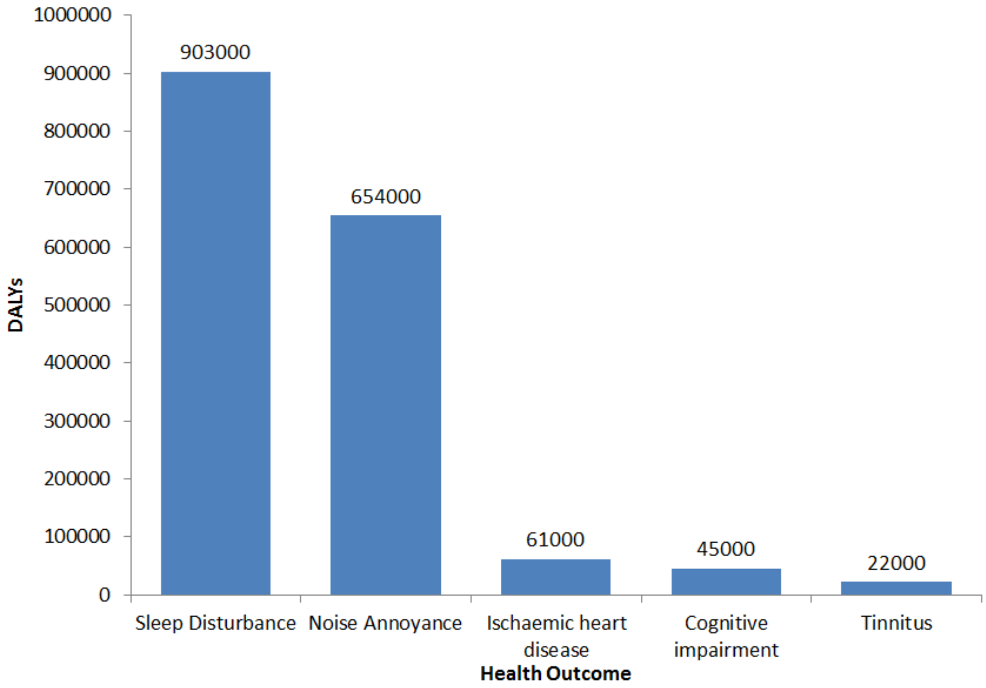


Figure 4-9: DALYs attributed to environmental noise exposure in Europe - adopted from Basner *et al.* (2014)

The disability-adjusted life year (DALY) can be explained as a measure of overall effect of diseases, expressed as the number of years lost due to ill-health, disability or early death (Wikipedia, 2014a).

Environmental noise and its potential effects on community sleep disturbance is studied in-depth in a recent review study Basner *et al.* (2014) summarised the findings in the literature confirming the bad effects of noise on sleep. Noise interfere with the quality of sleep by affecting and changing the sleep structure which may include difficulty to go into sleep, early awakenings, reduced deep sleep, rapid eye movements during sleep (Basner *et al.*, 2010, Basner *et al.*, 2011). Moreover, 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).

There are numerous other examples in the literature which studied the adverse effects of noise on sleep on land-based applications and most of these research studies focussed on the effects of transportation noise on the community. It can be said that there is a common agreement amongst the researchers that noise adversely affects the sleep quality.

However, when the same issue is investigated on board ships the main source of background noise is not the environmental noise but the ship itself where the seafarers are supposed to work and live on board. Therefore, sleep disturbance is a greater problem for seafarers simply because they do not only sleep in an environment with high background noise levels but are also exposed to other factors such as motions, vibration and long working shifts. According to Muzet (2007) in terms of noise induced sleep disturbance, shift-workers are thought to be in the high-risk group. Hence, considering the unique environment of ships and experiences of seafarers in this environment it is important to conduct research on ships. There are some studies on noise induced sleep disturbance which were conducted in the maritime domain; for example research conducted by Tamura *et al.* (1997) on the 3 subjects show that at 65 dB that ship engine noise has adverse effects on crew sleep. A further study by the same author focused on the effects of ship noise on sleep and habituation to noise by utilising 4 subjects (Tamura *et al.*, 2002). It was observed that the participants' sleep was habituated to a noise level of 60 dB (A) to some extent considering the subjective sleep parameters but this outcome was not visible in the sleep parameters measured by actigraphy. It was also shown that sleep deprivation due to noise exposure did not significantly affect the physical tasks but cognitive tasks were greatly affected (Belenky *et al.*, 1987, How *et al.*, 1994, Archibald, 2005). In another study Hansen and Holmen (2011) researched sleep disturbances among offshore fleet workers by investigating two different shift types. They found that workers who work 6 hour shift (6 hours on, 6 hours off) were more affected by noise when compared to 12-hour shift (12 hours on, 12 hours off) workers. In another study high levels of exposure to noise was associated with poorer sleep efficiency and sleep disturbance (Smith *et al.*, 2001).

Regulatory bodies also responded to these needs by defining maximum allowed noise levels in crew cabins. The IMO defined the noise limit for the crew cabins as 60 dB(A) or 55 dB(A) depending on the size of the vessel (IMO, 2012a). On the other hand, the American Bureau of Shipping defines 50 dB(A) as the limit due to the need for addressing comfort, communication and performance needs of the crew (ABS, 2001). However, according to a report published for the World Health Organisation (Berglund *et al.*, 1995) the noise level (equivalent continuous sound pressure level) during the sleeping period should not exceed 30-35 dB(A). Even due to practical reasons on ships this may not be achieved, the fact is that there is a big gap between the limits defined by maritime domain for sleeping areas when compared to land based suggestions.

4.6.3 Effects of noise on performance

Many research studies from other industrial sectors were focussed on understanding the effect of noise exposure on worker performance. The majority of these studies, mainly through the application of controlled experiments, tried to obtain statistical relationships between noise level and human performance.

4.6.3.1 Accidents and injuries

One of the most unwanted consequences of undesirable human performance is when an accident or casualty is caused. Yet, it is hard to confidently explain to what extent noise exposure causes these accidents. This was the main motivation for Wilkins and Acton (1982) in conducting an extensive review study on noise and accidents where they conclude that noise is a contributory factor in the occurrence of occupational accidents. It is shown that noise exposure, together with noise-induced hearing loss, interfere with the safety of industrial life and 12.2 % of accidents can be related to noise exposure (Picard *et al.*, 2008). In another study it was shown that people who worked in noisy environments were involved in more accidents than those who worked in low noise areas (Cohen, 1974). 35 % of people working in noisy condition had more than 15 injuries over 5 years while the same statistic is only 5 % for people who worked in low noise areas. In a further study Melamed *et al.* (2004) this time found that complex jobs combined with noise exposure result in higher risk of having an occupational injury. Results of aforementioned studies are also in agreement with the early research by Weston and Adams (1932) who found that efficiency of weavers who wear hearing protection was higher (by 12%) when compared to those who are not wearing any protection.

Unfortunately, there was no research study that was found in the literature, which investigated the relationship between noise and accidents in maritime domain. However, marine accident investigation studies show that factors like communication, inattention and fatigue are commonly attributed to shipping accidents (Rothblum, 2000, MAIB, 2004a, DeCola and Fletcher, 2006) and noise exposure can easily be a direct contributor of these factors.

4.6.3.2 Effect of noise on task performance

The effect of noise on task performance has been widely researched between different sectors and many of the studies reported adverse effects. For example the European Agency for Safety and Health at Work (EASHW) reports that increasing noise levels from 60 dB(A) to 70 dB(A) resulted in 4 times more mistakes at assembly work. (EASHW, 2005) EASHW also reported that work tasks related to sensomotoric coordination takes more time to achieve the same quality. Moreover, it was also shown that tasks that require attention and concentration are likely to get affected most by noise. This is important because according to Dobie (2003), today work on ships is more mental than physical compared to many years ago.

Therefore, noise is likely to cause a risk on ships especially for cognitive tasks. As a result, it is important to investigate the effects of noise exposure on cognitive performance.

In relation to this, previous research shows that cognitive performance can be adversely affected by noise (Hygge *et al.*, 2002, Lercher *et al.*, 2003, Boman, 2004, Stansfeld *et al.*, 2005). Furthermore, research conducted by Smith (1988) over 65 people showed that noise affected participants performance and affected their estimation capability adversely. There is also evidence in the literature that exposure duration is also important in terms of resulting cognitive performance in noise. Research shows that subjects need to be exposed to moderate noise for at least 30 minutes before it influences the their performance during the task of naming colours and reading colour names (Smith and Broadbent, 1985).

4.6.3.3 Vigilance Performance

For seafarers, vigilance is one of the relevant skills that they should have to conduct their daily duties safely (e.g. watch keeping). Vigilance can be defined as a state of readiness to detect and respond to certain specified small changes occurring in the environment (Mackworth, 1957). A vigilant person will be prepared to watch the potential danger and difficulties likely to occur hence vigilance is a really important skill to have for seafarers especially for safe navigation. Even it was not researched enough in maritime domain, effects of noise on vigilance performance is often researched by other industrial sectors. Especially operators or vehicle drivers who are required to maintain good levels of attention and stay vigilant to the changes around them were often subjected to vigilance performance studies. Findings of the study conducted by Dalton *et al.* (2007) demonstrate that noise have a detrimental effect on driving related tasks. High-volume noise decreases the vigilance and may take away the concentration and attention which is necessary for driving performance. Considering that a watchkeeping task is a similar but more complex task than driving, it is surprising that literature lacks similar experiments conducted on ship simulators. It was explained that complex tasks are more likely to be effected by noise. According to Button *et al.* (2004) high noise impaired reaction times of human during a simple vigilance task but it decreased performance during a complex vigilance task.

Moreover, according to Broadbent (1954) when a human is exposed to 90 dB(A) continues noise level over 15 minutes his or her vigilance performance will be affected adversely. This shows exposure time is also important factor for adverse effects of noise to appear. Importance of exposure duration is further explained by another study which showed that the number of errors increased during a reaction time task when subjects had been in 75 dB(A) noise for 5 hours in comparison to the errors in 2 hours (Smith and Miles, 1985). As it can be seen the similar adverse effects of noise can be obtained with different combinations of noise intensity and exposure durations.

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, Smith *et al.*, 2003, White *et al.*, 2012).

Even though most of the studies report adverse effects of noise exposure on performance, results of some studies show conflicting findings amongst different studies. This demonstrate that the relationship between the noise exposure and human performance may change depending on the duration of noise exposure, type of noise, demography of the subjects, type and complexity of the task. In a review study, Smith (1989) analysed many different types of noise-performance studies and confirmed that noise has detrimental effects on performance but this effects are complicated and influenced by factors (such as type of task, type of noise, individual factors) which are still partially known. Unfortunately, this situation makes the findings and lessons learnt from other industrial sectors to be less relevant to shipping and therefore not transferrable to maritime domain.

4.6.3.4 Stress

In previous sections some key outcomes of noise exposure were explained. Literature demonstrates that noise exposure can lead to annoyance, sleep disturbance which is directly related to fatigue, interferes with speech and communication, impairs with cognitive and vigilance performance. All these adverse effects especially in long term cause occupational stress. The World Health Organization (WHO) defines occupational stress as “the response that people may have when presented with work demands and pressures that are not matched to their knowledge and abilities and which challenge their ability to cope”. Stress is known to affect both psychological and physiological components which may affect the cardiovascular systems and metabolism. Research study by Melamed and Froom (2002) showed that performing complex and demanding tasks in noise is stressful and has physiological and psychological impacts.

Moreover, Loewen and Suedfeld (1992) also showed that college students reported more disturbance and stress when compared to the silent condition. Moreover, in a field study O’Donnell Personal Stress Inventory (PSI) questionnaires were used to determine stress levels of 62 workers. Results showed that noise as an occupational factor contributed to high occupational stress levels (Naeini and Tamrin, 2014). Similarly research showed that a decrease in the noise levels at the workplaces decreased psychosocial job stress (Leather *et al.*, 2003).

In following paragraph ‘European Agency for Safety and Health at Work’ describes how noise adversely affect human by causing stress (EASHW, 2005).

> *“Noise affects the central nervous system and causes physiological reactions that can become stress reactions due to their intensity, rate of repetition and the state of mind. Naturally, noise acts as a wake-up call. Sudden or unwanted noise alerts the human body and activates the stress response. This biological alarm serves to increase the release of stress hormones (cortisol), blood pressure, and heart rate (all signs of elevated physiological stress), and to prepare the body to react to noise threats. If the stress hormones are released constantly and these changes in the body are prolonged with no real outlet, harm to the organism will be caused in the long term. Inability to control the source or intensity of the noise will add to its stressful impact”*

Even though noise on ships is very unpleasant, it is very common to hear from seafarers that they refer to noise as something to get used to. This situation can be explained by the 'learned helplessness' theory. Since seafarers are exposed to that unpleased noise for extended periods for months they develop what is called 'learned helplessness' syndrome. The term 'learned helplessness' is described as a condition when people feel helpless to avoid negative situations because previous experience has shown them that they do not have control (Boyd, 2014). Even though it may seem harmless, it needs to be remembered that this syndrome is linked with reduced motivation, job satisfaction and depression. Moreover, under such stressor human attention will become selective by focusing on the main task while reducing the performance of secondary tasks which cause information to be processed less efficiently and increase risk taking and result in accidents especially when dealing with complex tasks (EASHW, 2005). This kind of performance problems and similar behaviours are often observed shipping accident investigations. However, shipping industry lacks fundamental knowledge and awareness on these issues which so far prevented them from improving the working conditions.

4.7 Existing models of human response to noise

It is necessary to mention that there was no human response models identified in the literature which explains the relationship between noise on board ships and resulting human response. Instead, in the maritime domain noise related modelling efforts were mainly focused around structural noise propagation and estimating the noise emissions rather than the resulting human response. Therefore, in this section some of the annoyance models available in the literature outside the maritime sector were reviewed. These models may not be directly applicable to maritime sector but the modelling techniques and approaches used together with the lessons learnt from these modelling studies will benefit the future human response modelling in shipping.

4.7.1 Franken and Jones Approach

For sure human response and perception is a complex issue to deal with. The human response model proposed by Franken and Jones (1969) is important because it is one of the earliest studies recognising this complexity and after careful review of available studies proposed an approach which is still applicable. Franken and Jones explained that response to high noise intensity events like aircraft flyovers are primarily a function of total noise energy however response to lower noise levels such as ground transportation noise, is affected by non-physical determinants of noise as well as the noise level which are shown as below;

- Individual differences in susceptibility to noise.
- Adaptation levels to noise as a function of past experience, immediate or long-term.
- The meaning of the sound.
- The meaning of the source of noise.
- The activity of the listener.
- The appropriateness of the environment

4.7.2 Predictions of noise disturbance from transportation noise (community noise annoyance models)

Noise from the airports and its effects on the residents living in that neighbourhood has been a concern for researchers for a long time. As a result, numerous research studies were focussed on identifying the relationship between the noise levels and subjective human annoyance by developing models. Hazard (1971) examined this relationship by considering objective measures of noise and psychological conditions which affect the resulting annoyance. As part of this study interviews were conducted within 12 miles of major airports noise measurements and 4212 interviews were conducted. Different noise exposure indexes were then calculated including composite noise rating (CNR), and modified noise and number index (NNI), noise exposure forecast (NEF), and composite noise index (CNI) and speech interference level (SIL). 53 predictors of annoyance were obtained through the interviews which then evaluated and reduced to 7 as shown below;

- Fear
- Distance
- Belief in misfeasance
- Importance of airport
- Noise susceptibility
- Adaptability
- City
- Noise exposure variable (CNR)

For the noise exposure variable they have tested above mentioned exposure indexes and CNR was selected. By the inclusion of CNR into the psychological factors, proposed prediction model was able to describe 63% of the variance which was better than the other exposure indexes.

Shepherd (1971) studied the reasons for rising number of number of complaints near Luton airport due to aircraft noise. The study aimed to generate a link between the complaints and noise exposure. In order to achieve this complaint statistics between 1968 and 1971 were collected. Following predictors were used;

- Socio-economic status (SES) of each community where complaints came from
- PNL (average peak fly-over perceived noise level)
- Number of flyovers per day

After the analysis following model was developed;

$$= 0.80(PNL) + 0.02(Number\ of\ flyovers) - 4 \times SES - 50$$

Equation 4-2

The model shown in Equation 4-2 predicts number of complaints per thousand head of population for a particular community. SES shown in the Equation 4-2 is a scale of socio-economic situation of that particular community and location (1: Highly desirable location, 5: Undesirable Location). It was shown that people with higher socio-economic status were getting more adversely affected by noise.

Hall *et al.* (1985) developed a probabilistic model by using the different activity interferences to define annoyance. Logit analysis was used to estimate two sets of equations;

- First, activity interference probabilities were predicted as function of noise level. Activity interferences include indoor speech, outdoor speech, difficulty getting to sleep and awakening.
- Then, annoyance probability was calculated as a function of aforementioned activity interferences.

$$f = -2.24 + 1.44PSPOUT + 1.00PSPIN + 1.61PAWAKE$$

Equation 4-3

Equation 4-3 combines the 3 interference probabilities to predict probability of overall annoyance. In Equation 4-3, PSPOUT is probability of outdoor speech interference, PSPIN is probability of indoor speech interference while PAWAKE is the probability of awakening. This model is generic and applicable to combined noise sources.

Most of the community noise annoyance studies use a similar approach when modelling the relationship between noise and annoyance. It is widely accepted and common that most studies (McKennell *et al.*, 1963, Leonard and Borsky, 1973, Guski, 1999) include pshyco-social components as a predictor. However, according to a study which re-analysed the psychosocial variables of several studies (Alexandre, 1976) the only clear cause of annoyance is the noise. This finding shows us that psyco-social factors are important when estimating noise annoyance however these factors may differ from one community to another. This conclusion is also in-line with the study of Wilson *et al.* (2013) where he supports the models that derive noise-annoyance relationships on a community-by-community basis.

In Section 4.6.3.4 it was explained how noise effects human body and may cause health problems in long term. Fyhri and Aasvang (2010) studied the issue of noise and poor health where they tried to model the relationship between road traffic noise and cardiovascular problems. The results of this study showed no relationship between noise exposure and cardiovascular problems.

In a more recent study, Miedema and Oudshoorn (2001) presented a model developed from the data generated in noise annoyance studies (aircraft, road traffic and railways separately). As noise descriptors, they have used "day–night level" (DNL) and "day–evening–night level" (DENL) as noise descriptors.

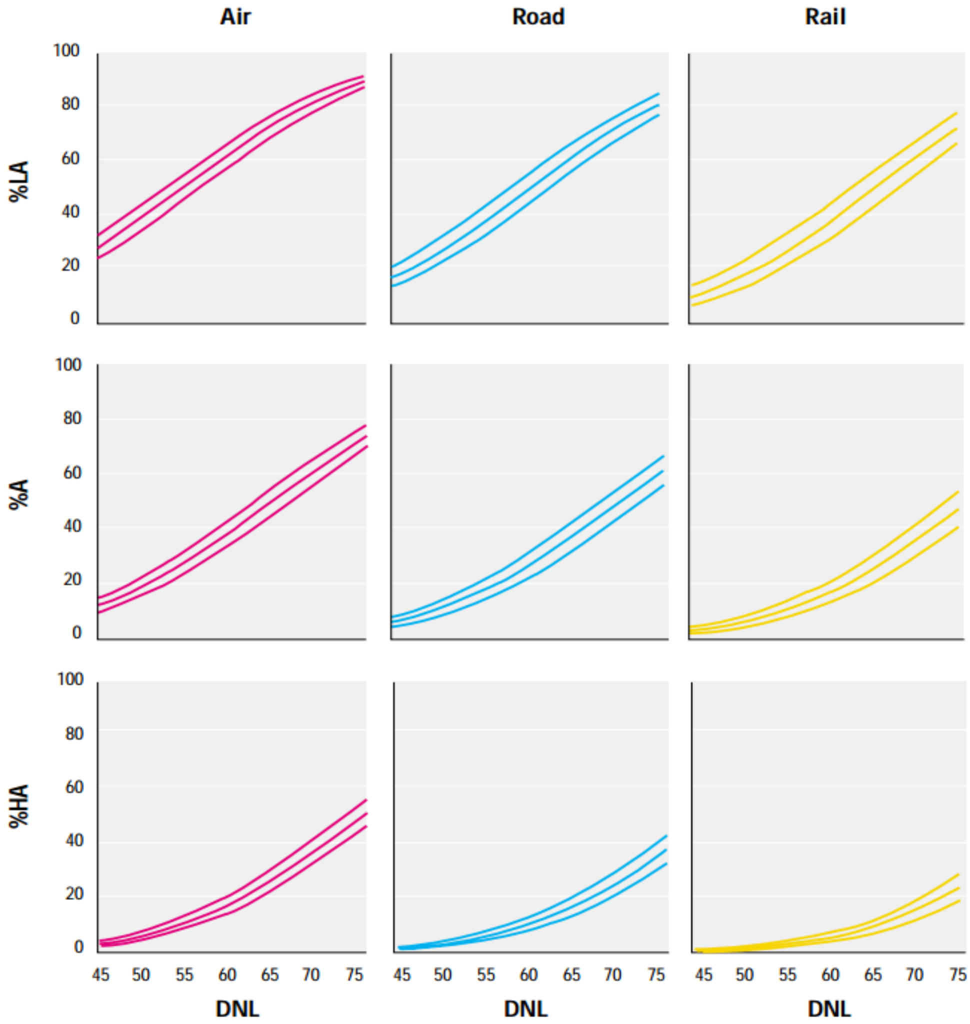


Figure 4-10: The %LA, %A, and %HA for aircraft, road traffic, and railways as a function of DNL, together with 95% confidence intervals (Miedema and Oudshoorn, 2001)

Figure 4-10 display the percentage of people who are (at least) a little annoyed (annoyance ≥ 28), annoyed (annoyance ≥ 50), and highly annoyed (annoyance ≥ 72).

In the aviation sector the studies of human response to noise (in an environmental context) have been taken into next level through the EU funded SEFA Project (Sound Engineering for Aircraft) which aimed to analyse and determine parameters of aircraft noise which are correlated with aircraft noise annoyance, and design optimum noise signatures (Berckmans *et al.*, 2008).

It is also important to mention about the research project called Genlyd developed a model to calculate noise annoyance (Pedersen, 2007). In the Genlyd model different scales for measuring noise annoyance were developed. Many explanatory factors were taken into account and separately (e.g. noise source, personal factors). In this study ordinal logistic regressions were used to develop the relationships, the logistic function was selected because it was considered that the S-Shaped curve (as shown in Figure 4-11) represents the noise annoyance very well. So below certain level the noise annoyance will be zero or closed to zero and when the perceived loudness exceed a certain threshold annoyance will rapidly increase.

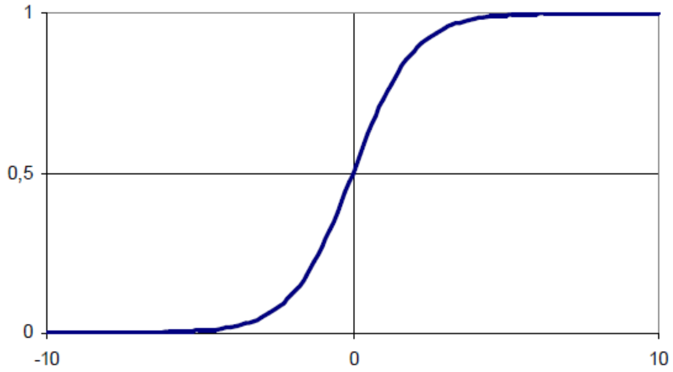


Figure 4-11: The logistic function(Pedersen, 2007)

Some noise annoyance models utilised fuzzy approach for prediction. Most of the models utilised fuzzy rule base (also known as expert systems) where a human expert proposes a set of rules based on linguistic variables. This approach was explained in the research paper of Botteldooren *et al.* (2002) where they presented a fuzzy rule based model for community noise annoyance.

Effects of noise on speech interference were explained before in section 4.6.1. A relevant modelling study has also been observed in the literature. Zaheeruddin and Jain (2008) used noise level, distance between speakers and age of listener to predict the effect of noise level on speech interference. The developed models are demonstrated in Table 4-3. Models are given as a function of noise levels (dB(A)) with distance and age as parameters. It can be seen that when the distance between speaker and listener increased sentence intelligibility decrease. However, sentence intelligibility of young people does not appear to get affected by distance in noise levels up to 55 dB(A). On the other hand when noise level increases the speech intelligence dramatically decreases. It can be seen that, sentence intelligibility reaches almost zero at noise levels over 70 dB(A).

Table 4-3: Sentence intelligibility (%) (Zaheeruddin and Jain, 2008)

Noise level (dB(A))	Sentence intelligibility (%)								
	Short distance			Medium distance			Long distance		
	Young	Middle aged	Old	Young	Middle aged	Old	Young	Middle aged	Old
45	97	97	90	97	97	90	97	90	80
50	97	97	90	97	97	90	97	90	80
55	97	97	90	97	97	90	97	90	80
60	97	90	80	97	90	80	90	80	65
65	90	80	65	90	80	65	80	65	45
70	65	45	30	45	30	18	30	18	8
75	1	1	1	1	1	1	1	1	1

There are also some studies in literature which focussed on developing models which predict the human efficiency under noise. Pal and Bhattacharya (2012) focussed on researching the effects of traffic noise on human performance. They have conducted noise measurements near busy roads and simultaneously interviewed 270 individuals who work in offices near these roads. They used fuzzy inference system for modelling the relationship between noise and efficiency. The model developed (R^2=0.77) is shown in Figure 4-12 in a graphical representation. Noise levels shown in the graph are given in dB(A) where noise duration is in hours.

It can be observed that, 10 hours of exposure to a noise level of 50 dB(A) can result work inefficiency levels around 50 %.

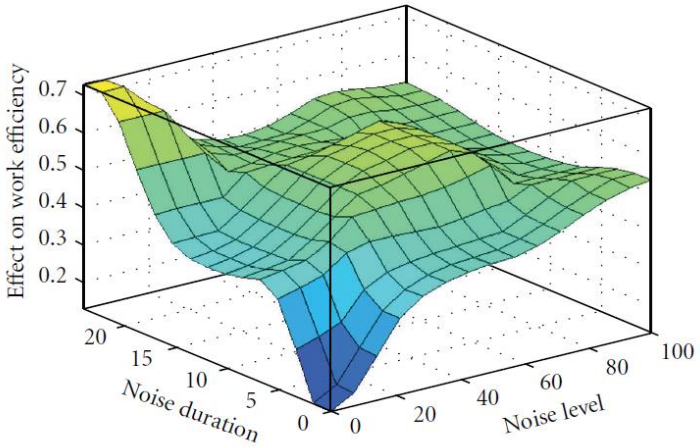


Figure 4-12: Effect on work efficiency VS Noise Level and Noise Duration (Pal and Bhattacharya, 2012)

In another similar study Zaheeruddin and Garima (2006) used a neuro-fuzzy approach for modelling the human efficiency. In their model they have used noise level, type of task and exposure time as predictors.

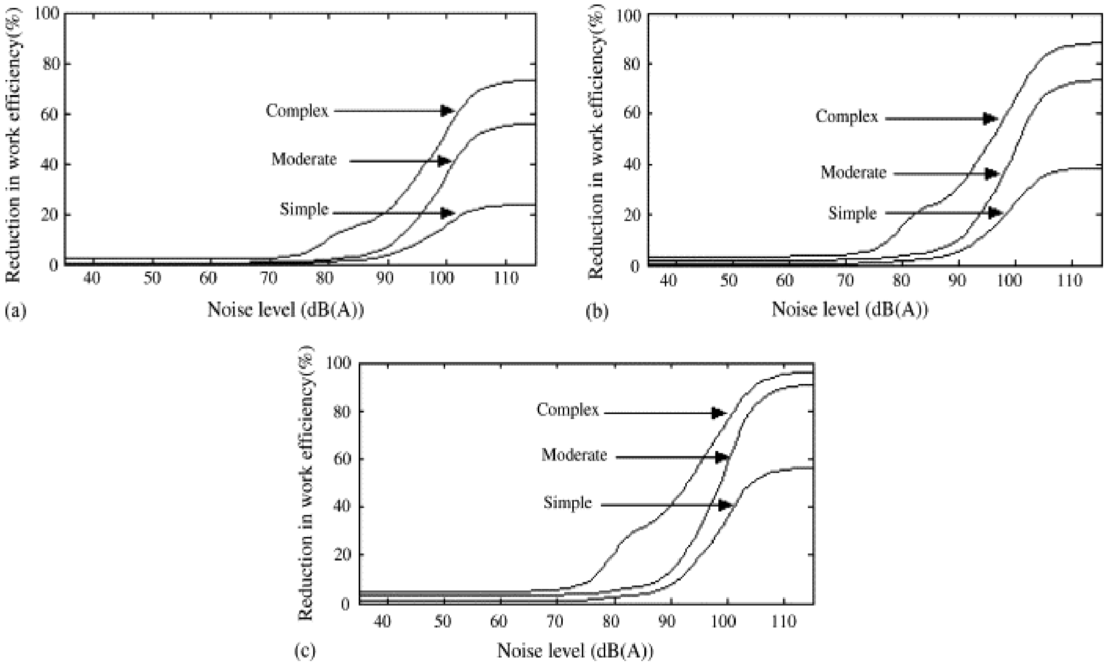


Figure 4-13: Human efficiency at ‘short’ exposure time (a) at ‘medium’ exposure time (b) and at ‘long’ exposure time (c) (Zaheeruddin and Garima, 2006)

It can be seen that the efficiencies predicted between Figure 4-12 and Figure 4-13 are inconsistent. This inconsistency can be explained by the findings of Wilson *et al.* (2013) about the differences between communities. Moreover, Fuzzy modelling is generally visited when dealing with high level of interrelated factors and simple linear models do not yield in good models. Therefore, the rule-base in fuzzy models is designed by human expert that introduces subjectivity and may affect results. Another limitation with fuzzy approach is the fact that the theoretical basis vary for different determinants of human response which makes it difficult for the experts to develop the fuzzy rule base effectively.

4.7.3 In vehicle human response models

Noise level inside road transport vehicles is a concern for manufacturers since the in vehicle noise is directly related with customer satisfaction which may have commercial impacts. Therefore, researchers focussed on researching the effects of inside noise quality on passengers. For example Tsuge *et al.* (1985) studied the rumbling noise in cars during acceleration which is annoying for passengers. According to their study the discomfort depends on the phase, frequency and magnitude of each frequency component, therefore they analysed the shape of the time domain noise envelope and found good correlations between noise annoyances. Similar approach was also used by Murata *et al.* (1993) who aimed to develop objective measures for the evaluation of noise through combination of physical values and then link these values with subjective evaluations. Studies conducted in road transport seem to focus on more the physical and tonal characteristics of noise rather than involving many individual factors. Moreover, systematic measurements and controlled experiments were often used to see the effects of different engine running conditions. Moreover, since the results and predictions of these studies were derived from data generated in controlled conditions or experiments, they represent a specific condition. Hence, it is hard to generalise the results.

It was explained before that noise exposure is often related to health problems. Bruno *et al.* (2013) addressed this issue by conducting a study on 200 bus drivers from a public transport company. The statistical analysis showed that engine noise is the main contributor of discomfort. It was also reported in their study that people experiencing high noise annoyances were also having higher results of health problems reported. Findings of this study are very interesting however specific findings of these kinds of studies are rarely transferable even within the same sector.

4.7.4 NASA's ride comfort model

NASA (National Aeronautics and Space Administration) conducted an experimental investigation on in-vehicle human response to noise and vertical vibration (Leatherwood, 1979). In this study it was aimed to achieve following:

- determine the effects of noise and vibration on human discomfort,
- develop a prediction model for human response
- and develop set of curves for ride quality design.

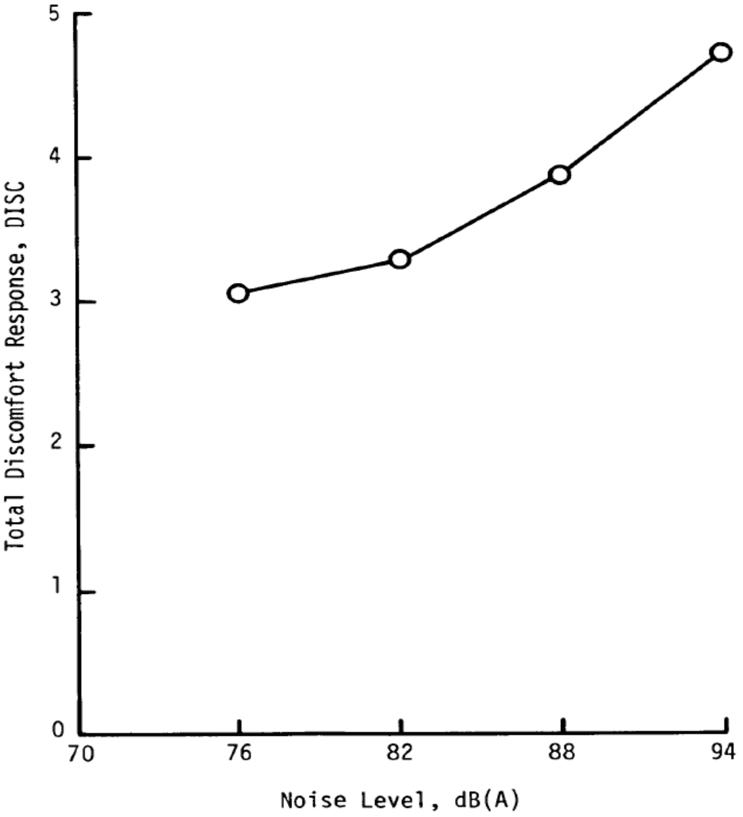
A total of 60 subjects were involved in the experiments of which 49 were female and 11 were male with an age ranging between 18 and 62. The hearing of each subject was ensured before the experiments through an audiometric test. In this study the independent variables used were; (1) A-weighted noise level, (2) noise octave-band centre frequency, (3) vibration discomfort level and (4) vibration frequency. Dependent variable was the discomfort experienced by the subjects.

During the experiments a number of noise and vibration combinations (which are similar to those that can be experienced in an airplane) were used in a simulator and resulting subjective feedbacks of the participants were collected. Subjects were asked to evaluate the ride comfort after each combination. Results showed that main effects of f_v (vibration frequency, Hz), A (vibration discomfort level, DISC), L_A (octave-band A-weighted sound pressure level, dB (A)) f (octave-band centre frequency, Hz), were statistically significant (at 0.05 level). One of the outcomes of this suggest that in order to accurately predict the passenger ride comfort knowledge of the levels and frequency content of noise and vibration are required to be known.

As an output of developed model NASA developed and presented a set of noise & vibration criteria (see Figure 4-14 and Figure 4-15).

In Figure 4-14 the effect of noise level was shown in the top graph, where the total human response was averaged over factors f_v, A and f. In the same figure the bottom graph shows the relation between noise and octave band centre frequency.

It can be seen that the range of 250Hz – 1000Hz is the most comfortable for the passengers. High and low frequency not only results in higher annoyance for the same noise level but also the human discomfort at these frequencies increase more rapidly when noise level is increased. The study focussed on the combined effects of noise and vibration therefore in the graphs the ‘total discomfort scale’ is shown with regards to changing noise level and frequency characteristics.



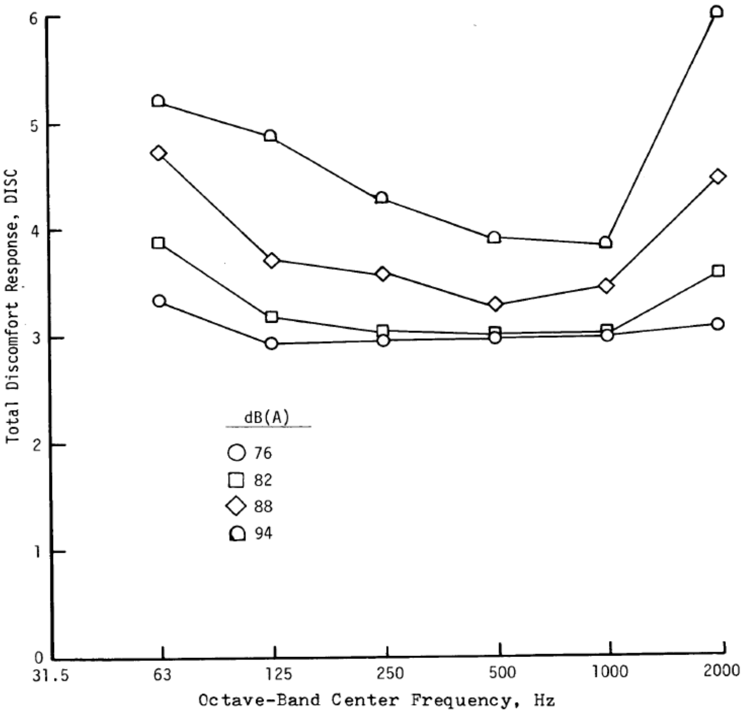


Figure 4-14: Top graph: Total discomfort response as function of noise level, Bottom graph: Interaction of noise level and octave-band centre frequency (Leatherwood, 1979)

Figure 4-15 demonstrates the noise discomfort as function of noise level and vibration discomfort. As expected combination of noise and vibration has an adverse effect in total annoyance.

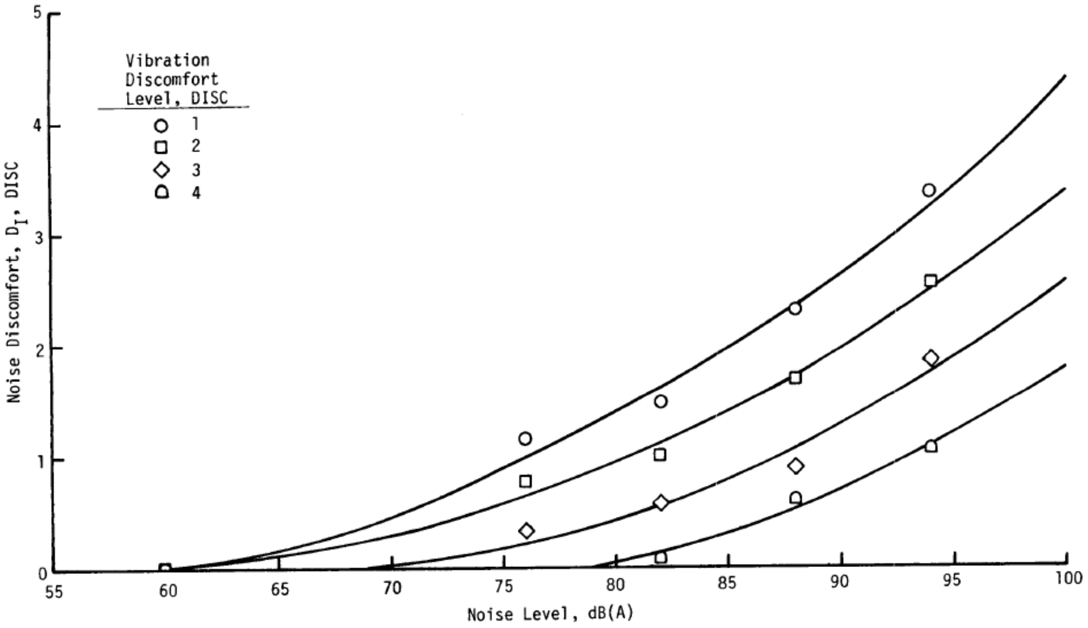


Figure 4-15: Discomfort due to noise as a function of noise level and vibration discomfort (Leatherwood, 1979)

It is important to mention that the noise level range tested in the experiments was between 76 dB(A) - 94 dB(A) therefore the criteria shown below is limited to this range. Moreover if someone is to use this model for design purposes it is also important to remember that the results represent a specific noise conditions and may not be applicable fully to another types of noise.

4.8 Current standards/rules/regulations on noise control

The effects of noise exposure on an individual have been previously discussed in the previous sections. However, it is necessary to mention that health effects noise exposure (both in short term and long term) has been globally accepted and proven. The resulting health effects of noise exposure at work alerted the regulatory bodies to develop and implement laws and regulations to prevent workers health from the noise at work. Therefore in this section current regulatory framework will be researched and explained.

4.8.1 ILO - Ambient factors in the work place

The International Labour Organisation (ILO) is the tripartite United Nations (UN) agency bringing together the governments, employers and workers to jointly work on the labour issues promoting decent work for all throughout the world. ILO is aiming to promote rights at work, encourage decent employment opportunities, enhance social protection and strengthen the dialogue in handling the work related issues (ILO, 2012).

ILO published “Ambient Factors in the Workplace” (2001) under its codes of practice which provides generic guidance on the role, obligations and responsibilities of competent authorities, employers as well as rights of workers focusing on the hazardous effects of ambient factors in the working environment. Code discusses the general principles of prevention and control on hazardous substances, Ionizing radiation, electric and magnetic fields, optical radiation, heat and cold, noise and vibration.

In the section 9 of the code, noise at work is discussed which involves guidance on the following:

- **Assessment**, to ensure that the established safe levels of exposure by the national or international norms to noise will not be exceeded.
- **Prevention and control**, in order to eliminate or decrease the risks to minimum practicable levels, employers responsibilities have been explained and suggestions has been made to prevent such risks.
- **Health surveillance**, suggesting employers to conduct appropriate health surveillance.
- **Training and information**, to suggest employers to implement appropriate training in order to increase workers awareness on hazards of noise exposure and means of prevention.

Even though the general responsibilities and guidance have been made available for the interested bodies, in the ILO’s Code of Practice on “Ambient Factors in the

Workplace", there is no exposure limit defined. However, in the annex of the document, references are made to couple of ISO standards.

4.8.2 USA's Noise Control Law (CFR1910.95)

OSHA (Occupational Safety and Health Administration) is the federal agency founded in 1970 under the United States Department of Labour. OHSA deals with the safety and health in the workplace by developing and enforcing standards as well as developing training and assistance to ensure the safe working conditions for man and woman.

One of the early works of OHSA was the promulgation of the standard on 'occupational noise exposure' in 1971 which was accepted as US law. In order to incorporate the hearing conversation amendment, it was revised in 1981 (OSHA, 1981a).

The aim of the CFR 1910.95 is to protect workers' health from the harmful effects of noise exposure. In order to achieve this objective the CFR 1910.95 defines permissible noise exposure values for continuous noise. Permissible noise exposures for workers are given in Table 4-4, where noise is considered as continuous, if the variations in noise level involve maxima at intervals of 1 second or less (OSHA, 1981a).

Table 4-4: Permissible noise exposures (OSHA, 1981a)

Duration per day, hours	Sound pressure level, dB(A) (Slow Response)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	112

Permissible noise levels and the duration for that noise level that a worker can be exposed to that level is designed to ensure that worker’s noise dose(D%) value do not exceed 100% in a working day as well as ensuring that workers are not exposed to noise levels greater than 115 dB(A).

Noise dose (D%) is an indicator of workers noise exposure which can be calculated by the Equation 4-4 for an A weighted noise level which is considered as constant during the total length of the work (t). t is given in hours.

$$D(\%) = 100 \times \frac{t \times 2^{\left(\frac{L-90}{5}\right)}}{8}$$

Equation 4-4

However, in practice noise level is almost never constant through the entire working day but workers are exposed to different noise levels. In that case the Equation 4-5 can be used to calculate the workers overall noise dose for the entire shift.

$$D(\%) = 100 \times \left(\frac{1}{8} \sum_{i=1}^{n} t_i \times 2^{\left(\frac{L_i-90}{5}\right)}\right)$$

Equation 4-5

The permissible exposure level can also be given in TWA (Time Weighted Average (8 hour)) which is another way of defining workers exposure level. TWA can be defined as a constant sound level over an 8 hour shift which will result in the same noise dose which was measured. Therefore Equation 4-6 ensures and enforces that permissible exposure level of TWA 90 dB(A) is not exceeded. TWA can be calculated by Equation 4-6

$$TWA = 16.61 \times log_{10}\left(\frac{D\%}{100}\right) + 90$$

Equation 4-6

The CRF 1910.95 also defines an exposure limit to the impulsive or impact noise, which should not exceed 140 dB peak sound pressure level. Where noise with peaks occurring less often than once a second is considered as impulsive noise

The CRF 190.95 enforces the following:

- When permissible exposure level (PEL) is exceeded administrative (e.g. reducing the workers noise exposure through limiting his or her time spent in the noisy environments) or engineering (e.g. reducing the noise emissions or transmission of noise through design) controls should be applied to mitigate the noise level below PEL.
- If the noise levels cannot be mitigated below PEL through feasible administrative or engineering controls hearing protection should be used to ensure the exposure levels in the protected ear is below PEL.
- Action level is defined as TWA 85 dB(A) and when workers exposure is equal or exceed the action level then Hearing Conservation Program (HCP) should be implemented

4.8.2.1 Hearing Conservation Program

The aim of HCP is to protect the health of those workers' who are exposed to high noise levels during their duties. CFR 1910.95 enforces employers to implement and manage an effective HCP if the workers' noise exposure equal or exceed the defined action level of TWA 85 dB(A) or in other words when workers' noise dose (D%) equal or exceed 50%. The main parts of the HCP are explained below:

- **Monitoring program** should be implemented if the noise exposure of workers are equal or exceed action level.
    - Actual exposure values of the workers who are exceeding or expected to exceed the defined action level should be measured at least once.
    - Measurements should be repeated when there has been a change in the workplace or the process which may result in an increased noise exposure level.

  - Information should be given to workers about their actual exposure levels to noise when their exposure is equal or exceeding the action level.

- **Audiometric testing program** should be established and maintained if the noise exposure of workers are equal or exceed action level.
  - The program should be provided free of charge to workers
  - Audiometric tests should be performed by an competent person
  - A baseline audiogram should be obtained in the first 6 months of workers' exposure to a noise level equal or above action level. This audiogram should be repeated annually to compare the workers' hearing to the baseline audiogram to obtain the threshold shift. This audiogram should be repeated annually to assess the workers threshold shift.
- **Hearing protectors** should be made available with no cost to the workers whose noise exposure are equal or exceed action level.
  - Employers should ensure the usage of hearing protectors for the workers whose exposure level exceeds the defined action level of TWA 85 dB(A) and experienced a standard threshold shift. Standard threshold shift is an average shift of 10 dB(A) or more in workers' hearing at 2, 3, and 4KHz in either ear compared to the baseline audiogram.
  - Usage of hearing protectors also mandatory for the workers whose baseline audiogram has not been established yet.
  - Option should be given to employees to choose the best suitable hearing protection from variety of options.
  - Training to ensure the proper usage and care of hearing protectors should be given to employees.
  - Employers are required to ensure the proper initial fitting and supervise correct usage.

    - Hearing protectors should decrease the employee’s exposure levels to 8 hour TWA of 90 dB(A) or less. If a worker experiences a threshold shift, hearing protectors should decrease the employee’s exposure level to the defined action level or less.
- **Training program** should be implemented by the employer ensuring the employee participation.
    - Each employee whose exposure to noise is equal or above the action level should receive training and this training program should be repeated annually.
    - Information should be given to workers on the effects of noise on hearing, hearing protectors as well as audiometric testing and its procedures.

4.8.3 EU’s Noise Control Directive (2003/10/EC)

European Union (EU) developed set of directives in order to protect the workers from the hazards of physical agents in the workplace in the perspective of health and safety. As part of the EU’s Physical agents directives on 6th of February 2003 EU published the specific directive ‘on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise)’ (EC, 2003).

The directive applies to the activities where workers are exposed to the risks of noise at work. Therefore the aim of this directive is to protect the workers’ health from the hazardous effects of noise exposure at the workspace. Directive uses the following terminologies;

- **Peak Sound Pressure**, which is defined as maximum level of ‘C’ weighted instantaneous sound pressure. Following formula can be used to estimate the peak sound pressure, which was initially recorded in ‘Pa’.

$$L_{Cpeak} = 20 \times log_{10}\left(\frac{P_{Cpeak}}{20}\right)$$

Equation 4-7

Where L_{Cpeak} is ‘C’ weighted peak sound pressure and P_{Cpeak} is peak pressure in Pa

- **Daily noise exposure level ($L_{EX,8h}$)**, which is defined as 8-hour time weighted average of workers’ daily exposure to noise. For the daily noise exposure level directive adopts the definitions of ISO 1999:1990 (ISO, 1990). If the noise level throughout the working shift is considered to be constant then workers’ exposure to noise can be calculated by the following formula(Equation 4-8)

$$L_{EX,8h} = L_{Aeq} + 10 \times log_{10}\left(\frac{T_e}{8}\right)$$

Equation 4-8

Where L_{Aeq} is ‘A’ weighted constant noise level and T_e is the duration of exposure to this noise level.

However in practice, noise levels in a workplace vary depending on the location or operating conditions. Therefore workers daily noise exposure level ($L_{EX,8h}$) will be combination of different periods of noise exposure. In that case Equation 4-9 can be used to estimate the overall noise exposure level.

$$L_{EX,8h} = 10 \times log_{10}\left(\frac{1}{8}\sum_{i=1}^{n} T_{ei} \times 10^{\left(\frac{L_{Aeqi}}{10}\right)}\right)$$

Equation 4-9

- **Weekly noise exposure level (LEX,8h)**, can be defined as the time weighted average of daily noise exposure values calculated for a five 8-hour workdays. Similar to daily noise exposures the directive uses the definitions of ISO 1999:1990 (ISO, 1990) for weekly noise exposure level. Equation 4-10 can be used to calculate the weekly noise exposure level of a worker for the 'n'th day of the week.

$$L_{EX,8h} = 10 \times log_{10}\left(\frac{1}{5}\sum_{i=1}^{n} 10^{\left(\frac{L_{EX,8hi}}{10}\right)}\right)$$

Equation 4-10

It is noted that weekly noise exposure levels are required to be used when there are significant differences in a worker's noise exposure levels between the working days.

In the light of aforementioned terminologies following sections will describe the details of the aforementioned directive.

The directive 2003/10/EC, in order to protect the workers' health from the hazardous noise exposure in the workplace enforces action and limit values which require specific action when exceeded. These action and limit values are shown in Table 4-5.

Table 4-5: Exposure limit and action values (EC, 2003)

Limit & Action Values	Daily Exposure Levels	Peak Sound Pressure Levels
Exposure limit values	L_{EX},8h = 87 dB(A)	P_{peak} = 200 Pa or 140 dB(C)
Upper exposure action values	L_{EX},8h = 85 dB(A)	P_{peak} = 140 Pa or 137 dB(C)
Lower exposure action values	L_{EX},8h = 80 dB(A)	P_{peak} = 112 Pa or 135 dB(C)

Exposure limit value is the daily or weekly noise exposure or peak sound pressure levels that must not be exceeded. When testing workers exposure levels against these values the attenuation achieved through wearing Personal Protective Equipment (PPE) can be taken into account.

Exposure action values are the magnitudes of daily or weekly noise exposure or peak sound pressure levels which if reached employers should take certain actions to mitigate the noise levels to allowed safe levels or reduce the adverse effects of the noise. The attenuation effects of wearing PPE should not be included when testing exposure levels of workers against these values. The directive brings obligations to employers, which are summarised in the following sections.

4.8.3.1 Risk assessment

If the nature of work involves exposing workers to noise employers are required to carry our risk assessment irrespective to the levels of noise. Employers can take measurements to identify the noise levels or information available through machinery suppliers can also be used together with the work patterns of workers for the purpose of this risk assessment. Risk assessment aims to determine if the exposure levels of workers reaches or exceeds the defined limit and action values. Towards identifying the mitigation measures a risk assessment is required to take into account the exposure levels of workers (e.g. level and duration of exposure), defined action and limit values, other indirect effects of noise on health and safety (e.g. warning signals), existence of quieter equipment, (if administered by employer) exposure to noise beyond working hours, information from health surveillance and availability of adequate hearing protectors. Risk assessment needs to be reviewed and updated periodically or if there is a change in the noise exposures.

4.8.3.2 Limitation of exposure

The directive enforces that exposure levels should never increase beyond the exposure limit values if that happens employers should take immediate actions to reduce the noise exposure levels. The reasons for such overexposures need to be investigated and preventive measures need to be implemented to avoid recurrence.

If the noise exposure exceeds the upper action values defined by this directive then employers should reduce the exposure to noise through technical or organisational measures.

4.8.3.3 Measures to Eliminate or Reduce Exposure

It is required by the directive that risks should be reduced or eliminated at the source if practicable. Otherwise risks can be reduced or eliminated through taking following into account:

- alternative working methods
- alternative equipment and machinery
- better workplace design and layout
- information and trainings to workers for correct use of equipment and to reduce their exposures
- technical measures to reduce noise emissions or propagation of noise (shields, enclosures, isolation, damping)
- maintenance of equipment and workplace
- better organisational planning in order to reduce risk through limited duration of exposure or adequate rest periods

4.8.3.4 Hearing Protection

Even though the technical and organisational measures are implemented, noise exposure exceeds the lower exposure limit then employers are required to make appropriate hearing protectors for eliminating the risks available for the workers. Employers are required to make usage of hearing protectors mandatory when exposure level reaches or exceeds the upper action levels.

4.8.3.4.1 Information and Training

The directive requires workers and/or their representatives to receive information and training when the lower exposure values are exceeded. The aforementioned information and training shall cover following:

- nature of risks
- measures taken for the elimination of risks
- exposure action and limit values of the directive
- results of risk assessment

- appropriate and effective usage of hearing protectors
- the importance and how to detect the signs of hearing damage and the way to report
- Health surveillance and its function
- Minimised noise exposure through safe work practices.

4.8.3.4.2 Health Surveillance

In order to detect the noise induced hearing loss at an early stage and therefore to protect the workers' hearing the directive places requirements on the health surveillance of workers. As a result employers are required to make preventive audiometric testing available for those workers whose noise exposure levels exceed the lower action values. If the exposure level of a worker exceeds the upper action value then it is a right of those workers to have hearing checks by a doctor. If the results of health surveillance show the existence of hearing damage due to exposure to work related noise, then that individual needs to be informed as well as preventive measures should be taken by the employer to eliminate the risks. Workers with similar noise exposures should be arranged for health surveillance.

Key provisions of the EU's noise directive is summarised in (Figure 4-16)

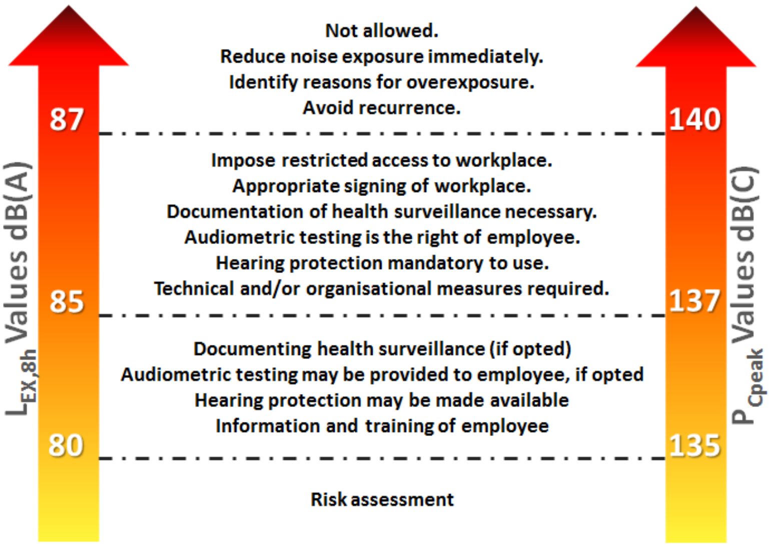


Figure 4-16: Summary of EU's noise control directive

4.8.4 Noise related norms specific for ships and human on board

This section will investigate and summarise the noise related norms specific to ships. In particular, noise control rules of International Maritime Organisation (IMO) and International Labour Organization (ILO) will be reviewed and described.

4.8.4.1 IMO Resolution A.468 (XII) - Code on Noise Levels on board Ship

In 1981, IMO issued Resolution A.468(XII): 'the code on noise levels on board ship' (IMO, 1981) in order to encourage noise control on board ships within the framework of international guidelines. The code aims to ensure safe working conditions for the crew on board in order to prevent them from the consequences of noise exposure, such as:

- Noise induced hearing loss
- Interference with speech communication
- Masking audible alarms
- Generation of additional stress and interference with decision making
- Lack of comfort and recovery

The code applies to the ships which are equal or bigger than 1600 gross tonnage (GT), code can also be applied to ships smaller than 1600 GT as far as practicable.

The code is not intended for the passenger spaces and does not apply to dynamically supported craft, fishing vessels, pleasure yachts not engaged in trade, and other specific vessels types such as; pipe-laying barges, crane barges, mobile offshore drilling units, ships of war and troopships, ships not propelled by mechanical means.

In order to achieve standard measurement procedures for the application and effectiveness of the code, measurement procedures described in detail covering the following aspects:

- Operating Conditions at Sea
- Operating Conditions at Port

- Environmental conditions
- Actual measurement procedure
- Measurement positions
- Measuring equipment and requirements

4.8.4.1.1 Maximum acceptable noise levels

The code defines the noise levels for each location as shown in Table 4-6 however it is also clearly stated in the code that that these are not suggested levels but the maximum allowed levels. The limit levels shown in Table 4-6 are A weighted noise levels.

Table 4-6: Limits on noise levels imposed by IMO resolution A.468(XII) (IMO, 1981)

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

4.8.4.1.2 Time exposure limits

The IMO Noise Code defines the exposure limits to ensure that the crew on-board will not be exposed to an Leq(24) exceeding 80 dB(A). In spaces where the noise level exceeds 85 dB(A) the use of hearing protection and/or the limitation of exposure in terms of time are prescribed. Figure 4-17 shows a detailed representation of exposure limits. As it can be seen in Figure 4-17, the graph is divided into zones and in each zone specific requirements on the duration of exposure as well as ear protection to be used are described.

Each zone requires specific action with regards to following two bullet points combined.

- **Time duration of exposure:**

  None (forbidden) / Occasional /Daily
- **Ear protection:**

  None / Muffs / Plugs / Muffs + plugs

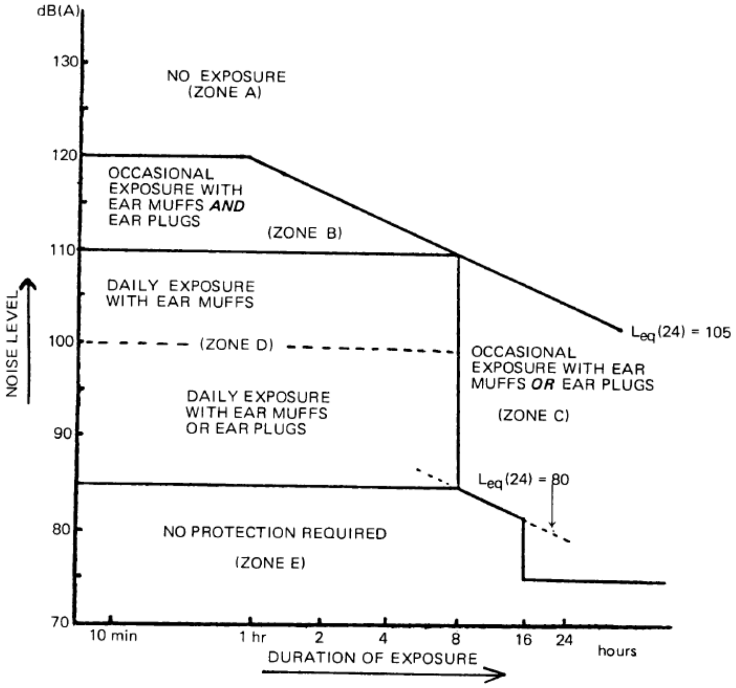


Figure 4-17: Allowable daily and occasional noise exposure zones – IMO A.468(XII) (IMO, 1981)

4.8.4.1.3 Hearing Conservation Programme

If the workers routinely work in areas where the noise levels are similar to zone D in Figure 4-17 then it is suggested that hearing conservation programme is to be implemented. Under the hearing conservation programme, the code prescribes to train seafarers to make them aware of the hazards of noise and to monitor ear acuity.

4.8.4.1.4 Ear Protection

In cases where noise cannot be mitigated to desired levels at its source through application of engineering controls, effective ear protection should be provided to seafarers who are entering into such spaces.

The ear protectors have to ensure the following insertion loss, expressed in terms of overall dB(A) reduction and dB reduction in frequency (Octave bands). The ear protectors are assumed in the code to provide the protection as given in Table 4-7.

Table 4-7: Protection provided by ear protectors (IMO, 1981)

Type	Protection
Ear plugs	- 20 dB(A)
Ear muffs	- 30 dB(A)
Ear plugs + ear muffs	- 35 dB(A)

4.8.4.2 New IMO Code on Noise Levels on Board Ships

At the IMO there has been a debate to update the current noise framework in the Maritime Safety Committee, who finalised the draft code on noise levels on board ships and published in the MSC 90th session report (IMO, 2012b). In MSC 91, the committee adopted the contents of the code on noise levels on board ships which came into force in 1st of July 2014. Main changes/updates that the new code will bring are discussed below;

Maximum acceptable sound pressure levels have been updated, with some minor changes in the definitions of the classes of spaces on board and a reduction of 5 dB of the limits in many of them. The new levels are shown in Table 4-8.

Noise exposure limits have been updated with the requirement that crew members should never be exposed peak values exceeding 135 dB(C) without protection. In terms of determining the noise exposure of crew members a simplified method has been described and included in the Appendix 4 of the code.

Table 4-8: Limits for noise levels (dB(A)) in the updated noise code (IMO, 2012b)

Designation of rooms and spaces	Ship size	
	1,600 up to 10,000 GT	≥10,000 GT
Work spaces		
Machinery spaces	110	110
Machinery control rooms	75	75
Workshops	85	85
Non–specified work spaces (other work areas)	85	85
Navigation spaces		
Navigating bridge and chartrooms	65	65
Listening posts, incl. navigating bridge wings and windows	70	70
Radio rooms (with radio equipment operating but not producing audio signals)	60	60
Radar rooms	65	65
Accommodation spaces		
Cabin and hospitals	60	55
Mess-rooms	65	60
Recreation rooms	65	60
Open recreation areas (external recreation areas)	75	75
Offices	65	60
Service spaces		
Galleys, without food processing equipment operating	75	75
Serveries and pantries	75	75
Normally unoccupied spaces		
Spaces not specified	90	90

Appendix 3 (Suggested Methods of Attenuating Noise) of the code has been updated by the inclusion of requirements on noise prediction at the design stage as well as the use of noise cancelling equipment.

In terms of warning notices, an example, which can be used on-board, is provided in Table 4-9.

Table 4-9: Example of warning notice suggested in the code (IMO, 2012b)

Signs at the entrance to noisy rooms	
80-85 dB(A)	high-noise level – use hearing protectors
85-110 dB(A)	dangerous noise – use of hearing protectors mandatory
110-115 dB(A)	caution: dangerous noise – use of hearing protectors mandatory – short stay only
>115 dB(A)	caution: excessively high-noise level – use of hearing protectors mandatory – no stay longer than 10 minutes

4.8.4.3 SOLAS International Convention for the Safety of Life at Sea

The SOLAS Convention is issued by IMO and generally regarded as the most important of all international treaties concerning the safety of merchant ships. The first version of SOLAS was adopted in 1914 and amended several times until 1974 (IMO, 1974).

Relevant section of SOLAS with the provisions to noise control is contained in Chapter II-1 part C Regulation 36 with title “Protection against noise”.

In the Regulation 36, it was required to take measures to reduce machinery noise in machinery spaces to acceptable levels as determined by the Administration. If the noise reduction at the source cannot be achieved then appropriate insulation should be applied or refuge from noise should be provided for crew. Ear protectors should be made available for the crew entering such places with high noise levels.

However, there was no link between the SOLAS and aforementioned IMO Noise Code before. Therefore, the Noise Code was not treated as mandatory. The issue has been recognised and SOLAS is reformulated to make the noise limits mandatory through introducing the new regulation II-1/3-12 which requires new ships to be constructed in accordance with the revised Noise Code which sets out mandatory maximum noise level limits for ship spaces. As a result, the new IMO Noise Code supersedes the previous non-mandatory Code, adopted in 1981 by resolution A.468(XII).

4.8.4.4 ILO Maritime Labour Convention (MLC)

ILO prepared its Maritime Labour Convention (ILO, 2006) in order to achieve decent working conditions for seafarers. In order MLC to come into force it was required to be ratified by at least 30 member states representing minimum 33 per cent of world gross tonnage which was reached on 20th August 2012. The MLC will come into force on 20th August 2013. MLC covers wide range of factors to achieve the intended aim of better working conditions for seafarers. Relevant regulations on noise are described below.

In the MLC, Guideline B.3.1.12 (Prevention of noise and vibration) requires accommodation and recreational facilities, are to be placed as far as practicable from the main noise sources. Acoustic insulation materials are required to be used in the noisy areas and structures. In order to protect engine room personnel, sound proof control rooms should be provided and preventive measures should be taken to reduce noise emissions. For the noise limits the MLC refers to the previously discussed ILO code of practice - Ambient factors in the workplace (ILO, 2001).

Moreover, in Guideline B4.3.2 (Exposure to noise) the health and safety protection requirements for noise exposure state that the competent authority is to review the problem of noise on board ships in a continuous manner aiming for better protection for seafarers from the hazardous noise exposures. This review should take into account the effects of noise exposure on hearing health and comfort of seafarers. Following measures are requested to be considered:

- Seafarers should be instructed on the bad effects of noise exposure and proper use of hearing protection

- Hearing protection devices should be provided for the seafarers
- Exposure levels to noise should be decreased and risks should be assessed.

4.8.4.5 International Noise [ISO] standards

In the last 20 years, International Organization for standardization (ISO) put a lot of effort into the standardization of industrial acoustics and occupational noise. A recent review of European and International standards relevant to noise control at the workplace is conducted by Jacques (2009). In this review the relevant ISO standards are grouped in 3 categories.

- Noise sources: ISO 11688 (design low noise machinery), ISO 3740, ISO 9614 and ISO 11200 (measurement of noise emission from machinery), ISO 4871 (noise declaration)
- Noise Reduction along propagation path: design of technical means and measurement of performance
- Workplace noise: ISO 11690 (design low-noise workplaces), ISO 14257 (characterization of acoustical performance of rooms), ISO 9612 (measurement of occupational noise exposure)

These standards were adopted as European standards, and as national standards by many countries. The standards are mostly generic and applicable to all different areas. The details of ISO standards will not be discussed in detail hence they are well adopted into the regulatory framework discussed before. However, Table 4-10 summarises the relevant ISO noise standards.

Table 4-10: List of relevant ISO standards

Standard	Title Acoustics
Generic standards	
ISO 1999:1990	Determination of occupational noise exposure and estimation of noise-induced hearing impairment
ISO 1996-1:2003	Acoustics – Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures
ISO 1996-2:2007	Acoustics -- Description, measurement and assessment of environmental noise -- Part 2: Determination of environmental noise levels
ISO/TS 15666:2003	Acoustics -- Assessment of noise annoyance by means of social and socio-acoustic surveys
Generic machinery standards	
ISO 11688-1	Low noise design: a recommended methodology for low-noise design
ISO 11688-2	Low noise design: a handbook on noise generation mechanisms in machinery
ISO 3740 series	Noise emission measurement: determination of the sound power level using sound pressure level measurements; Determination of sound power levels of noise sources -- Guidelines for the use of basic standards
ISO 9614-1 and 9614-2	Noise emission measurement: determination of the sound power level using sound intensity measurements
ISO 11200 series	Noise emission measurement: emission sound pressure level at workstations, with a variety of accuracy grades and in a variety of environments
ISO 11689	Comparison of noise emission values: a method for processing noise emission data made available through noise declarations by manufacturers
ISO 4871	Noise declaration and verification of declared values; integrates in a simple manner the sophisticated information developed in ISO 7574 series
ISO 2923:1996	Acoustics -- Measurement of noise on board vessels
In situ standards for employees	
ISO 11690-1	Low-noise workplaces design: recommended practice: ways to reduce noise and recommended noise control strategies

Standard	Title Acoustics
ISO 11690-2	Low-noise workplaces design: recommended practice. The various technical means available for reducing noise in situ a the source, on the transmission path and a the workstation itself
ISO 11690-3	Low-noise workplaces design: recommended practice. The assessment of the acoustical behaviour of industrial rooms and basics on room acoustics. Predictive acoustics methods
ISO 14257	Room acoustics: spatial sound distribution curves
ISO 11546-1	Measurement of acoustical performance of noise-attenuating devices. Methods for determining the sound insulation of machinery enclosures: laboratory conditions
ISO 11546-2	Measurement of acoustical performance of noise-attenuating devices. Methods for determining the sound insulation of machinery enclosures: in situ
ISO 11957	Measurement of acoustical performance of noise-attenuating devices. The laboratory an in situ determination of the sound insulation performance of cabins
ISO 11691	Measurement of acoustical performance of noise-attenuating devices. The acoustical performance of silencers: a survey method for the laboratory measurement of the insertion loss of ducted silencers without flow
ISO 11802	Measurement of acoustical performance of noise-attenuating devices. The acoustical performance of silencers: In situ determination of the insertion loss or the transmission loss of silencers.
ISO 11821	Measurement of acoustical performance of noise-attenuating devices. A method for determining in terms of insertion loss the in situ acoustical performance of removable screens
ISO 15667	Design of noise-attenuating devices: the design of enclosures and cabins
ISO 14163	Design of noise-attenuating devices: the design of silencers
ISO 9612	Noise exposure measurement at the workplace.

4.8.4.6 Comfort Classes by Classification Societies

Classification societies are objective bodies that inspect and control the production, maintenance and condition of a ship, provides statuary services as well as assisting stakeholders of maritime industry. The role of classification societies have been recognised by the IMO in its SOLAS convention (IACS, 2011). Class societies introduced comfort notations to ensure the wellbeing and comfort of human on board through utilisation of international standards which are already in application. Comfort class rules developed by each classification society in order to ensure the comfort on board ships can be realistically achieved with regards to noise and vibration. In their comfort class rules, classification societies provide the noise and vibration criteria which ships are required to fulfil in order to obtain the desired grading. However, the number of grading and the types of ships that these rules apply to differ from one classification society to another. Table 4-11 shows the number of grading and application area for each comfort class adopted by class societies.

Table 4-11: Summary of Comfort Class Rules by each Classification Society

Classification Society	Grading	Grading Description	Application
American Bureau of Shipping (ABS)	2	COMF, COMF+	New and existing passenger vessels carrying more than 12 passengers
Bureau Veritas (BV)	3	1,2,3	New and existing passenger vessels without restriction
Det Norske Veritas (DNV)	3	1,2,3	No restriction on ship types for the application of the rules
Germanisher Lloyd (GL)	5	E,1,2,3,4	This notation is applicable to passengers' vessels of more than 120 m
Lloyd's Register (LR)	3	1,2,3	These rules address two types of ship: - Passenger (e.g. cruise ships, ro-ro ferries) - Cargo (e.g. container ships, tankers) No length limitation
Registro Italiano Navale (RINA)	3	A,B,C	The requirements apply to conventional passenger and cargo ships. For ships less than 65m special consideration will be given by the Society.

It can be seen that, the comfort class rules generally are intended for the application to passenger vessels, where comfort is a commercially important standard. Even though most of the classification societies define 3 grades for their comfort classification as can be seen from Table 4-11 ABS defines 2 grades where GL introduces 5 different grades for comfort classification. A relevant study has been conducted in EU FP7 SILENV Project (SILENV, 2010) in order to compare the noise criteria defined in the classification society’s comfort notations. The following table (Table 4-12) is adopted from the aforementioned study to depict the commonalities and differences between comfort notations for passenger areas.

Table 4-12: Comparison of Noise Criteria for passenger spaces

	Grade 1								Grade 2								Grade 3					
	ABS		BV	DNV	GL		LR	RINA	ABS		BV	DNV	GL		LR	RINA	ABS	BV	DNV	GL	LR	RINA
	1	2			E	1			1	2			2	3						4		
Passenger first class cabins	45	-	45	44	44 48	46 50	45	45	45	-	47	47	48 52	50 54	47	50		50	50	52 56	50	55
Passenger standart cabins			49	49	46 52	48 54	49	50			53	52	50 56	52 58	52	55		56	55	54 60	55	60
Outside installations (swimming pools, sport desks. Promenade desks..)	65	70	65	65	64	66	67 70	65	65	70	70	65	68	70	72 75	70		75	70	75	72 75	70
Discotheque, ballroom	60	55	65	55	52 56	54 58	55	55	60	55	68	58	56 60	58 62	58	60		72	62	60 64	62	65
Restaurant, lounge	55		55						55		58							62				
Libraries	55		53				50	52	55		56				55	57		59			60	63
Theatre	60							55	60							60						65
Shops	55	65	60				60		55	65	63				62			65			65	
Gymnasium	65						55		65						58						62	
Corridors	60	65			54	56		60	60	65			58	60		65				62		70
Staircase					56	58							60	62						64		
Hospital	45	55	55	55	54	56	50	50	45	55	57	55	58	60	55	55		60	60	60	60	60

4.9 Discussions

Throughout the whole literature review conducted in this PhD study, it is evident that there is a lack of noise related human response studies on ships. Moreover, noise awareness in the maritime industry is very low which makes the matter more critical for the efficiency and safety of shipping operations as well as for the health and wellbeing of seafarers and passengers on board.

When dealing with noise with regards to human response, not only the intensity of noise is important but also the frequency components which should be considered. Therefore, any noise measurements related to the human response should capture the full noise spectra which can then be processed to reflect different weighting factors. However, without the recorded noise spectra such investigations are not possible.

In terms of the auditory health effects of noise, the intensity and the exposure duration are the two very important factors. The literature on the auditory health effects of noise is very rich and there seems to be a global understanding/agreement on this matter. As a result exposure-response relationships have been developed and findings are well integrated into current norms. Therefore, it was considered as unnecessary to focus on further researching the auditory health effects of noise in this PhD study.

However, even though current norms well integrate the aforementioned health effects into their criteria it needs to be mentioned that current compliance of ships with these noise regulations is questionable since there is no studies identified in the literature reporting the crew noise exposure levels on board ships. Moreover, due to aforementioned lack of awareness and knowledge on noise, development of a simple tool to calculate/estimate noise exposure levels of crew on board ships is considered to be useful.

This chapter reviewed and reported current regulations extensively. From this review it is obvious that the methodology of each regulation is similar. In general, each regulation aims to cover noise exposure related risk, limitations of exposures, and usage of hearing protection. Even though all regulations follow similar logic, for this PhD study two of the existing noise norms (namely; EU Physical Agents Directive and IMO’s Noise Code) were found more interesting to focus on. EU’s noise regulation is the most recent and defines the limits on human exposure levels. On the other hand, IMO’s noise code defines limit values for compartments and presumes that when these limits are complied with human noise exposures will be within the acceptable limits. It is possible to say that, EU’s approach is the safer since it always suggests monitoring the human exposure and prevents hazardous noise exposures. EU physical Agents Directive should be encouraged to be followed during the operational life of the ships. However, with current levels of awareness and understanding it is very optimistic that any ship will be continuously monitoring or assessing the exposure levels. Therefore, IMO’s approach can be considered as an effective tailored solution for shipping that limits the noise emissions at each compartment of the ship at the design stage hence aims to achieve acceptable levels of noise exposure. However, following points can be considered as problematic with IMO’s approach,

- IMO’s noise limits are currently overrun by the Classification society’s norms as well as ship owner’s requirements.
- The hearing protection levels defined in IMO’s noise code is too optimistic.
- It is likely that the noise levels in ships to increase during operational life of the ships. Therefore, noise levels are needed to be re-tested during the operational life of the vessel.
- Especially for accommodation areas, such as cabins more stringent noise limits could have been defined. Because solutions are available to achieve lower levels which are already in use by many ships.
- IMO’s location definitions are open to interpretation. IMO should make it clearer by providing detailed list of location type examples.
- Once ships comply with the compartment based requirements of the IMO’s noise code it seems like the developed documentation takes its place on the

shelf and never been referred to or updated during operational life of the ship.

Hence, at least for EU ships, both EU and IMO approach should be used in a hybrid way.

Review of regulatory framework also revealed that regulatory framework considers the health effects of noise exposure and do not consider the performance or comfort aspects. Hence, creating scientific findings and facts in this area may assist regulators to take those factors into account when defining noise limit values for compartments.

On the other hand, review of the existing research studies shows that there is sufficient evidence that noise exposure have various other effects on human, including communication interference, stress, annoyance, sleep disturbance, fatigue etc. This proves that more importance should be given to lower the noise limits if these effects also observed on board ships.

However, it was also observed that there is an inconsistency in the findings of different studies which researched the effects of noise on performance. This is due to the fact that effects of noise exposure on performance are also affected by the type of task being observed. This situation makes it necessary to conduct more noise related human response studies in the maritime domain.

Moreover, it was also identified that for a specific task, human response is affected by two main factors; (1) physical quantities of noise (2) Psychosocial factors of individuals. Additionally, these individual factors tend to change from one community to another and there is a variety of factors reported in the literature. Therefore, when modelling human response to noise on board ships it is important to apply a questionnaire capturing various explanatory factors so that the meaningful ones can be utilised in the models.

Existing models were also investigated and it appears that the estimations made by different models are not consistent. This is another proof that the models predictions are only valid for the specific cases that their data is collected from. Therefore, the predictions are varying from one to the other. This necessitates the development of human response models for the noise on board ships.

In terms of ‘noise vs human response’ research, two types of approaches exist; one is experimental investigation while the other is through field studies (e.g. collection of subjective feedbacks of human from a community). Both approaches are valid and had advantages and disadvantages;

- Experimental studies may provide more accurate observations of the effects since most of the other factors likely to affect human response are tried to be controlled.
- Experimental studies are more expensive and it is more difficult to attract participants to take part in an experimental study.
- Field studies are more cost effective and more data can be generated in a more cost effective way to develop more accurate models.
- The data collected from field studies reflect the real life conditions, hence, the collected response are considered to be more realistic than the ones artificially generated in laboratory experiments.
- However, the human response data collected from the field studies may be affected by other influencers of human response. Hence, the collected data and developed models are specific to the community that they belong to.

Therefore, in this PhD study firstly, an experimental study will be designed to research the effects of noise exposure, then a field data collection study from different ships will be organised to generate a database of ‘noise vs human response’. Finally, obtained data will be used to model the human response to noise on ships.

4.10 Chapter Summary

In this chapter, existing noise related norms and previous research studies focussing on the human response have been reviewed. The lack of global agreement on the non-auditory effects of noise was attributed to the fact that the findings of each research is specific to the type of task being investigated, the characteristics of the community being observed, the type and intensity of the background noise. Therefore, it was shown that there is an urging need for conducting similar human response to noise studies in maritime domain since the findings of other studies from different sectors are not directly transferable to shipping. It was also observed that regulatory norms should be updated to consider the factors like performance and wellbeing due to exposure.

Chapter 5. APPROACH ADOPTED

5.1 Chapter Overview

This chapter briefly defines the approach adopted to achieve the aims and objectives (Chapter 3) of this PhD research study. The approach adopted in this study consists of the following: (1) Literature review; (2) Analysis of the current situation on board ships related to noise; (3) The design of controlled experiments to reveal the potential effects of noise on crew performance; (4) Model human response to noise, through the collection of human response data with simultaneous noise measurements; (5) Compare the model results with the current shipboard noise criteria. Each phase is further explained in the subsequent sections.

5.2 Mind Map of Approach Adopted

In Chapter 2, a brief overview of the related human factors topics was presented. Results of this review revealed the specific issue of 'human response to noise on board ships' has not received sufficient attention in the maritime domain. Therefore, this topic was chosen to be addressed within this thesis. In order to address the identified gap and achieve the defined aims and objectives of this study, it was important to establish a clear and simple strategy. Human response to noise is a complex topic which was never studied before in the maritime domain. In the absence of a proven methodology in studying the human response to noise, this PhD study adopts an approach which will examine different techniques in order to ensure that a foundation of human response to noise can be built which will be applicable to the maritime domain. Hence, a simple mind map (Figure 5-1) of the approach adopted in this thesis was created. As it can be seen, each step shown in the mind map is representing a different phase of this PhD study.

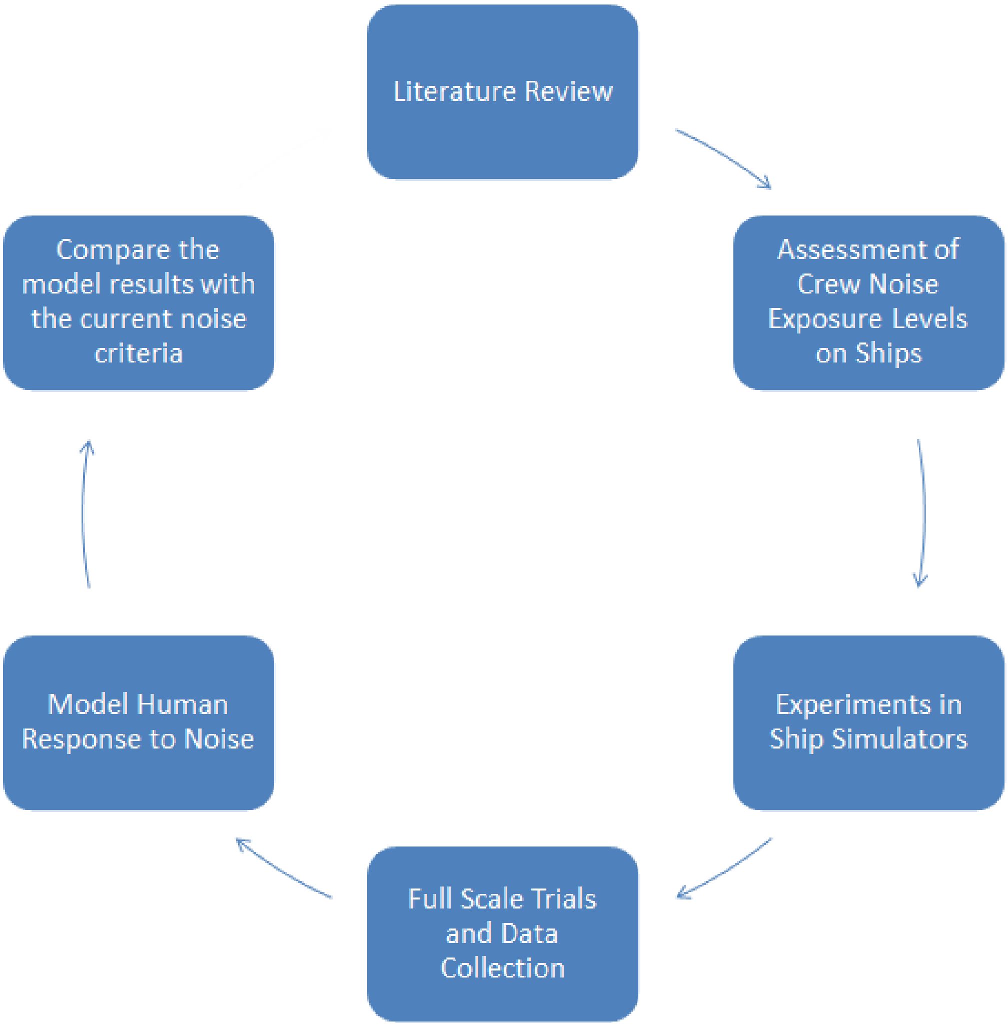


Figure 5-1: Mind map of the PhD study

5.3 Literature Review

Before proceeding with the experimental investigations, field studies and statistical modelling which are planned in this PhD study, it was important to conduct a detailed literature review in the topic: 'human response to noise'. Earlier in this thesis, it was mentioned that there was almost no studies identified in the literature addressing the effects of noise on board ships. Therefore, lessons learnt from the research conducted in other industries needed to be investigated in order to take into account all the important factors identified before.

In order to set up a valid experimental study in an on-board ship environment the methods of experimental design was reviewed and utilised in the ship simulator based noise experiments. Experimental studies in the literature were also investigated with the aim of identifying the available objective and subjective measures of human response to noise. Appropriate applicable measures were integrated into the experiments conducted in this study.

Existing models in terms of the human response to noise were studied to understand the mathematical representation of these models as well as the different components and variables included in these models. Differences in models were considered with the potential of implementing successful features in the new model which will be developed in this study.

Moreover, it was also imperative to obtain a reasonable understanding on the requirements of current applicable noise standards. Hence, the approach of current regulatory framework can be understood and limitations can be identified.

5.4 Analyse the current situation on-board ships related to noise

When protecting the human health from the hazardous effects of noise exposure in a workplace, there is a common agreement and approach of different regulatory norms which differ little. However, when compared to land-based workplaces, ships have unique problems that needed to be considered. High noise levels inside ships combined with the extended working hours of crew, inappropriate resting conditions and the lack of awareness make the problem of noise exposure on ships more serious than those workplaces in land-based sectors. Moreover, due to the remoteness of shipping, it is also difficult to closely monitor the noise exposure conditions on board ships. Since, there was no previous reference for noise exposure assessments on ships identified, it was considered necessary to investigate the current situation on board ships and demonstrate the problem in terms of noise exposure.

A field study was conducted to measure noise levels on 6 different tanker ships. The collected noise measurements were cross referenced with the crew’s work patterns on tanker ships Then, the noise exposure levels of the crew were calculated and compared with the defined industry limit levels. Exposure calculations were done according to the methodology of the EU Physical Agents Directive and the IMO's Noise Code.

5.5 Design and conduct controlled experiments to reveal the potential effects of noise on crew performance

Most of the studies in the literature try to understand the effects of noise exposure on human performance through conducting controlled laboratory experiments. However, during the progress of this thesis no studies were identified in the literature which investigated the effects of noise in a ship environment. Moreover, understanding the complex issue of human performance under noise requires controlling the other factors which may affect the performance. Therefore, an experimental study was designed and conducted in a full mission ship bridge simulator. After reviewing previous studies and key concepts of experimental design the following was decided;

- Minimum of 20 subjects to be involved in the experiments
- Standard instructions to be given to the subjects but they are not to be informed about the main aim of the study
- Each subject should take the experiment 3 times under different noisy conditions but they are restricted to take one experiment a day in order to prevent cumulative effect.
- The order of experiments are to be counterbalanced to counteract the learning effect
- The following measures are decided to be used to monitor performance; (1) Subjective feedback through a questionnaire, (2) Vigilance performance through a Peripheral Detection Task (PDT), (3) Passage performance through analyses of the ship's route from radar.

The collected human response data will be analysed to show the potential relationships between noise and human performance. Statistical tests will be conducted to show the reliability of the relationships reported.

5.6 Full scale trials and data collection

After establishing significant relationships between noise exposure and human response, efforts will be focussed on the development of models predicting the human response to noise on ships. Such models can only be developed when there is enough human data available of different noise levels. Therefore, questionnaires will be developed and applied on board ships together with simultaneous noise measurements. This task will be implemented with the support of the EU FP7 SILENV Project. Noise measurements were conducted on 15 different commercial vessels together with the application of questionnaires.

Two sets of questionnaires were developed; comfort questionnaires and performance questionnaires. Comfort questionnaires were applied to passengers and crew members when they were off-duty. Performance questionnaires were applied to crew members when they were on-duty.

5.7 Model human response to noise,

The collected human response ratings will be organised and analysed via the SPSS statistical programme. In order to select the dependent variables which will represent human comfort and performance, first the variability of the collected responses will be investigated. Then, the correlation analysis and finally and factor analysis will be investigated.

The selected dependent variables (e.g. noise annoyance) and explanatory variables (e.g. age, gender) will then be modelled statistically by visiting linear regressions, ordinal logistic regressions and binomial logistic regressions. Models with a good fitness and highly significant model parameters will be obtained. Comparisons of the model results with the current noise regulations applicable to ships will be made.

The developed models are envisaged to be the first of a kind in maritime sector. They will allow for the estimation of the human response to the noise levels on ships providing a tool for the designers to take the resulting human response into account at the design stage of the ships. Another area that the models are envisaged to be utilised in is the development of a human oriented noise criteria. Therefore, the models will be used to assess the effectiveness of a current norm. The IMO’s noise code will be selected as being the most relevant noise standard applicable to ships. The IMO’s noise limits for each compartment will be taken and assessed in regards to human comfort and performance levels that could be achieved if the ship was built in compliance with IMO. The results will be investigated and based on the outcomes of this study a new human oriented noise criteria will be proposed.

5.8 Chapter Summary

The approach adopted for this PhD study was briefly reported in this chapter. The methodology was presented in terms of following major phases; (1) Literature Review, (2) Analysis of the current situation on-board ships related to noise, (3) Conducting controlled experiments to reveal the potential effects of noise on crew performance, (4) Development of human response models to noise and (5) Comparison of the model results with the current noise regulations and proposal of a new criteria.

Chapter 6. CREW NOISE EXPOSURE ON BOARD SHIPS AND COMPARATIVE STUDY OF APPLICABLE STANDARDS

6.1 Chapter Overview

In this section, the aim is to investigate the noise exposures of crew on board ships against the applicable regulations and provide a foundation for the rising concern of noise on board ships. This chapter will outline a field study in which noise levels of compartments in chemical tankers have been recorded and cross-referenced with crew work patterns obtained through a questionnaire. The resulting noise exposure levels of the crew have then been calculated, analysed and compared to the relevant noise exposure criteria.

6.2 Background

In order to assess the noise exposure levels of crew on board a ship during normal operation, there are two main factors which need to be known.

- Firstly, what are the noise levels in an area where the crew inhabit and work.
- Then, what is the time spent by the crew in that location.

Gathering this information is rather more complicated than it seems, because the noise levels on board a ship fluctuates rapidly from one location to another. Even within the close vicinity of the same location, the noise level can change dramatically depending on the operational and environmental conditions. For example, in the machinery area the crew can be exposed to a wide range of noise levels in close proximity; ranging from the engine room where noise levels can be above 110 dB(A), to the much quieter control room. On the other hand, crew members never stay stationary in the one location for the whole day. Instead, they are moving around different locations of the ship to fulfil responsibilities on board.

6.3 Methodology of Study

In order to address the issues mentioned above, a methodology for the proposed study of investigating the noise exposures of crew on board ships against the applicable regulations noise levels was created. The methodology can be defined by three main sections; Identification of crew work patterns, Noise measurements and Analysis (Figure 6-1).

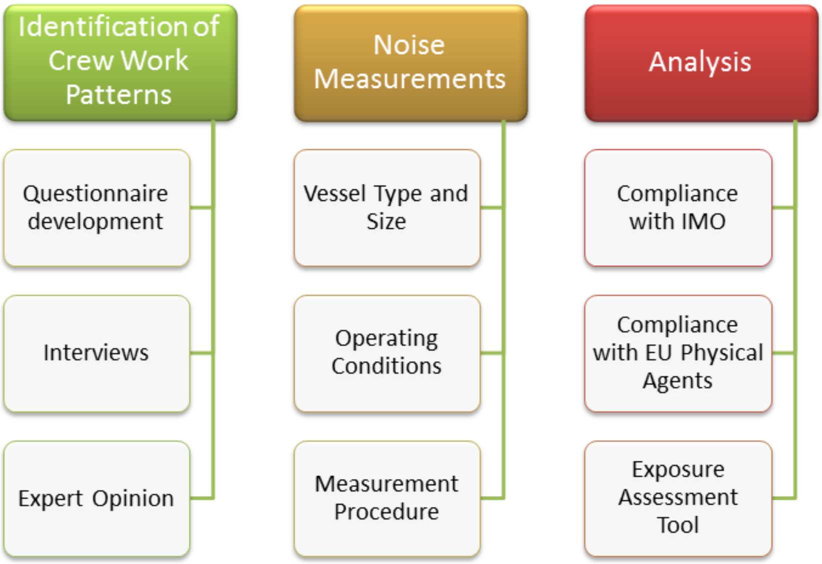


Figure 6-1: Overview of the study

In this study, the vessel selected for purpose of implementing the methodology mentioned above was oil/chemical tanker vessels, which are selected due to author's accessibility to those types of vessels and their crew.

6.3.1 Identification of crew work patterns

The definition of crew work pattern in the context of this chapter refers to the locations and timings spent by each crew within those locations on board over a 24 hour period. Timings and locations include all activities of the crew when on and off duty. In order to identify the crew work patterns of the various ranks of crews on board a review of available literature and resources was conducted. The purpose was to investigate the existence of data that showed the average times and locations in which the crew spends time on board ships on a daily basis.

Unfortunately, this data was not available. The only available information was the tables of ‘seafarers' shipboard working arrangements and formats of records of seafarers hours of work and rest’ required by the ILO’s Convention N. 180 (Seafarers' Hours of Work and the Manning of Ships Convention) and IMO's STCW Convention, 1978. However, this data only recorded overall work and rest times at sea and in port and did not include a breakdown of the locations and timings of places worked on board.

Therefore, the decision was taken to develop and distribute a questionnaire to capture the work patterns of crew members. The questionnaire created was a simple matrix in which participants were asked to input the amount of time they had spent in each predefined workplace categories over a 24-hour period. The workplace categories in the questionnaire had been developed, in cooperation with seafarers and maritime educators, to ensure all locations on board ships were appropriately represented.

The questionnaire was distributed to 80 seafarers working on oil/chemical tankers, and a return rate of 32.5% (26 questionnaires) was achieved. Results of the questionnaire are displayed in Table 6-1. For each workplace category and rank, the results of all the respondents have been averaged to give an overall average representation of how much time each rank off crew member spends in each location on board a generic chemical tanker.

It should be noted that the reliability of the work patterns identified in Table 6-1 depend on the quality of the responses. For example, for the role ‘Oiler’ it was estimated that 8 hours were spent in engine room, however in reality the actual time spent is most likely less. While some results shown in Table 6-1 have a high error margin due to a small number of respondents, the methodology remains valid.

Table 6-1: Work –Patterns of Crew (in hours)

Role	Bridge	Engine Room	E/R Other	Cargo Control Room	Galley	Cabinet	Mess room	Main Deck / Cargo Area	Accommodation Other Areas	Forecastle	Aft Deck	Upper Decks (Lifeboat-etc)	Other	Total
Master	5.00	0.14	0.08	1.00	0.04	10.40	2.02	0.90	0.50	0.08	0.08	0.08	3.68	24.00
1st Officer	7.80	0.08	0.12	2.10	0.18	8.06	2.00	1.50	0.22	0.46	0.28	0.38	0.82	24.00
2nd Officer	8.40	0.04	0.04	1.40	0.00	8.10	2.30	1.20	0.22	0.32	0.48	0.48	1.02	24.00
3rd Officer	8.50	0.04	0.04	1.40	0.00	8.18	2.30	1.00	0.32	0.28	0.28	0.64	1.02	24.00
Chf. Engineer	0.44	4.80	1.96	0.44	0.12	10.02	2.20	0.24	0.50	0.04	0.06	0.06	3.12	24.00
2nd Engineer	0.02	7.90	2.10	0.50	0.12	9.52	2.30	0.44	0.48	0.02	0.04	0.14	0.42	24.00
3rd Engineer	0.00	8.13	1.63	0.25	0.00	9.75	2.88	0.43	0.43	0.00	0.00	0.03	0.50	24.00
Boatswain	1.84	0.10	0.02	0.34	0.02	9.26	2.80	7.20	0.54	0.78	0.62	0.28	0.20	24.00
A/B Seaman	4.00	0.00	0.00	0.10	0.02	9.22	3.00	5.40	0.44	0.76	0.60	0.26	0.20	24.00
O. Seaman	4.00	0.00	0.00	0.10	0.02	9.22	3.00	5.40	0.44	0.60	0.76	0.26	0.20	24.00
Pumpman	0.67	0.17	0.03	0.60	0.03	9.83	2.67	8.00	0.40	0.37	0.63	0.10	0.50	24.00
Donkeyman	0.00	6.33	3.00	0.03	0.03	10.60	3.00	0.20	0.40	0.00	0.00	0.07	0.33	24.00
Oiler	0.00	8.00	1.75	0.25	0.00	9.75	3.00	0.28	0.43	0.10	0.10	0.10	0.25	24.00
Cook	0.02	0.00	0.00	0.00	9.20	10.10	3.40	0.10	0.70	0.04	0.08	0.08	0.28	24.00
Steward	0.08	0.00	0.00	0.00	3.40	9.86	4.60	0.02	5.76	0.00	0.02	0.04	0.22	24.00
Deck cadet	8.50	0.00	0.00	0.50	0.00	7.00	3.00	1.00	0.00	0.50	0.50	1.00	2.00	24.00
Engine cadet	0.00	8.00	2.00	0.50	0.00	9.00	3.00	0.50	0.50	0.00	0.00	0.00	0.50	24.00

6.3.2 Noise Measurements

The exposure level of a worker is typically calculated by the use of a noise dosemeter. This is a specialized sound level meter that logs the noise level information throughout the working shift or a period of time (CCOHS, 2004). For the purpose of this study, a dosemeter could have been used to assess the 'real time' exposure levels of the crew, but due to limitations in access to seafarers this was not practicable. Therefore, the decision to record fixed point noise level readings of various compartments on board various ships using a handheld sound level metre was made.

While the 'real time' exposure levels of the dosemeter would reflect the high and low noise extremes in addition to the overall average noise level of the crew's daily routine more accurately and realistically, utilising a constant noise level recording was deemed to provide an appropriate representation of noise levels on board.

In this study, six oil/chemical tanker ships of similar sizes and design speed have been selected to measure the sound levels of various compartments on board (Table 6-2). While it is generally accepted that even in sister ships noise levels can differ significantly, due to many different reasons such as; construction, equipment, maintenance etc., an attempt to bring similar and comparable noise levels can be at least made in the selection of vessels of similar sizes and design speeds.

Table 6-2: Details of the vessels used in this study

No	Ship Type	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

All the vessels listed in Table 6-2 were new vessels, and the noise measurement studies were carried out during sea trials. During the measurements, the ships were in a fully loaded condition and cruising at design speed. The vessel's speed was monitored and validated by an independently verified Global Position System (GPS). In Figure 6-2 some pictures from one of the sea trials can be seen.

Figure 6-2: Pictures from one of the noise measurement campaign

During the trials, the air conditioning and ventilation systems were in operation. During the measurements, crew members were either not in the measured room or were asked to stay silent. All sea trials were conducted on a calm day to minimise the effect of external factors. For reference, measurement conditions were recorded. An example is shown in Table 6-3.

Table 6-3: Measurement Conditions

Heading	Value
Condition	
Draught forward	4.4 m
Draught aft	5.6 m
Depth of water under keel	Deeper than 100 m
Ship Course	270°
Weather conditions	
Wind force (direction + velocity)	Calm
Sea state	Calm
Performance	
Propulsion machinery power	9840 kW(100% MCR)
Main engine/Propeller rpm	127 rpm/127 rpm
Number of propulsion machinery units operating	1

Heading	Value
Auxiliary Equipment	
Number of diesel auxiliary engines operating	1
Other auxiliary equipment operating	0
Shaft generator	N/A
Ventilation	Operating
Engine Room Fans	Operating
Air Condition	Operating

The noise measurements were conducted with a sound level metre (Bruel Kjaer Hand Held Analyser Type 2250). All decks in the accommodation and work areas were surveyed and recorded for noise levels. For each measurement point, the sound level meter was positioned in the middle of each compartment or room. After 30 seconds of data acquisition, the obtained data was averaged automatically by the device. Therefore, the noise levels recorded for each measurement point are average weighted dB(A) values for that duration. The recorded noise levels were plotted on the ship's general arrangement plan. An example can be seen in Figure 6-3.

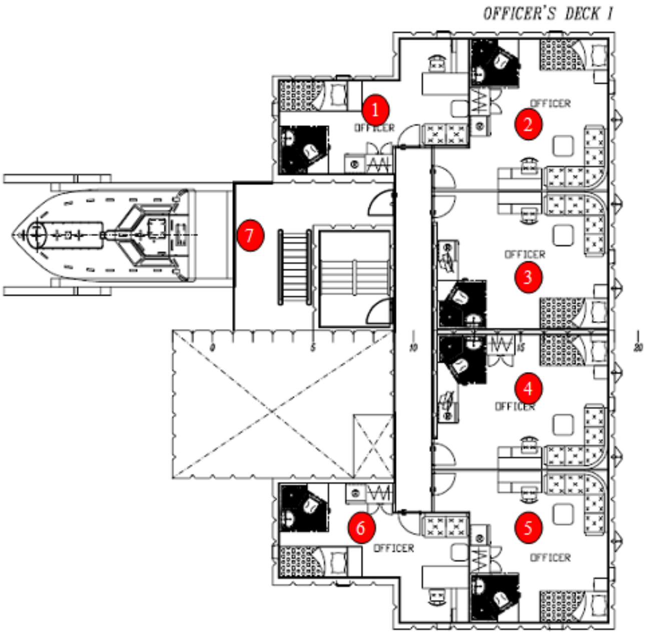


Figure 6-3: Measurement locations plotted on general arrangement plan

The results of noise measurements are shown in Table 6-4 and Table 6-5

Table 6-4: Summary of noise measurements for ship no 1-3

	Ship No 1		Ship No 2		Ship No 3	
Point No	**Place of Measurement**	**Measured Value dB(A)**	**Place of Measurement**	**Measured Value dB(A)**	**Place of Measurement**	**Measured Value dB(A)**
1	Wheel house CL	58.7	Wheel house CL	58	Wheel house CL	59
2	Wheel house Port	58.2	Wheel house Port	58	Wheel house Port	58
3	Wheel house Stb	57.9	Wheel house Stb	58	Wheel house Stb	58
4	Communication	58.9	Radio station	57	Communication	60
5	Chart Room	61.8	Chart Room	56	Chart Room	59
6	Pilot Room	57.8	Pilot Room	55	Pilot Room	59
7	Chief Officer Saloon	54.1	Lifeboat Station	75	Chief Officer Saloon	52
8	Chief Officer Bedroom	59.1	3rd Officer's Room	61	Chief Officer Bedroom	50
9	Chief Engineer Bedroom	53.2	Chief Officer's Room	57	Chief Engineer Bedroom	55
10	Chief Engineer Saloon	58.6	Captains Saloon	55	Chief Engineer Saloon	54
11	Captains Saloon	54.2	Captains Bedroom	57	Captains Saloon	50
12	Captains Bedroom	58.2	Chief Engineer Bedroom	54	Captains Bedroom	51
13	Owners Bedroom	55.1	Chief Engineer Saloon	56	Owners Bedroom	59
14	Owners Saloon	57.3	2nd Engineer	57	Owners Saloon	56
15	Hospital	54.3	3rd Engineer	60	Hospital	60
16	3rd Officer	55.5	Crew Room	58	3rd Officer	55
17	2nd Engineer Bedroom	55.2	Crew Room	59	2nd Engineer Bedroom	57
18	2nd Engineer Saloon	54.4	Crew Room	58	2nd Engineer Saloon	53
19	Electrician	54.2	Crew Room	57	Electrician	54
20	3rd Engineer	56.6	Crew Room	55	3rd Engineer	54
21	2nd Officer Bedroom	55.4	Crew Room	54	2nd Officer Bedroom	54
22	2nd Officer Saloon	57.1	Crew Room	59	2nd Officer Saloon	59
23	Lifeboat Station	79	Crew Room	58	Lifeboat Station	76
24	Crew Room	55.1	Rescue Boat Station	68	Crew Room	60
25	Crew Room	55.3	Officer's Mess Room	57	Crew Room	58
26	Crew Room	56.2	Crew's Mess room	61	Crew Room	58
27	Crew Room	53.5	Cargo Control room	61	Crew Room	57
28	Officer Mess room	55.4	Hospital	58	Officer Mess room	58
29	Crew Room	57.1	Infirmary	60	Crew Room	57
30	Crew Room	57.4	Galley	68	Crew Room	60
31	Rescue Boat Station	76.6	Provision Store	63	Rescue Boat Station	91
32	Crew's Mess room	62.5	Pantry	68	Crew's Mess room	62
33	Cargo Control room	60	Dressing Room/Laundry	74	Cargo Control room	61
34	Officers Dining Room	57.3	Engine Control Room	74	Officers Dining Room	60
35	Office	58	Selenoid Room	75	Office	61
36	Galley	68.2	Workshop	82	Galley	65
37	Provision Store	64.4	Incinerator	84	Provision Store	74
38	Engine Store	85.5	Steering Gear Room	87	Engine Store	88
39	Eng Room Workshop	84.8	Boiler Compartment	94	Eng Room Workshop	80
40	Eng. Aux. Room	94.6	Auxiliary Engine	104	Eng. Aux. Room	94
41	Engine Control Room	73.2	M.E. Port	103	Engine Control Room	74
42	Selenoid Room	79.8	M.E. Stb	103	Selenoid Room	82
43	Dressing Room/Laundry	74.2	Framo Room	89	Dressing Room/Laundry	74
44	Eng. Aux. Room	87.8	Separator Room	88	Incinerator Room	91
45	Eng. Aux. Room	92.8	Aft of Engine	107	Eng. Aux. Room	93
46	Auxiliary Engine	100.1	Engine Port	106	Auxiliary Engine	103
47	Port	103.1	Engine Stb	105	Port	104
48	Stb	102.1	Fore of Engine	105	Stb	103
49	Separator Room	85.7			Separator Room	88
50	Hydraulic Unit Room	92.4			Hydraulic Unit Room	93
51	Boiler Compartment	91.5			Boiler Compartment	92
52	Steering Gear Room	93.2			Steering Gear Room	93
53	Aft of Engine	110			Aft of Engine	110
54	Engine Port	108.7			Engine Port	108
55	Engine Stb	108.2			Engine Stb	109

Table 6-5: Summary of noise measurements for ship no 4-6

	Ship No 4		Ship No 5		Ship No 6	
Point No	**Place of Measurement**	**Measured Value dB(A)**	**Place of Measurement**	**Measured Value dB(A)**	**Place of Measurement**	**Measured Value dB(A)**
1	Wheel house CL	63	Wheel house CL	58	Wheel house CL	62
2	Wheel house Port	62	Wheel house Stb	59	Wheel house Port	64
3	Communication	61	Wheel house Port	56	Wheel house Stb	64
4	Wheel house Stb	61	Wing Stb	70	Communication	65
5	Chart Room	60	Wing Port	71	Chart Room	62
6	Wing Stb	68	Chart Room	58	Bridge Wings	74
7	Wing Port	69	Radio Room	57	Chief Officer Saloon	57
8	Laundry	58	Free Fall Lifeboat	78	Chief Officer Bedroom	55
9	Office	58	1st Engineer	54	Captains Bedroom	56
10	Chief Engineer Saloon	57	Bedroom	48	Captains Saloon	58
11	Chief Engineer Bedroom	53	Chief Engineer	52	Chief Engineers Saloon	55
12	Captains Bedroom	55	1. Mate	56	Chief Engineers Bedroom	56
13	Captains Saloon	56	Bedroom	52	1st Engineer Saloon	59
14	Owners Bedroom	56	Captain	53	1st Engineer Bedroom	59
15	Pilot	58	Crew Port	53	Crew	64
16	Free Fall Lifeboat	73	Crew Strb	54	Lifeboat Station	79
17	1st Asst. Engineer	59	Cook	51	Crew	66
18	1st Engineer Bedroom	57	Bosun	52	Crew	63
19	1st Engineer Saloon	56	Motorman	53	Crew	60
20	2nd Officer	55	Ch Mate	51	Crew	58
21	3rd Officer	54	Bedroom	48	Crew	57
22	Chief Officer Saloon	56	Rescue Boat port	73	Crew	60
23	Chief Officer Bedroom	56	Chemical Change	67	Crew	59
24	2nd Engineer	58	Provision Room	71	Crew	60
25	Electric Eng.	58	Galley (with fans on/off)	62/72	Crew	66
26	Crew Room	57	Mess Room	60	Crew's Mess room	64
27	Crew Room	55	Cargo Control room	55	Cargo Control room	65
28	Crew Room	57	Saloon	55	Crew	62
29	Crew Room	54	Boiler Room	91	Officer's Mess room	62
30	Crew Room	57	Workshop	75	Pantry	72
31	Crew Room	57	Weld Area	75	Galley	67
32	Crew Room	59	Engine Control Room	67	Provision Store	67
33	Crew Room	57	Change Room	59	Infirmary	68
34	Crew Room	57	Laundry	63	Engine Control Room	74
35	Infirmary	63	Spare Room Port	57	Dressing Room/Laundry	75
36	Hospital	60	Spare Room Stb	59	Eng. Room Workshop	86
37	Rescue Boat	81	Gym Room	61	Workshop Store	-
38	Laundry and changing room	59	Store	84	Boiler Room	90
39	Officers Mess room	62	Incinerator	86	Steering Gear Room	87
40	Crew's Mess Room	63	Separator room	81	Incinerator Room	89
41	Cargo Control room	64	Auxiliary Engine Room	87	Inert Gas Room	88
42	Ship Office	61	Steering Gear Room	86	Generator Room (Auxiliary Engine)	93
43	Pantry	73	Engine Room Aft	101	Engine Room Platform (Port)	103
44	Galley	64	Engine Room Forward	102	Engine Room Platform (Stb.)	103
45	Provision Room	68			Separator Room	91
46	Cold Store	68			Aft of Engine	109
47	Engine Control Room	77			Engine Port	107
48	Eng. Room Space	91			Engine Stb	106
49	Eng. Room Space	91			Fore of Engine	106
50	Workshop & Store	88				
51	Eng. Room Space	93				
52	Incinerator Room	101				
53	Store	74				
54	Selenoid Room	82				
55	Hydraulic Valve Control & Foam Room	73				
56	Steering Gear Room	94				
57	Auxiliary Engine	100				
58	Framo Room	93				
59	Separator Room	94				
60	Eng. Room Space	104				
61	Aft of Engine	103				
62	Engine Port	103				
63	Engine Stb.	105				
64	Fore of Engine	105				

As seen in Table 6-4 and Table 6-5 each ship has differing layouts, configurations and compartments. For each ship, there were also a different number of measurements taken. In order to calculate the noise exposures of the crew and to be able to conduct a comparative study, it was necessary to group the similar locations together to match with the workplace categories (as in Table 6-1) used in the questionnaires for crew work patterns (time spent in each location).

Therefore, similar locations in each ship were grouped together according to the workplace categories and results are shown in Table 6-6. As a result of grouping the similar locations together, noise measurements of these locations were also grouped together, and an average value was calculated for each category. For example, the noise level shown under the category ‘cabin’ in Table 6-6 is the mean (average) noise level of all cabins in that ship. However, deciding which compartments are to be grouped under a category was not always as simple as in the example of category ‘cabin’. Therefore, in order to complete this task, an experienced captain was consulted to group the measurements from each ship under the categories shown in Table 6-6. So as explained, the noise levels shown in Table 6-6 are not single measurements but average of many measurements from similar compartments.

Table 6-6: Grouped locations and corresponding average noise levels (in dB(A))

Ship No	Bridge	Engine Room	E/R Other	Cargo Cont. Room	Galley	Cabin	Mess room	Accom. Other areas	Upper Decks (Lifeboat etc.)
1	58.9	95	84.4	60	66.3	55.8	58.4	58	77.8
2	57	96.8	85.3	61	66.3	57.2	59	64	71.5
3	58.8	96.6	87.3	61	69.5	55.4	60	65	83.5
4	63.4	96	84.6	64	68.3	56.4	62.5	59.8	77
5	61.3	87.9	72.7	55	68.3	52.1	57.5	61	75.5
6	65.2	96.6	86.5	65	68.7	59.5	63	71.5	79

6.3.3 Analysis

After gathering the noise measurements from the compartments of the various oil/chemical tankers and the crew's work patterns in terms of locations and time spent there; the average exposure levels of the crew were calculated in line with the IMO's 'Resolution A.468' and the EU's 'Physical Agents Directive'. There are numerous examples of rules and regulations and standards available for managing noise, which have been reviewed extensively in Chapter 4. However, aforementioned regulations were decided as the most applicable and useful for the purpose of this study.

In essence, both regulations calculate exposure using the following formulation:

$$L_{EX,xh} = 10 \times log_{10}\left(\frac{1}{X}\sum_{i=1}^{n} T_{ei} \times 10^{\left(\frac{L_{Aeqi}}{10}\right)}\right)$$

Equation 6-1

Where:

$L_{EX,xh}$ X hours equivalent noise exposure level of crew

L_{Aeq} is A weighted constant noise level,

X is the equivalent working day value (either 8 or 24 hours),

n is the number of locations the crew member inhabited

T_e is the duration of exposure to this noise level.

In the case of the IMO's 'Resolution A.468', X is 24 hours and for the EU's 'Physical Agents Directive' X is 8 hours. After calculation of the noise exposure levels, detailed analysis were conducted following the methodologies (Refer to Chapter 4) defined in both regulations.

The initial methodology of the analysis section of this study can be separated into three main parts:

- First, noise levels measured from ships (Table 6-4 and Table 6-5) were checked against the maximum allowable noise levels defined by IMO for each location type.
- Second, exposure assessments have been carried out in accordance with the methodology described by both the IMO and EU. Calculated exposure values have been compared with the criteria defined by both regulations.
- Finally, the effect of hearing protectors were assumed to have a significant effect on the resulting exposure limit values of crew, therefore exposure calculations were repeated in order to take into account the different approaches of estimating the noise reduction rate of hearing protectors in both the IMO and EU approaches.

As mentioned above, both regulations require hearing protection to be used in certain cases. The IMO’s approach is to mandate the use of hearing protections when entering noisy locations, whereas the EU requires the usage of hearing protection when the exposure level of the worker matches or exceeds the upper action value.

For this study, in order to allow comparison of both the IMO’s and EU’s noise exposure calculations the same hearing protection has been used. At this point, it is vital to mention that estimating the noise reduction rate provided by the use of hearing protection becomes critical. The IMO’s noise code defines the attenuation level which can be achieved by the usage of specific hearing protection. However, the performance of hearing protectors in a real operational environment (Figure 6-4) is known to be different from that of a controlled laboratory environment. The Occupational Safety and Health Administration (OSHA) addresses this issue by suggesting a method for estimating the attenuation that can be achieved by using of hearing protection.

Figure 6-4: Usage of Hearing protection in ships

OSHA (1981b) has suggested the use of following formulas in order to calculate the hearing protection levels that can be achieved by the usage of hearing protectors:

$$\text{Estimated Exposure } (\text{dB(A)}) = \text{ TWA } (\text{dBC}) - \text{ NRR}$$

Equation 6-1

$$\text{Estimated Exposure } (\text{dB(A)}) = \text{ TWA } (\text{dB(A)}) - (\text{NRR} - 7)$$

Equation 6-2

Where NRR is the "Noise Reduction Rate" number which is supplied by the manufacturer and the TWA is the "Time Weighted Average" of noise. If the TWA is not available in a 'C' weighting, an 'A' weighted TWA can be used with a 7 dB correction factor as shown in Equation 6-2.

In cases where dual protection is being used, the same logic can be used in order to take the effect of the second hearing protector into account by adding 5 dB to the noise reduction rate of the higher rated protection device. (NRRh)

$$\text{Estimated Exposure (dB(A))} = \text{TWA (dBC)} - (\text{NRRh} + 5)$$

Equation 6-3

$$\text{Estimated Exposure (dB(A))} = \text{TWA (dB(A))} - [(\text{NRRh} - 7) + 5]$$

Equation 6-4

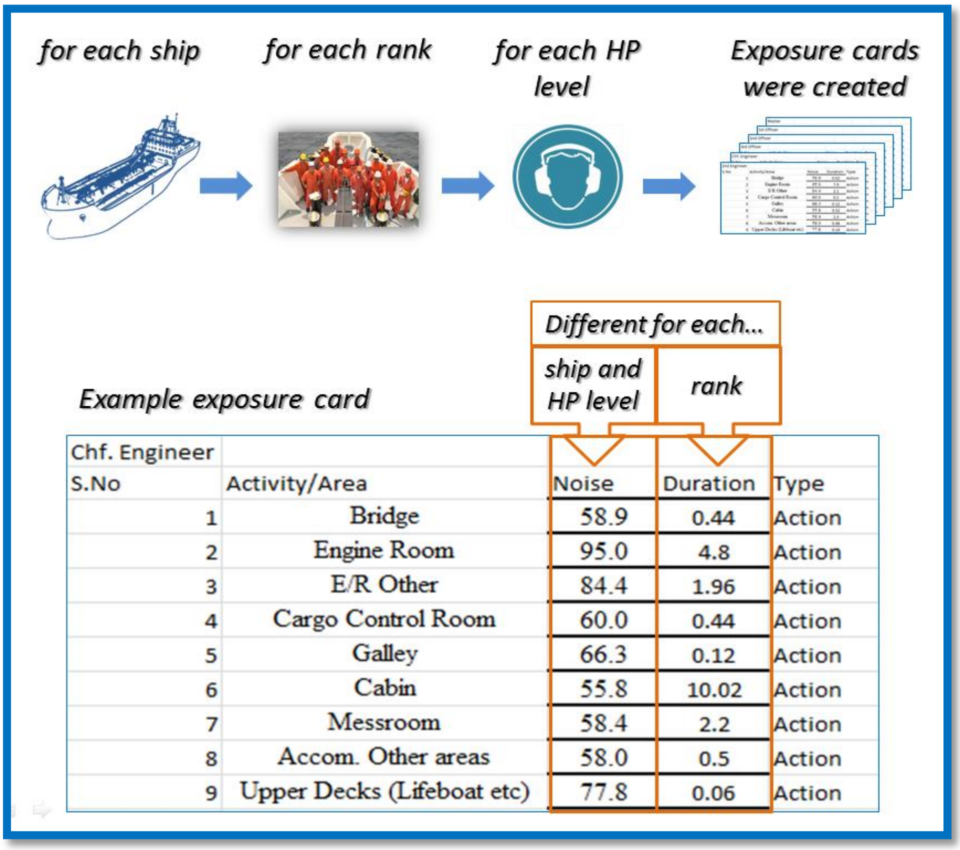
Moreover, OHSA also recommends that a correction factor of 50% should also be used on top of the manufacturer's NRRs due to differences in between laboratory conditions and a real workspace environment. Other considerations included in the 50% reduction in the protection factor are; misuse, unsuitable application and design limitations of the hearing protection.

Therefore, noise assessments were carried out in this study for each seafarer on each ship including the different approaches used for estimating the noise reduction rate of hearing protectors.

In this study, the different HP protection levels are represented through the following definitions:

- HP0: There is no hearing protection used
- HP1: The IMO's estimated hearing protection levels are used
- HP2: OSHA's correction for using 'A' weighted TWA is applied to the noise reduction rates of hearing protection devices
- HP3: OSHA's correction factor from laboratory-obtained NRR to a real work environment is applied.

Taking into consideration all this information, exposure cards were prepared for each rank and ship. An example exposure card is demonstrated in Figure 6-5.



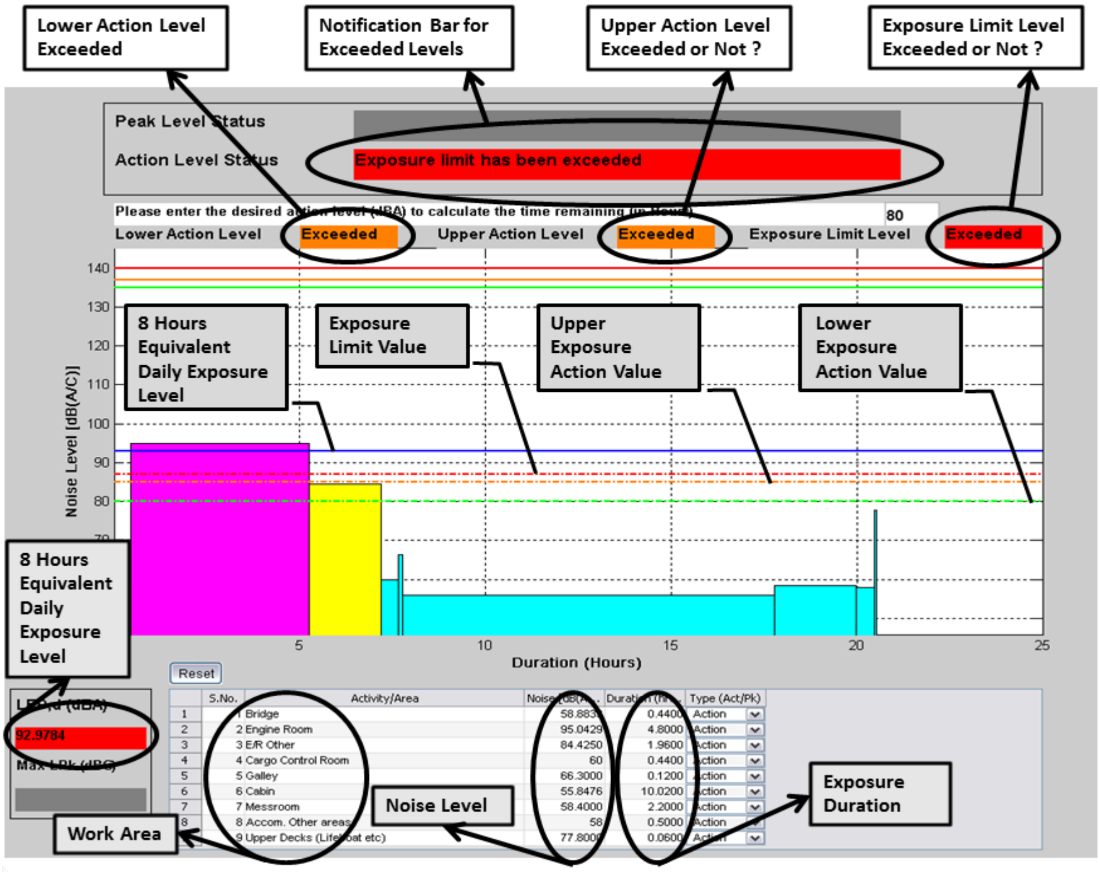
Chf. Engineer				
S.No	Activity/Area	Noise	Duration	Type
1	Bridge	58.9	0.44	Action
2	Engine Room	95.0	4.8	Action
3	E/R Other	84.4	1.96	Action
4	Cargo Control Room	60.0	0.44	Action
5	Galley	66.3	0.12	Action
6	Cabin	55.8	10.02	Action
7	Messroom	58.4	2.2	Action
8	Accom. Other areas	58.0	0.5	Action
9	Upper Decks (Lifeboat etc)	77.8	0.06	Action

Figure 6-5: Example exposure card

For every crew rank and vessel, the details on the exposure cards were inputted into an in-house developed MatLab tool, hereafter referred to as the 'Noise Exposure Calculator', which calculated the resulting exposure levels of seafarers from the given noise levels and duration of exposure to that noise level. The noise exposure calculator has been developed to model the EU Physical Agents Directive. The Noise Exposure Calculator calculates the 8-hour-equivalent noise exposure values, for given exposure times and noise levels, and also displays the limits that are defined in the EU Physical Agents (Noise) Directive.

A small module has also been developed to calculate the 24-hour-equivalent exposures on which the IMO criteria is based. The Noise Exposure Calculator was developed together with a graphical user interface (GUI) which makes it user friendly and easy to use. However, the primary aim of the GUI is to allow the user to have a visual demonstration of the potential noise exposure levels of a worker before they are exposed to the actual noisy environment. Moreover, it gives the user the flexibility to change and modify exposure durations and create new shifts with different exposure levels. Indeed this provides the needed information for optimising the use of man hours in workspaces of ships by avoiding the risk of hazards that may be caused by noise exposure in the work environment.

The Noise Exposure Calculator also shows the remaining time for the crew member to continue working in the same environment without exceeding the exposure limits or levels. It also displays the time history of the exposure that demonstrates the critical areas where high exposures occurred and therefore preventive improvement actions can be taken. Figure 6-6 introduces the Noise Exposure Calculator and describes the features of the graphical user interface.



Action Level Status: Exposure limit has been exceeded

Please enter the desired action level (dBA) to calculate the time remaining (in Hours): 80

Lower Action Level: Exceeded

Upper Action Level: Exceeded

Exposure Limit Level: Exceeded

LEP,d (dBA): 92.9784

Max LPk (dBC):

	S.No.	Activity/Area	Noise [dB(A...	Duration (h...	Type (Act/Pk)
1	1	Bridge	58.883	0.4400	Action
2	2	Engine Room	95.0429	4.8000	Action
3	3	E/R Other	84.4250	1.9600	Action
4	4	Cargo Control Room	60	0.4400	Action
5	5	Galley	66.3000	0.1200	Action
6	6	Cabin	55.8476	10.0200	Action
7	7	Messroom	58.4000	2.2000	Action
8	8	Accom. Other areas	58	0.5000	Action
	9	Upper Decks (Lifeboat etc)	77.800	0.0600	Action

Figure 6-6: Noise Exposure Tool

6.4 Results

6.4.1 IMO Noise Code A. 468

In presenting the results of this study the first step, as referred to the analysis methodology, was to check the compliance of the ships with the IMO's Resolution A.468 (XII). The results, seen in Table 6-7, show that out of a total of 315 noise measurements of all vessels only 13 recordings exceeded the criteria. In investigating the particular vessels, it can be seen that Ships No. 1 and No. 3 were found to be in full compliance with all measurement points below the criteria. Only one measurement point each from Ships No. 2 and No. 5, and 4 and seven measurement points from Ships No. 4 and No. 6 respectively were found to be exceeding the specified limits. The average extent that the recordings of the various vessels exceeded the maximum noise requirements of the IMO was 3.5 dB(A) which shows according to the regulation that the ships with exceeding points could comply with minor adjustments or improvements.

Table 6-7: Measurement points where the noise level exceeds the defined criteria

Ship No	Measurement No	Place of Measurement	Compartment Type (IMO Res 468 XII)	Max dB(A) IMO Res A468	Measured Value dB(A)
2	8	3rd Officer's Room	Cabins and hospitals	60	61
4	35	Infirmary	Cabins and hospitals	60	63
4	37	Rescue Boat	Open recreation areas	75	81
4	47	Engine Control Room	Machinery Control Room	75	77
4	50	Workshop & Store	Workshops	85	88
5	5	Wing Port	Listening post, including navigation bridge wings and windows	70	71
6	15	Crew	Cabins and hospitals	60	64
6	17	Crew	Cabins and hospitals	60	66
6	18	Crew	Cabins and hospitals	60	63
6	25	Crew	Cabins and hospitals	60	66
6	28	Crew	Cabins and hospitals	60	62
6	33	Infirmary	Cabins and hospitals	60	68
6	36	Eng. Room Workshop	Workshops	85	86

The next step was to calculate the IMO's 24-hour-equivalent exposure assessment according to the following formula and Noise Exposure Calculator:

$$L_{EX,24h} = 10 \times log_{10}\left(\frac{1}{24}\sum_{i=1}^{n} T_{ei} \times 10^{\left(\frac{L_{Aeqi}}{10}\right)}\right)$$

Equation 6-5

In Table 6-8 the results of the 24-hour-equivalent exposure assessment are summarised. The table is presented in a matrix format, wherein each row a particular rank or rate is displayed and the different approaches of estimating the effects hearing protection (HP) are shown under each ship in the columns. The values highlighted in red indicate the crew members of particular ships that have been calculated to exceed the 24-hour-equivalent noise exposure level of 80 dB(A).

With respect to the usage of hearing protection, the IMO clearly defines what type and when hearing protection should be worn. The IMO also defines the expected attenuation from the hearing protection. However, results show that the IMO's approach over-predicts the actual attenuation level that can be achieved through the usage of the hearing protection devices. In Table 6-8 and Table 6-10 this situation can be seen when the exposure level of a crew role is investigated. Primarily, the difference between HP1, HP2 and HP3 demonstrates how the estimation method for the hearing protection level can affect the noise exposure level of a crew member significantly.

Table 6-8: 24-hour-equivalent exposure levels based on the IMO criteria.

	Ship1				Ship2				Ship3				Ship4				Ship5				Ship6			
Role	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**
Master	73.1	62.5	64.0	67.6	74.7	59.3	63.1	68.5	74.7	61.9	64.3	68.8	74.0	63.6	65.1	68.6	66.2	58.2	59.1	61.5	74.8	63.5	65.2	69.1
1st Officer	71.3	64.8	65.4	67.2	71.7	59.9	62.3	66.8	73.4	66.4	67.1	69.1	72.2	63.6	66.2	68.1	65.2	61.1	61.4	62.4	73.1	65.3	66.2	68.5
2nd Officer	68.8	63.5	63.9	65.3	69.7	59.5	60.9	64.4	71.3	67.1	67.4	68.4	69.7	64.5	64.9	66.2	63.7	61.3	61.5	62.0	70.7	65.6	66.0	67.3
3rd Officer	69.0	64.2	64.6	65.8	69.8	60.0	61.3	64.5	71.8	68.2	68.4	69.3	69.9	65.0	65.3	66.6	64.2	62.1	62.2	62.6	71.0	66.3	66.6	67.8
Chf. Engineer	**88.2**	74.7	77.4	**82.2**	**89.9**	70.1	77.0	**83.5**	**89.8**	70.2	76.9	**83.3**	**89.1**	75.1	78.1	**83.1**	**80.9**	64.8	69.0	74.6	**89.8**	70.3	76.9	**83.3**
2nd Engineer	**90.3**	75.5	78.9	**84.2**	**92.1**	72.2	79.1	**85.6**	**91.9**	72.4	79.0	**85.4**	**91.3**	75.9	79.6	**85.0**	**83.1**	66.0	70.8	76.7	**91.9**	72.2	78.9	**85.4**
3rd Engineer	**90.4**	74.8	78.6	**84.2**	**92.2**	72.3	79.2	**85.7**	**92.0**	72.2	79.0	**85.5**	**91.4**	75.2	79.4	**85.1**	**83.2**	65.5	70.7	76.8	**92.0**	72.2	79.0	**85.5**
Boatswain	71.6	61.4	62.8	66.3	73.2	58.9	62.0	67.1	73.5	65.1	66.0	68.7	72.5	62.0	63.6	67.1	65.1	58.6	59.2	61.0	73.3	63.6	64.9	68.1
A/B Seaman	60.1	60.2	60.2	60.2	57.7	57.7	57.7	57.7	64.6	64.6	64.6	64.6	61.2	61.3	61.3	61.3	58.9	58.9	58.9	58.9	63.6	63.6	63.6	63.6
O. Seaman	60.1	60.2	60.2	60.2	57.7	57.7	57.7	57.7	64.6	64.6	64.6	64.6	61.3	61.3	61.3	61.3	58.9	58.9	58.9	58.9	63.6	63.6	63.6	63.6
Pumpman	73.6	60.6	63.1	67.7	75.4	59.0	63.3	69.0	75.3	62.1	64.7	69.3	74.6	61.5	64.0	68.6	66.6	56.2	57.7	61.2	75.3	62.2	64.7	69.3
Donkeyman	**89.4**	76.4	78.9	**83.5**	**91.2**	71.3	78.2	**84.7**	**91.1**	71.4	78.1	**84.6**	**90.4**	76.7	79.5	**84.3**	**82.1**	66.2	70.3	75.9	**91.0**	71.4	78.1	**84.5**
Oiler	**90.4**	75.0	78.7	**84.1**	**92.1**	72.2	79.1	**85.6**	**92.0**	72.3	79.0	**85.5**	**91.3**	75.4	79.5	**85.0**	**83.1**	65.7	70.7	76.7	**91.9**	72.2	79.0	**85.4**
Cook	63.2	63.3	63.3	63.3	63.2	63.2	63.2	63.2	66.5	66.6	66.6	66.6	65.0	65.0	65.0	65.0	64.6	64.6	64.6	64.6	66.2	66.2	66.2	66.2
Steward	60.6	60.6	60.6	60.6	62.1	62.1	62.1	62.1	64.4	64.4	64.4	64.4	62.5	62.5	62.5	62.5	61.8	61.8	61.8	61.8	67.3	67.3	67.3	67.3
Deck cadet	64.7	64.8	64.8	64.8	65.2	60.2	60.2	60.2	69.9	69.9	69.9	69.9	65.1	65.1	65.1	65.1	63.2	63.2	63.2	63.2	67.0	67.0	67.0	67.0
Engine cadet	**90.4**	75.3	78.8	**84.2**	**92.1**	72.2	79.1	**85.6**	**92.0**	72.1	79.0	**85.5**	**91.3**	75.8	79.6	**85.1**	**83.1**	65.7	70.8	76.7	**91.9**	72.2	79.0	**85.4**

***HP0:** There is no hearing protection used. **HP1:** The IMO's estimated hearing protection levels are used **HP2:** OSHA's correction for using 'A' weighted TWA is applied to the noise reduction rates of hearing protection devices. **HP3:** OSHA's correction factor from laboratory-obtained NRR to a real work environment is applied.*

From Table 6-7 and Table 6-8, it can be seen that while ships are complying with the IMO's compartment based requirements, when compared to the individual exposure levels of crew, the maximum permissible noise exposure levels are being exceeded in certain cases. From Table 6-8 it can be seen that the engine room based crew, and locations are at the highest risk of exposure.

The problem identified with the IMO's methodology is that the calculation of the maximum permissible noise exposure limits for the crew with hearing protection is based on protection factors that are assumed to 100% effective. As mentioned before, this is impossible to achieve in a real working environment. This is reflected in Table 6-10 where the correction factors are correctly calculated according to OSHA's industry standard methodology. This leads to the possibility of the crew being at risk from noise exposure.

6.4.2 EU Physical Agents Directive

In order to compare the exposure levels of the crew and various ships further, analysis was carried out this time utilising the EU's Physical Agents Directive. The results are demonstrated in two parts. Firstly, exposure levels of crew were calculated and assessed against the exposure action values defined in the EU Directive. Then, only the noise exposure values of crew that exceeded the actions values were calculated and assessed against the defined limit values in the directive. The reason for dividing the results into two stages is simply because the effect of using hearing protection needs to be considered when assessing the exposure levels against the limit values. However, when assessing against the action values the effect of hearing protection devices is not considered.

As described in detail in the previous sections, according to the EU Physical Agents directive employers should make available hearing protection for workers when the 8-hour-equivalent noise exposure is equal to or exceeds the 'lower exposure action value. Moreover, when an 8-hour-equivalent noise exposure of workers reaches the 'higher exposure action value' employers must ensure the usage of the hearing protection (please refer to Figure 4-16).

Therefore, after calculating the 8-hour-equivalent noise exposure, through utilising Equation 6-3 and the Noise Exposure Calculator, Table 6-9 shows the 8-hour-equivalent noise exposure calculation compared against the defined exposure action values.

$$L_{EX,8h} = 10 \times log_{10}\left(\frac{1}{8}\sum_{i=1}^{n} T_{ei} \times 10^{\left(\frac{L_{Aeqi}}{10}\right)}\right)$$

Equation 6-3

In Table 6-9, each row represents different ranks and rates while each column depicts the various ships. The 8-hour-equivalent exposure values which are below the defined ‘lower exposure action value’ of 80 dB (A) are marked with a green “✓”, where an amber “!” is used to show the calculated exposure values exceeding the ‘lower exposure action value’. In cases where the ‘upper exposure action value’ of 85 dB (A) is exceeded then a red “x” is displayed. It can be seen that similar to the results of Table 6-8, those people at most risk of exposure are the ones who work predominantly in and around the engine and machinery spaces.

Table 6-9: Assessment of 8-h-equivalent crew exposure levels against action levels

Role	Ship 1	Ship 2	Ship 3	Ship 4	Ship 5	Ship 6
Master	✓ 77.8	✓ 79.5	✓ 79.5	✓ 78.8	✓ 71.0	✓ 79.5
1st Officer	✓ 76.1	✓ 76.4	✓ 78.2	✓ 77.0	✓ 70.0	✓ 77.9
2nd Officer	✓ 73.5	✓ 74.5	✓ 76.1	✓ 74.5	✓ 68.5	✓ 75.5
3rd Officer	✓ 73.8	✓ 74.5	✓ 76.6	✓ 74.6	✓ 69.0	✓ 75.7
Chf. Engineer	✗ 93.0	✗ 94.7	✗ 94.6	✗ 93.9	✗ 85.7	✗ 94.5
2nd Engineer	✗ 95.1	✗ 96.8	✗ 96.7	✗ 96.0	✗ 87.8	✗ 96.6
3rd Engineer	✗ 95.2	✗ 97.0	✗ 96.8	✗ 96.1	✗ 88.0	✗ 96.7
Boatswain	✓ 76.4	✓ 78.0	✓ 78.3	✓ 77.3	✓ 69.9	✓ 78.1
A/B Seaman	✓ 64.9	✓ 62.5	✓ 69.4	✓ 66.0	✓ 63.6	✓ 68.3
O. Seaman	✓ 64.9	✓ 62.5	✓ 69.4	✓ 66.0	✓ 63.6	✓ 68.3
Pumpman	✓ 78.4	⚠ 80.1	⚠ 80.1	✓ 79.4	✓ 71.4	⚠ 80.0
Donkeyman	✗ 94.2	✗ 95.9	✗ 95.8	✗ 95.1	✗ 86.9	✗ 95.8
Oiler	✗ 95.1	✗ 96.9	✗ 96.7	✗ 96.1	✗ 87.9	✗ 96.7
Cook	✓ 68.0	✓ 68.0	✓ 71.3	✓ 69.8	✓ 69.4	✓ 71.0
Steward	✓ 65.4	✓ 66.8	✓ 69.1	✓ 67.3	✓ 66.5	✓ 72.0
Deck cadet	✓ 69.5	✓ 70.0	✓ 74.7	✓ 69.9	✓ 67.9	✓ 71.8
Engine cadet	✗ 95.1	✗ 96.9	✗ 96.7	✗ 96.1	✗ 87.9	✗ 96.7

✓ : Neither Action nor Limit Values Reached
⚠ : Lower Exposure Action Value Reached or Exceeded
✗ : Upper Exposure Action Value Reached or Exceeded

In accordance with the EU directive, the results that are equal or exceed the ‘upper exposure action value’ in Table 6-9 are required to be recalculated taking into account the effect of the hearing protection devices.

Table 6-10 presents the results of the additional exposure calculations that have taken into account the effect of different levels of attenuation achieved through the usage of hearing protection (HP0, HP1, HP2, HP3). The red cells in Table 6-10 highlights the conditions that exceed the noise ‘exposure limit value’ of 87 dB (A) defined by the EU directive. The results in Table 6-10 further prove that, when the OHSA’s correction factor (HP3) is taken into consideration when calculating the attenuation that can be achieved by the use of hearing protectors, crew members working close to engine room areas are being exposed to dangerous levels of noise.

Table 6-10: 8-hour-equivalent exposure levels based on the EU Physical Agents Directive.

	Ship1				Ship2				Ship3				Ship4				Ship5				Ship6			
Role	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**	**HP0**	**HP1**	**HP2**	**HP3**
Master	77.8	-	-	-	79.5	-	-	-	79.5	-	-	-	78.8	-	-	-	71.0	-	-	-	79.5	-	-	-
1st Officer	76.1	-	-	-	76.4	-	-	-	78.2	-	-	-	77.0	-	-	-	70.0	-	-	-	77.9	-	-	-
2nd Officer	73.5	-	-	-	74.5	-	-	-	76.1	-	-	-	74.5	-	-	-	68.5	-	-	-	75.5	-	-	-
3rd Officer	73.8	-	-	-	74.5	-	-	-	76.6	-	-	-	74.6	-	-	-	69.0	-	-	-	75.7	-	-	-
Chf. Engineer	**93.0**	79.5	82.2	**87.0**	**94.7**	74.9	81.8	**88.2**	**94.6**	75.0	81.7	**88.1**	**93.9**	79.8	82.8	**87.8**	85.7	69.6	73.8	79.4	**94.5**	75.1	81.6	**88.1**
2nd Engineer	**95.1**	80.3	83.7	**88.9**	**96.8**	77.0	83.9	**90.3**	**96.7**	77.1	83.8	**90.2**	**96.0**	80.7	84.4	**89.8**	**87.8**	70.8	75.6	81.5	**96.6**	77.0	83.7	**90.2**
3rd Engineer	**95.2**	79.5	83.4	**88.9**	**97.0**	77.0	84.0	**90.5**	**96.8**	76.9	83.8	**90.3**	**96.1**	80.0	84.2	**89.8**	**88.0**	70.2	75.5	81.6	**96.7**	77.0	83.8	**90.2**
Boatswain	76.4	-	-	-	78.0	-	-	-	78.3	-	-	-	77.3	-	-	-	69.9	-	-	-	78.1	-	-	-
A/B Seaman	64.9	-	-	-	62.5	-	-	-	69.4	-	-	-	66.0	-	-	-	63.6	-	-	-	68.3	-	-	-
O. Seaman	64.9	-	-	-	62.5	-	-	-	69.4	-	-	-	66.0	-	-	-	63.6	-	-	-	68.3	-	-	-
Pumpman	78.4	-	-	-	80.1	-	-	-	80.1	-	-	-	79.4	-	-	-	71.4	-	-	-	80.0	-	-	-
Donkeyman	**94.2**	81.2	83.7	**88.3**	**95.9**	76.1	83.0	**89.5**	**95.8**	76.1	82.9	**89.3**	**95.1**	81.5	84.3	**89.1**	**86.9**	71.0	75.0	80.6	**95.8**	76.1	82.8	**89.3**
Oiler	**95.1**	79.7	83.5	**88.9**	**96.9**	77.0	83.9	**90.4**	**96.7**	77.1	83.8	**90.2**	**96.1**	80.2	84.2	**89.8**	**87.9**	70.4	75.5	81.5	**96.7**	77.0	83.7	**90.2**
Cook	68.0	-	-	-	68.0	-	-	-	71.3	-	-	-	69.8	-	-	-	69.4	-	-	-	71.0	-	-	-
Steward	65.4	-	-	-	66.8	-	-	-	69.1	-	-	-	67.3	-	-	-	66.5	-	-	-	72.0	-	-	-
Deck cadet	69.5	-	-	-	70.0	-	-	-	74.7	-	-	-	69.9	-	-	-	67.9	-	-	-	71.8	-	-	-
Engine cadet	**95.1**	80.1	83.6	**88.9**	**96.9**	77.0	83.9	**90.4**	**96.7**	76.8	83.8	**90.2**	**96.1**	80.5	84.4	**89.8**	**87.9**	70.5	75.5	81.5	**96.7**	76.9	83.7	**90.2**

HP0: *There is no hearing protection used.* ***HP1:*** *The IMO's estimated hearing protection levels are used* ***HP2:*** *OSHA's correction for using 'A' weighted TWA is applied to the noise reduction rates of hearing protection devices.* ***HP3:*** *OSHA's correction factor from laboratory-obtained NRR to a real work environment is applied*

6.5 Discussion

As seen from the results above, the noise exposure assessments based on the IMO's and EU's criteria show that crew members who are generally working in and around engine and machinery areas have noise exposure levels failing to comply with either of the two regulations. Therefore, crew who work in these areas need sophisticated hearing protection and/or carefully planned shift patterns to prevent hazardous noise exposures.

In terms of limitations of this study, it is important to mention that the presence of peaks (peak sound pressure) and resulting noise exposures were ignored. This was because the C-weighted peak noise levels were not collected when the measurements were carried out. However, since the peaks are considered and assessed in the EU directive separately, the exposure assessments in this study will not be affected. In fact, it is envisaged that if the peak noise were also included in this study it could potentially mean more crew members could have been found to be in non-compliance with the EU Physical Agents Directive.

Moreover, this study focussed on a specific ship type of chemical tanker and vessels in this study were selected from similar size and design speeds as far as practicable. In other words, noise data and work patterns reported in previous sections were obtained from selected number of ships. Therefore, finding should not be generalised to other ship types and sizes. It needs to be considered that different work patterns and noise levels will result in different noise exposure levels. However, results show that most of the exposure levels were directly affected by high level noise which exist machinery areas. This situation will not change from one ship to another and specific focus should be given to the prevention of hazardous noise exposures in engine room areas.

Both the EU Physical Agents Directive and the IMO Noise Code are applicable to ships. The IMO Noise Code aims to protect the crew on board by defining maximum allowed noise levels for ship compartments whereas the EU directive is not specific for shipping and therefore has a more generic approach of directly focusing on the human and defining exposure action and limit values. On ships using 24 hour equivalent noise exposure values is considered to be more appropriate since crew in 24-7 inhabited on board.

Furthermore, although the noise levels in the compartments of the ships are meeting the criteria set by the IMO, the exposure assessments show that noise exposure levels of the crew who work and live in those compartments do not comply with exposure limits defined by both regulations when OHSA's hearing protection factor recommendations were taken into account.

Environmental factors and changes in operational conditions may easily affect the noise levels on board ships, because the EU directive directly focuses on the human and defines limits for the noise exposure, EU's approach seems more effective and sustainable. However, the IMO noise code is the only reference to regulation in terms of allowed noise levels on ships at the design and construction stage unless there are specific contractual requirements defined by the ship owner or class societies.

Also applying modifications is easier and economically more feasible at the design and construction stage than later. Moreover, sophisticated hearing protection (e.g. high protection active hearing muffs allowing two-way communication) needs to be used in compartments with high noise levels but these devices are far more expensive than the simple models and due to the lack of regular inspections and lack of awareness such sophisticated hearing protection is almost never available for the use of crew members. Hence achieving the noise attenuation as described in the IMO noise code is also not realistic in most of the cases. As a result, more impact can be achieved at the design stage of ships by minimising the noise at the source. Therefore, the maximum noise levels defined by IMO need to be evaluated and reformed to ensure the safe noise exposure levels of crew members.

On the other hand at the operational stage, it is necessary to estimate the noise exposure level of a crew member before exposing the worker to actual noisy environment and adjust and design work shifts of crew members in accordance with the defined safe limits. Results of this study show that while some workers are exceeding, the others are well below the exposure limit values. An equal distribution of noisy tasks to crew members may result in better overall noise exposure levels. However, in reality not every crew member can cover other ranks work, hence everyday tasks which can be done by every rank can be identified and distributed to achieve lower noise exposure levels or manning level in the high risk areas can be increased. One of the proposed functions of the created 'Noise Exposure Calculator' is to allow shipping companies to calculate noise exposures in advance to assist in this task of reducing overall noise exposure of crew members.

Overall it needs to be noted that both the IMO noise code and the EU Physical Agents directive are developed with the ultimate aim of preventing human health from hazardous noisy conditions. However, effects of noise have been studied by many researchers in different industrial domains (please refer to section 4.6 for more detail) and it is known that noise may affect the human performance, comfort by causing fatigue, lack of concentration and situational awareness as well as annoyance. As the technology used on ships continues to evolve and crew numbers follow a decreasing trend, the human operator becomes the limiting element of the ship when considered as a whole system. Therefore, researching into the effects of noise on shipping operations and the development of new noise criteria which also takes human performance and wellbeing into account is necessary. The effects of noise exposure on different shipping operations need to be identified and researched, and the findings incorporated into the new regulations and guidelines. In this way, not only human health can be protected but also by achieving better human practice on board ships safer and more comfortable shipping operations can be achieved.

6.6 Chapter Summary

In this chapter results of a comparative study on chemical tankers in terms of crew noise exposure were reported. Noise exposure levels of crew on tanker ships were assessed according to the methodologies defined in the EU Physical Agents Directive and IMO’s Noise Code. Overall, it needs to be said that even though ships in this study were built under IMO’s requirements some crew members were still under risk. Moreover, the limits defined by both regulations were based on the health concerns and effects of long term noise exposure on crew wellbeing and performance were neglected. The results and findings of this study provide the focus for the subsequent chapters of this thesis in expand conducting research in identifying and modelling the effects of noise on crew performance.

Chapter 7. AN EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF NOISE ON CREW PERFORMANCE

7.1 Chapter Overview

In Chapter 5, it was shown that crew exposure levels are not in compliance with the current regulatory framework. However, it was also well-known that the regulatory framework is developed to protect the health of the employees, and the effect of noise exposure on the crew performance and wellbeing has not been taken into account. This outcome became the primary motivation for this chapter which aims to investigate the effects of noise on the performance of a crew on board ships. Therefore, in this chapter, an experimental study was designed and conducted in a full-mission ship simulator in order to identify the relationship between noise exposure and crew performance.

7.2 Background

Various aspects of on board environmental conditions of ships have the potential to affect the crew performance/wellbeing and noise has been identified as one of them. As indicated in the literature review section (Chapter 4) of this thesis, there is a lack of human performance and wellbeing research related to noise levels on board ships when compared to other industries. There is also the issue that there is no particular agreement between researchers as results of various studies have been shown to contradict. Some experiments suggest that noise can improve human performance while others report detrimental effects due to noise. This contradiction in research outcomes can be attributed to the following reasons:

- Each researcher used different types of noise in their experiments.
- Participants involved in different experimental studies were not similar in terms of demographics; subject groups were different.

- Almost all experimental studies aimed to identify the effect of noise on task performance, but different researchers used different tasks; the cognitive load of the tasks was not standard between studies.

This study therefore aims, through experimental research, to identify a link between noise exposure and crew performance on board ships that considers the bullet points above.

7.3 Methodology of Study

As mentioned above, the whole purpose and aim of this experimental study is to examine the possible effects noise can have on human performance during on board operations. The first step was to establish experimental boundaries in terms of what locations on board should be focused on, which rank of crew should take part and what task or tasks should be conducted. After careful consideration it was decided on the following:

Location: The ship's bridge on a Full Mission Ship Handling Simulator

Reasoning: Due to access limitations of only having access to a 'Full Mission Ship Handling Simulator' (FMSHS) it was decided to utilise this option. Modern FMSHSs provide a very accurate representation of an actual vessel's operating environment and characteristics. It also had the advantage of being able to control variables in a controlled and non-safety critical environment

Participants: Total of 21 individuals with a minimum of 1 year's seagoing experience

Reasoning: In order to contribute to an accurate portrayal of conditions and job tasks on board, it was decided to use only the individuals with a minimum of 1 year seagoing experience. In this study, the majority of participants would be coming from officer cadets currently studying at a maritime academy.

Task: Navigation of a difficult and busy passage between two fixed points in 'real' simulation conditions

Reasoning: Due to time restraints of gaining access to participants and the FMSHS it was decided to set a task which would require a high level of attention and alertness to be maintained. This would increase the chances of seeing any changes in participant performance levels even in a short time duration.

After the boundaries of the experiment had been decided on, the performance criteria and how this study would capture them were defined:

- Subjective feedback – Participants complete self-reporting questionnaires before, during and after the experiment
- Vigilance performance - Participants are given a Peripheral Detection Task (PDT) to measure task load
- Passage performance – Participants passage summary is recorded for analysis

Finally, the specific details and steps of the experiment were finalised. A summary of the experimental study can be seen in Figure 7-1.

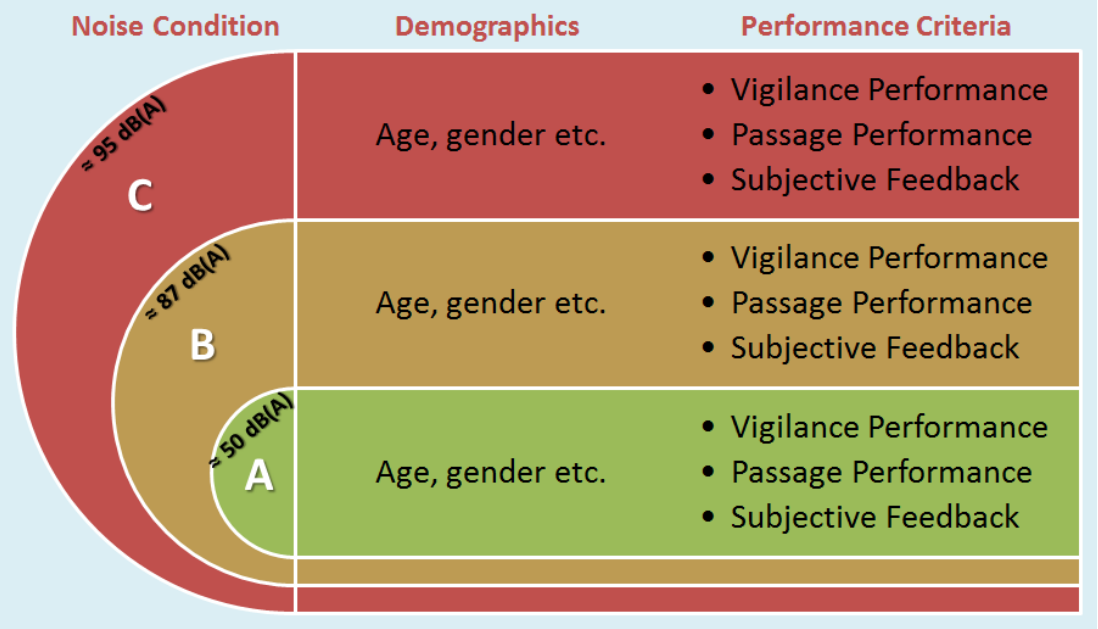


Figure 7-1: Summary of the experimental study

7.3.1 Full Mission Ship Bridge Simulator

The ‘Full Mission Ship Handling Simulator’ (FMSHS) utilised in this experimental study was built by Japanese Marine Science (JMS) and is located in Istanbul Technical University’s (ITU) Tuzla Campus (Figure 7-2). It is a state of the art simulator used in the training of seafarers and research. The FMSHS is fully capable of replicating realistic bridge operations for a wide variety of maritime scenarios and is fully programmable to the needs of the user. In brief, seven projectors are installed in the simulator room. Through these projectors, imagery is generated by projected onto a circular screen offering a realistic 240^0 view from port wing to starboard wing. All data relating to navigational manoeuvres carried out in the simulator was recorded within the simulators main computer system for the purpose of further analysis of the participant’s passage performance

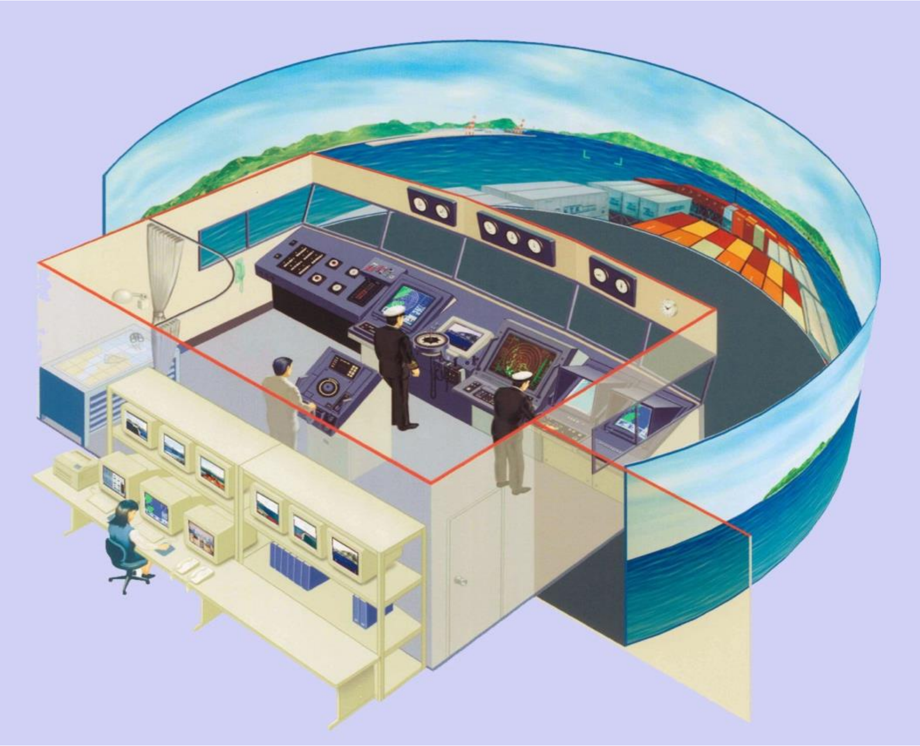


Figure 7-2: Full Mission Ship Handling Simulator (JMS, 2002)

7.3.2 The Scenario

After choosing the task to be utilised in this study, navigation of a difficult and busy passage between two fixed points in ‘real’ simulation conditions, specific scenario information and inputs had to be defined. These experimental scenario details were designed in a manner that maximised the potential for capturing data in the restricted time frame available, as well as ensuring important variables were defined to allow for ease of comparison between experiment participants.

The specific details of the scenario can be summarised as shown in the bullet points below:

- The navigation of the Bosphorus Strait in Istanbul, Turkey was selected as the physical location of the scenario. The navigation of the Bosphorus is known to be one of the most difficult transits due to having inconsistent currents, channel widths and turns requiring extensive steering in different sections of the passage. Figure 7-3 shows the map of the passage scenario.
- The passage within the strait was from south to north starting from a bridge known as the Bosphorus Bridge and finishing at the second one which is known as the Fatih Sultan Mehmet Bridge. The reason for selecting this route was due to the fact that a difficult manoeuvre against a strong current at the point known as Kandilli was required.
- A two way lane transit was implemented within the strait that had vessels travelling north on the right and those traveling south in the left. During this study the strait had traffic coming in both directions. The participants were given a plotted course within the lane which they were instructed to follow as best they could.
- The vessel used in the scenarios was a 220 meters long container ship with a breath of 32 meters. The vessel was fully loaded to its design condition with containers placed on the deck to reflect normal operation. This caused a minor visual obstruction on the overall visibility from the bridge.

- The speed of the vessel was kept constant for each participant. This was an attempt to increase levels of alertness through increasing the complexity of the task.
- Each scenario will last no more than 15 minutes which ensures that the exposure levels of participants were not exceeding the legal limits.
- During the scenario participants were also required to maintain acceptable level of communication with other vessels and respond to any calls through the VHF radio

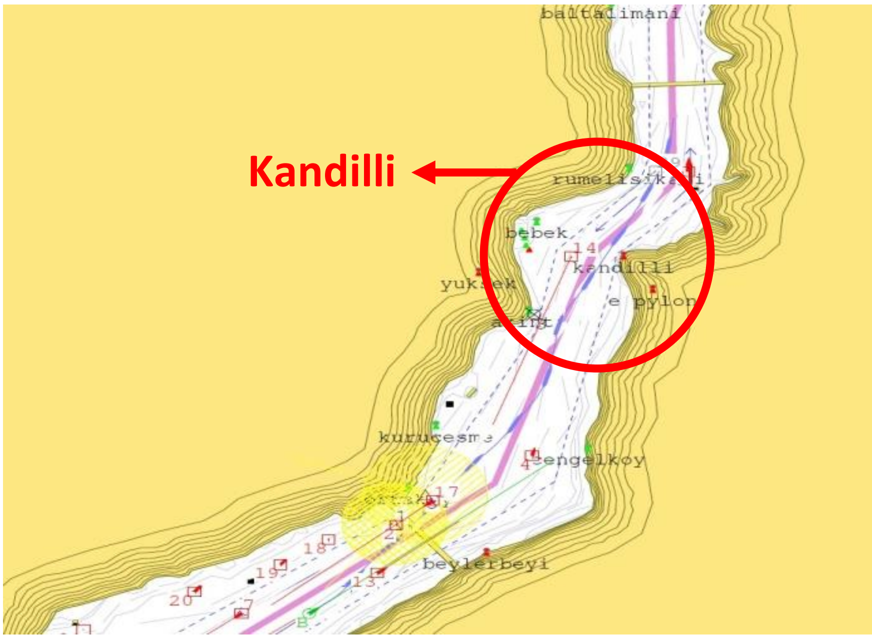


Figure 7-3: Map of the Bosphorus Passage

7.3.3 Peripheral Detection Task Setup

After defining the scenario, the mechanism in which the vigilance performance of the participant during the scenario had to be defined and then created.

A Peripheral Detection Task (PDT) is a test commonly used in experimental psychology, which is essentially a secondary task given to participants along with their original work duties. A PDT is proven in literature to measure the task load as well as the remaining resources from the original task. A PDT has been used in other transport modes (Martens and Van Winsum, 2000, Olsson and Burns, 2000, Patten *et al.*, 2006). However, to the best knowledge of the author, a PDT had not been tried on ships yet. Due to its successful application in other transport domains as well its simple methodology, a PDT was decided to be used in this research study as a measure of participants' vigilance performance.

The methodology of a PDT, requires participants to respond to randomly generated stimuli in their peripheries and measures the reaction time, number of missed stimuli and wrong response as the indicators of performance. Therefore, the PDT equipment which was necessary to be used during experiments was designed and developed in house at the University of Strathclyde. The setup of the PDT equipment included the following components;

- a Laptop
- a digital to analogue converter
- an LED light which is attached to a cap that the subjects were required to wear during experiments.
- a button which was attached to a glove

The LED Light and the button were connected to the digital to analogue converter, while digital analogue converter was linked to the laptop where the time history of the LED light blink times and the button response times were kept. A software called Spike2 (Cambridge Electronic Design, version 6) was used for the real time visualisation of the PDT experiment while keeping a log of times of LED lit and responses of the subjects, which were then analysed in order to evaluate the vigilance performance of the subject. The time interval between two red lights was programmed to randomly change between 15 to 20 seconds. Once activated the LED light stayed on for 1 second before going off again. Participants were instructed to respond to the red LED light as soon as they seen it light up by pressing the button which was attached to their thumb of the dominant hand. If participants failed to respond to a stimuli for 3 seconds or longer, then that situation was recorded as a 'missed stimuli'. It was clearly explained to all participants that the priority was watch keeping duty, and the safe navigation of the passage was of utmost importance.

Figure 7-4 visually explains the equipment used during the PDT test.

Figure 7-4: Peripheral Detection Task

7.3.4 The Noise Element

As the aim of this experimental study is to investigate the impact of noise on crew performance, the methodology of introducing noise to the experiment had to be defined.

In this study it was decided that participants would be asked to repeat the scenario of navigating a vessel through the Bosphorus Strait three times at different levels of background noise. The levels of background can be defined as the following:

Condition A: The background noise of the simulator environment (around 50 dB(A))

Condition B: Recorded noise at 87 dB(A) of a ship bridge deck generated artificially via loudspeakers placed in the simulator room.

Condition C: Recorded noise at 95 dB(A) of a ship bridge deck generated artificially via loudspeakers placed in the simulator room.

All noise levels were validated throughout the experiments by confirming with a sound meter at the point where the participant would be standing throughout the experiment.

Auditory fatigue can be defined as persons’ temporary loss of hearing due to noise exposure. The damage to ear can be temporary or permanent, and research shows that noise exposure or daily noise exposure can have an impact on the temporary threshold shift (Lin *et al.*, 2009). Moreover, researchers have also investigated the fact that exposure duration may contribute to human fatigue (Saremi *et al.*, 2008). In this study, in order to avoid fatigue and/or boredom effects participants were not allowed to take more than one experiment per day.

In order to prevent participants getting familiar (i.e. to cancel the learning effect) with the ship, course, traffic and environmental conditions (i.e. the scenario set within this experiment), the order that the participants were taking the experiment were counterbalanced appropriately. While counterbalancing does not get rid of the order effects, it ensures any confounding effects are cancelled out.

In addition, to prevent disparities in the results, the true purpose and objective of the study was not disclosed to the participants.

Finally, advice was given to participants that any high noise exposure (e.g. a loud concert), heavy physical training, mental fatigue or illnesses should be avoided in the 24 hours previous to completing an experimental scenario to avoid impacts on the participants’ performances in the experiments. This was further monitored in the responses of the questionnaire (explained in the next section) which each participant was required to complete before each experiment. (APPENDIX A)

7.3.5 Questionnaires

In this study, it was of great importance that demographic data and subjective feedback of the participants are recorded. Within this experimental study three questionnaires were developed:

- **Part A:** applied before each experiment to collect demographic information as well as the information on participant's condition before the experiments
- **Part B:** applied after each experiment set to collect the participants feelings about the experiment set that he/she has just completed.
- **Part C:** applied after the participant has completed all three experiment sets to collect participant's comparative subjective feelings on condition A condition B and Condition C.

A summary of the questions asked in the questionnaire can be seen in Table 7-1.

Table 7-1: Survey Questions

Questionnaires	Question Number	Description
Part A	Q1	Age
	Q2	Gender
	Q3	Duration of Sleep
	Q4	Time of Last Meal
	Q5	Illness
	Q6	Medication
	Q7	Noise exposure
	Q8	Cognitive activity
	Q9	Physical activity
	Q10	Sensitivity to noise
Part B	Q11	Experiment set completed
	Q12	Annoying
	Q13	Stressful
	Q14	Hard to concentrate
	Q15	Tiring
Part C	Q16	Easier to achieve
	Q17	More annoying
	Q18	More tiring
	Q19	Harder to Concentrate
	Q20	Noise affect crew on board
	Q21	Open ended question on noise on-board

All subjective questions in all the questionnaires utilise either a five or three point Likert scale.

7.4 Results

7.4.1 Participant Analysis

The participants of this experiment were 21 voluntary subjects of which 16 were male and 5 were female. An equal distribution in terms of gender was not possible due to the lack of female seafarers. However, this unavoidable selection bias in the subject group was not foreseen to have a potential to affect the main aims of this study. Figure 7-5 demonstrates the gender distribution amongst the subjects.

In order to standardise the subject group, participants were chosen from seafarers with a minimum 12 months of sea going experience (mean: 19 months). The majority of the subjects in this study were selected from final year students of the ITU Maritime faculty who have, on average, 12 months of seagoing experience, while the remaining subjects had substantially more. Details of the subject group analysed in this study are summarised in Table 7-2.

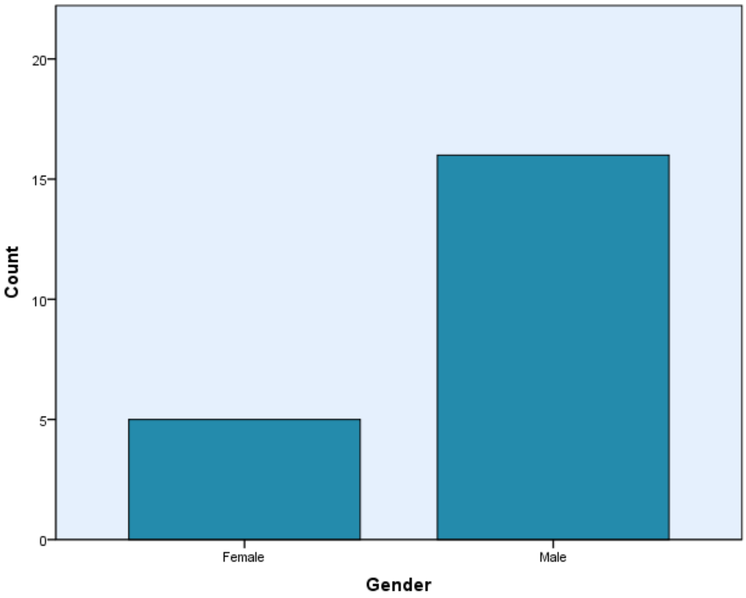


Figure 7-5: Histogram of Gender

The participants' ages in this study ranged from 21 to 32 years (mean: 24.57), with a standard deviation of 2.803. Figure 7-6 demonstrates the age distribution of participants in a histogram graph. In Table 7-2, the mean age for each crew category is also given. It can be seen that when moved from lower ranks to higher ranks, the mean age increases.

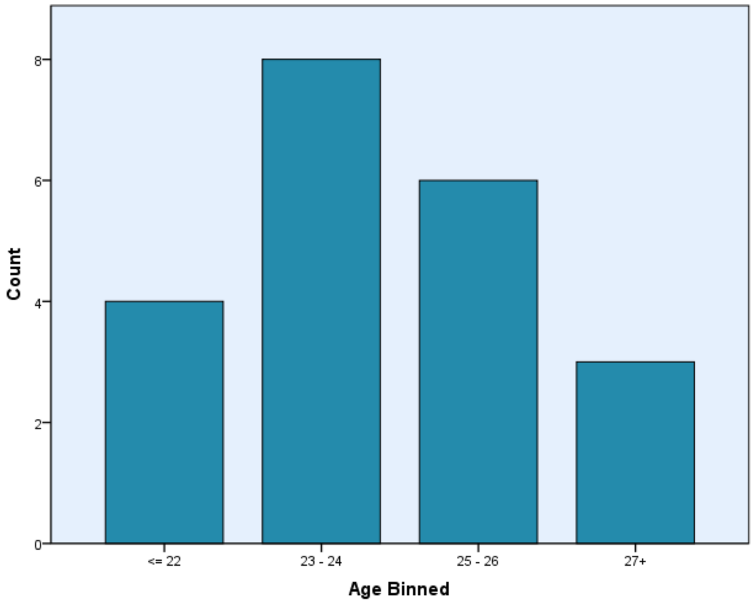


Figure 7-6: Histogram of Age

Health effects of noise are more likely to correlate with the noise level and exposure duration and this phenomenon is well accepted and integrated into standards and regulations (as explained in Chapter 4). However, the association of human annoyance and loss of concentration to noise is more difficult due to the fact that there is a lot of subjectivity involved. There may be many other factors involved when noise annoyance is considered. One of these factors is noise sensitivity which in turn influences the human response and therefore important to be considered. However, the term 'Noise Sensitivity' is not very well defined. This problem was addressed by Soames Job (1999) who tried to offer a formal definition to noise sensitivity as well as reviewed the literature related to noise sensitivity. Soames Job (1999) introduced the following definition for noise sensitivity:

"Noise sensitivity refers to the internal states (be they physiological, psychological [including attitudinal], or related to life style or activities conducted) of any individual which increase their degree of reactivity to noise in general"

In this study subjects' sensitivity to noise measured through a self-report. Participants were asked about their noise sensitivity which was given in a Likert scale (not sensitive at all to very sensitive). This method is the most practical and therefore common way for measuring noise sensitivity. For more information please refer to above study by Soames Job.

Table 7-2: Subject Demographics

		Number of Participants	Gender		Age		Experience	
		Count	Female Count	Male Count	Mean	Standard Deviation	Mean	Standard Deviation
Current Rank	**Cadet**	15	2	13	23.33	1.29	12.00	.00
	3rd Officer	1	1	0	24.00	.	15.00	.
	2nd Officer	2	1	1	25.50	.71	18.00	.00
	Chief Officer	3	1	2	30.33	2.08	56.00	6.93
	Total	**21**	**5**	**16**	**24.57**	**2.80**	**19.00**	**15.74**

Participants sensitivity to noise is shown in Figure 7-7 (skewness: 0.578, std. error of skewness: 0.501) where numbers 1-5 indicates likert scale categories of sensitivity to noise. (1: not sensitive at all, 2: little sensitive, 3: sensitive, 4: very sensitive, 5: extremely sensitive).

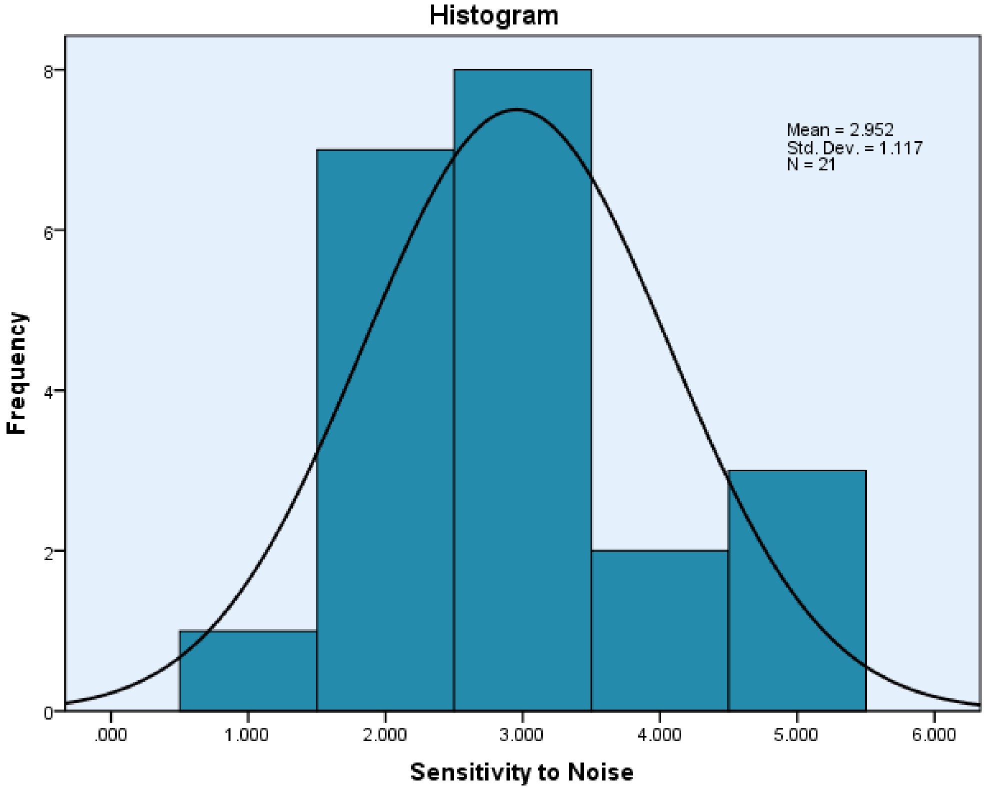


Figure 7-7: Participants' Sensitivity to Noise

7.4.2 Subjective Feedback

When dealing with collection of human response data subjective feelings of human is often referred to, through application of questionnaires or interviews. As introduced in Section 7.3.5 a questionnaire was applied to participants before the experiments in order to capture their physical and mental condition during the experiments (Part A in Table 7-1), another questionnaire was also applied after completion of each experiment in order to capture participants' feelings about the experiment that they have just completed (Part B in Table 7-1) and a final questionnaire was also given to subjects after they complete all 3 experiments in order to capture their comparative feelings about each noise condition (Part C in Table 7-1). Subjective feelings of the participants collected through the questionnaires are shown in following paragraphs.

Participants response to the statement; "During the experiments I felt annoyed" is demonstrated in Figure 7-8.

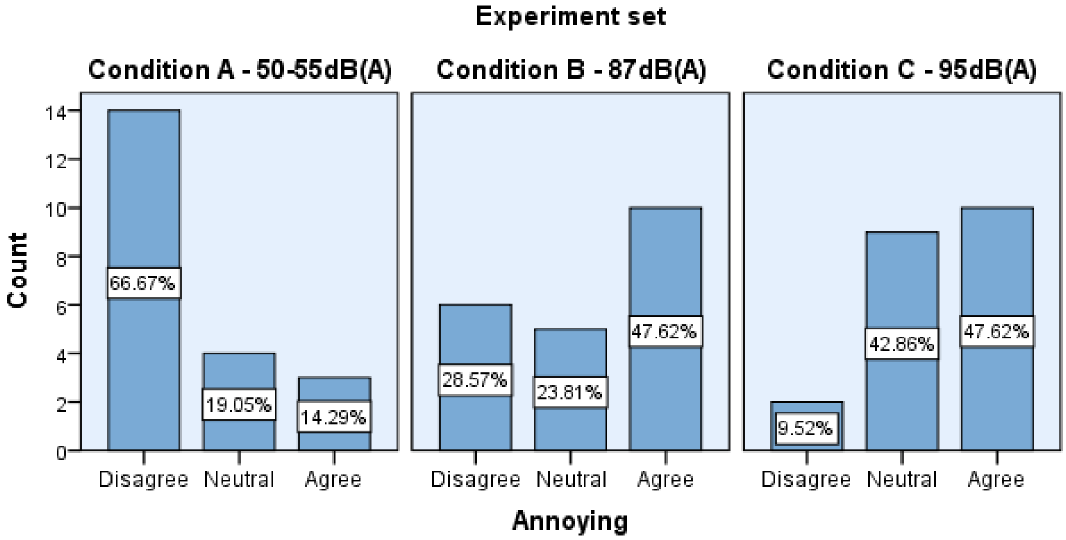


Figure 7-8: During the experiments I felt annoyed

It can be seen from Figure 7-8 that subjects tend to agree with this statement more when the noise level gets higher showing that the noise level. Keeping in mind that 1 represents "Disagree", 2 represents "Neutral" and 3 represents "Agree" participants' mean response for Condition A is calculated as 1.4762 (std dev: 0.74960) which shows that participants do not find the Condition A annoying. For Condition B the average response is 2.1905 (std dev: 0.87287) which shows people are slightly getting annoyed. For Condition C average response is 2.3810 (std dev: 0.66904) which prove that participants are more annoyed in this condition.

Furthermore, it is important to test if there is a relationship between the noise level and the participants reporting annoyance. In order to do that Pearson Chi-Square test is calculated via statistical package SPSS. P=0.002 was obtained suggesting that the null hypothesis which is shown below should be rejected.

H_0= "Noise condition and the participants annoyance response are independent of each other".

Therefore, it can be said that there is a significant relationship between the Noise level and the Participants' annoyance.

In the next question participants were asked to agree or disagree with the statement, “During the experiment I felt stressed”. Figure 7-9 shows that when the noise level increased participants agreed that they felt stressed during experiment.

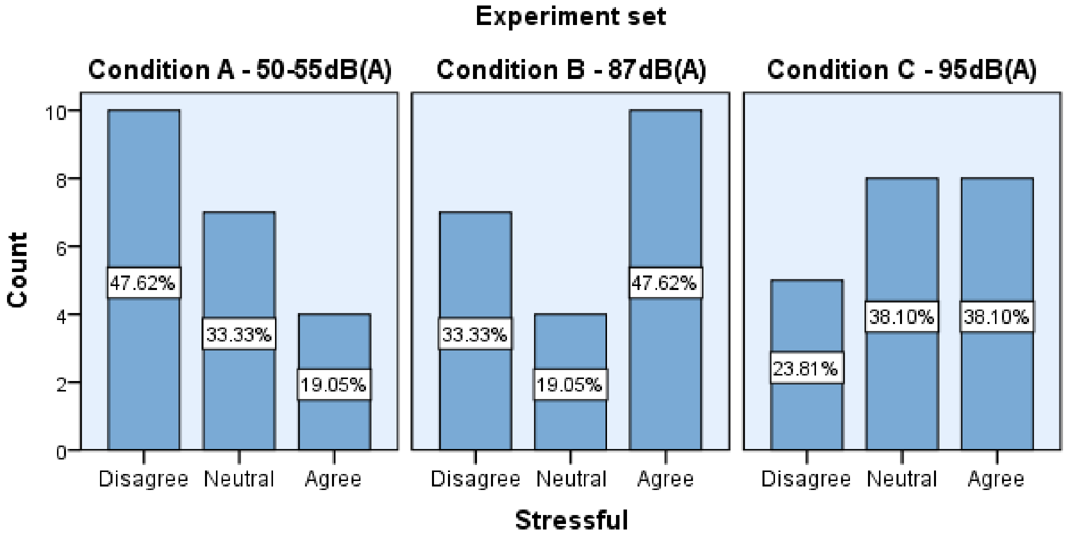


Figure 7-9: During the experiment I felt stressed

Mean responses of participants’ for Condition A, Condition B and Condition C are respectively 1.7143 (std dev: 0.78376), 2.1429 (std dev: 0.91026) and 2.1429 (std dev: 0.79282). However, the Pearson Chi-Square test does not suggest any significant relationship between noise level and participants’ stress reporting (P=0.228)

Then, participants were asked to associate themselves with the statement “During the experiment I had difficulty to concentrate”. Results are shown in Figure 7-10 which does not display a clear trend of difference between experiment sets. Mean participant responses are for Condition A, 1.4762 (std dev: 0.87287); for Condition B 1.7143 (std dev: 0.84515) and for Condition C 1.6667 (std dev: 0.85635) which show that for all 3 of the conditions participants do not agree that they had problem to concentrate. Pearson Chi-Square test also does not suggest a relationship between noise condition and hard to concentrate (P=0.219)

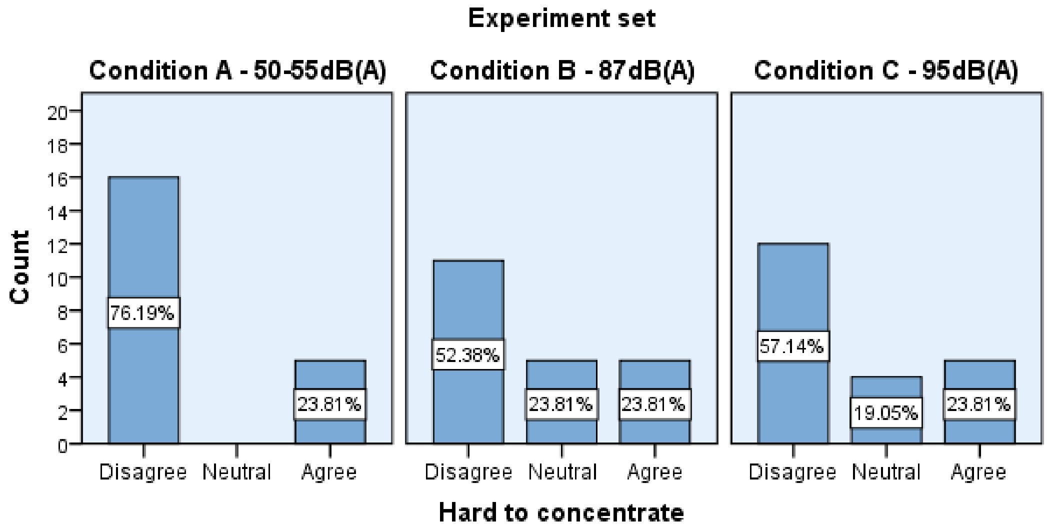


Figure 7-10: During the experiment I had difficulty to concentrate

Finally, participants were asked to agree or disagree with following statement: "After the experiments I feel tired". Figure 7-11 shows that there is a clear increase in reported tiredness between the Condition A and Condition B. However, in Condition C it appears that the tiredness improves compared to Condition B. Mean participant responses for tiredness are as follows; for Condition A: 1.5714 (std dev: 0.74642), for Condition B: 2.2857 (0.78376) and for Condition C: 1.9048 (std dev: 0.94365). Pearson Chi-Square test suggests nearly significant relationships between noise level and tiredness (P=0.053).

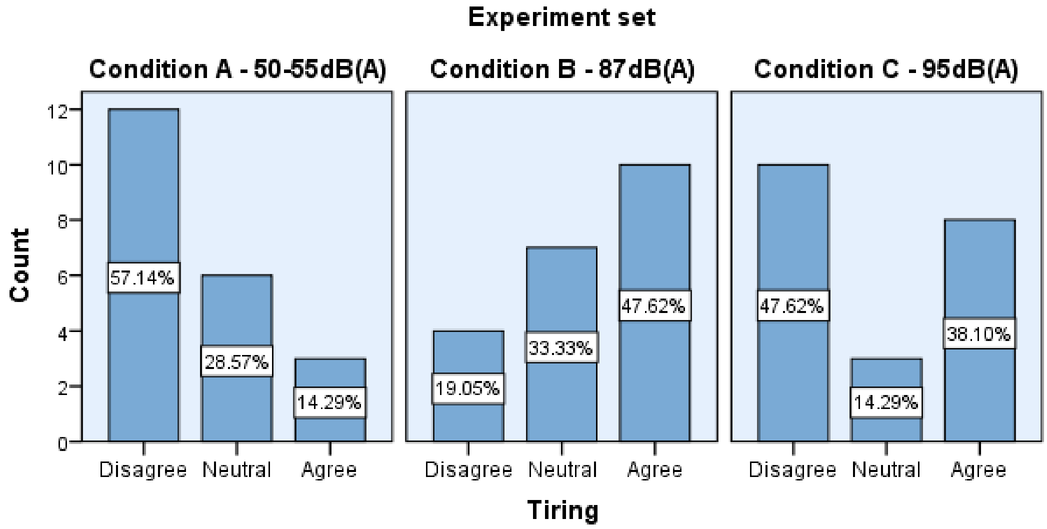


Figure 7-11: After the experiments I feel tired

It needs to be noted that the gender effect may cause a difference in participants' response, for example, female participants may be getting more affected by noise than the male participants. In order to investigate this situation mean responses of male and female participants are compared in Table 7-3. It can be seen that Female participants tend to report more annoyance, stress, concentration difficulty and tiredness after experiments when compared to male participants.

Table 7-3: Comparison of means for gender

Report

Gender		Annoying	Stressful	Hard to concentrate	Tiring
Female	Mean	2.3333	2.5333	1.7333	2.2667
	N	15	15	15	15
	Std. Deviation	.81650	.74322	.88372	.88372
Male	Mean	1.9167	1.8333	1.5833	1.8125
	N	48	48	48	48
	Std. Deviation	.84635	.80776	.84635	.84189
Total	Mean	2.0159	2.0000	1.6190	1.9206
	N	63	63	63	63
	Std. Deviation	.85179	.84242	.85059	.86699

Based on the above mean response results, it can be said that females are reporting 22% more annoyance, 38 % more stress, 9 % more concentration difficulty, 25 % more tiredness. In these experiments gender has been separated and a different a response to noise in relation to gender has been observed. However, due to the small sample size no conclusive comments can be made.

After the completion of all 3 of the experiments participants were asked to complete Part C of the questionnaire which allows them to compare the 3 noisy conditions. Participants were first asked about which experiment set they found easier to achieve. The answers given to this question are shown Figure 7-12. Most (71.43%) of the participants reported that they found 'Condition A' easier to achieve.

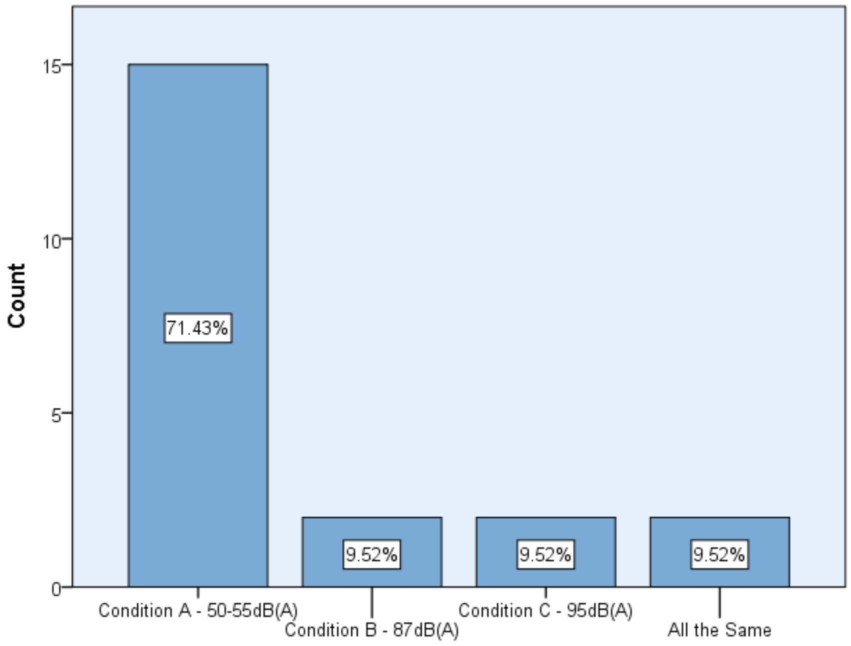


Figure 7-12: Which experiment set did you find easier to achieve?

Furthermore, participants were asked to pick the most annoying experiment set. 61.90 % reported 'Condition C' as the most annoying experiment set which can be seen in Figure 7-13.

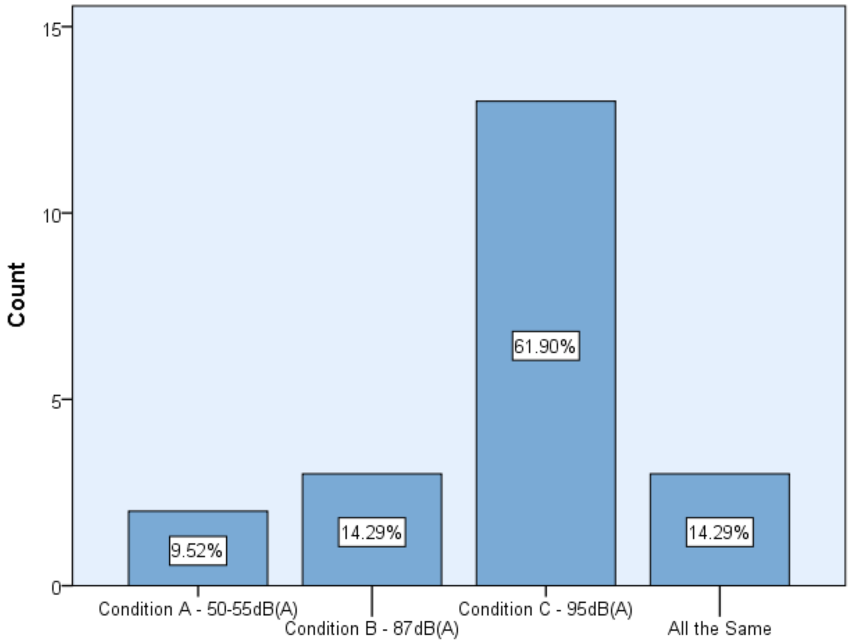


Figure 7-13: Which experiment set did you find more annoying?

Moreover, 47.62 % of participants think that 'Condition C' is harder to concentrate while 33.33 % thinks that it is more difficult to concentrate in 'Condition B'. It needs to be noted that both conditions (‘Condition B’ and ‘Condition C’) have background noise which can be though as the reason for the concentration loss. The distribution of participants’ response to this question can be found in Figure 7-14.

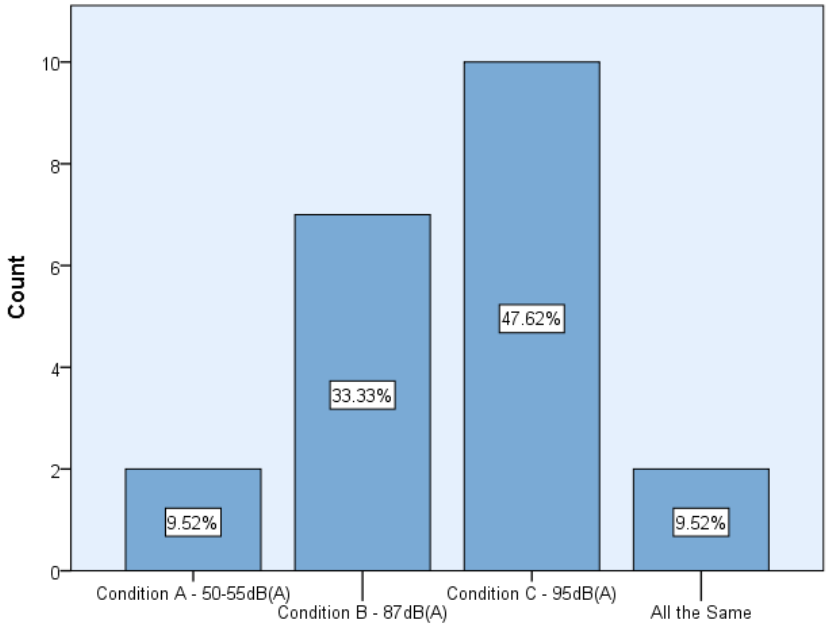


Figure 7-14: Which experiment set did you find harder to concentrate?

Finally, Figure 7-15 shows that 61.90 % of the participants felt more tired in ‘Condition C’, while 23.81% felt more tired in ‘Condition B’.

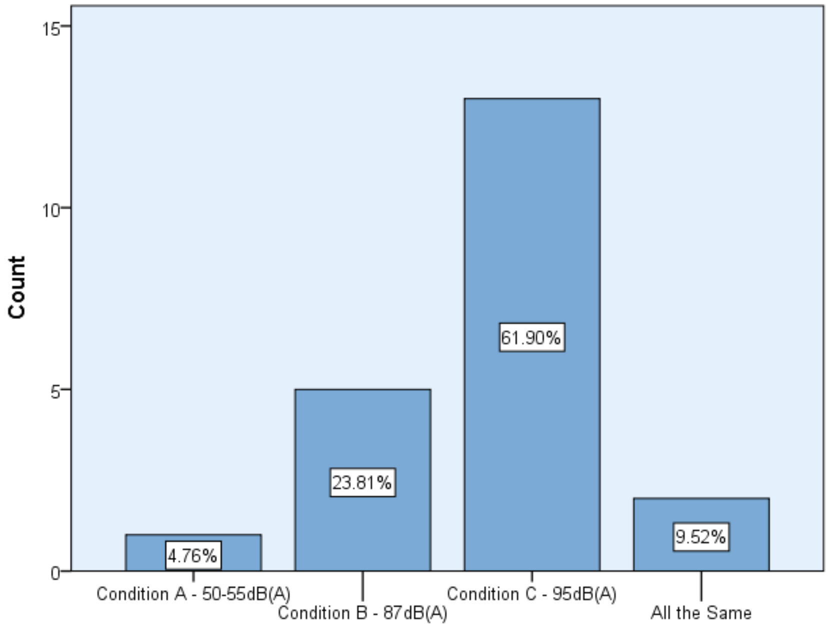


Figure 7-15: Which experiment set did you find more tiring?

Within the Part C of this questionnaire participants were also asked to provide their view on, whether the noise on board ships affects the crew performance or not. It can be seen from Figure 7-16 that apart from 2 people everyone agreed that noise levels on board ships are likely to affect crew performance.

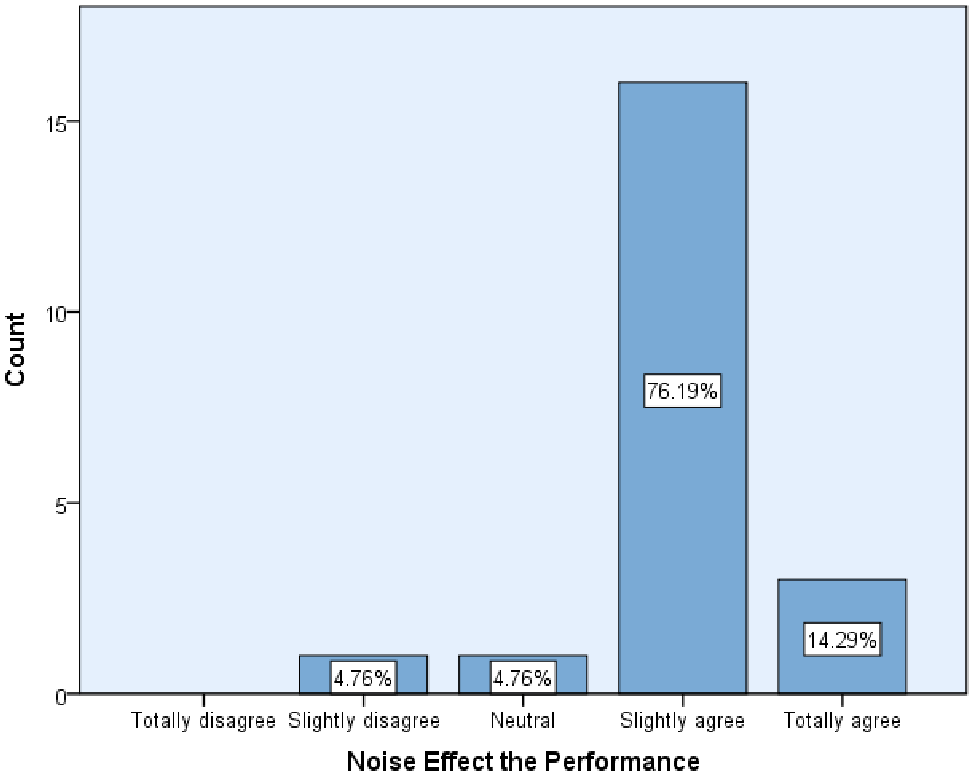


Figure 7-16: Noise levels are likely to affect crew performance on board

7.4.3 Vigilance performance

In terms of measuring the vigilance performance of the subjects, the ultimate aim of the study was to investigate the relationship between background noise and the response times. It was previously explained that the PDT is a secondary task given to the subjects to measure the load of the primary task, i.e. remaining available resources of the participant from the primary task. In this study the primary task that was being observed was the watch keeping and safely steering the ship through the busy channel. It was considered that application of a PDT test would work as a means of objective assessment for the vigilance performance of the participants. On the other hand, the ‘null hypothesis’ (H_0), which will be tested for its validity is shown below;

H_0: There is no difference between the response times of the participants who are exposed to different background noise levels (‘Condition A’, ‘Condition B’ and ‘Condition C’)

In order to test the null hypothesis ANOVA analysis was conducted in SPSS statistical package, results of which are shown below in Table 7-4.

Table 7-4: Results of ANOVA analysis

Response Time

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.898	2	.449	5.963	.003
Within Groups	216.993	2882	.075		
Total	217.891	2884			

In this study P<0.05 was assumed to be significant. Therefore, P=0.003 shows that there is a significant relationship between background noise and participants’ response times. In other words, the possibility of achieving these reported differences between different noise conditions by chance is less than 0.3%. Hence, there is 99.7 % chance that the findings reported above are true. This means that the null hypothesis needs to be rejected.

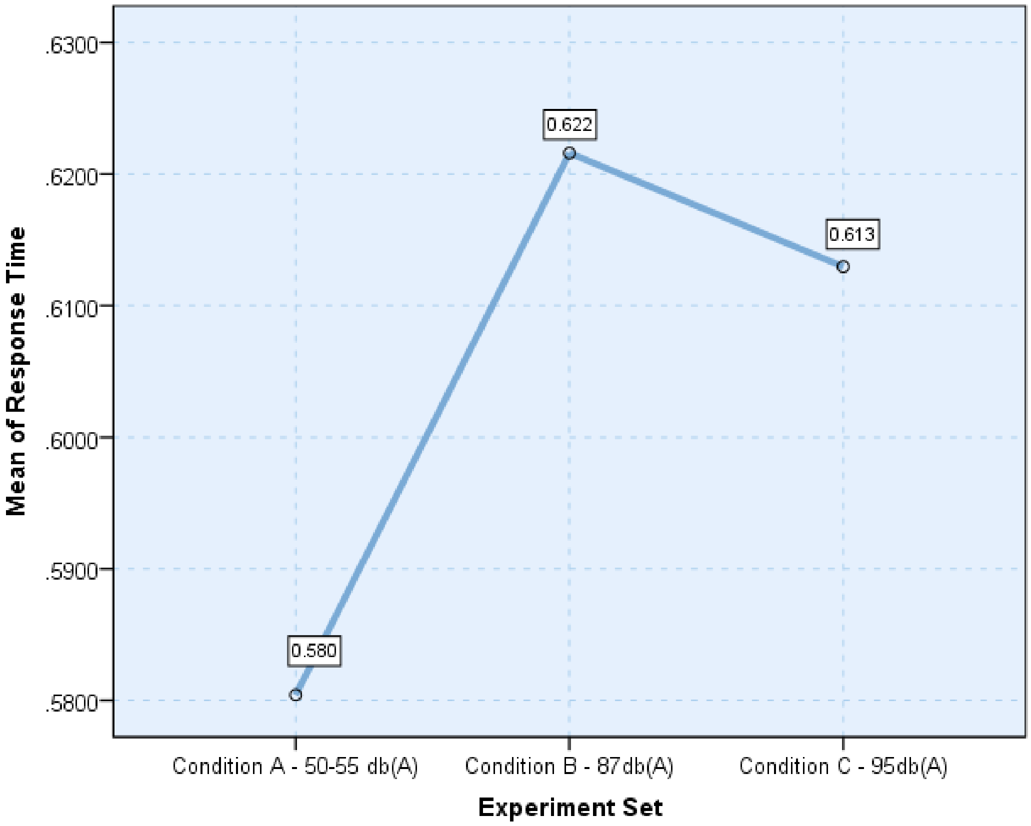


Figure 7-17: Plot of mean response times vs experiment set

P statistic does not tell the relationship between the groups but tells that response times of subjects, who are exposed to difference background noise levels, are significantly different from each other. In order to investigate how peoples mean response rates differ between 'Condition A', 'Condition B' and 'Condition C', Figure 7-17 was prepared. It can be seen that the mean response time of subjects is:

- 0.580 in 'Condition A' where there is no background noise,
- 0.622 in 'Condition B' with 87dB (A) background noise
- 0.613 in 'Condition C' with 95dB (A) background noise.

This shows that the vigilance performance of the subjects is getting affected by the existence of a background noise.

Moreover, in Table 7-5 descriptive statistics of participants' response times are shown.

Table 7-5: Descriptives for Response Time

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
Cond. A	928	.580409	.2653447	.0087104	.563315	.597504
Cond. B	1006	.621600	.2635266	.0083086	.605296	.637905
Cond. C	951	.612965	.2936723	.0095230	.594277	.631654
Total	2885	.605504	.2748665	.0051174	.595470	.615538

It can be seen that increasing noise level from 'Condition A' to 'Condition B' is resulting in 7.1% increase in the response time of participants. Similarly, increasing the noise level from 'Condition A' to 'Condition C' results in 5.6% increase in participants' response time. However, it is also observed that from 'Condition B' to 'Condition C' there is 1.4 % improvement in response rates.

In the literature it is possible to find proof to the fact that women get more adversely affected by noise exposure when compared to men (Gulian and Thomas, 1986, Fried *et al.*, 2002). However, it is necessary to clarify that, findings of those research studies are not directly comparable due to the fact that results of such studies are heavily dependent on the task being assessed. For that reason, it was considered worthwhile to investigate the effect of gender on the observed response rates.

Table 7-6: Descriptives for gender effect on response time

		Response Time			
		Valid N	Mean	Standard Error of Mean	Standard Deviation
Cond A	Female	230	0.5931	0.0162	0.2459
	Male	698	0.5762	0.0103	0.2715
Cond B	Female	256	0.6868	0.0147	0.2358
	Male	750	0.5994	0.0098	0.2689
Cond C	Female	242	0.6864	0.0227	0.3533
	Male	709	0.5879	0.01	0.266

Table 7-6 and Figure 7-18 show that mean response time for female participants are higher than the male participants as well as female are getting more adversely affected by the increase in background noise. For example when noise level increased from Condition A to Condition B female participants' response time gets affected by 15.8% while under same condition male participants get affected by only 4.0%.

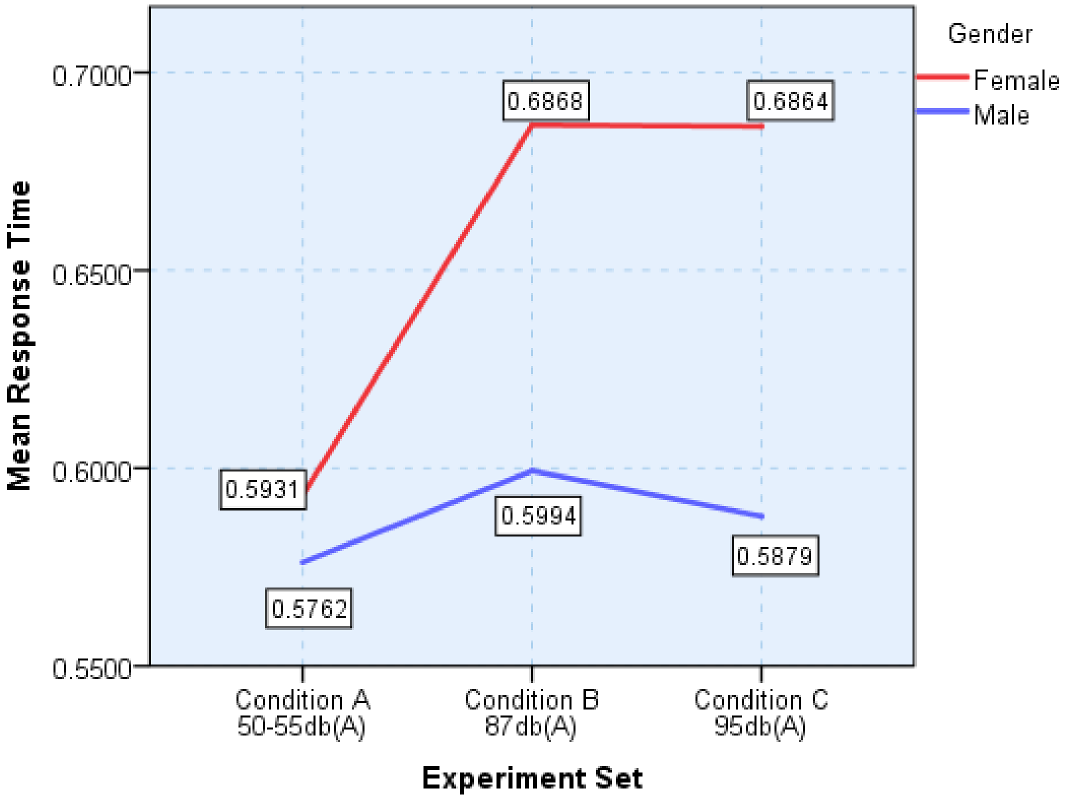


Figure 7-18: Gender effect on response rates

Similarly, 'number of missed stimuli' and 'number of wrong response' was also analysed with an aim to use them as an indicator of vigilance performance. However, no meaningful conclusions were drawn from the above two criteria. The reason found behind this problem was the fact that results were heavily biased by some of the participants' high wrong response or missed stimuli rates. In order to explain it a little better following example can be examined: for example in 'Condition B' average number of missed stimuli is 3.19 however there is one participant who missed 13, similar problem exist in each condition which in turn makes the results biased towards these outliers. It has been realised that missed stimuli and wrong response can be effectively used as a performance indicator if we would be comparing the task loads of different job tasks on board a ship.

7.4.4 Passage Performance

Before each experiment, participants were given clear directions about the passage scenario. Every participant was told that safety of the passage is utmost importance, therefore, all collision avoidance rules, separation rules of the channel need to be obeyed. In order to make the scenario as standard as possible the passage plan was decided by the instructors and given to the subjects. Since all the subjects were told to follow same route, it was decided that the deviations from this planned route can be used as a performance indicator of the passage.

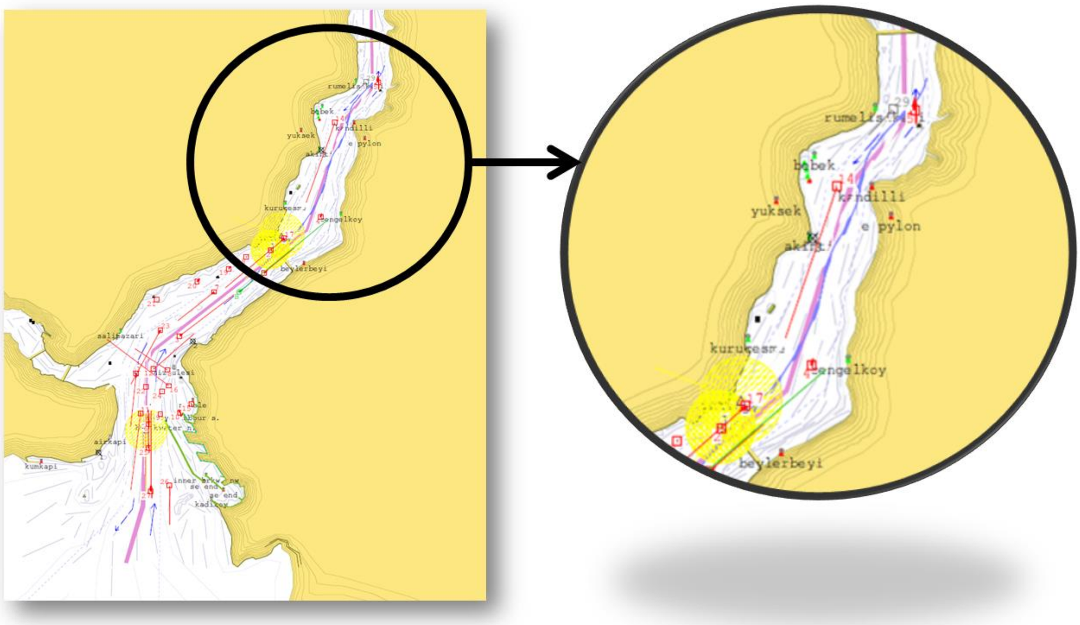


Figure 7-19: Passage summary generated by the simulator after each experiment

After each experiment, the simulator software was able to generate a passage summary which clearly shows the actual route that the ship has travelled during the passage scenario. Figure 7-19 shows an example of the passage summary in which the blue line represents the actual route that the ship has travelled during the passage. The aim was to use this actual route line and compare it with the route that participants were told to follow, and the deviations measured in between two could be used as an error in the scenario. In order to be able to calculate the deviations from original route, all result files were regenerated in electronic format and scaled to same ratio to allow comparability. There were 21 subjects participated in this study and therefore 63 passages to be analysed. Each passage summary was scanned and transferred to electronic domain. Then, all these picture files were resized to have the same scale to be able to compare with each other objectively. Then, all these image files were processed and manually regenerated in a 3D-drawing software called RhinoCeros. Figure 7-20 demonstrates the creation process of each passage. Once the scenarios are regenerated in RhinoCeros, the software had the capability to generate detailed point files, which were used as the coordinates of the ship during the passage. These coordinates then used to calculate the deviations.

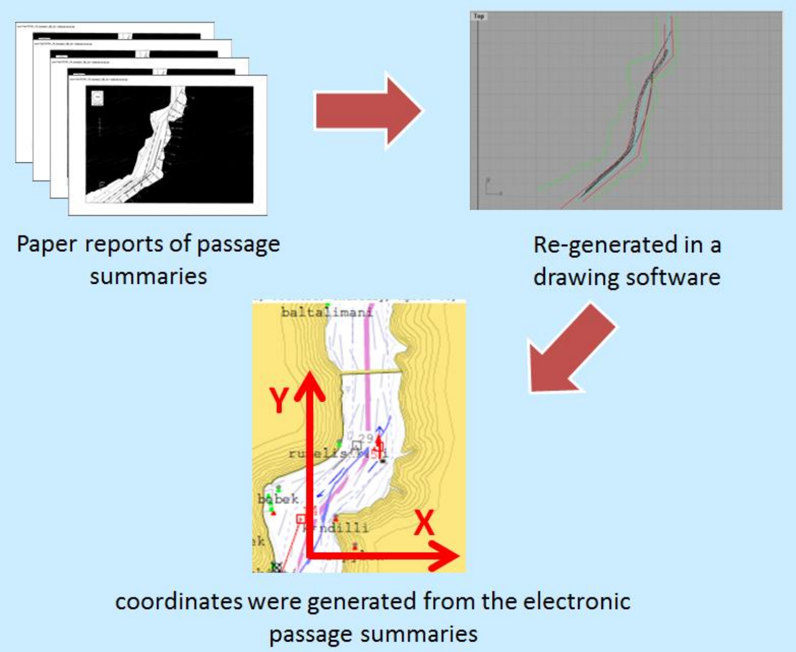


Figure 7-20: Conversion of paper reports to electronic format

By using the point files (i.e. coordinates) each passage was regenerated as shown in Figure 7-21.

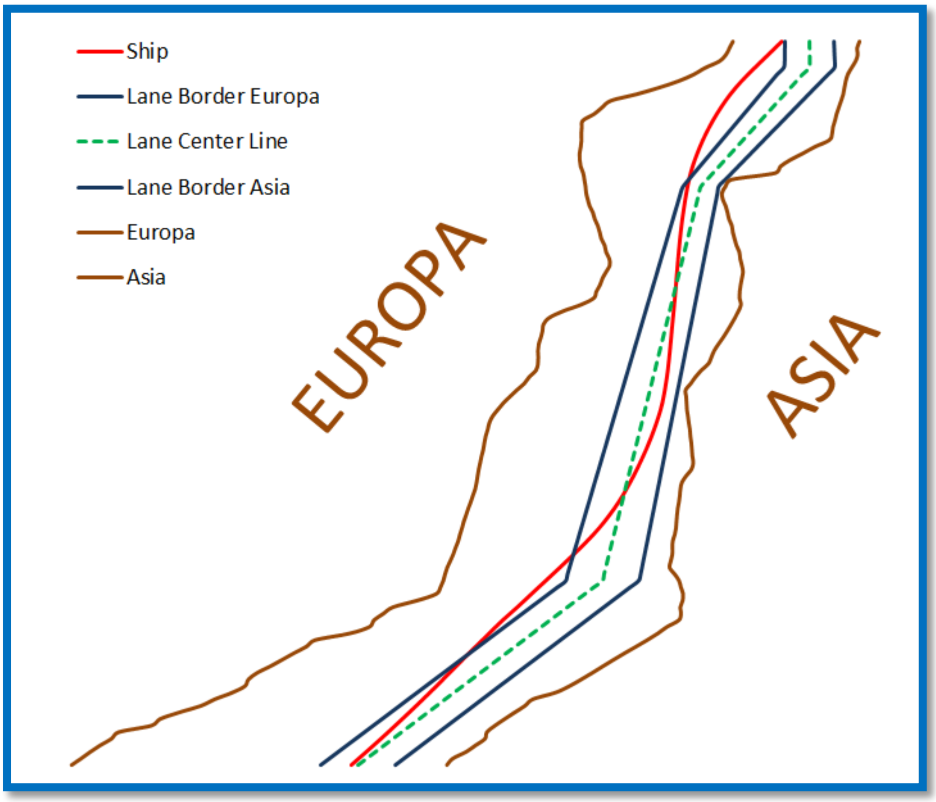


Figure 7-21: Regenerated passage summary.

In Figure 7-21, the actual route that the ship travelled during the scenario is represented by the red line, while the blue lines represents the lane that the ship needs to stay in as this is a rule of this channel, brown lines represent the land and in between brown lines is the Bosporus channel. Finally the green dashed line represents the ideal route that each participant was asked to follow during the passages.

All passage summaries were analysed based on the following three criteria as part of subjects' passage performance.

- Deviation from ideal route/dashed centreline (CL)
- Deviation from the nearest lane border
- Distance travelled outside the lane

Figure 7-22 visually demonstrates the each criterion. 'Deviation from ideal route (CL)' means the horizontal distance between the actual position (red line) of the ship and the ideal route (green line). Similarly, ‘Deviation from the nearest lane border’ is the horizontal distance between the actual position of the ship (red line) and the lane border (blue line), this criteria is only calculated when the ship goes outside the lane defined by two blue lines. Finally, ‘Distance travelled outside the lane’ is the length of the route that the ship travelled outside the defined lane.

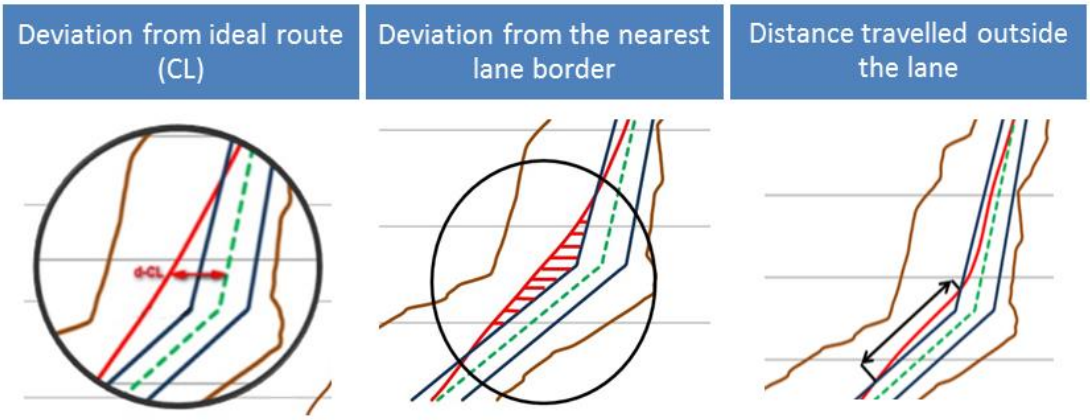


Figure 7-22: The criteria to evaluate participants’ passage performance

In shipping busy channel passages complex tasks which require advance planning and high level of attention and concentration to follow the route as planned. Therefore, investigation of the deviations from the ideal route is a useful measure to assess the success of the passage.

Table 7-7: Descriptive statistics for ‘deviation from the ideal route’

		Deviation from the ideal route				
		Count	Sum	Mean	Standard Deviation	Standard Error of Mean
Experiment Set	50-55 db(A)	2331	878.10	.38	.29	.01
	87db(A)	2331	1129.77	.48	.36	.01
	95db(A)	2331	927.34	.40	.28	.01

It can be seen from Table 7-7 that from ‘Condition A’, which has no background noise generated, to the ‘Condition B’ and ‘Condition C, where background noise exist, the deviation of the ship from the ideal planned route was increased. It is important to mention that a notable improvement has been observed from

'Condition B' to 'Condition C'. Figure 7-23 demonstrates the total and mean deviation from the ideal planned route.

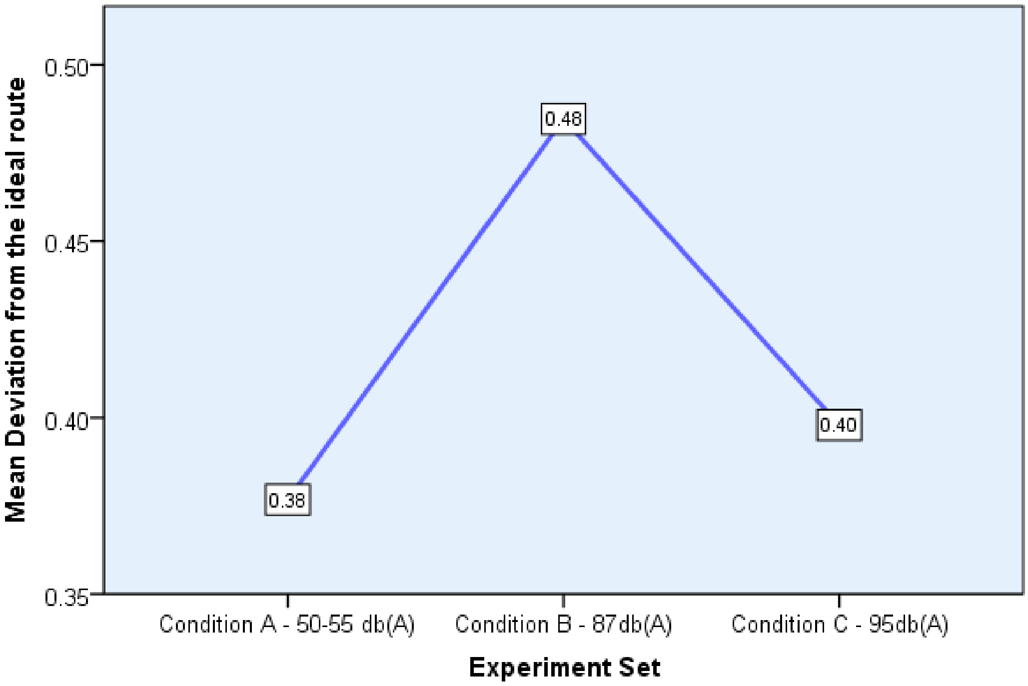


Figure 7-23: Mean for 'Deviation from the ideal route'

In order to test the significance of the relationship, ANOVA analysis was conducted in SPSS and results are shown in Table 7-8. P=0.000 shows that there is a significant relationship between noise level and 'Deviation from the ideal route'.

Table 7-8: Results of ANOVA analysis for 'Deviation from the ideal route'

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Deviation from the ideal route	Between Groups	15.263	2	7.632	79.504	.000
	Within Groups	670.982	6990	.096		
	Total	686.246	6992			

Moreover, effect of gender on 'deviation from the ideal route' has been investigated by plotting them separately in Figure 7-24. Results reveal that female participant tent to deviate from the ideal route more than the male, however the percentage difference between conditions follow similar trend between male and female. Effect of age was also investigated however there were no trend identified.

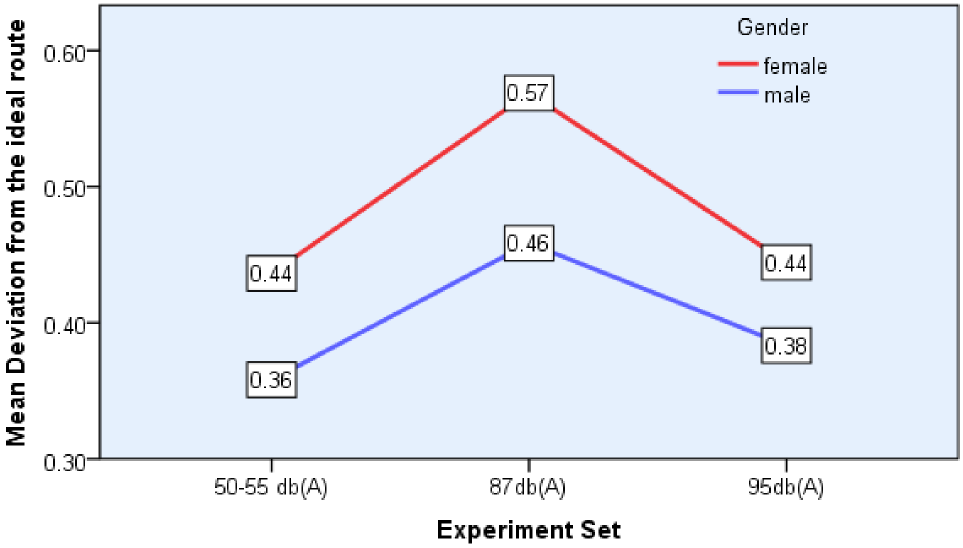


Figure 7-24: Gender effect on 'deviation from the ideal route'

In shipping, channel passages are always complex because of higher risks of collision and grounding due to the traffic and heavy manoeuvring needs. In order to reduce risks of collusions and to be able to regulate the shipping traffic in the channels, there are lanes defined which a ship needs to keep on similar to roads in road transport. In a channel like Istanbul Bosporus it is very important to avoid going outside the lane, therefore, 'Deviation from the nearest lane border' was considered to be an important criteria to assess subjects' passage performance.

Table 7-9: Results of ANOVA analysis for 'Deviation from the nearest lane border

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Deviation from the nearest lane border	Between Groups	7.493	2	3.746	92.100	.000
	Within Groups	284.337	6990	.041		
	Total	291.830	6992			

First of all, ANOVA analysis was conducted in SPSS in order to assess the relationships and results are shown in Table 7-9. P=0.000 was obtained from ANOVA analysis which proves the existence of significant relationship between noise and ‘Deviation from the nearest lane border’. In other words, there is less than 0.1% chance that results obtained by chance rather than being significant.

Table 7-10: Descriptive statistics for ‘Deviation from the nearest lane border’

		Deviation from the nearest lane border				
		Count	Sum	Mean	Standard Deviation	Standard Error of Mean
Experiment Set	50-55 db(A)	2331	182.44	.08	.17	.00
	87db(A)	2331	348.62	.15	.26	.01
	95db(A)	2331	191.46	.08	.16	.00

In Table 7-10, total deviation from the nearest lane border is shown along with, means and standard deviations. The change in mean deviation is also visually demonstrated in Figure 7-25.

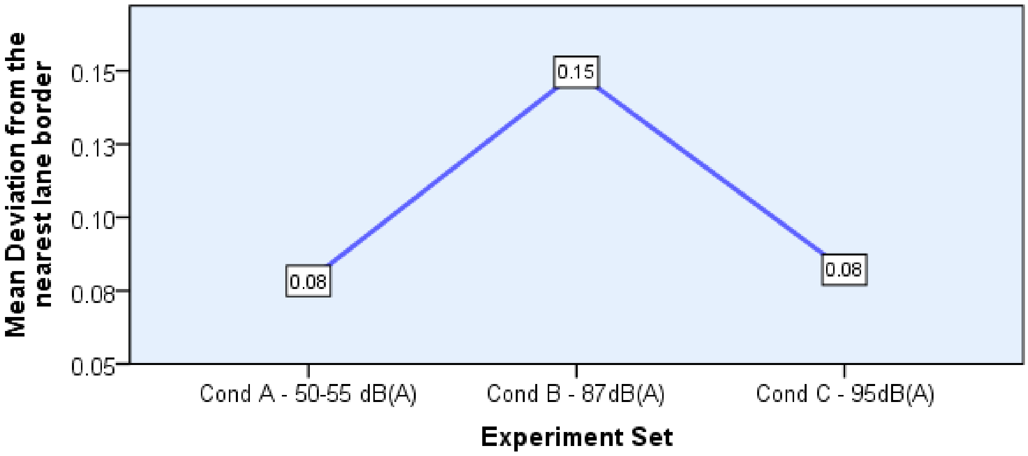


Figure 7-25: Mean for ‘Deviation from the nearest lane border’

It can be seen that average deviation outside the lane increases from ‘Condition A’ to ‘Condition B’. However, from ‘Condition B’ to ‘Condition C’ amount of deviation improves back to almost same level.

Moreover, Figure 7-26 shows the effect of gender on the results of ‘Deviation from the nearest lane border’. Similar to the previous criteria female participants tend to deviate more from the lane however percentage change between conditions look similar between male and female participants.

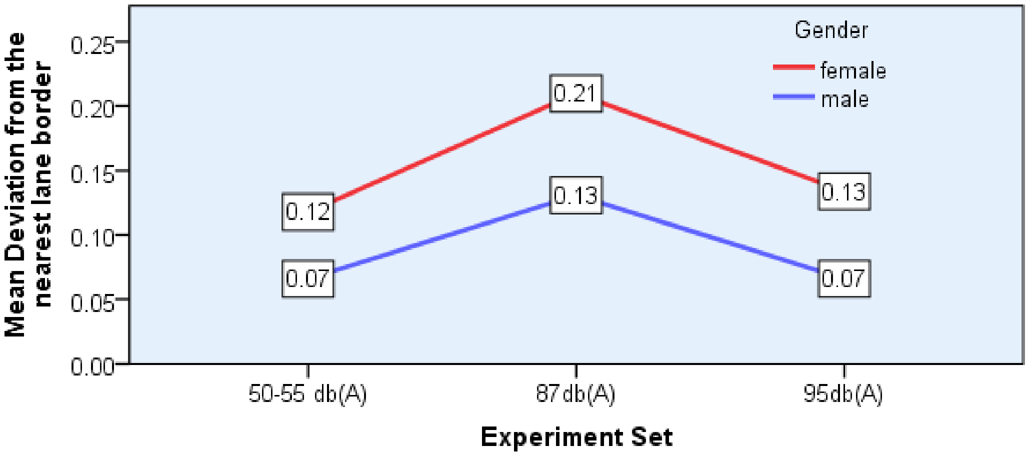


Figure 7-26: Gender effect on 'Deviation from the nearest lane border'

Similar to the 'Deviation from the nearest lane border' another criteria selected was 'Distance travelled outside the lane'. In fact the aforementioned two criteria are similar and probably correlated. However, the length of the actual route travelled outside the lane indicates the amount of time that the ship violated the separation rule and hence exposed to higher risk of collusion. Results of ANOVA analysis are shown in Table 7-11.

Table 7-11: Results of ANOVA analysis for 'Distance travelled outside the lane'

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Distance travelled outside the lane	Between Groups	.241	2	.120	33.242	.000
	Within Groups	25.297	6990	.004		
	Total	25.538	6992			

P =0.000 was obtained from the ANOVA analysis which shows significant relationships and suggest that the null hypothesis of no relationship should be rejected.

Moreover, Table 7-12 shows the descriptive statistics for the 'distance travelled outside the lane' while Figure 7-27 demonstrates the difference between Noise conditions in terms of average deviations

Table 7-12: Descriptive statistics for 'Distance travelled outside the lane'

		Distance travelled outside the lane				
		Count	Sum	Mean	Standard Deviation	Standard Error of Mean
Experiment Set	50-55 db(A)	2331	93.14	.04	.06	.00
	87db(A)	2331	124.73	.05	.06	.00
	95db(A)	2331	99.31	.04	.06	.00

Same trend also exist for this criteria('Distance travelled outside the lane'), which 'Condition B' appears to be the one which affects the participant performance most adversely while no notable changes can be observed between 'Conditon A' and 'Condition C'.

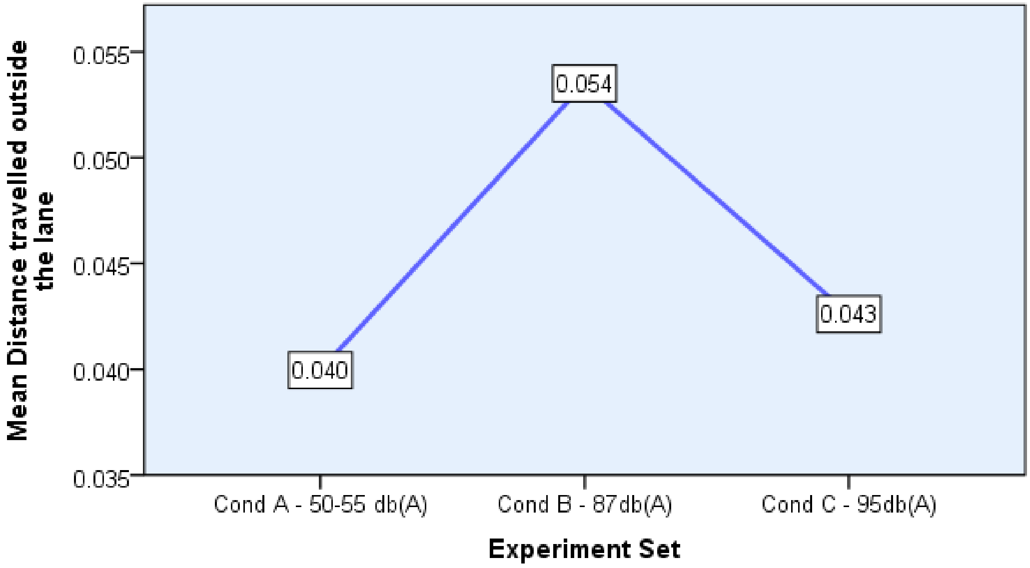


Figure 7-27: Mean for 'Distance travelled outside the lane'

Finally, gender effects has been shown in Figure 7-28 which is in agreement with the previous two passage performance criteria. Female participants were found to be travelling outside the safe lane more than the male participants. However, the relative change in distance between the noise conditions does not show much difference between male and female.

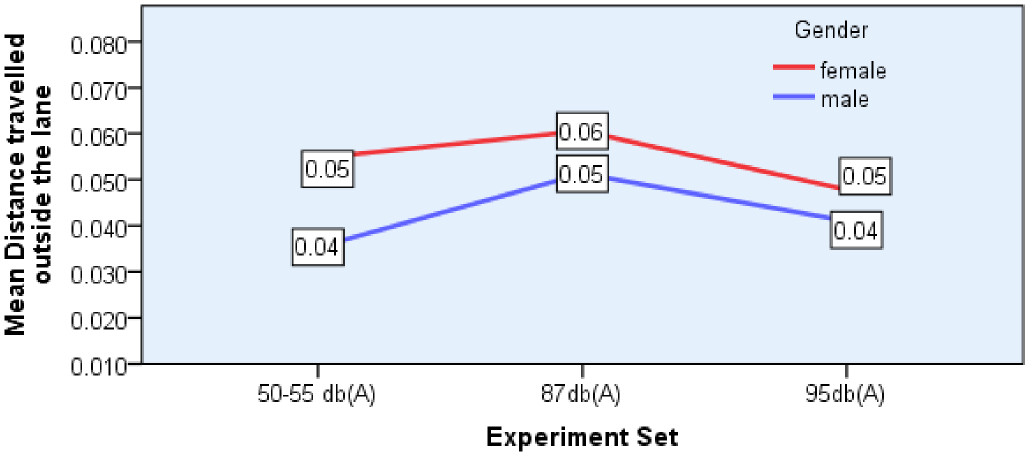


Figure 7-28: Gender effect on 'Distance travelled outside the lane'

7.5 Discussion

Annoyance and tiredness is important due to the fact that crew do not only work on board but also live on board. If the noise on-board ships reaches to levels where it is annoying for crew, in long term it would cause fatigue and result in affecting crew performance and wellbeing adversely.

Results of vigilance performance suggest that being exposed to background noise affects significantly ($P<0.05$) the performance of the crew, by making the task more demanding and making them less vigilant to their peripheries. This may result in the officer of watch being less alert and may affect the safety of the operation adversely. Hence, special attention can be given to those areas which require high levels of attention and vigilance when designing the noise levels.

Moreover, participants' subjective feedback, results of vigilance performance as well as the results of passage performance, indicates that female subjects are more prone to noise and they tend to get more adversely affected by background noise. This is in line with the findings of similar research in other domains (Gulian and Thomas, 1986, Fried *et al.*, 2002). Therefore, when modelling the 'human response to noise' gender can be considered as an explanatory variable in the models.

On the other hand, in some cases it was observed that in Condition C (95dB(A)) subjects' performance appeared to improve. Moreover, number of participants mentioned that they were more alert in this condition due to the high level of noise.

The improvement in results in high level noise condition could be attributed to the fact that the high noise level in short durations may improve the performance especially by keeping people alert. The matter was also discussed in Chapter 4 where it was explained that noise can act as a wake-up call. Human body reacts to high level sudden noise by releasing hormones to prepare body to react the threats. Broadbent (1954) reported that continuous exposure to noise (over 90 dB(A)) requires more than 15 minutes to result in a decrease in the performance. Since the experiments conducted in this study did not last more than 15 minutes participants may have not been reached to a state that they would get adversely affected. However, this alertness cannot be sustained long durations and the person who is exposed to such high levels of noise is likely to get fatigued. In order to make more confident comments about this matter more research should be conducted.

Since the performance outcomes of the subjects showed significant relationships with noise, it was also tried to model these effects, however the modelling efforts did not yield in good models. However, this study has been the motivation to focus on modelling human response to noise by systematic measurement and data collection from ships which will be explained in next Chapters.

To the author's knowledge, this study is the first ever experimental study conducted in full mission ship simulators aiming to research on the effects of noise exposure on crew performance and wellbeing on ships. And more experiments should be conducted with a background noise of different type and intensity, during different shipping tasks.

Participants of this experimental study was not equally distributed in terms of gender therefore future studies can be designed with more female participants and gender effects can be observed more confidently.

7.6 Chapter Summary

In this chapter the effects of noise on the crew performance and wellbeing has been researched through the experimental study conducted in a full mission ship bridge simulators. The most important outcome of this study was, in fact, establishing significant relationships between the noise exposure and the performance/wellbeing of the crew in a shipboard environment. Moreover, to the best knowledge of the author experiments conducted in this PhD study were the first time that performance effects of noise in a shipboard environment were investigated. Therefore, the results of this study were considered as a good contribution to the literature. Table 7-13 shows the summary of significant relationships identified in this study.

Table 7-13: Summary of significant relationships

Part	Criteria	Test	P
Subjective feedback	During the experiments I felt Annoyed	Pearson Chi Square	P=0.002
Subjective feedback	After the experiments I feel tired	Pearson Chi Square	P=0.05
Vigilance Performance	Peripheral Detection Task (Response Times)	ANOVA	P=0.003
Passage Performance	Deviation from the ideal route	ANOVA	P=0.000
Passage Performance	Deviation from the nearest lane border	ANOVA	P=0.000
Passage Performance	Distance travelled outside the lane	ANOVA	P=0.000

The following was also reported by the majority of the subjects; (1) ‘Condition A’ is easier to achieve, (2) ‘Condition C’ is most annoying, (3) It is more difficult to concentrate in ‘Condition C’, (4) ‘Condition C’ is more tiring when compared to other conditions.

Chapter 8. DATA COLLECTION AND FIELD STUDY

8.1 Chapter Overview

In order to develop noise related human response models, it was necessary to conduct noise measurements on board ships while collecting corresponding human feedback in those noise levels simultaneously. Thus, necessary data was collected systematically through a number of field studies. This chapter summarises the data collection activities, demonstrates the measurements and human response data as well as explaining the procedures followed during field studies. Available data which will be demonstrated in this chapter was collected as part of EU funded FP7 SILENV Project (SILENV, 2009). Following steps were followed to collect necessary data as shown in Figure 8-1.

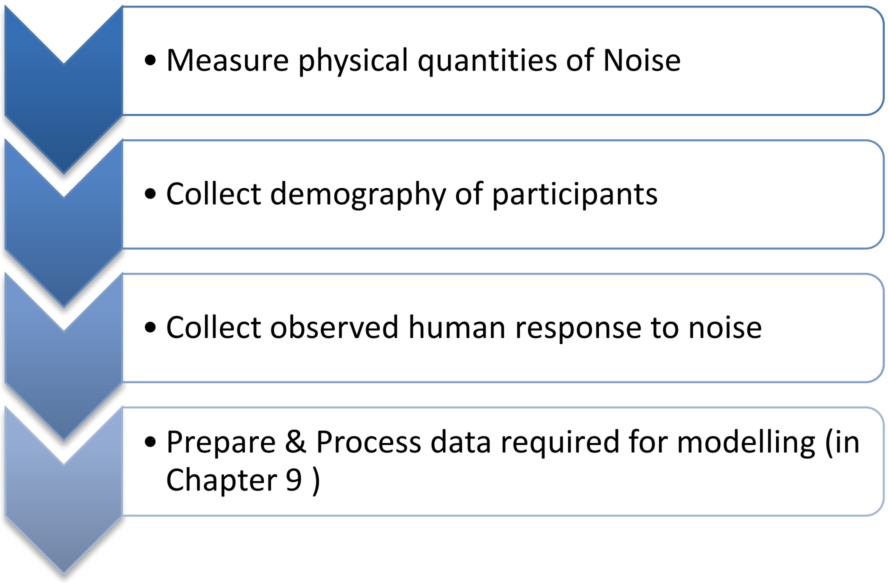


Figure 8-1: Stepwise description of data collection

8.2 Data Collection Methodology

In order to develop statistical models which predict human response to noise on board ships, a lot of data needed to be collected through numerous field studies on different types of ships. Therefore, it was necessary to define a data collection methodology to standardise the way these data generated from different field studies so that the collected data can be compared analysed and processed together to develop generic human response models.

8.2.1 Noise Measurements

The aim of conducting noise measurements on board ships is to collect and evaluate objective noise data for the 'receiving position' which means it is not important where and how the noise comes from but it is necessary to measure the amount of noise perceived by human in various locations of the ship. This includes measurements to be performed in quite a detailed list of positions on board simultaneously with the human response surveys. However, conducting simultaneous measurements may not always be practical especially on big ships (e.g. passenger vessels) where numerous questionnaires are distributed in different locations of the ship at the same time. In those cases it was found acceptable to conduct benchmarking measurements (i.e. sample measurements) throughout the ship when all equipment should be in normal operation at the design conditions (If possible, measurements can be repeated under different operational conditions). Ship should be sailing on a constant course at the most representative operational condition depending on the type and typical route of the ship. Ship loading condition should be as close as possible to typical operational condition. During noise measurements doors and windows in a space should be kept closed.

For the noise measurements the procedures of ISO 2923 (ISO, 1997a) was followed and following issues were considered.

Type 1, precision grade, sound level meter as described by ANSI (1983) should be used to carry out noise measurements. According to International Electrotechnical Commission (IEC) (IEC, 2002b) the accuracy of the precision grade meter for sound emitted from a typical medium size machine is ±1 dB(A). Free field type microphones should be used.

When measuring noise on open decks or in presence of an air movement a wind screen should be used. Noise measurement device should be calibrated before and after the measurement campaign. In accordance with the requirements of IEC (2002b) sound level meters should be tested periodically with periods no longer than 2 years and the date of the last verification should be registered. Also the acoustic calibrator used for the sound level meter calibration should be tested in a laboratory once a year. Calibrator should be Type 1 as described by IEC (2003b)

Unless measurements are being taken at recreational or eating places, it is important to take special care to avoid irrelevant background noise such as people talking, music, any temporary work by crew etc. Measurements should be performed at a height between 1.2 and 1.6 m from the deck. The distance between the two measurement points should not be greater than 7 meters and measurement points should be at least 0.5 meters away from the space boundaries.

Ideally, it is important to record raw noise data (recorded noise spectrum) so that different frequency weightings can be applied on the spectrum to test which noise weighting will result in a better correlation with the collected human response data (i.e. which noise weighting will better represent the collected human response).

However, if noise spectrum cannot be collected during measurement campaigns then “A” weighted noise level measurements will be required as the least. In that case noise measurements should be carried out using A-weighting filter i.e. in dB(A) over the entire frequency range and at least in 1/3 octave bands between 31.5 and 8,000 Hz. The meter should be set to slow response and at least 5 seconds of measuring time should be allowed. For fluctuations more than 5 dB(A), or in case of cyclic, irregular or intermittent sound, an integrating meter should be used (over a period of 30 seconds) which is set to A-weighting.

8.2.2 Collecting Human Response Data

In order to model the human response to noise, two different types of questionnaires were developed to capture the subjective feelings of human on board vessels through a self –report study.

Both questionnaires were aimed to be deployed during the real operation of the ships in locations where simultaneous noise measurements were being conducted. Performance questionnaire was designed to be distributed amongst the crew members when they were on duty. However, comfort questionnaires were for distribution to both passengers and crew members during their rest time. The questionnaires applied in this PhD study can be found in APPENDIX B

For both questionnaires, participants were asked to fill them for a location where they have spent more than 30 minutes to ensure that enough noise exposure is achieved.

On the other hand, it was critical to capture the accurate information of where these questionnaires were filled. Failing to identify the location of a questionnaire correctly will lead us to either coming up with wrong conclusions or to miss some valuable information. In order to avoid this it was agreed to print the ship plan on the back of the questionnaires and participants were asked to mark their locations on board. In this way it was considered that the locations of questionnaires can be linked more accurately with the measured noise levels.

The sample plans printed on the back of the questionnaires can be found in APPENDIX C.

Figure 8-2 below summarises the procedure of data collection from ships.

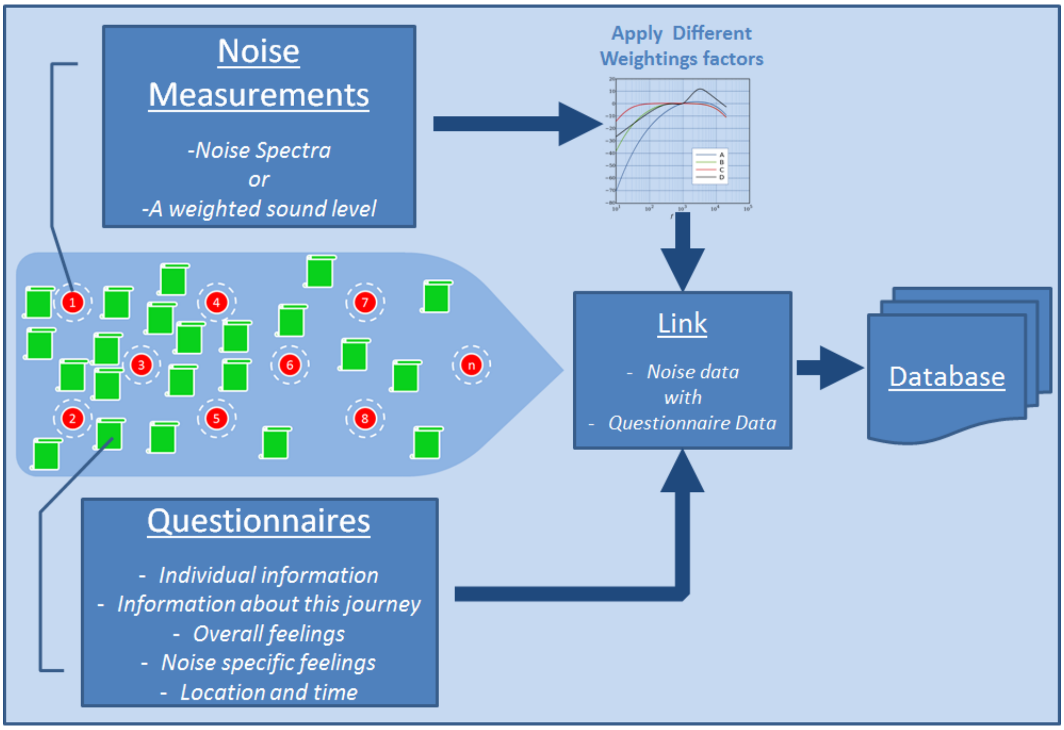


Figure 8-2: Summary of data collection

8.3 Summary of collected data

As it was mentioned before, it was crucial to be able to link the questionnaires (subjective noise feelings) with the noise level (or spectra, if available) recorded at that location. In order to effectively achieve this, each questionnaire had a plan of the ship (Figure 8-3) at the back of it so that participants of the survey could pin point their location on board.

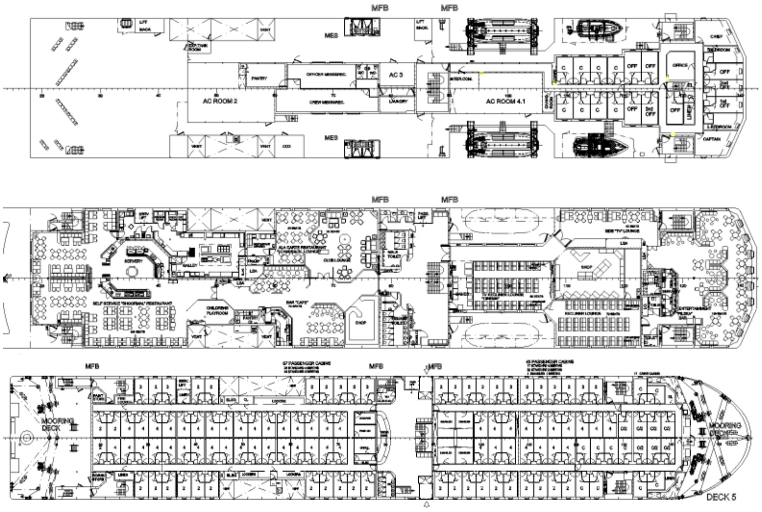


Figure 8-3: Example ship plan printed at the back of questionnaires

One of the limitations when linking the location information to the collected questionnaires was the uncertainty of the indicated location by the participant. Ideally, the questionnaires should have been distributed and collected from the same location where noise levels were being measured at the same time. However, in some cases the questionnaires were not collected simultaneously with the measurements but given to passengers and crew members at the beginning of the journey. This resulted in some level of uncertainty with regards to the questionnaire being filled about one particular location or is it a combination of various locations that the participants had been on board. Moreover, in some cases, participants wrote the deck number where they were on, rather than marking their exact location on the deck plan. This made it impossible to determine their exact location.

Another limitation of the data was related to the noise measurements. For some of the vessels both 'A' weighted overall values as well as noise spectra were available while the other vessels only had overall noise levels measured. Unavailability of spectral information for some vessels had an adverse effect on the number of data which can be utilised for modelling while taking into account the effect of different frequency weightings. Summary of the available data is shown in Table 8-1.

Table 8-1: Summary of Available Data

Vessel name	Available questionnaire data			Availability of Spectra
	Comfort	Performance	Exact location	
FRV 1	16	15	No	-
FRV 2	16	17	No	-
FRV 3	6	6	No	-
FRV 4	14	12	No	-
Fishing 1	10	10	No	-
Fishing 2	6	6	No	-
Merchant 1	14	16	No	-
Merchant 5	38	33	No	-
Passenger 1	0	13	No	Yes
Passenger 2	14	19	Yes	Yes
Passenger 3	87	26	Yes	Yes
Passenger 5	243	25	Yes	Yes
Passenger 6	29	0	No	-
Passenger 7	34	0	No	-
LNG	7	16	Yes	Yes
Total sum	**534**	**214**		

8.4 Field Study and Data Collection

Summary of data is shown in Table 8-1 which was collected from different ships by the partners of SILENV Project. The field study on 'Passenger 5' was conducted as part of this PhD study. It was necessary to conduct a new field study to increase the number of human response data because, the total number of questionnaires from other measurement campaigns were insufficient to develop successful models. The field study conducted on 'Passenger 5' is summarised in the following.

8.4.1 Ship details

Measurement campaign, in which the author was involved in, was conducted on a steel passenger vessel which was built in 2002. Name of the vessel and the operator is not disclosed in this study due to the confidentiality agreement. Therefore, throughout the thesis this passenger vessel is referred to as 'Passenger 5'. It had a design speed of 24 knots and had following main particulars & machinery;

- Length between perpendiculars (m): 125
- Breadth (m): 20
- Draught (m): 5.4
- Capacity: seating for 600 persons and 100 cabins with a total of 300 beds
- Displacement (Fully loaded) (Tonnes): 7500
- Main Engine: Power (kW): 4 x 5400.
- Auxiliary Engines: Power (kW): 2 x 715
- Propeller: 2 X 10800kW (178 rpm)

General arrangements of the Passenger 5 can be seen in APPENDIX C.

8.4.2 Noise Measurements

Noise measurements and human response surveys were conducted between the 8th and 10th of October 2011 in the North Sea. Data was collected during normal commercial operation when 'Passenger 5' was shuttling between Aberdeen and Shetland Islands. Figure 8-4 shows the passenger vessel and its typical route.

Figure 8-4: Passenger Vessel and the Map of Measurement Area.

In order to ensure the quality, noise measurements conducted on board 'Passenger 5' were done in accordance with the measurement methodology explained in previous section. During the measurements water depth was most of the time over 50m and the sea condition was moderate to calm. Measurements were conducted with a calibrated measurement device; B&K Photon+ measurement system which is composed of a hand held meter (Serial: 5388302), a microphone (Serial: 2754897) and a laptop for digitising the measurement signal. The measured noise data can be found in APPENDIX C.

8.4.3 Collected Human Response Data

Questionnaires were distributed simultaneously with the noise measurements on board 'Passenger 5'. It was very important to achieve good participation rate to the human response questionnaires during the measurement campaign. Therefore, 6 researchers worked together, four of them were distributing and collecting questionnaires while the other two were conducting the noise and vibration measurements.

Figure 8-5: Measurement team

At the beginning of the journey researchers stayed at the ticket check point in order to welcome and brief the passengers about the human response surveys and how they should be filled. In order to capture the location information successfully the questionnaires had the ships plan on the back of them. Also following two methodologies were applied to increase the success rate.

- Passengers were asked to fill in the questionnaires with regards to the noise levels in their cabins. They were also informed to leave the questionnaires in their cabins at the end of the journey before they depart. The questionnaires were then collected by researchers from passenger cabins while checking the location stated on them in order to ensure the location was correctly marked.
- On the other hand, throughout the voyage researchers stayed in the common areas of the ship such as bars, restaurants etc. in order to distribute and collect questionnaires (as well as mark the location information where necessary) from the passengers who were spending time in common areas.

Example of common areas are shown in Figure 8-6

Figure 8-6: Common Areas

From the ‘Passenger 5’ measurement campaign 243 comfort questionnaires and 25 performance questionnaires were collected. Considering that there were around 500 passengers on ‘Passenger 5’ the questionnaire return rate was around 50%. The questionnaires were combined with the other questionnaires collected within the SILENV project and results are given in Table 8-2.

Table 8-2: Summary of Noise Data Linked to Questionnaires

Ship	Available Questionnaires		Fair Linking Quality		Vague Linking Quality		Overall A-Weighted Levels (1=yes, 0=no)	Digital Spectra Available (1=yes, 0=no)
	Comfort	Performance	Comfort	Performance	Comfort	Performance		
Fishing1	10	10	7	9	0	0	1	0
Fishing2	6	6	6	6	0	0	1	0
FRV1	16	15	10	10	0	0	1	0
FRV2	16	17	6	7	7	7	1	0
FRV3	6	6	4	2	0	1	1	0
FRV4	14	12	8	8	1	0	1	0
Merchant5	38	33	6	9	1	0	1	0
Merchant1	14	16	13	11	1	5	1	0
Merchant2	0	0	0	0	0	0	1	0
Merchant3	0	0	0	0	0	0	1	0
Merchant4	0	0	0	0	0	0	1	0
Passenger1	0	13	0	4	0	8	1	1
Passenger2	14	19	8	13	5	6	1	1
Passenger3	87	26	32	6	28	14	1	1
Passenger4	0	0	0	0	0	0	1	0
Passenger8	0	0	0	0	0	0	1	0
Passenger6	29	0	0	0	29	0	1	0
Passenger7	34	0	0	0	34	0	1	0
LNG	7	16	7	16	0	0	1	1
Passenger5	243	25	216	20	6	3	1	1

The above table is self-explanatory; however, it is important to explain the term “linking quality”. When attaching noise data to the questionnaires, the location indicated on the questionnaires was used to identify the passengers’ or crew members’ location on board, then the noise measurement for that location was found and linked to the questionnaires.

However, in some cases it was not quite easy to achieve this task due to the following reasons:

- Location was not circled on the map of the ship and/or location was not clearly written.
- Location mentioned or circled on the map included a very large area for which there were many measurements available.
- Location was very clear but there were no measurements taken nearby.

Due to above reasons linking noise to questionnaires was not always confidently done. Therefore, a dichotomous variable was created indicating the linking quality (0=vague and 1=fair). At the modelling stage this dichotomous variable (linking quality) can be used as a confounding factor if necessary.

8.5 Analysis of Collected Data

8.5.1 Analysis of questionnaires

As mentioned before human response data was collected through two different types of questionnaires (Performance and Comfort surveys).

Both questionnaires were developed to collect information on the demographics (e.g. age, gender), overall feeling of the participant, location on board & time when questionnaire is filled out and finally the subjective feelings of participant about noise levels.

In both Table 8-3 and Table 8-4 the first column of shows the categorisation of the collected human response, second column depicts the original question number in the survey questionnaire, third column shows a short description of the collected response, while fourth column depicts the dependent variables that are likely to be modelled.

Table 8-3: Categorisation of the collected response (Comfort)

Categories	Question Number	Description	Dependent Variable
Individual	Q1	Age	
	Q2	Gender	
	Q3	Frequency of sea travel	
	Q8	Time spent on board	
Overall feeling	Q9	Overall comfort rating	[O1]
	Q11	Main source of discomfort	
	Q10	Steps to avoid discomfort	
	Q12	Incidence of headaches	
Location & time	Q4	Date	
	Q5	Time	
	Q6	Location aboard	
	Q7	Time spent at this location	
	Q13	Main activity at this location	
Noise	Q14	Noise – loudness	[N1]
	Q15	Noise – annoyance	[N2]
	Q16	Noise – comfort	[N3]
	Q17	Noise – disturbance of conversation	[N4]
	Q18	Noise – sleep disturbance	[N5]
	Q19	Kind of noise most disturbing	
	Q20	Location most disturbing	

As can be seen from Table 8-3, there are several questions in the questionnaire aimed to collect subjective human response to noise. All those subjective responses to noise that can be modelled individually have been coded in column four as dependent variables within square brackets as N1, N2, N3, N4, N5 where N stands for Noise. On the other hand, there is another dependent variable which is participant's rating of his/her overall feeling of discomfort, coded as O1.

Table 8-4: Categorisation of the collected response (Performance)

Categories	Question Number	Description	Dependent Variable
Individual	Q1	Name	
	Q2	Age	
	Q3	Gender	
	Q4	Years worked at sea	
	Q5	Rank / role	
	Q10	Time spent on board	
	Q11	Hours slept during past resting period	
Overall feeling	Q12	Sleep quality	[O2]
	Q13	Fitness rating	[O3]
	Q14	Overall feeling of well being	[O1]
	Q17	Main source of discomfort	
	Q15	Steps to avoid discomfort	
Location & time	Q6	Date	
	Q7	Time	
	Q8	Location aboard	
	Q9	Time spent at this location	
	Q16	Main activity at this location	
Noise	Q18	Noise – loudness	[N1]
	Q19	Noise – annoyance	[N2]
	Q24	Noise – comfort	[N3]
	Q25	Noise – disturbance of conversation	[N4]
	Q20	Noise – effort performing task	[N6]
	Q21	Noise – quality impairment	[N7]
	Q22	Noise – fatigue	[N8]
	Q23	Noise – concentration	[N9]

Similar to the comfort responses, the subjective responses to noise and to overall feeling questions of the performance survey participants are grouped together, where noise ratings are coded as N1, N2, N3, N4, N5, N6, N7, N8, N9 while the overall feeling questions are coded as O1, O2, O3 which will be used to identify the dependent variables likely to be modelled.

In the questionnaires all the subjective response data collected from the participants are of ordinal type. These ordinal categories are respectively; ‘not at all’, ‘a little’, ‘moderately’, ‘very’ and ‘very much’. In the questionnaire some questions also had ‘not applicable’ as an answer which gave the participants an option to skip that question. When a participant selected ‘not applicable’ as an answer those questions were treated as a missing value during the analysis. The aforementioned subjective ordinal response data was coded from 1 referring to least discomfort to 5 referring max discomfort (can be seen in APPENDIX A). However, there were some questions which were opposite to this convention. [O1] in comfort questionnaire, [N3] in both comfort and performance questionnaires are examples of such questions. In order to keep the response ratings consistent and of same polarity, answers collected for these questions were inverted by subtracting them from 6.

In Figure 8-7 the responses given to the overall feeling of comfort in comfort questionnaire and overall feeling of wellbeing in performance questionnaires are shown in a boxplot graph which allows a quick graphical comparison of the responses coming from different vessels. Moreover, the variation of the responses given to the question overall feeling of comfort on each vessel can be seen in Figure 8-7 as well. For example, in ‘Fishing Vessel 1’ responses collected for [O1] are either ‘neutral’ or ‘bad’ to the question while in ‘Passenger Vessel 5’ all answer categories are visible. As explained, before the responses given to [O1] in comfort questionnaires were inverted to have the same polarity with other questions. Only variable [O1] is demonstrated in Figure 8-7 because [O1] was considered as demonstrating the level of overall human satisfaction (or in other words overall feeling of comfort or wellbeing) in each vessel type. The comfort feelings demonstrated in Figure 8-7 shows that more adverse human response ratings were observed in fishing vessels. It is quite well-known that achieving lower noise levels in fishing vessels is more difficult because the vessels are generally small and engine is close to accommodation areas. However, it can be seen that FRV vessels, despite being small as well have better human response ratings.

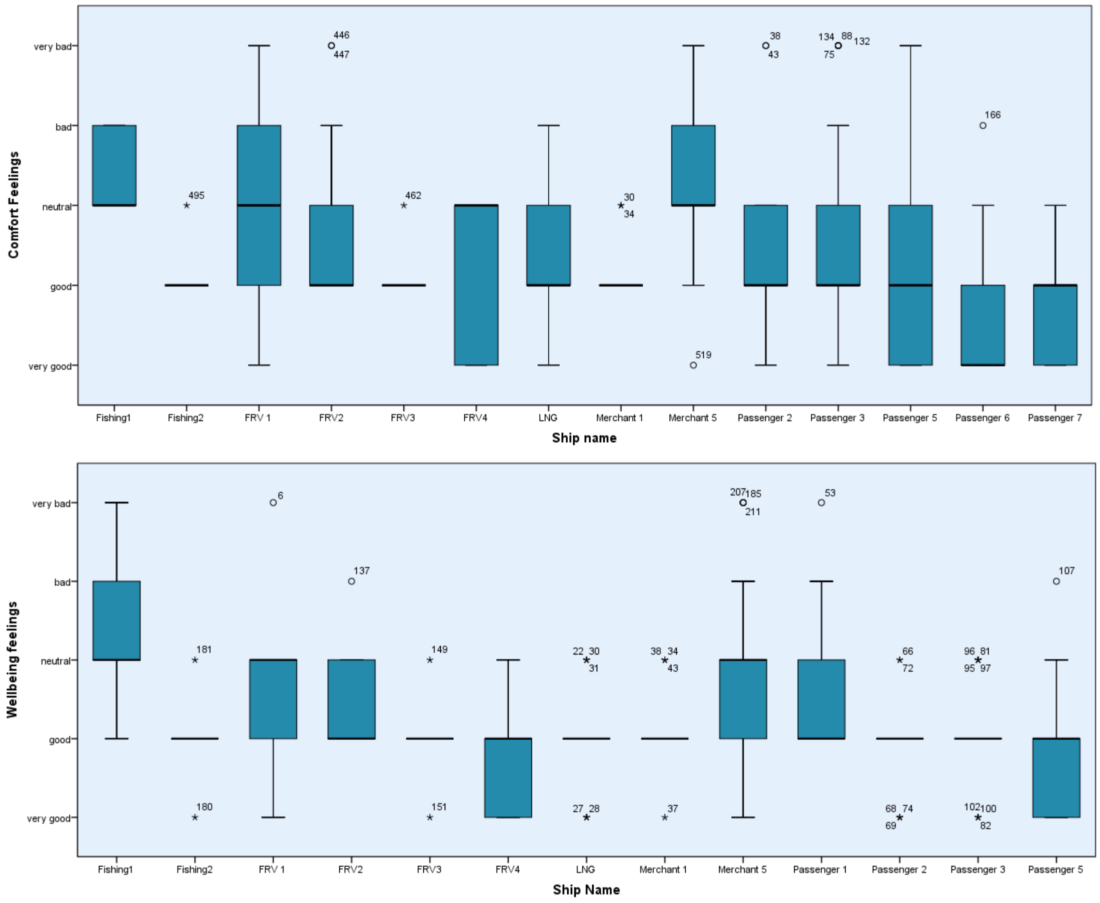


Figure 8-7: Boxplot of the responses for the variable [O1]

In Figure 8-8, mean participant response for each vessel is shown. Each line in the figure represents a question and circle markers correspond to the mean participant response for that question from a specific vessel. In Figure 8-8 the top half of the figure depicts the mean responses of comfort questionnaires (Noise – loudness [N1], Noise – annoyance [N2], Noise – comfort [N3], Noise – disturbance of conversation [N4], Noise – sleep disturbance [N5], Overall comfort rating [O1]) while the bottom figure summarises the mean responses given to the performance questionnaires. (Noise – loudness [N1], Noise – annoyance [N2], Noise – comfort [N3], Noise – disturbance of conversation [N4], Noise – effort performing task [N6], Noise – quality impairment [N7], Noise – fatigue [N8], Noise – concentration [N9], Overall feeling of well-being [O1])

From Figure 8-8, it can be seen that the mean participant response varies from one vessel to another, while variables follow similar trend when moving between vessels. This result was expected since the noise levels would also vary between vessels resulting in different human response.

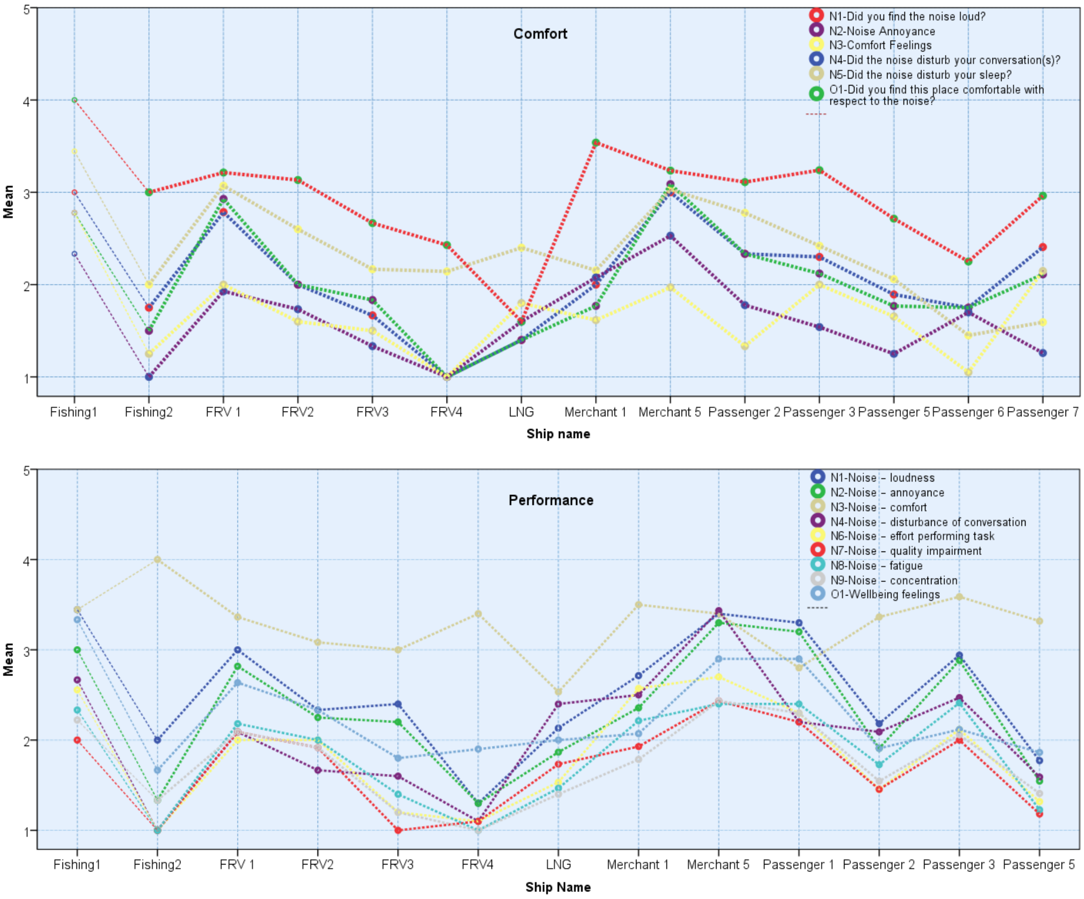


Figure 8-8: Mean participant response

In the questionnaires there were some questions in which participant were required to choose one option from the given categories. These categories were all of nominal type. Figure 8-9 to Figure 8-11 are the summaries of answers given to these questions. It may be noted that the total number of responses for each vessel displayed in Figure 8-9 to Figure 8-11 do not match with the total number of response collected from each vessel. The participants who did not answer these questions or who ticked more than 1 category in the questionnaire were removed together with the people who ticked the ‘other’ category.

Figure 8-9 depicts answers given to the question ‘which of these options caused you the most discomfort?’ for each vessel type. Upper graph represents the comfort questionnaires while below graph represents the performance questionnaires. It is obvious from both graphs that the major contributors of discomfort on board are noise and vibration. These results are consistent with the complaints of human. For example, in Passenger 5 vibration problems in crew accommodation areas was identified during measurements. Similarly, participants of the questionnaire also report that vibration is the biggest concern for them in terms of discomfort.

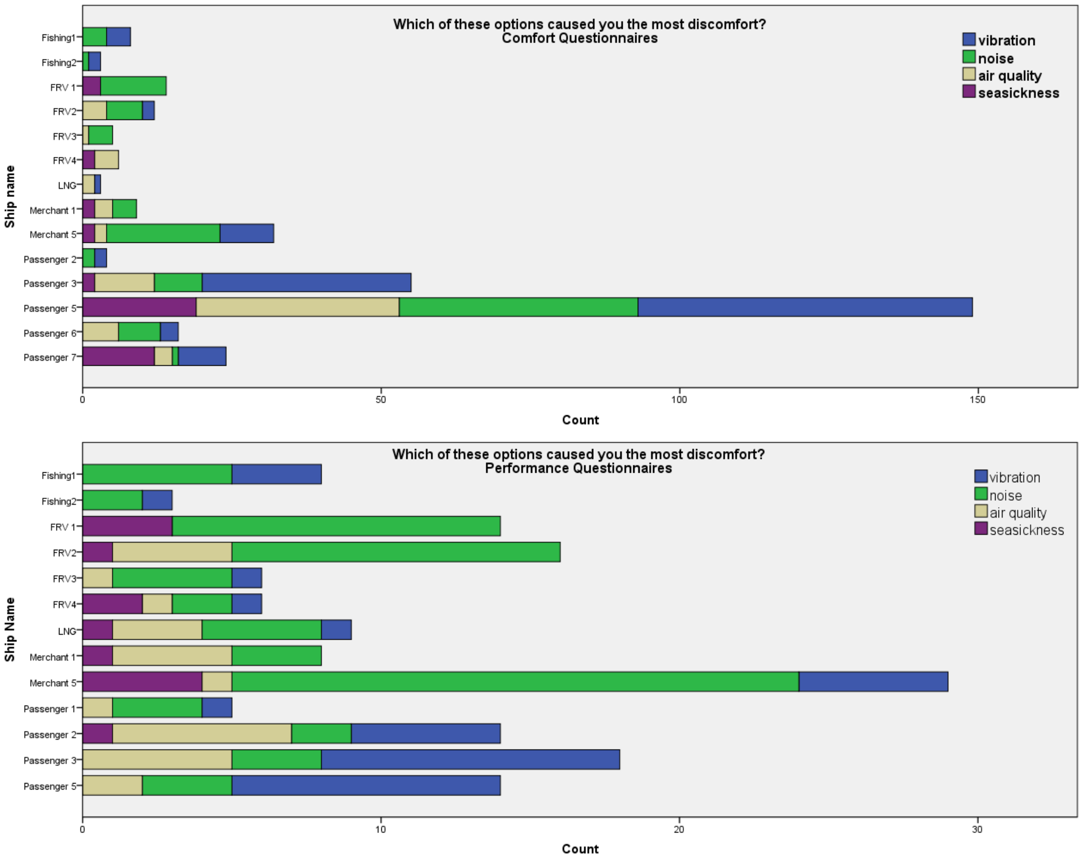


Figure 8-9: Main Source of Discomfort

In Figure 8-10, the responses given to the question ‘what kind of noise was the most disturbing?’ are shown in the top panel, while bottom panel displays the answers given to the question ‘which location was most disturbing with respect to the noise?’. These two questions were not included in the performance questionnaires, for that reason, the result are only shown for comfort questionnaires. It can be seen that engine noise was found as the most disturbing by the majority of the participants. It is not surprising to find that engines as the main sources of noise on board ships were disturbing people. Moreover, in the same graph it can be seen that cabins were reported as the location that participants get annoyed the most by noise. However, noise level in cabins are relatively lower than most of the other locations of the ships. It can be said that people need more comfort in their cabins and they are likely to get annoyed even in lower noise levels than normal.

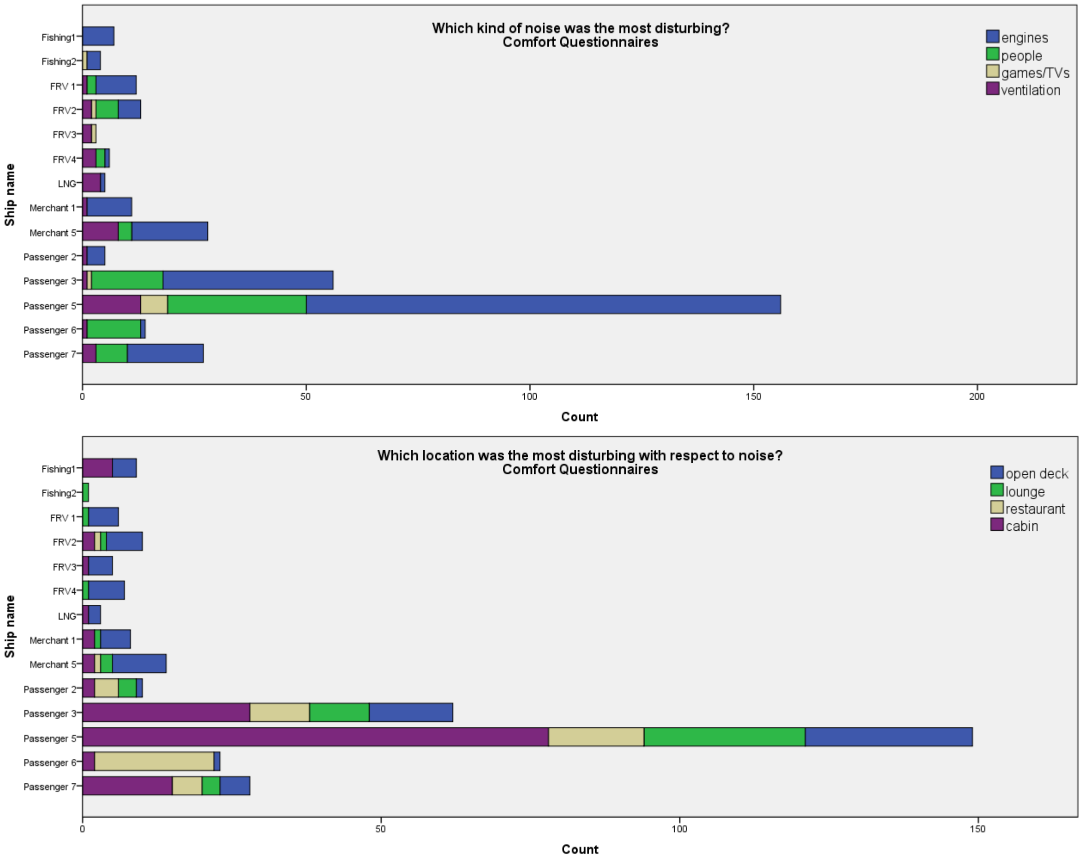


Figure 8-10: Most Disturbing Noise Type and Location

Finally, Figure 8-11 displays the answers given to the question ‘Which was your main activity during the time spent at this location?’ This question was an open ended question and for this very reason it was not included in performance questionnaires.

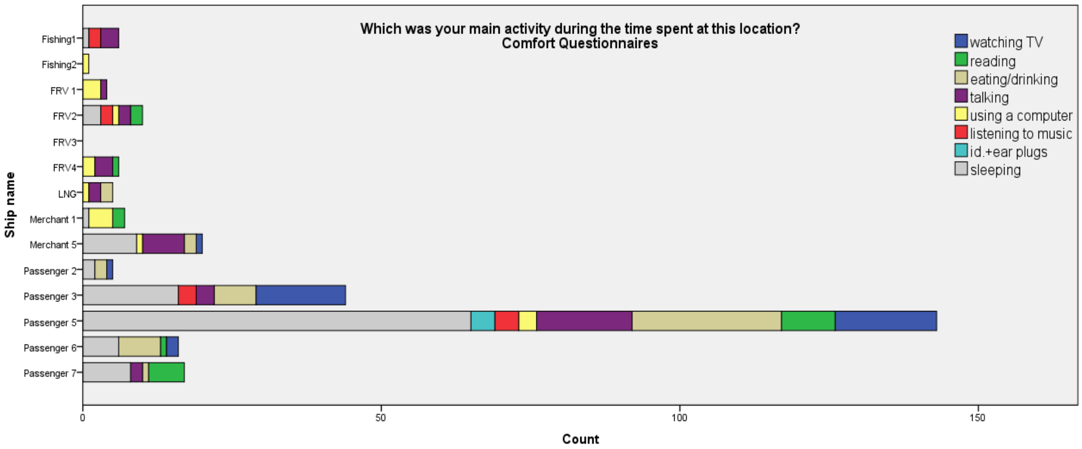


Figure 8-11: Participants Main Activity

Another important type of information collected through the questionnaires was the characteristics of the individuals (demography) for example age and gender. There are many examples in the literature that demographic information like age and gender was used as an a factor when estimating human response to noise (e.g. noise annoyance (Guski, 1999, Miedema and Vos, 1999)). Therefore, age and gender information are potential independent explanatory variables in the human response models and will further be analysed in the modelling chapter (Chapter 9). However, Figure 8-12 shows the boxplots graphs of the individual’s age per vessel while Figure 8-13 shows the overall age distribution for comfort and performance questionnaires. It can be observed that the variability of age is very poor for some vessels this is primarily attributable to the limited number of questionnaires returned from these vessels.

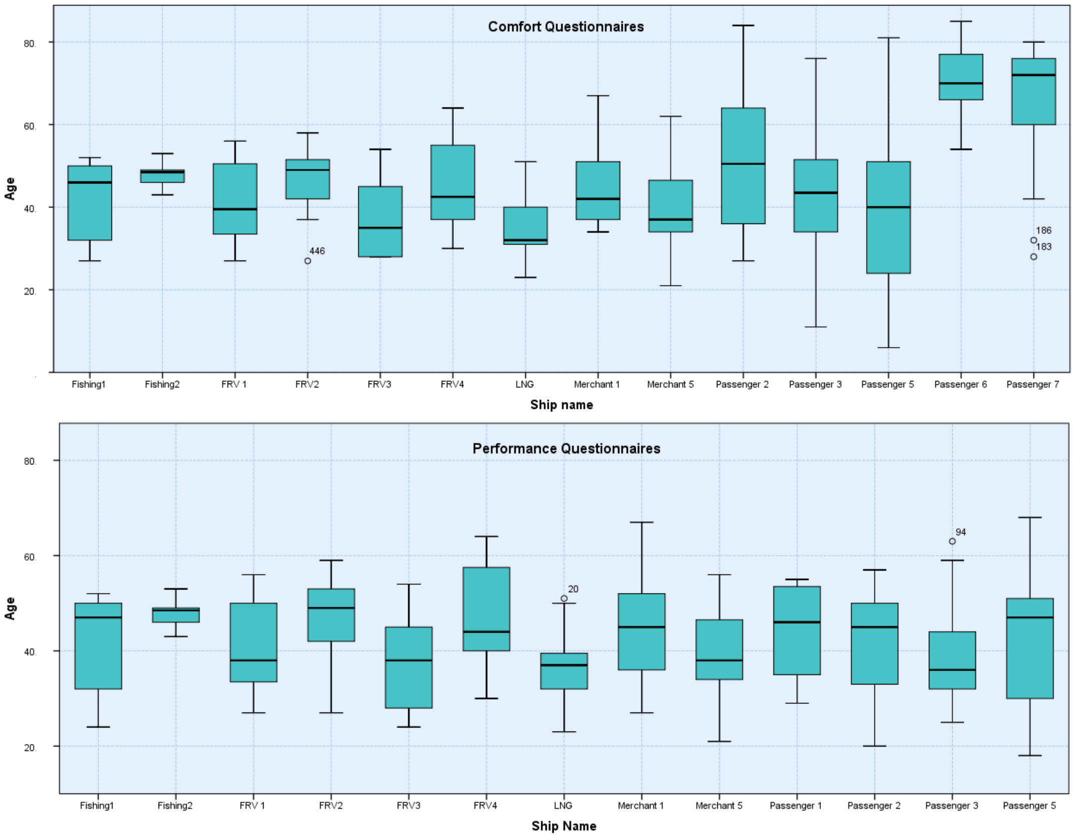


Figure 8-12: Boxplot of Age per Vessel

The mean age of the participants who joined the comfort questionnaires is 44.1 with a standard deviation of 17.3 where youngest person took part in the questionnaires is 6 years old and the oldest one is 85 years old.

Similarly for the performance questionnaires the mean age of the participants is 41.9 with a standard deviation of 10.7 where youngest person took part in the questionnaires is 18 years old and the oldest one is 68 years old.

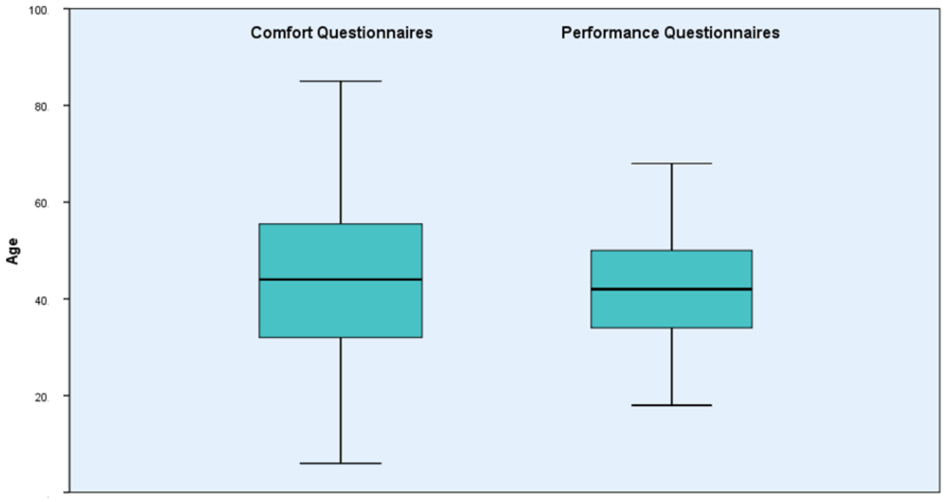


Figure 8-13: Boxplot of Overall Age

Gender is another important explanatory variable for modelling human response to noise. Figure 8-14 shows the distribution of the gender in performance and comfort surveys. Out of 526 valid answers given to gender question in comfort questionnaires 190 were females while 336 were males. In performance questionnaires this ratio was 39/173 out of 212 valid answers given. The corresponding percentages are shown on the Pie Charts in Figure 8-14.

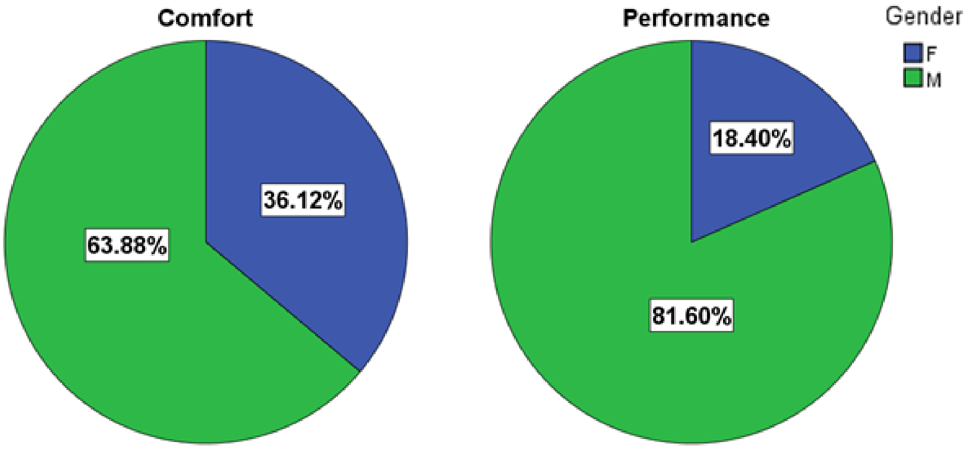


Figure 8-14: Pie Chart of Gender

8.5.2 Linking Noise Data to Questionnaires

Even though the maximum efforts were made during the data collection campaigns, due to lack of time or tight schedule on ships sometimes comfort questionnaires, other times performance questionnaires and in some cases both were not deployed/collected. Understandably, the noise data that is of interest for the modelling is the data for which a subjective human response is available. Therefore, noise data summarised in this section is for the cases where questionnaires were also available.

Data collection campaigns involved measurements of noise on board vessels and recording various characteristics of noise so that different parameters of the noise in a location can be linked to the collected human responses via questionnaires. This would allow different weighting factors of noise to be used and had potential to yield better models. As a result during measurement campaigns it was targeted to collect not only A-weighted overall noise levels (LAeq) but also aimed to capture the noise spectra which will allow testing different weightings.

Noise data was collected from various locations of each ship while they are in normal operation. Noise levels recorded from ships during these measurement campaigns ranged from 40 dB(A) to 120 dB(A). However, within the scope of modelling human response to noise, noise is an input variable which was believed to affect the resulting human response. Therefore, even though noise measurements were available for many locations of the ship, the noise data which was useful for modelling was limited to the noise data for which questionnaires were also collected from the same / nearby location(s).

The distribution of noise levels that were linked to the comfort questionnaires are shown in Figure 8-15. The top left graph in Figure 8-15 shows the histogram of A-weighted noise levels linked to the questionnaires where the top right and bottom left graphs represent Unweighted sound levels and C-Weighted sound levels respectively. The bottom right graph shows the side by side comparison of the boxplots of 3 aforementioned noise weightings. It is important to mention that the x-axis in the histograms shows the binned noise levels and the y-axis shows the number of measurements available within that range. In Figure 8-15, it is shown that between 3 different weightings shown, the distribution of A-Weighted Sound levels seems to be the closest to normal distribution.

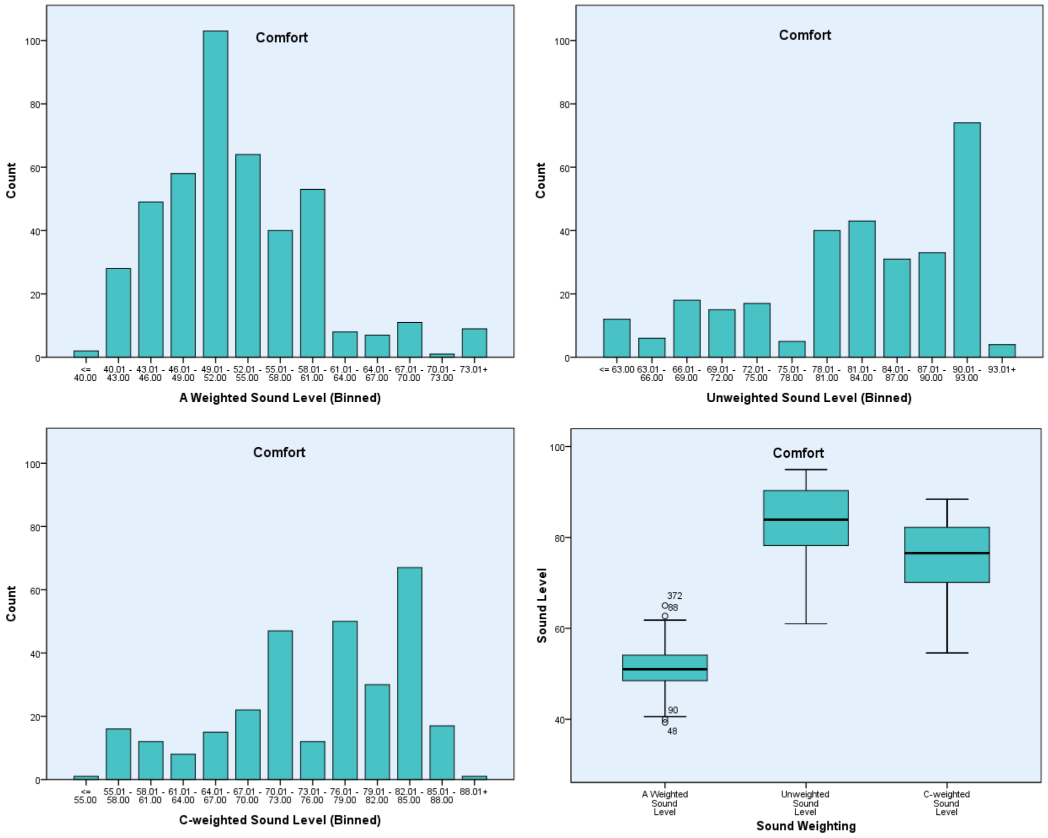


Figure 8-15: Histograms and Boxplot of Noise Data Attached to Comfort Questionnaires.

Similarly Figure 8-16 demonstrates the distribution of noise levels that were linked to the performance questionnaires and follows the same structure as explained in above for the comfort questionnaires.

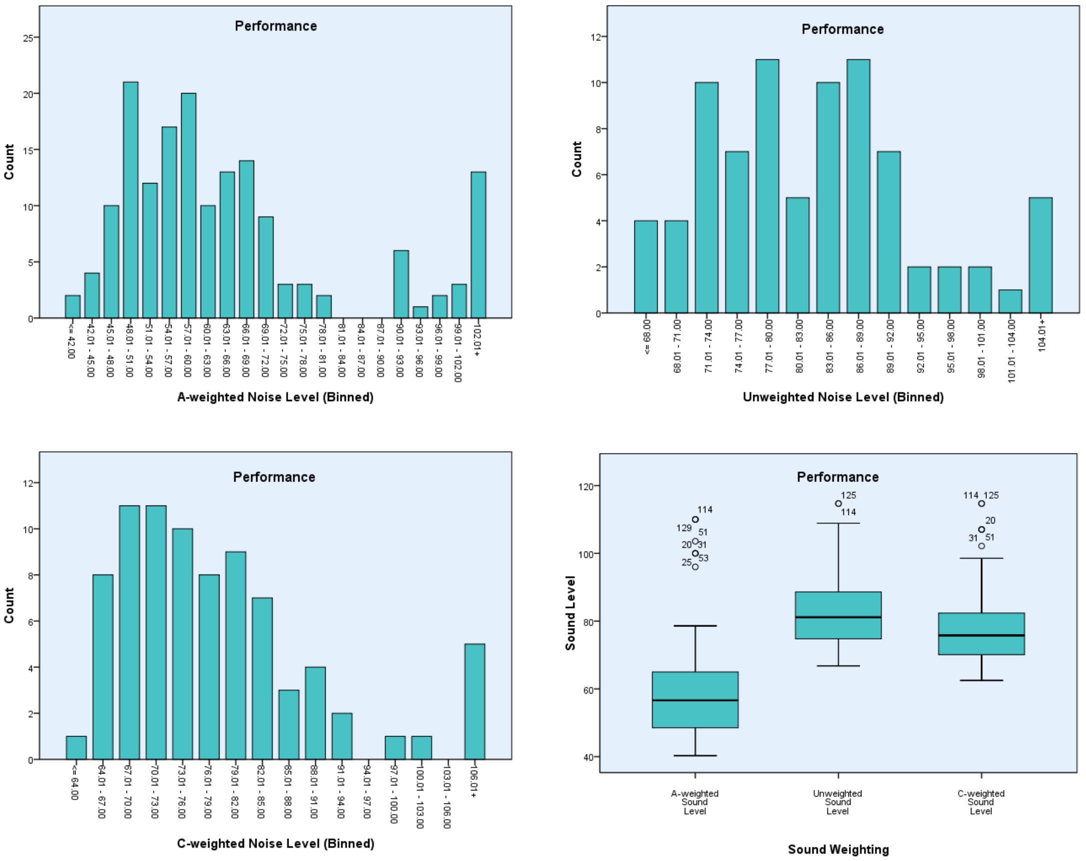


Figure 8-16: Histograms and Boxplot of Noise Data Attached to Performance Questionnaires.

The comparison of Figure 8-15 and Figure 8-16 reveals that higher noise levels were observed in performance questionnaires when compared to comfort questionnaires. This is very logical and due to the fact that passengers and crew when they are in their rest times do not occupy the spaces with high noise levels (e.g. engine room).

Moreover, in Figure 8-17 boxplots of noise levels per each vessel linked to comfort (top pane) and performance (bottom pane) questionnaires are shown. In the boxplots sample minimum and maximums are indicated with the small horizontal lines, the bottom and top sides of the boxes and thick horizontal line indicate respectively the first quartile, third quartile and median. Asterisks and little circles indicate outliners within the sample. It can be seen that noise levels from some of the vessels hardly show any variability. This has happened owing to very small number of questionnaires collected from those vessels.

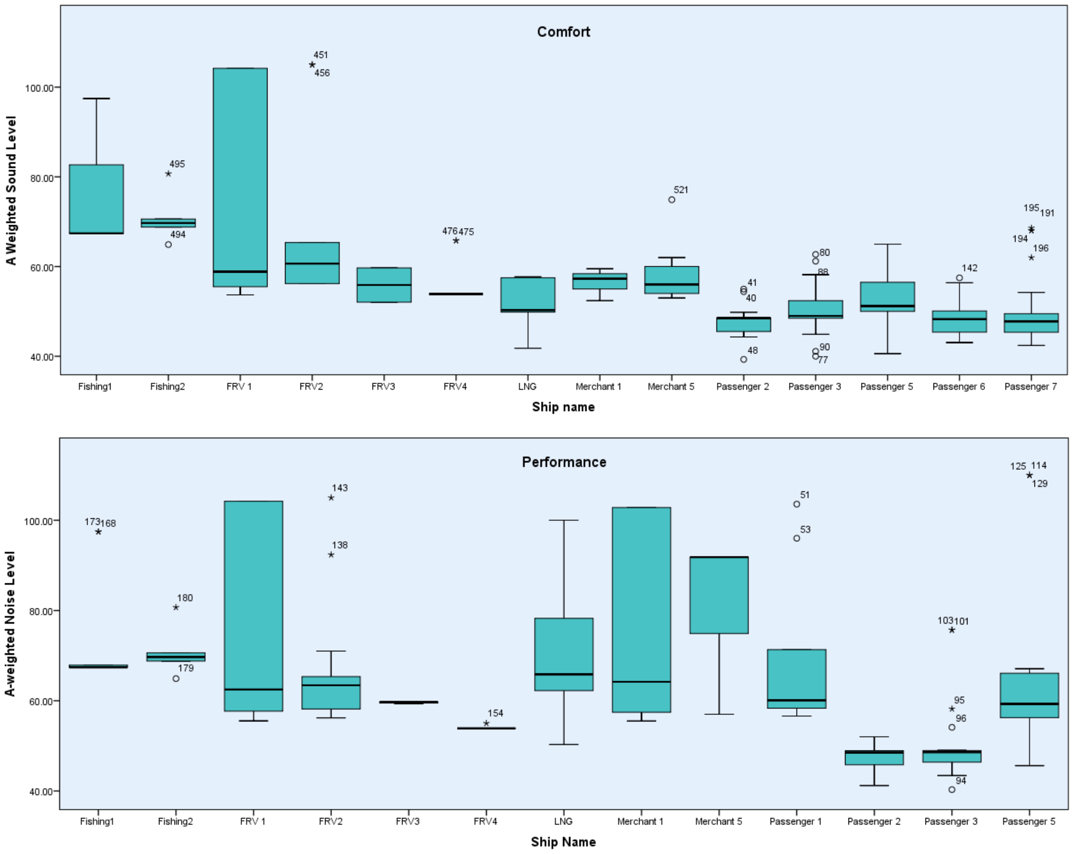


Figure 8-17: Boxplot of noise levels linked to performance questionnaires.

8.6 Chapter Summary

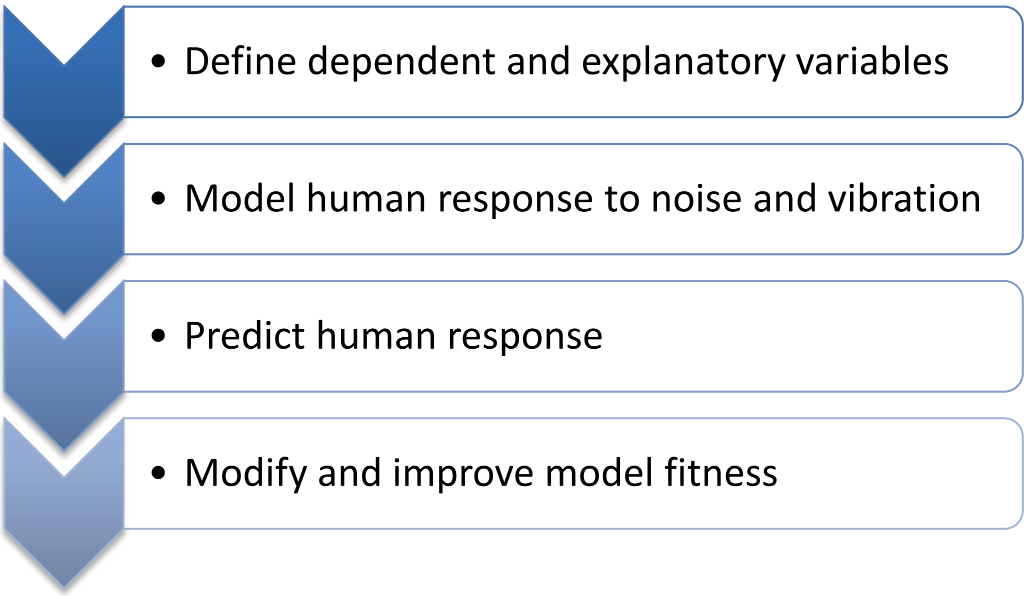
In this chapter the methodology and procedure followed for collecting the data related to human response to noise have been explained. Noise measurement procedures have been adopted from available measurement standards. Subjective feedbacks of human on board ships were collected through a self-report study. Due to the nature of their existence on board (worker and customer) the comfort perceptions of crew and passengers was expected to be different. Therefore, two separate questionnaires were developed to address comfort and performance issues. These questionnaires are given in the appendices of this PhD study and can be utilised in future to conduct similar study on board. In this chapter all collected human response data were processed and linked with the measured noise levels. An SPSS database was generated and utilised in the next chapter for modelling the human response to noise.

Chapter 9. MODELLING HUMAN RESPONSE TO NOISE

9.1 Chapter Overview

The ultimate aim of this chapter is to develop a model which can be used to predict the human response to noise on board ships. These models can be used to estimate the noise induced discomfort and performance reduction amongst passengers and crew members. Most importantly these models may be utilised at the design stage of ships to identify noise levels that they are likely to adversely affect the human performance and wellbeing so as to mitigate these before the ship is put into operation.

Overview of this modelling study is shown in step by step in Figure 9-1.



- Define dependent and explanatory variables
- Model human response to noise and vibration
- Predict human response
- Modify and improve model fitness

Figure 9-1: Summary of this study

9.2 Model Development

It is pertinent to mention that in this study there are two main categories of the human response data collected, one is comfort and the other is performance. Because separate questionnaires were developed for collecting comfort and performance response, it is prudent to model comfort and performance response to noise separately. Therefore, the following models were developed.

- Comfort due to Noise,
- Performance due to Noise,

However, these two models are not individual models but actually multiple models that predict selected dependent variables shown in Table 8-3 and Table 8-4. In order to model discomfort [N1], [N2], [N3], [N4], [N5], [O1] are used from the comfort questionnaires. Similarly, for the performance models [N1], [N2], [N3], [N4], [N6], [N7], [N8], [N9], [O1], [O2], [O3] are used from the performance questionnaires. The following sections outline the reasons for choosing these variables as representative of comfort / performance.

9.3 Modelling approach

The approach used for modelling the human response to noise was adopted from the SILENV Project's modelling approach which was also similar to the modelling approach used in an earlier EU Project called COMPASS (Turan, 2006).

Modelling of human response to noise can be divided into two main stages;

- **Stage 1 - Selection of informative variables**
- **Stage 2 – Prediction of human responses to noise**

In Stage 1 the questionnaire data summarised in the previous sections will be analysed to find the most appropriate variables that can be used in the models. The variables that will be used in the statistical modelling can be divided in to 2 main categories;

- Dependent variables:

  Questions in the questionnaire which aimed to collect the subjective human response, so that they were likely to be used as dependent variables in the response models, were shown in Table 8-3 and Table 8-4.

  These variables will further be analysed in order to identify whether it is worthwhile to include them into the models or not. In order to decide this first thing is perform comparison of variances to see whether the variables carry useful information for modelling. Then a correlation matrix will be generated to see how these variables are related to each other. Finally factor analysis will be conducted to select the variables to be modelled.

- Independent (Explanatory) variables**:**

  Besides the noise data some questions from the questionnaires may carry information which affects human response to noise. For example it was discussed in this thesis before that demographic information such as age and gender is related to noise annoyance (Guski, 1999, Miedema and Vos, 1999). Therefore, from Table 8-3 and Table 8-4 some questions which are under the 'individual' and 'location & time' categories may be used as independent explanatory variables in the models.

In Stage 2, the aim is to predict the selected dependent variables (i.e. subjective human response) from the noise data and selected independent explanatory variables. At this stage different weightings of noise can be taken into account to see which frequency weighting yields into better human response models.

In order to develop human response models, objective noise data (physical quantity) will be used as an input together with the aforementioned explanatory variables while subjective human response will be the output. Achieving the statistical fitness between the inputs and output will produce the models. The modelling approach is summarised in Figure 9-2.

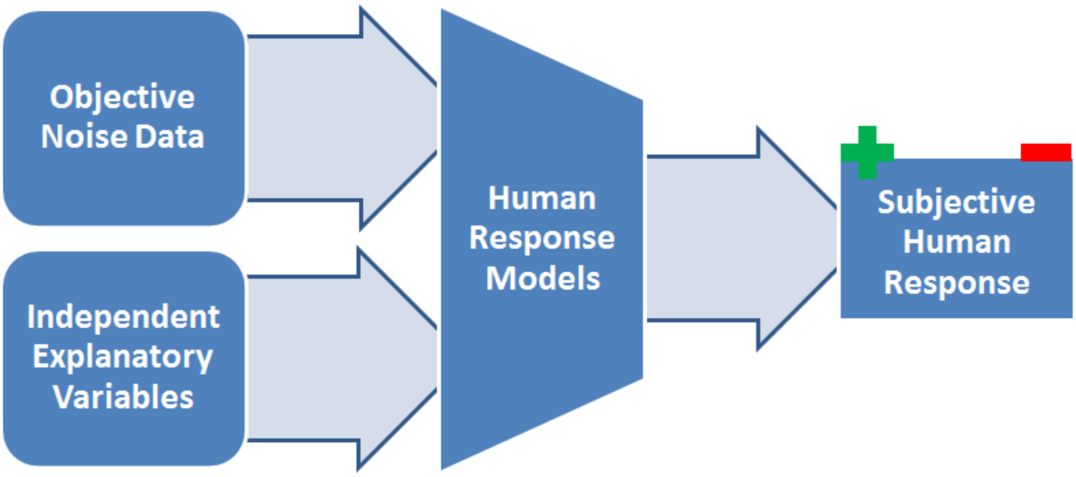


Figure 9-2: Summary of Model Structure

It is very important to decide what objective noise measure to be used. The ideal option would be to measure the physical quantities of objective data and develop a weighting which will provide the best statistical fitness. Objective measurement for noise would be measurement of noise spectrum on which different weightings can be applied to achieve the best fit. Figure 9-3 demonstrates the procedure of creating an objective measure from measured data.

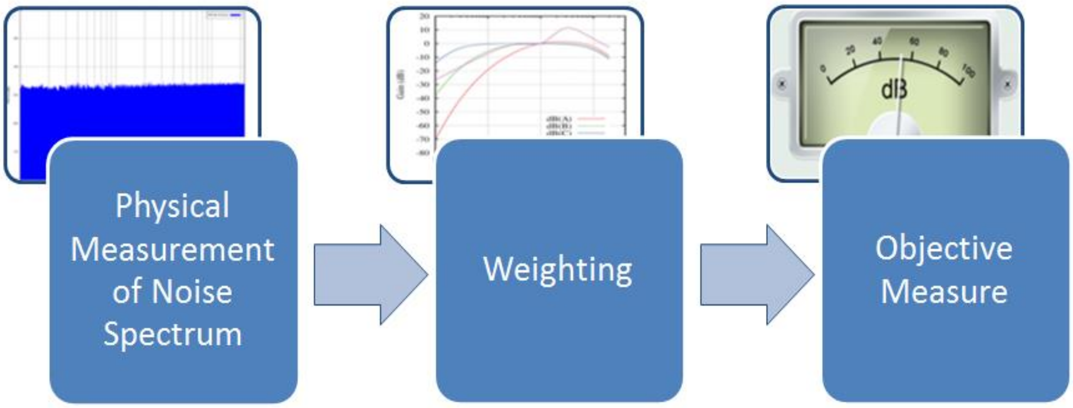


Figure 9-3: Construction of Objective Measure from Measured Physical Quantity

The weighting functions can be adopted from the literature. Therefore, in the scope of this PhD study different weighting functions will be applied on the measured spectrum to achieve the best fit. These weighting functions will be taken from international standards available in the literature. (IEC, 2002a, ISO, 2003a).

9.4 Stage 1 - Selection of informative variables

The quantities of human response data from each vessel was reported in previous sections. It was shown that there were not enough questionnaires returned from each vessel type which prevents the human response models which will be developed to take the vessel type into account when predicting the subjective human response. As a result the models that will be developed will be generic and create a link between the noise data and the subjective human response.

9.4.1 Selection of Dependent variables

In the Stage 1 of modelling it is targeted to select the dependent variables (i.e. subjective human responses from questionnaires). In order to be able to determine which questions from the questionnaire will be selected to be modelled, firstly analysis of variances, then correlations and finally factor analysis will be reported consecutively. These statistical analysis are conducted in a Statistical Analysis Software Package (IBM, 2010). The results will be interpreted however it is not in the scope of this PhD study to discuss the mathematical background and details of these statistical analysis techniques.

9.4.1.1 Variances

In statistics, variance is a measure which describes dispersion how far the data of a sample group stay apart (Montgomery and Runger, 2010). For example if all the participants who joined the questionnaires would rate their subjective response as same, then the variance will be equal to zero which indicates that there is no variability in the responses collected. For modelling purposes it is important to have some variability in the responses collected. Therefore, the aim in this sub-section is to identify and exclude the variables which fail to show and variability in their data. In order to visualise the variability Figure 9-4 was prepared showing the boxplot of subjective human response questions from the questionnaire. Boxplots are very useful in terms of giving a quick graphical indication of the sample group that is being analysed and also indicate the variability of the data. In Figure 9-4 top panel shows the data for subjective response questions in comfort questionnaires while bottom panel demonstrates same for performance questionnaires. Small horizontal lines placed at the tip of the vertical lines represent sample minimum and maximum. The bottom and top sides of the boxes and thick horizontal line in the middle indicate lower quartile, upper quartile and median respectively where small circles are the outliers in the data set. As it can be seen from Figure 9-4, all the variables show a satisfactory level of variance therefore at this stage there is no reason for excluding any of the questions from the modelling.

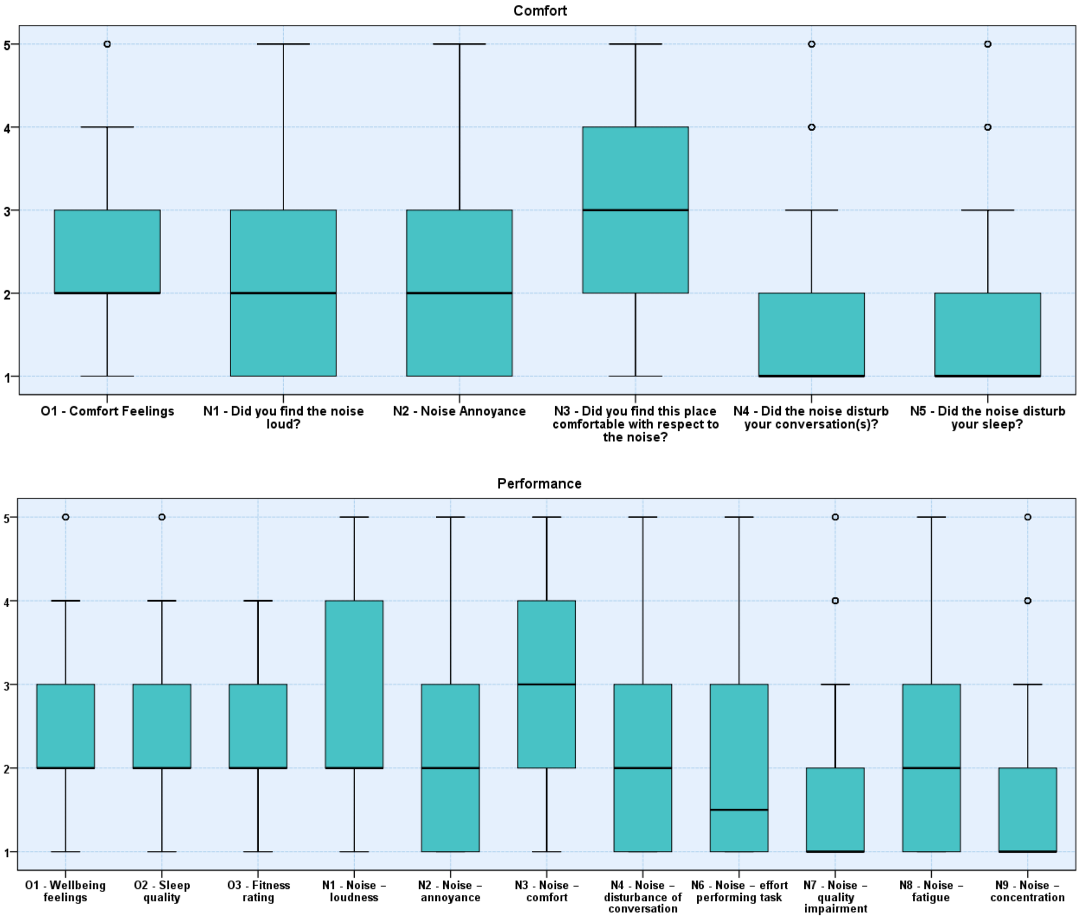
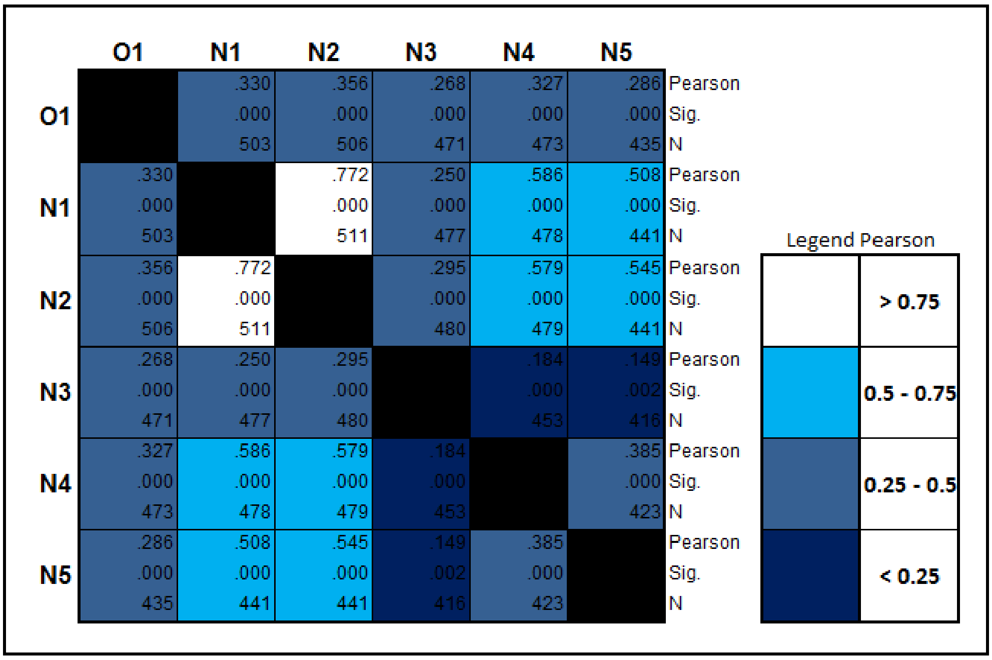


Figure 9-4: Variance of the subjective human response data

9.4.1.2 Correlations

After investigating the variability in the response data the questions will be further investigated in order to identify weather they carry useful and unique information or not. As described in the approach, a correlation matrix will be generated between the questions to identify how each subjective response question relates to each other. A correlation matrix is a square matrix which shows the correlations between the variables. The elements on the diagonal of the matrix are unity (Montgomery and Runger, 2010). Figure 9-5 and Figure 9-6 displays the correlation matrixes. In both matrixes non-significant correlations (>0.05) are excluded by marking them black. In the correlation matrices 'Pearson' Correlation indicates the strength and the direction of the correlation where 'Sig.' shows the probability of obtaining that Pearson Correlation by chance. Finally, N shows number of cases. High correlations between variables are coloured white. These high correlations create redundancy and therefore can be modelled together. For example it appears that the questions N1 and N2 are highly correlated. N1 represents the question 'Did you find the noise laud?' while N2 represent 'Did you find the noise annoying?' It is very likely that those people who found the noise loud will also be the ones who were annoyed with the noise level. For that reason there is no need to model both of the variables since when one from N1 and N2 is modelled, it will also represent the other. These high correlations will be considered in 'Section 9.4.1.4' when selecting variables for the modelling.

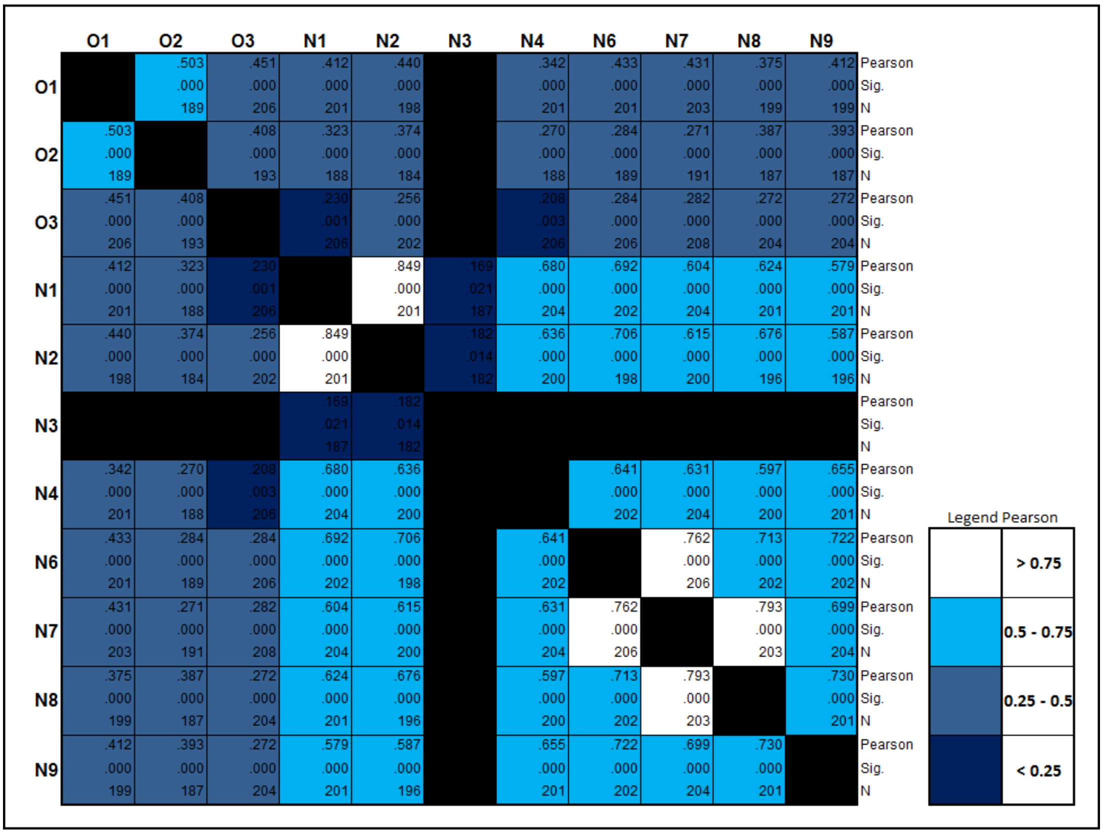


	O1	N1	N2	N3	N4	N5	
O1		.330	.356	.268	.327	.286	Pearson
		.000	.000	.000	.000	.000	Sig.
		503	506	471	473	435	N
N1	.330		.772	.250	.586	.508	Pearson
	.000		.000	.000	.000	.000	Sig.
	503		511	477	478	441	N
N2	.356	.772		.295	.579	.545	Pearson
	.000	.000		.000	.000	.000	Sig.
	506	511		480	479	441	N
N3	.268	.250	.295		.184	.149	Pearson
	.000	.000	.000		.000	.002	Sig.
	471	477	480		453	416	N
N4	.327	.586	.579	.184		.385	Pearson
	.000	.000	.000	.000		.000	Sig.
	473	478	479	453		423	N
N5	.286	.508	.545	.149	.385		Pearson
	.000	.000	.000	.002	.000		Sig.
	435	441	441	416	423		N

Legend Pearson

	> 0.75
	0.5 - 0.75
	0.25 - 0.5
	< 0.25

Figure 9-5: Correlation Matrix (Comfort Questionnaires)



	O1	O2	O3	N1	N2	N3	N4	N6	N7	N8	N9	
O1		.503	.451	.412	.440		.342	.433	.431	.375	.412	Pearson
		.000	.000	.000	.000		.000	.000	.000	.000	.000	Sig.
		189	206	201	198		201	201	203	199	199	N
O2	.503		.408	.323	.374		.270	.284	.271	.387	.393	Pearson
	.000		.000	.000	.000		.000	.000	.000	.000	.000	Sig.
	189		193	188	184		188	189	191	187	187	N
O3	.451	.408		.230	.256		.208	.284	.282	.272	.272	Pearson
	.000	.000		.001	.000		.003	.000	.000	.000	.000	Sig.
	206	193		206	202		206	206	208	204	204	N
N1	.412	.323	.230		.849	.169	.680	.692	.604	.624	.579	Pearson
	.000	.000	.001		.000	.021	.000	.000	.000	.000	.000	Sig.
	201	188	206		201	187	204	202	204	201	201	N
N2	.440	.374	.256	.849		.182	.636	.706	.615	.676	.587	Pearson
	.000	.000	.000	.000		.014	.000	.000	.000	.000	.000	Sig.
	198	184	202	201		182	200	198	200	196	196	N
N3				.169	.182							Pearson
				.021	.014							Sig.
				187	182							N
N4	.342	.270	.208	.680	.636			.641	.631	.597	.655	Pearson
	.000	.000	.003	.000	.000			.000	.000	.000	.000	Sig.
	201	188	206	204	200			202	204	200	201	N
N6	.433	.284	.284	.692	.706		.641		.762	.713	.722	Pearson
	.000	.000	.000	.000	.000		.000		.000	.000	.000	Sig.
	201	189	206	202	198		202		206	202	202	N
N7	.431	.271	.282	.604	.615		.631	.762		.793	.699	Pearson
	.000	.000	.000	.000	.000		.000	.000		.000	.000	Sig.
	203	191	208	204	200		204	206		203	204	N
N8	.375	.387	.272	.624	.676		.597	.713	.793		.730	Pearson
	.000	.000	.000	.000	.000		.000	.000	.000		.000	Sig.
	199	187	204	201	196		200	202	203		201	N
N9	.412	.393	.272	.579	.587		.655	.722	.699	.730		Pearson
	.000	.000	.000	.000	.000		.000	.000	.000	.000		Sig.
	199	187	204	201	196		201	202	204	201		N

Figure 9-6: Correlation Matrix (Performance Questionnaires)

9.4.1.3 Factor Analysis

After reporting the results of correlations, the aim is to go one step deeper and perform factor analysis. Factor Analysis is a statistical technique which takes large number of variables and tries to find a solution that the data can be summarised by the use of smaller set of common factors (Pallant, 2004). One of the requirements of a data set to be suitable for the factor analysis is the sample size. In simple terms the bigger sample size is better, however, Tabachnick *et al.* (2001) suggest to have more than 300 cases for factor analysis. As a result the sample size used for the modelling in this thesis satisfies the criteria suggested for the size by Tabachnick *et al.* (2001). Another requirement is the strength of inter-correlations between the questions. Tabachnick *et al.* (2001) suggests the construction of a correlation matrix and investigation of the correlation coefficients bigger than 0.3. If there are really a few correlations above this level then factor analysis may be inappropriate to be performed. Fortunately investigation of correlation matrixes shown in Figure 9-5 and Figure 9-6 suggests that the sample used in the analysis is also appropriate to perform factor analysis.

In order to simplify the interpretation of the results a rotation of factors is performed. This does not affect the result but just presents the loadings in a pattern which makes it easier to interpret. Therefore, a rotation of factors was performed using SPSS (method: varimax).

9.4.1.3.1 Comfort questionnaires:

Firstly the KaiserMeyer- Olkin Measure of Sampling Adequacy (KMO) value is 0.803 and Barlett's Test of Sphericity value is significant (P=.000) which suggests that the factor analysis is appropriate for the sample. Also a scree plot is generated to test number of factors to be retained. The point in Figure 9-7 where the slope disappears is considered as the break point and the factors before that point needs to be retained since they will represent the most of the variability in the data.

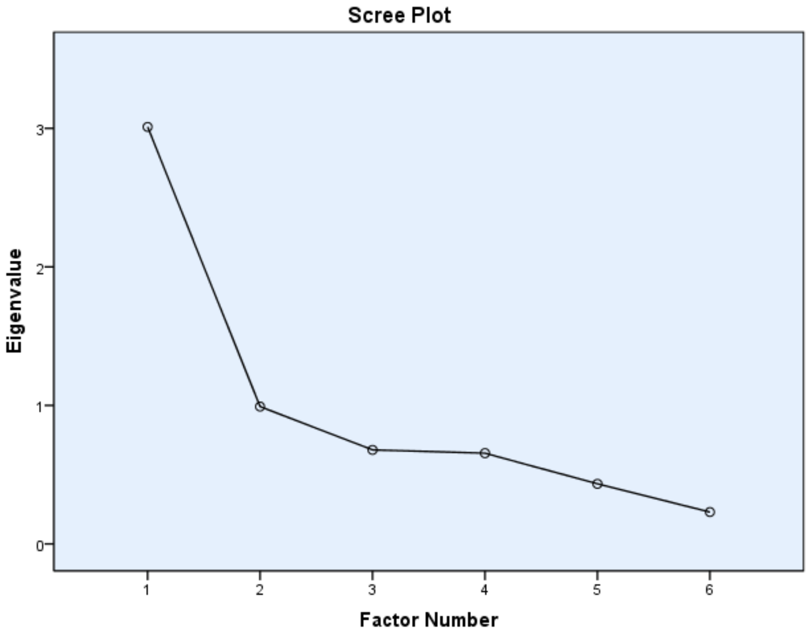


Figure 9-7: Scree plot (comfort)

Communalities show how much of the variance in each question has been explained by the extracted factors where rotated factor matrix shows the loadings for which the bigger the absolute value of the loading, the more the factor contributes to the variable. As a result, two factors were selected and loading factors and communalities for the questions are shown in Table 9-1.

Table 9-1: Rotated Factor Matrix and Communalities (Comfort)

	Factor		Communalities
	1	2	Initial
O1	.189	.982	.234
N1	.849	.202	.628
N2	.847	.234	.642
N3	.179	.257	.102
N4	.615	.261	.406
N5	.526	.200	.290

9.4.1.3.2 Performance Questionnaires

Same structure is also followed for reporting the results of the factor analysis for performance questionnaires. The KaiserMeyer- Olkin Measure of Sampling Adequacy (KMO) value is 0.897 and Barlett's Test of Sphericity value is significant (P=.000) which suggests that the factor analysis is also appropriate for the sample.

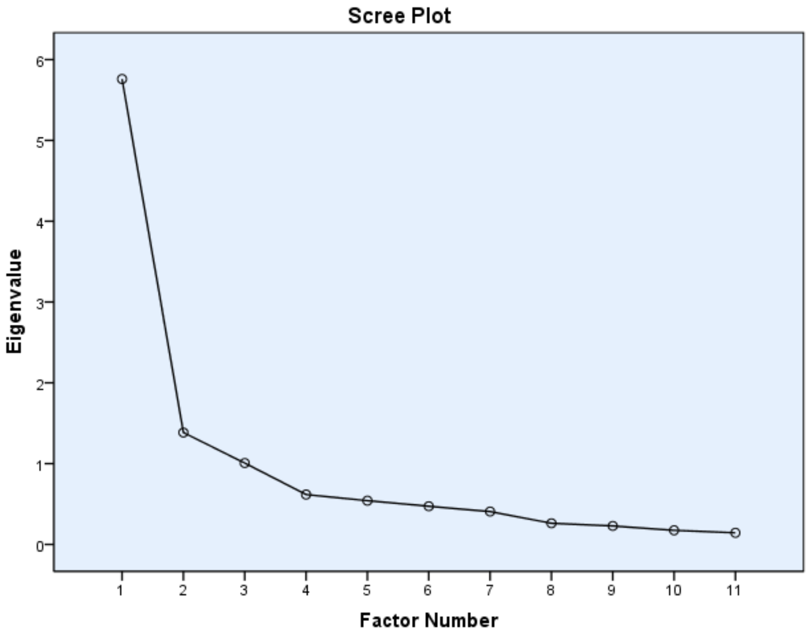


Figure 9-8: Scree plot (performance)

Also a scree plot is generated to test number of factors to be retained. Similarly, a scree plot was generated in order to assist decision making in the number of factors to be retained. By investigation of the results it was decided to select three factors for which loading factors and communalities for questions are shown in Table 9-2.

Table 9-2: Rotated Factor Matrix and Communalities (Performance)

	Factor			Communalities
	1	2	3	Initial
O1	.292	.193	.624	.455
O2	.106	.167	.789	.418
O3	.190	.070	.582	.308
N1	.429	.840	.131	.736
N2	.504	.702	.210	.758
N3	.049	.213	.061	.056
N4	.572	.468	.142	.558
N6	.759	.402	.194	.735
N7	.827	.254	.220	.730
N8	.775	.295	.292	.745
N9	.740	.218	.352	.681

9.4.1.4 *Selection of subjective ratings to take into account*

Interpretation of the results of common factor analysis (9.4.1.3) and correlation analysis (9.4.1.2) resulted in following conclusions;

For comfort, it can be seen from Figure 9-5 that Noise Loudness (N1) and Noise Annoyance (N2) are highly correlated (Pearson Correlation Coefficient = 0.772). Therefore, it can be said that the questions asked in N1 and N2 were perceived by the subjects as same or similar so N1 and N2 responses are actually judgements on the same perceptual variable. Moreover, it can also be seen from Figure 9-5 that N4 (Disturbance of Conversation) is also correlated with N1 and N2 (with the Pearson Correlation Coefficient of 0.586 and 0.579 respectively). N1 and N2 are also appearing to correlate with N5 (Sleep Disturbance) (with respective correlation coefficients of 0.508 and 0.545). On the other hand, from Table 9-1 it can be seen that N1, N2, N4 and N5 are all linked to the same perceptual variable since they are all loading the same factor. However it can also be seen from Table 9-1 that N4 and

N5 have smaller factor weightings when compared to N1 and N2. As a result, from the aforementioned 4 variables N2 (Annoyance) was selected to represent the perceptual variable. The reason for choosing N2 instead of N1 was simply due to the belief that annoyance is the direct indication of discomfort and therefore makes more sense over loudness. It was also expected that loudness (N1) would be correlated with the noise levels but responses collected for this variable cannot be directly associated with the feelings of the respondents on that noise but more likely will represent the physical amount of the sound that respondent perceive. However N2 (Annoyance) is highly correlated with the loudness (N1) because it is very likely that people who found the noise loud will also be the ones who were annoyed. But it can easily be said that this annoyance is not only the product of loudness but also affected by other subjective measures such as the fluctuations, sharpness and tonalness etc. Similarly for the second factor, O1 (Overall Feeling of Discomfort) was selected because it has a very high factor weighting as it can be seen in Table 9-1.

For the performance, Figure 9-6 shows that N1 (Severity) and N2 (Annoyance) are highly correlated. Similarly O1 (Overall Feeling of Wellbeing) and O2 (Sleep quality) are correlated while finally answers given to questions N2-N9 also seems to be correlated. Moreover, interpretation of the factor matrix (Table 9-2) produced three different groups of questions (O1 - O3 loading factor 3, N1 - N3 loading factor 2 and N4 - N9 loading factor 1). O1 - O3 show the overall ratings, N1-N3 show more annoyance ratings where N4 - N9 show the performance ratings. As it can be seen from Table 9-2 N7 (Quality Impairment) has the biggest factor weighting and it is a direct indication of performance, as a result, from the group ‘N4 - N9’, N7 was selected. Furthermore, from the group ‘N1 - N3’, N2 (Annoyance) was selected due to the similar reasons which were explained in comfort section. Finally, O1 (Overall feeling of wellbeing) was selected to represent the O1-O3. For the factor 3 in Table 9-2 it can be argued that O2 (sleep quality) could have been used. The reason why O1 was selected when O2 had bigger factor rating, was due to the fact that sleep quality can be effected by many other factors and is not directly representing the performance. Moreover, selecting O1 would keep it consistent with the comfort models.

Table 9-3 demonstrates the summary of selected dependent variables to be focussed in both comfort and performance models.

Table 9-3: Selected dependent variables to be modelled.

	Variables
Comfort	**N2c** - Annoyance **O1c** - Overall feeling of discomfort
Performance	**N2p** - Annoyance **N7p** - Quality impairment **O1p** - Overall feeling of wellbeing

9.4.2 Selection of Independent (Explanatory) variables

Some questions from the questionnaires were designed to collect the required information for independent variables such as age, gender, etc. In order to use an independent variable in a model, it is desirable for that independent variable to be able to explain the variance in the dependent variable. Therefore, if an independent variable does not have any descriptive power on the dependent variable, in the context of this thesis subjective response questions does not show any dependence on the explanatory variables, then there is no need to include them in the models. In order to test this condition ANOVA analysis is going to be performed on the selected dependent variables in Table 9-3. It is important to demonstrate a linear dependence between subjective responses and explanatory variables. Therefore, from Figure 9-9 to Figure 9-20 a visual demonstration of these dependencies are displayed.

9.4.2.1 Age

In order to investigate the effect of people’s age visually, selected dependant variables from Table 9-3 are plotted against age as shown in Figure 9-9 below.

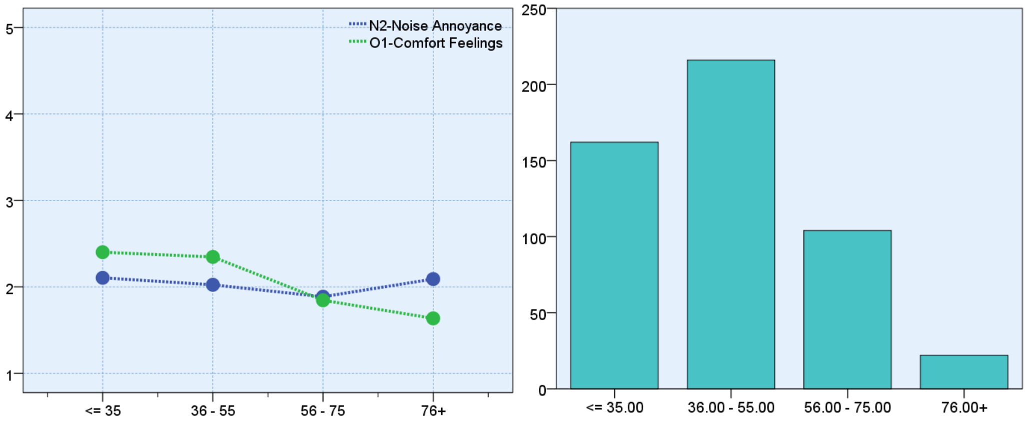


Figure 9-9: Left Panel: Response variables as function of age, Right Panel: Distribution of people’s ages binned into groups in comfort questionnaires. *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

First of all, the age of participants was binned in to 4 different groups for better visibility. People who were ‘35 years old or younger’ were grouped together while the other three groups were respectively; ‘36 to 55’ years old, ‘56 to 75’ years old and finally people with ages ‘76 or over’. Numbers on the vertical axis in the left pane graphs represent the comfort and performance feelings of participants 1 least annoyed or performance degraded to 5 most annoyed or performance degraded (this description also applies following figures: Figure 9-9 to Figure 9-20). It appears that the O1-Comfort feelings depend on the age as the response rating tends to get smaller (which means people getting less annoyed) when the age increases. However, for N2-Noise annoyance no obvious trend was identified therefore it is hard to comment on the effect of age. This will further be investigated.

Following the same methodology, Figure 9-10 demonstrates the effects of age on the response variables for performance questionnaires. It is important to mention that age group ‘76 or over’ was not observed in performance questionnaires; hence that category is reported empty. For the all response variables (N2, N7 and O1) in comfort questionnaires there are no clear trends observed from the graphs.

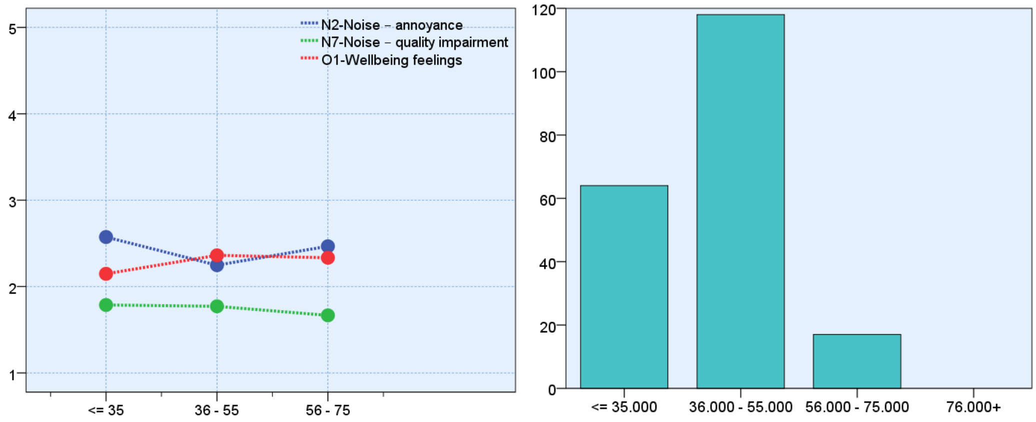


Figure 9-10: Left Panel: Response variables as function of age, Right Panel: distribution of people's ages binned into groups in Performance Questionnaires. *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

9.4.2.2 Gender

Figure 9-11 and Figure 9-12 demonstrate the effect of gender on the response variables in the comfort and performance questionnaires. In these figures, the right pane displays the distribution of gender. In comfort and performance questionnaires, the investigation of the graphs shows that male are more annoyed or performance degraded. This situation is more obvious in performance questionnaires.

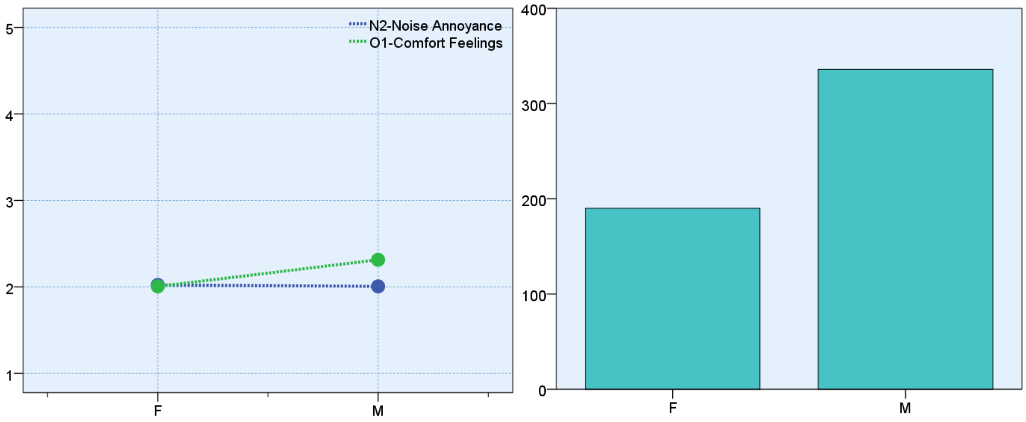


Figure 9-11: Left Panel: Response variables as function of gender, Right Panel: distribution of gender (Comfort Questionnaires). *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

It can be seen that female were underrepresented in both of the performance and comfort questionnaires.

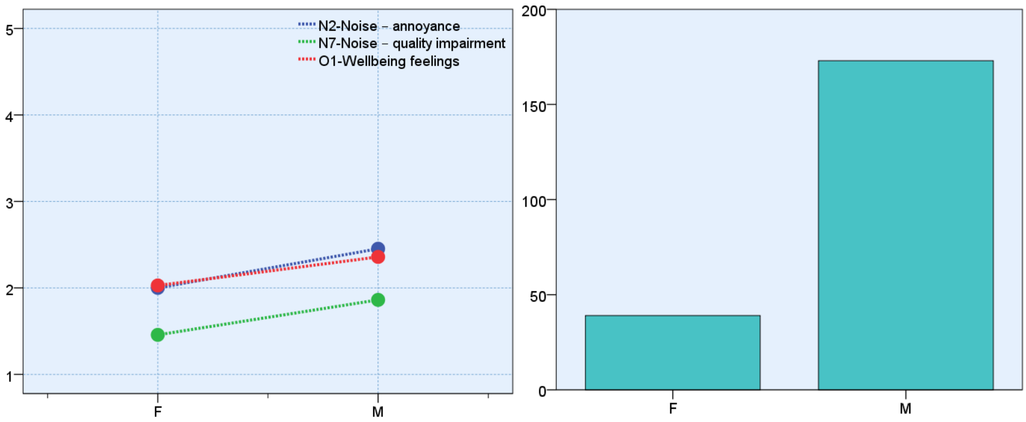


Figure 9-12: Left Panel: Response variables as function of gender, Right Panel: Distribution of gender (Performance Questionnaires) *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

9.4.2.3 Time Spent on Board

Figure 9-13 and Figure 9-14 show the subjective response variables in comfort and performance questionnaires as a function of time spent on board. The question for the 'time spent on board' was an open ended question in the questionnaires hence for simplicity the collected 'time spent on board' information from participants are binned in to 5 groups. For comfort questionnaires the categories were '1 day or less', '1 to 3 days', '3 to 5 days', '5 to 7 days' and '7 days or more' while for performance questionnaires following groups were used; '5 days or less', '5 to 10 days', '10 to 15 days', '15 to 20 days' and '20 days or more'

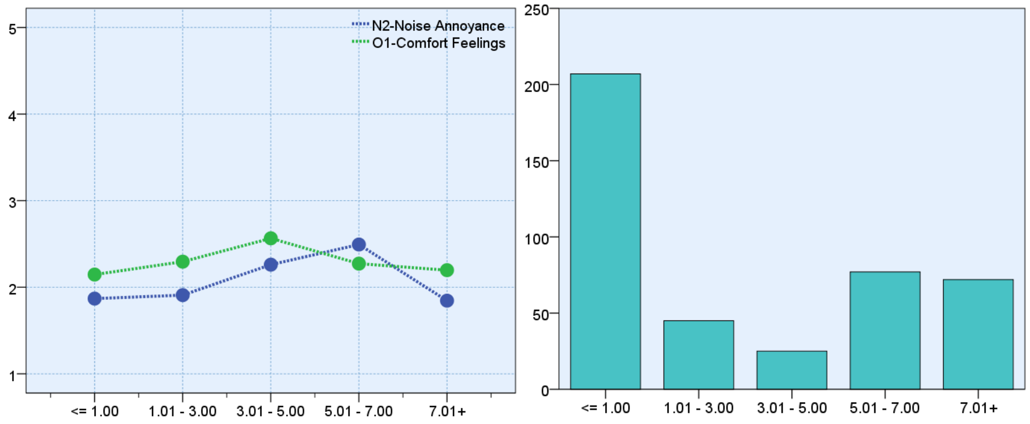


Figure 9-13: Left Panel: Response variables as function of time spent on board, Right Panel: Distribution of time spent on board (Comfort Questionnaires) *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

In both of the performance and comfort questionnaires, it is difficult to talk about the effect of time spend on board since there is no clear trend observed from the graphs.

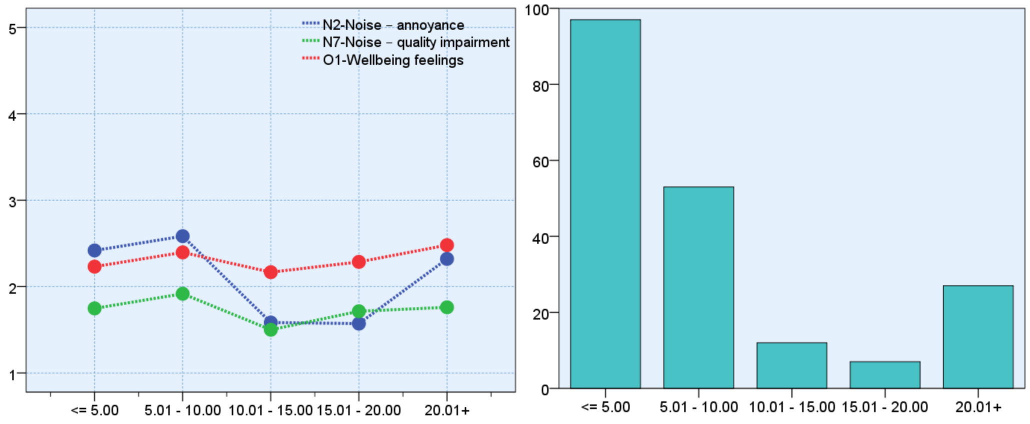


Figure 9-14: Left Panel: Response variables as function of time spent on board, Right Panel: Distribution of time spent on board (Performance Questionnaires) *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

Another important thing to mention is the fact that there is not an even distribution of responses in terms of time spent on board. Most of the participants appeared to spend less than one day on board for comfort questionnaires and less than ten days for performance questionnaires. This is due to the fact that passenger feedback was collected mainly from two ferries which conducted relatively short journeys.

9.4.2.4 Time Spent at the Location

Subjective response variables can be seen in Figure 9-15 and Figure 9-16 as a function of 'time spent at the location'. Time spent at the location is important because it may indicate the noise exposure duration which is interesting to investigate as it is taken into account by the regulatory norms (IMO, 1981, EC, 2003, IMO, 2012b). In comfort questionnaires it can be said that ratings of subjective responses tends to slightly increase (indicating more discomfort) with the increasing time spent at the location. However it is hard to comment on the performance questionnaires since there is no obvious trend is present. The information displayed on the right panes are the distribution of time spent at the location in performance and comfort questionnaires. For both questionnaires reported time spent at the location was binned in to following groups; '1 hour or less', '1 to 4 hours', '4 to 7 hours', '7 to 10 hours' and '10 hours or more'.

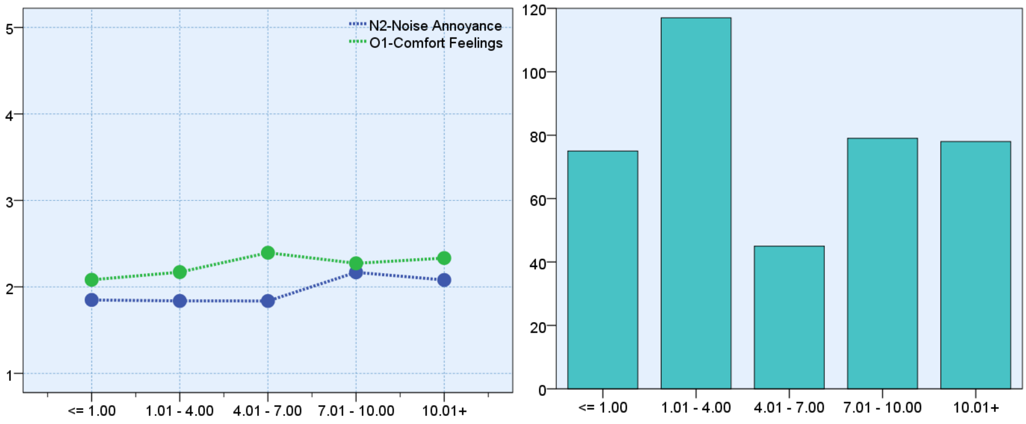


Figure 9-15: Left Panel: Response variables as function of time spent at the location, Right Panel: Distribution of time spent at the location (Comfort Questionnaires) *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

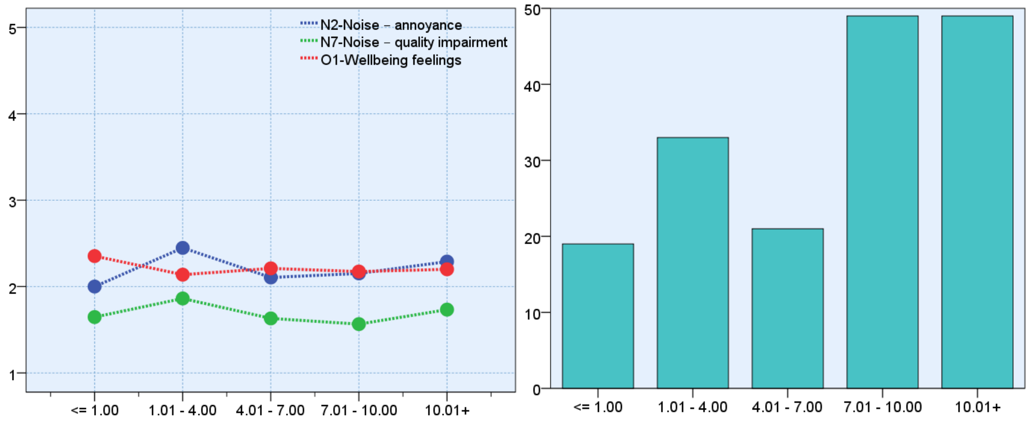


Figure 9-16: Left Panel: Response variables as function of time spent at the location, Right Panel: Distribution of time spent at the location (Performance Questionnaires) *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

9.4.2.5 Sea Travel Experience

Figure 9-17 and Figure 9-18 depicts the relationship between the 'sea travel experience' and subjective responses of the participants in performance and comfort questionnaires. Again, right hand pane in both graphs show the distribution of the sea travel experience amongst the participants. It needs to be noted that the question in comfort questionnaires was a multiple choice question while in comfort questionnaires it was asked in an open ended type (how many years you have worked at sea?). Therefore, responses collected for the sea travel experience for performance questionnaires were binned in to following groups; '2 years or less', '3 to 8 years', '9 to 14 years', '15 to 20 years', '21 to 26 years', '27 to 32 years', '33 to 38 years' and '39 years or more'.

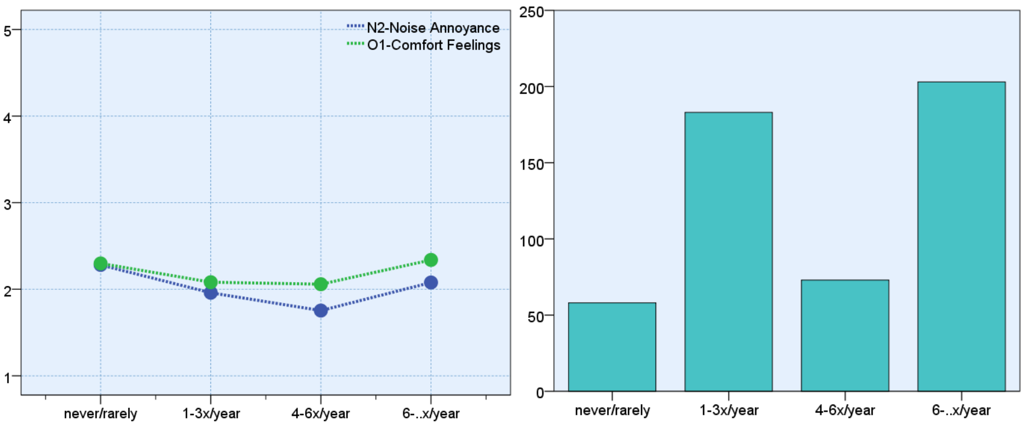


Figure 9-17: Left Panel: Response variables as function of Sea travel experience, Right Panel: Distribution of Sea travel experience (Comfort Questionnaires) *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

From both questionnaires it is hard to observe a trend of any dependence on sea travel experience.

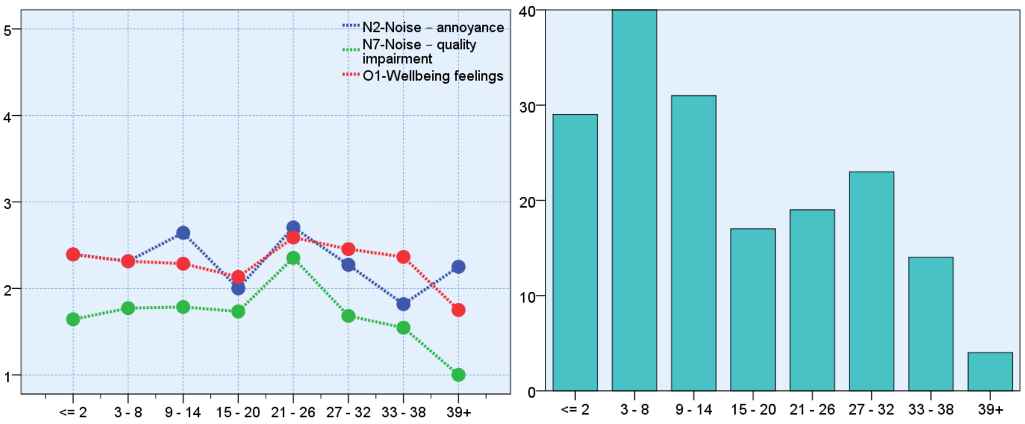


Figure 9-18: Left Panel: Response variables as function of Sea travel experience, Right Panel: Distribution of Sea travel experience (Performance Questionnaires) *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

9.4.2.6 Main Activity

Main activity of the people at their respective locations was asked only in the comfort questionnaires. Participants were asked to answer a multiple choice question with following answer categories: Categories: watching TV, reading, eating/drinking, talking, using a computer, listening to music, listening to music with ear plugs, sleeping. As can be seen there is also a category tagged with ‘0’ these are the people who did not choose one category but either wrote something else or chose more than 1 option. As a result there are majority of people who could not answer this question properly. Moreover, there is no obvious trend that shows dependence of subjective responses on main activity. Therefore it is very unlikely that ‘main activity’ will be included into models.

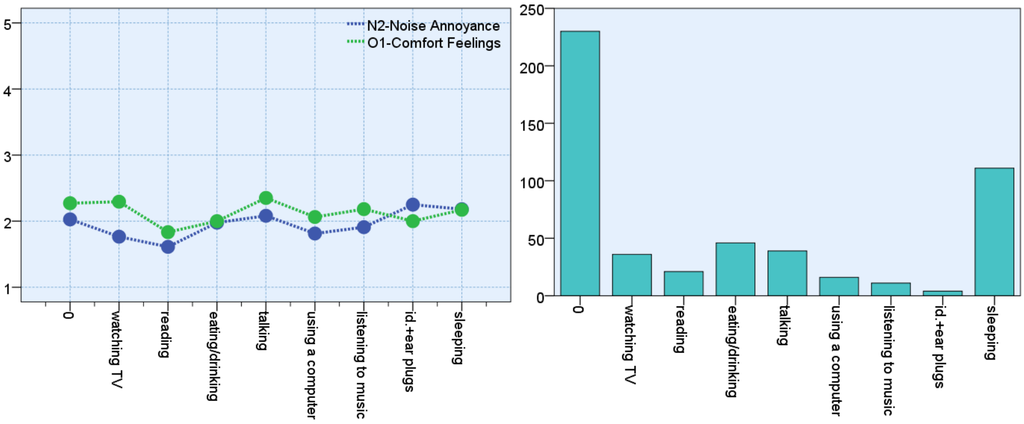


Figure 9-19: Left Panel: Response variables as function of main activity, Right Panel: Distribution of main activity (Comfort Questionnaires) *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

9.4.2.7 Hours Slept

In performance questionnaires, there was a question aimed to capture the sleep duration of crew in their most recent rest period (Such question did not exist in comfort questionnaires). Therefore, Figure 9-20 demonstrates the subjective response variables as function of the hours slept. From Figure 9-20, it may appear that people who has more than 11 hours of sleep show higher rates of subjective response (which indicates reduced performance) but it needs to be noted that there is almost no variance in that category. Therefore, it is hard to comment on any dependencies on sleep hours. For easier visualisation, hours slept was binned in to following categories: ‘2 hours or less’, ‘3 to 4 hours’, ‘5 to 6 hours’, ‘7 to 8 hours’, ‘9 to 10 hours’, and ‘11 hours or more’.

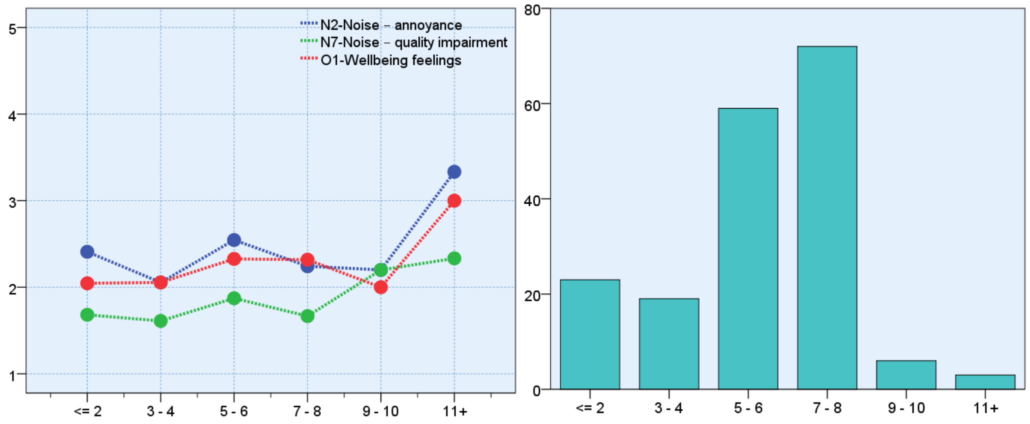


Figure 9-20: Left Panel: Response variables as function of hours slept, Right Panel: Distribution of hours slept (Performance Questionnaires) *(Vertical axis on the left pane: 1-Least Annoyed; 5-Most Annoyed, Right pane: Count)*

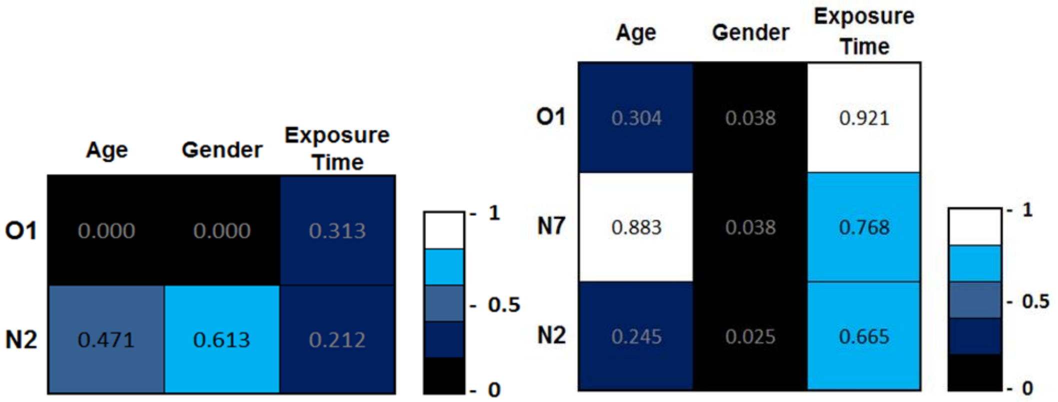
9.4.2.8 Selection of Independent (Explanatory) variables

Through careful investigation of the figures above (Figure 9-9 to Figure 9-20) following explanatory variables were selected as the potential independent variables to be included in the human response models.

- Age
- Gender
- Time spent at the location (Exposure time)

Finally, one way ANOVA test was applied between the selected explanatory variables and the subjective response variables in SPSS Statistics software package. The p statistics obtained from ANOVA analysis are demonstrated in Figure 9-21. P vales were divided into 5 equal groups and each coloured different for the easy interpretation.

Output tables of ANOVA analysis from SPSS can be found in APPENDIX D of this thesis.



	Age	Gender	Exposure Time
O1	0.000	0.000	0.313
N2	0.471	0.613	0.212

	Age	Gender	Exposure Time
O1	0.304	0.038	0.921
N7	0.883	0.038	0.768
N2	0.245	0.025	0.665

Figure 9-21: Resulting P values from the ANOVA tests displayed in a matrix format (Left Pane: Comfort Questionnaires, Right Pane: Performance Questionnaires)

9.5 Stage 2 - Predict human responses to noise

In the Stage 2 of modelling, the aim was to establish a link between the physical quantity of noise and the selected subjective response variables with the help of appropriate explanatory variables. As explained before ultimate aim of this section is to develop sub-models for each of the selected subjective dependent variables, these sub-models then can be used together forming the Performance and Comfort models for Noise. In brief, the aim is to develop 2 sub-models (N2 and O1) for the Noise Comfort Model and 3 sub-models (N2, N7 and O1) for Noise Performance Model.

9.5.1 Multiple Linear Regression Efforts

In order to achieve the targeted models firstly the linear regression models were addressed, however linear regression results suggested that the data set is not suitable for linear regression.

Each N2 (Noise annoyance) and O1 (Overall feeling of comfort) from comfort questionnaires and N2 (Noise annoyance), N7 (Quality impairment) and O1 (Overall feeling of wellbeing) form performance questionnaires were regressed against the objective measure of Noise (Laeq), and selected explanatory variables (Age, Gender, Time Spent). Also following interactions were tried to be included into the models;

Laeq * Age, Laeq * Gender, Laeq * Time Spent, Age * Gender, Age * Time Spent, Gender * Time Spent. Regressions were carried out in SPSS Statistics software package and the detailed results can be found in APPENDIX E.

Table 9-4: Summary of Multiple Linear Regressions

Model	SPSS Expression	Adjusted R^2	Mallows Cp	Residuals Normality Condition Satisfied?
COMFORT MODELS – NOISE				
N2: Noise Annoyance	N2 = 0.536+0.023xLaeq+0.027xTime_Spent	0.0419	3.2	No
O1: Overall feeling of comfort	O1 = 1.062+0.027xLaeq+0.000xLaeq*Age+ 0.025xGender*Time Spent	0.095	5.8	No
PERFORMANCE MODELS – NOISE				
N2: Noise Annoyance	N2 =1.303+0.027xLaeq-0.021xAge	0.1977	4.3	Yes
N7: Quality Impairment	N7 =0.334+0.020xLaeq	0.1239	3.1	No
O1: Overall feeling of wellbeing	O1 = 1.423+0.012xLaeq	0.0773	4.5	No

Table 9-4 displays the summary of multiple linear regression models resulted. As it can be seen from the Adjusted R^2 column, even the best model is only able to explain around 20% of variance in the independent variable. Residuals of a model represent the error in estimations which are obtained through comparing the observed responses to predicted responses. Residuals can be thought as the elements of unexplained variation by the fitted model and normally it is expected that the residuals should follow normal distribution. Otherwise, it can be said that residuals contain some information and structure that was not taken into account by the fitted model and therefore identification of this structure may lead better models (NIST/SEMATECH, 2003). It can be seen that almost all the models' residuals in Table 9-4 are not following the normal distribution. Therefore, interpretation of the results showed that the database which is being utilised in this thesis is not suitable for multiple linear regressions.

9.5.2 Ordinal Logistic Regression Efforts

After failing to achieve good fitness of models through multiple linear regressions, ordinal logistic regression was visited. Simply because the subjective response variables (dependent variables) selected to be modelled had 5 ordinal ratings (i.e. not at all, a little, moderately, very, very much) and ordinal logistic regression is a regression model which can used when the dependent variable is of an ordinal type with two or more response ratings. In this section of the thesis firstly, ordinal logistic regression procedure followed for the variable N2 (Noise Annoyance) from comfort questionnaires will be explained and then the summaries of all developed models will be presented.

The ordinal logistic regression used in this section is called ‘constrained cumulative logit model’ which is the most commonly used type for ordinal logistic regression (Hosmer Jr *et al.*, 2013). The constrained cumulative logit model predicts the cumulative logits (i.e. odds and probabilities) of ‘as severe or lesser’ responses of an ordinal variable to happen. The ordinal logistic regression can be considered as an extension of binomial logistic regression applicable to ordinal type of dependent variable. Therefore, the constrained cumulative logit model consists of several binomial type sub-models. Each sub-model predicts the probabilities of less than or equal to a level to occur.

The general from of the model is;

$$L = ln\left[\frac{\hat{p}}{1-\hat{p}}\right] = t - (B_1X_1 + B_2X_2 + \cdots + B_nX_n)$$

Equation 9-1

In the Equation 9-1, **‘L’** represents the natural log of cumulative odds of as severe of lesser event to happen where **‘t’** is the threshold level. $\mathbf{B_1}$ to $\mathbf{B_n}$ represent the slope while $\mathbf{X_1}$ to $\mathbf{X_n}$ represents each independent variable.

The logistic regression estimates the probabilities of occurrence of the dependent variable equal to or below certain level. Therefore it is understandable to order the ordinal variable categories in the way to make lower values represent worse higher values represent better conditions. For example, if people are asked to rate the service that they get in a restaurant for which the dependent variable has the following 4 levels; 'Poor', 'Fair', 'Good', 'Very good', then the labelling of these categories in ordinal logistic modelling should be as follows; '1:Poor', '2:Fair', '3:Good', '4:Very good'. As a result there will be 3 sub-models to be produced which is also shown below;

- **Sub-Model 1** will estimate the probability of observing the level '1-Poor'.
- **Sub-Model 2** will estimate the cumulative probability of observing the level '1-Poor' or '2-Fair'.
- **Sub-Model 3** will estimate the cumulative probability of observing the level '1-Poor' or '2-Fair' or '3-Good'.

Obviously the cumulative probability of observing level '4-Very good' and below is equal to 1 therefore, sub-model 4 is dropped.

Following the same logic, the response categories of N2 (Noise annoyance) from comfort questionnaires was reversed to achieve the labelling shown below;

- 1-Very much annoyed.
- 2-Very annoyed.
- 3-Moderately annoyed.
- 4-A Little annoyed.
- 5-Not annoyed.

As a result following 4 Sub-Models were generated

- **Sub-Model 1**, predicting the probability of being 'Very much' annoyed by the noise.
- **Sub-Model 2**, predicting the cumulative probability of being 'Very much' or 'Very' annoyed by the noise.

- **Sub-Model 3**, predicting the cumulative probability of being ‘Very much’ or ‘Very’ or ‘Moderately’ annoyed by the noise.
- **Sub-Model 4**, predicting the cumulative probability of being ‘Very much’ or ‘Very’ or ‘Moderately’ or ‘A little’ annoyed by the noise.

9.5.2.1 Hypotheses Test for Ordinal Regression

In order to check the validity of the estimated parameters following two hypotheses tests were conducted;

- **Test 1**: All slopes are equal to zero which may also mean all odds ratios are equal to 1 ($B_1 = B_2 = \ldots = B_n = 0$)
- **Test 2**: An independent variable individually has a slope of zero. ($B_n = 0$)

The ‘Likelihood ratio X^2 test’ was used to test and reject the null hypothesis for Test 1 ($B_1 = B_2 = \ldots = B_n = 0$) and Test 2 ($B_n = 0$)

9.5.2.2 Results of Ordinal Logistic Regressions

For the N2 (Noise Annoyance) from comfort questionnaires, a set of nested models were developed and compared by using the ‘Likelihood ratio X^2 test’ in the SPSS Statistics software package. The summary of the hypotheses tests are shared in Table 9-5. In the table the Likelihood ratio X^2 values are presented for the overall hypotheses tests only while the p-values are provided both overall and individual slope tests. L (A-weighted noise level), G (Gender) and TS (Time Spent at the location) and interaction terms were used as independent variables for the ordinal logistic regressions. In Table 9-5 the cells filled with grey represent the conditions where the calculated p-value for the test is smaller than 0.05 ($p < 0.05$) while cells filled with red represent the opposite. Best models for different number of independent variables are shown with a bold style.

Table 9-5: Summary of ordinal logistic regression models and hypotheses tests for N2

No.	Model	Likelihood Ratio x^2	d.o.f.	Overall Test p-value ($b_1 = b_2 = b_n = 0$)	Model Effects p-values $b_n = 0$						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**11.449**	**1**	**0.0007**	**0.0007**						
2	G	0.666	1	0.4143		0.4143					
3	A	2.451	1	0.1175			0.1175				
4	TS	3.441	1	0.0636				0.0636			
5	**L & G**	**18.156**	**2**	**0.0001**	**0.0001**	**0.0073**					
6	L & A	11.739	2	0.0028	0.0014		0.3378				
7	L & TS	16.259	2	0.0003	0.0002			0.0316			
8	**L & G & L*G**	**20.39**	**3**	**0.0001**	**0.0419**	**0.0633**			**0.135**		
9	L & A & L*A	11.741	3	0.0083	0.3176		0.9328			0.9662	
10	L & TS & L*TS	16.482	3	0.0009	0.0188			0.4294			0.6369
11	**L & G & A**	**19.844**	**3**	**0.0002**	**0.0002**	**0.0037**	**0.3718**				
12	L & G & TS	19.246	3	0.0002	0.0001	0.0611		0.0611			
13	L & A & TS	14.372	3	0.0024	0.0004		0.745	0.0788			
14	**L & G & A &TS**	**17.967**	**4**	**0.0013**	**0.0001**	**0.046**	**0.8392**	**0.1342**			

Following can be concluded from Table 9-5.

- For the single input ordinal models only L (A-weighted noise level) is passing the overall hypothesis test (see Model No: 1 in Table 9-5).
- L (A-weighted noise level) and G (Gender) was included for the best model with two independent variables. (see Model No: 5 in Table 9-5). Inclusion of G (Gender) caused an increase in the Likelihood ratio X^2 indicating better model fitness.
- Best models with three independent variables (i.e. Model No: 8 with interactions and Model No: 11 without interactions in Table 9-5) are not showing any significant contributions from the added interacting or non-interacting terms into models when compared to Model No: 5.
- The model with four independent variables also does not show any improvement when compared to Model No: 5.

Therefore, the best ordinal logistic regression model derived for N2 (Noise Annoyance) is the model with two independent variables L (A-weighted noise level) and G (Gender). Table 9-6 displays the ‘Parameter Estimates’ table which was generated by the SPSS Statistics software package.

Table 9-6: Parameter estimates for the ordinal logistic regression model with two independent variables (for N2 Noise Annoyance)

Parameter		B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
				Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Threshold	[N2r=1]	-5.194	0.6087	-6.39	-4.001	72.801	1	0	0.006	0.002	0.018
	[N2r=2]	-4.045	0.5614	-5.15	-2.945	51.907	1	0	0.018	0.006	0.053
	[N2r=3]	-3.065	0.5369	-4.12	-2.012	32.585	1	0	0.047	0.016	0.134
	[N2r=4]	-1.520	0.5199	-2.54	-0.501	8.544	1	0	0.219	0.079	0.606
Laeq		-0.040	0.0100	-0.06	-0.021	16.172	1	0	0.961	0.942	0.98
[Gender=1]		0.517	0.1933	0.139	0.896	7.166	1	0.01	1.678	1.149	2.451
[Gender=0]		0[a]	.	.	.	.	.	.	1	.	.
(Scale)		1[b]									

Dependent Variable: Noise Annoyance, Model: (Threshold), Laeq, Gender.

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

Therefore, the resulting ordinal logistic regression sub-models for N2 (noise annoyance) are shown Equation 9-2 below.

$$L_{(VeryMuch\ Annoyed)} = -5.194 - \left[-0.040L_{A_{eq}} + 0.517G\right]$$

$$L_{(VeryMuch-Very\ Annoyed)} = -4.045 - \left[-0.040L_{A_{eq}} + 0.517G\right]$$

$$L_{(VeryMuch-Very-Moderately\ Annoyed)} = -3.065 - \left[-0.040L_{A_{eq}} + 0.517G\right]$$

$$L_{(VeryMuch-Very-Moderately-ALittle\ Annoyed)} = -1.520 - \left[-0.040L_{A_{eq}} + 0.517G\right]$$

Equation 9-2

The logit expressions in Equation 9-2 can be transformed into probabilities by using the Equation 9-3 which can be derived from Equation 9-1.

$$\hat{p} = \frac{1}{1 + e^{-L}}$$

Equation 9-3

By using the Equation 9-3 and the resulting ordinal logistic regression sub-models for N2 (noise annoyance) in Equation 9-2 can be rewritten as shown in Equation 9-4.

$$\hat{P}_{(VeryMuch\ Annoyed)} = 1\ /\ (1 + e^{5.194 - 0.040 L_{Aeq} + 0.517G})$$

$$\hat{P}_{(VeryMuch-Very\ Annoyed)} = 1\ /\ (1 + e^{4.045 - 0.040 L_{Aeq} + 0.517G})$$

$$\hat{P}_{(VeryMuch-Very-Moderately\ Annoyed)} = 1\ /\ (1 + e^{3.065 - 0.040 L_{Aeq} + 0.517G})$$

$$\hat{P}_{(VeryMuch-Very-Moderately-ALittle\ Annoyed)} = 1\ /\ (1 + e^{1.520 - 0.040 L_{Aeq} + 0.517G})$$

Equation 9-4

Now the expressions shown in the Equation 9-4 can be utilised to estimate the cumulative probabilities of observing a noise annoyance level or below when the L (A-weighted noise level) and G (Gender) are known for a person. These estimated probabilities then can be used together to estimate the individual levels simply deducting the probability of observing an annoyance level and below from the one higher level of annoyance. As mentioned before the probability of the highest level of annoyance and below is equal to one.

9.5.2.3 Validation of parallel lines assumption

It can be observed from the developed ordinal logistic regression models (Equation 9-4) that slopes of L (A-weighted noise level) and G (Gender) are not changing between different sub-models. Because ‘constrained cumulative logit model’ assumes that the independent variables affect all levels of dependent variable the same and therefore, the results for different sub-models in Equation 9-2 and Equation 9-4 will be parallel lines or planes. This assumption can be checked by test of parallel lines in SPSS Statistics software package by comparing the -2 Log Likelihood for the constrained model which assumes the slopes are identical with the −2 Log Likelihood for the unconstrained model which allows the slopes to vary.

The difference between the two −2 Log Likelihood values is distributed as a chi-squared statistic. The rejection of the null hypothesis is not desirable because it will suggest that the lines are not parallel. The result of the 'Test of Parallel Lines' from SPSS can be seen in Table 9-7.

Table 9-7: Test of Parallel Lines for N2 (Noise Annoyance)

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	735.052			
General	732.348	2.703	6	0.845

The null hypothesis states that the location parameters

(slope coefficients) are the same across response categories.

a. Link function: Logit

Table 9-7 suggest that the null hypotheses cannot be rejected.

9.5.2.4 Evaluation of ordinal regression model

Since there is no equivalent of adjusted R^2 for the logistic regression models, in order to check the model fitness the following needs to be examined;

- Outliers (Index Plots of Leverages)
- Residuals (Index Plots of standardized deviance)
- Influence (Index Plots of Cook's D.)

It is relevant to mention that methods for identifying outliers and influential observations are not well developed for ordinal logistic regression. As a result it is common to generate a set of binary dependent variables from the ordinal dependent variables then run binary logistic regressions and detect outliers and influential observations via the methods available for binary logistic regression

For N2 (Noise annoyance) from comfort questionnaires following set of binary dependent variables were created as shown in Table 9-8. Then, four binomial logistic regression models were created accordingly and evaluated for the outliers and influential observations.

Table 9-8: Created binary dependent variables from the ordinal variables

Binary Variable	1	0
N2B1 (Very much annoyed)	“Very much” annoyed	“Very”, “Moderately”, “A little” and “Not at all”
N2B2 (Very much or Very annoyed):	“Very much” and “Very”	“Moderately”, “A little” and “Not at all”
N2B3 (Very much or Very or Moderately annoyed):	“Very much”, “Very” and “Moderately”	“A little” and “Not at all”
N2B4 (Very much or Very or Moderately or A little annoyed):	“Very much”, “Very”, “Moderately” and “A little”	“Not at all”

Evaluation of Binomial Logistic Regression on N2B1 (Very much annoyed) with L (A-weighted noise level) and G (Gender) independent variables is demonstrated below;

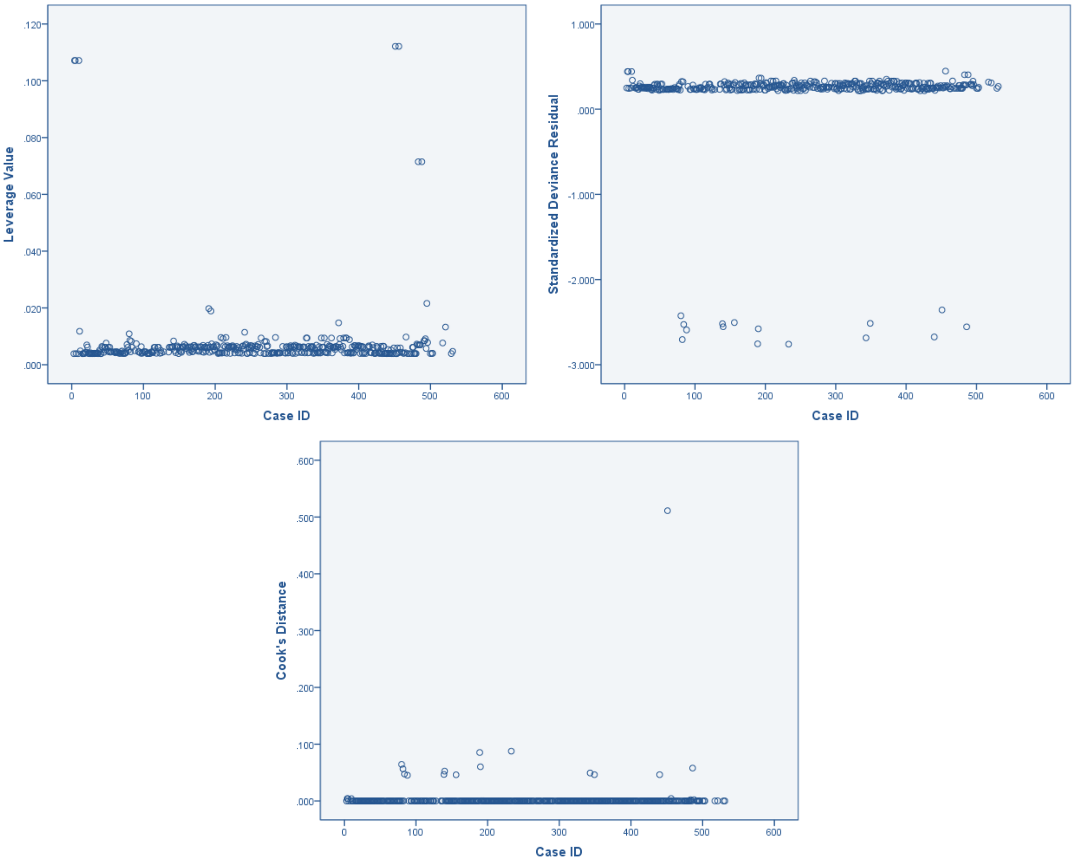


Figure 9-22: The index plots of leverages, standardized deviations, and Cook’s D (N2B1)

Figure 9-22 displays the index plots of leverages, standardized deviations, and Cook’s D. for N2B1. Following can be concluded:

- Form the top left pane of Figure 9-16 it can be seen that some of the observations show relatively large values of leverage which represent unusual values of input variables. Underlying reasons needs to be further investigated.
- Top right pane in Figure 9-16 display standardized deviance residuals which are severely biased towards the lower side. , standardized deviances larger than ±2 represent outliers therefore they also need to be considered.
- Finally, the figure in the bottom pane displays the Cook's D which is showing some cases which are highly influential with a potential to bias the predictions.

Moreover, similar graphical evaluation for was repeated for each of the other binomial variables (as shown in Table 9-8) and similar trends were observed for N2B2 – N2B4 (compared to N2B1 reported above). As a result, it was concluded that ordinal logistic regression model of N2 (Noise Annoyance) from comfort questionnaires was severely biased.

9.5.2.5 Summary of Ordinal Regression Models

In previous sections, the procedure of ordinal logistic regression modelling efforts were demonstrated on the dependent variable N2 (Noise Annoyance) of comfort questionnaires. Moreover, resulting models from ordinal logistic regressions for all selected dependent variables are demonstrated in Table 9-9.

For the models displayed in Table 9-9 the further details such as of hypotheses tests tables (showing the overall and individual hypotheses tests results as well as highlighting the selected models) and Parameter estimates tables (showing the Parameter estimates for the selected models) are shared in APPENDIX F.

Table 9-9: Summary of Ordinal Logistic Regressions

Model	SPSS Expression
COMFORT MODELS – NOISE	
N2: Noise Annoyance	$L_{(VeryMuch)} = -5.194 - \left[-0.040L_{A_{eq}} + 0.517G\right]$ $L_{(VeryMuch-Very)} = -4.045 - \left[-0.040L_{A_{eq}} + 0.517G\right]$ $L_{(VeryMuch-Very-Moderately)} = -3.065 - \left[-0.040L_{A_{eq}} + 0.517G\right]$ $L_{(VeryMuch-Very-Moderately-ALittle)} = -1.520 - \left[-0.040L_{A_{eq}} + 0.517G\right]$
O1: Overall feeling of comfort	$L_{(VeryMuch)} = -4.925 - \left[-0.038L_{A_{eq}} - 0.328G + 0.031Age\right]$ $L_{(VeryMuch-Very)} = -3.798 - \left[-0.038L_{A_{eq}} - 0.328G + 0.031Age\right]$ $L_{(VeryMuch-Very-Moderately)} = -1.806 - \left[-0.038L_{A_{eq}} - 0.328G + 0.031Age\right]$ $L_{(VeryMuch-Very-Moderately-ALittle)} = 0.446 - \left[-0.038L_{A_{eq}} - 0.328G + 0.031Age\right]$
PERFORMANCE MODELS – NOISE	
N2: Noise Annoyance	$L_{(VeryMuch)} = -5.291 - \left[-0.050L_{A_{eq}} + 0.036Age\right]$ $L_{(VeryMuch-Very)} = -3.606 - \left[-0.050L_{A_{eq}} + 0.036Age\right]$ $L_{(VeryMuch-Very-Moderately)} = -2.541 - \left[-0.050L_{A_{eq}} + 0.036Age\right]$ $L_{(VeryMuch-Very-Moderately-ALittle)} = -0.726 - \left[-0.050L_{A_{eq}} + 0.036Age\right]$
N7: Quality Impairment	$L_{(VeryMuch)} = -6.923 - \left[-0.042L_{A_{eq}}\right]$ $L_{(VeryMuch-Very)} = -5.241 - \left[-0.042L_{A_{eq}}\right]$ $L_{(VeryMuch-Very-Moderately)} = -4.337 - \left[-0.042L_{A_{eq}}\right]$ $L_{(VeryMuch-Very-Moderately-ALittle)} = -3.203 - \left[-0.042L_{A_{eq}}\right]$
O1: Overall feeling of wellbeing	$L_{(VeryMuch)} = -5.821 - \left[-0.028L_{A_{eq}}\right]$ $L_{(VeryMuch-Very)} = -4.666 - \left[-0.028L_{A_{eq}}\right]$ $L_{(VeryMuch-Very-Moderately)} = -2.710 - \left[-0.028L_{A_{eq}}\right]$ $L_{(VeryMuch-Very-Moderately-ALittle)} = 0.352 - \left[-0.028L_{A_{eq}}\right]$

9.5.2.6 Evaluation of ordinal logistic regression models and conclusion

In order to assess the fitness of the developed ordinal logistic regression models, index plots of predicted and observed (comfort as well as performance) subjective response ratings were generated. The 'predicted vs observed' plots are very good visual aid to get a fair idea about the fitness of the models to the sample data. From the graphs below (Figure 9-23 to Figure 9-27) it can be seen that for almost all of the models, there are fewer cases recorded for the higher categories of rating. Especially, for the highest two categories (i.e. "very" and "very much" very few cases were observed. This situation results in ordinal logistic regression to become biased. Therefore, it was concluded that ordinal logistic regression models were not satisfactory and therefore, it may be beneficial to try binomial regression by converting the ordinal response ratings in to dichotomous.

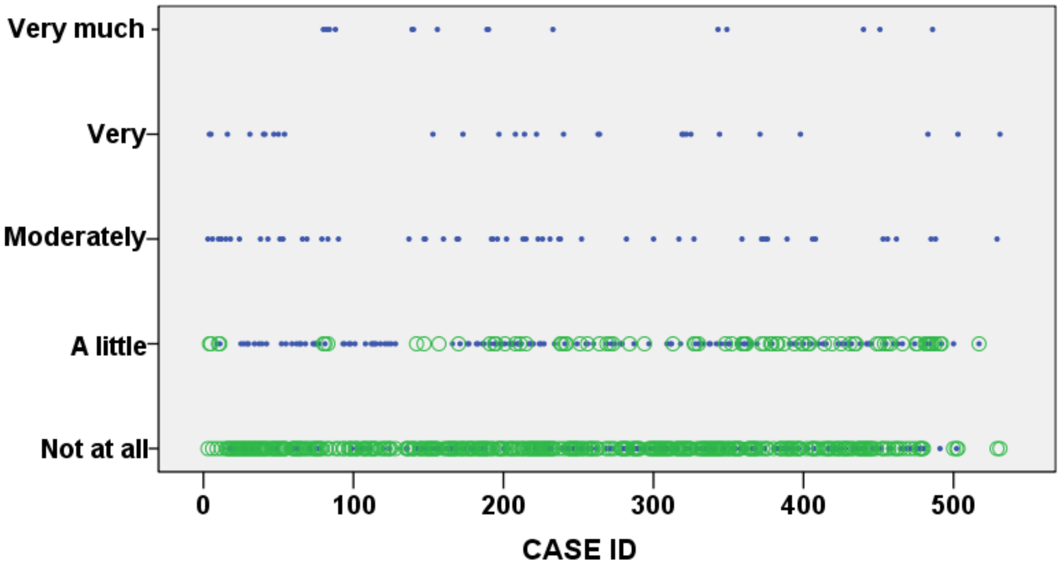


Figure 9-23: Ordinal regression index plot of predicted (circle) and observed (dot) comfort subjective rating N2

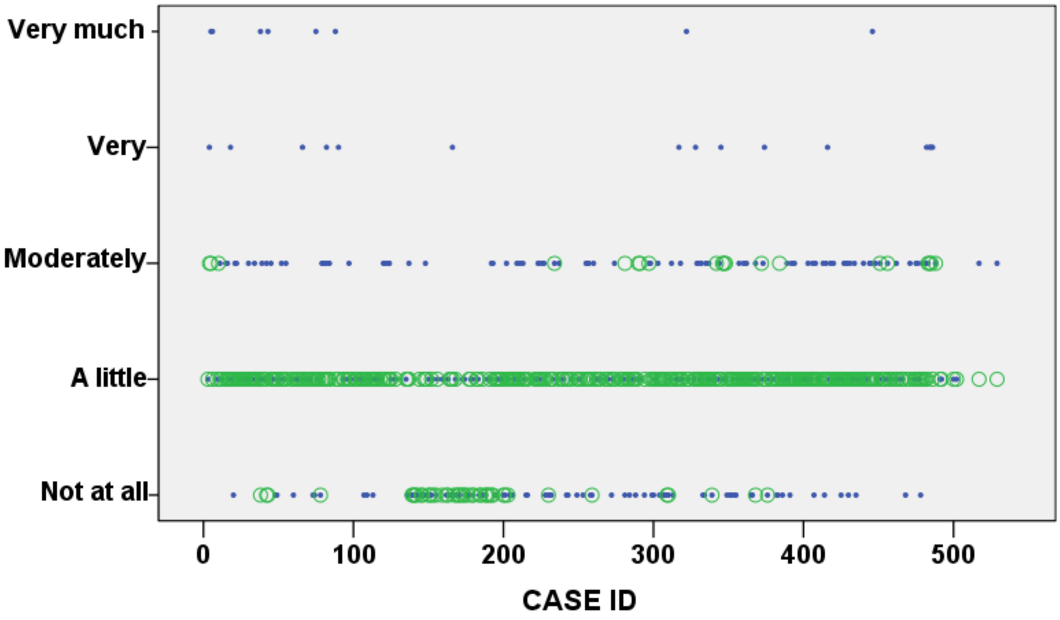


Figure 9-24: Ordinal regression index plot of predicted (circle) and observed (dot) comfort subjective rating O1

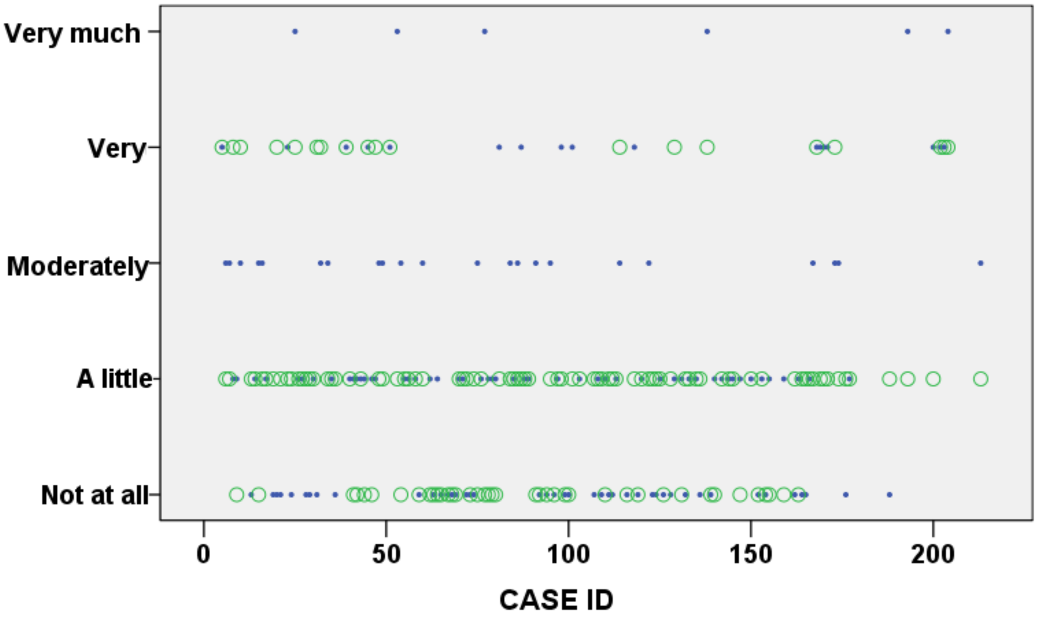


Figure 9-25: Ordinal regression index plot of predicted (circle) and observed (dot) performance subjective rating N2

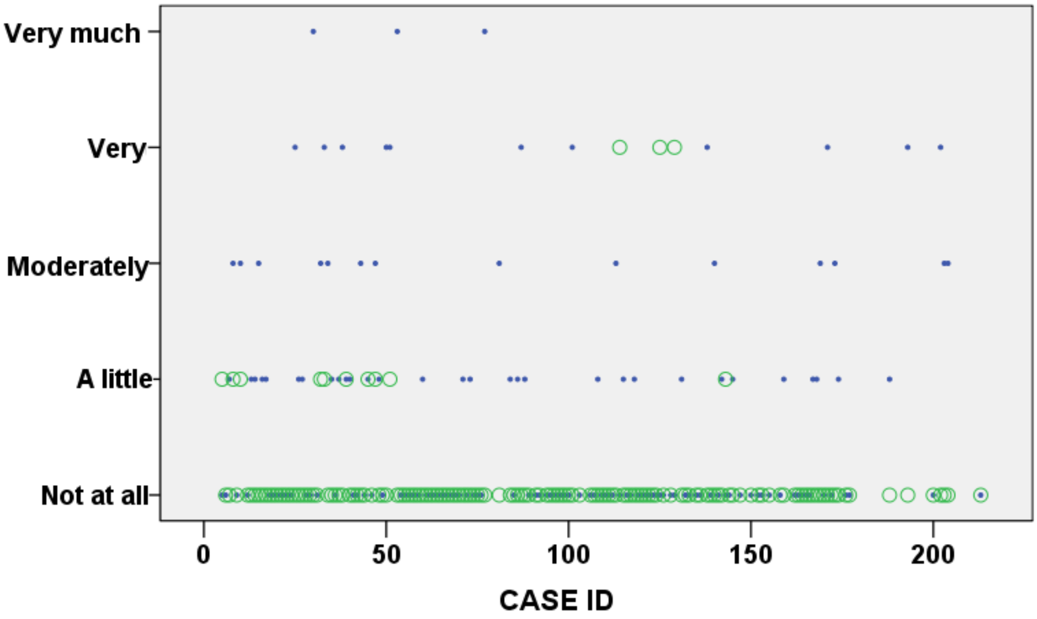


Figure 9-26: Ordinal regression index plot of predicted (circle) and observed (dot) performance subjective rating N7

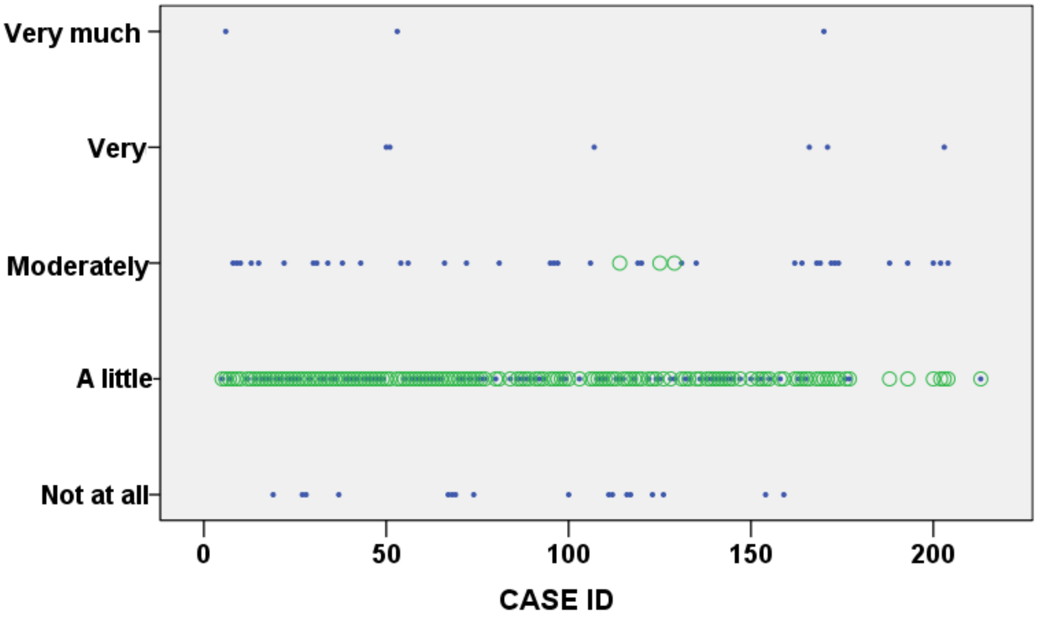


Figure 9-27: Ordinal regression index plot of predicted (circle) and observed (dot) performance subjective rating O1

9.5.3 Binomial logistic regression efforts

9.5.3.1 Background

As ordinal logistic regressions did not provide the models with good fitness, binomial logistic regressions were visited. This section will explain the procedure of binomial logistic regressions and discuss the results and generated models.

In binomial logistic regression is a very popular modelling approach which defines the relationship between many independent variables of different nature and a dichotomous dependent variable (Kleinbaum and Klein, 2010). The popularity of logistic regression comes from the logistic function (shown in Equation 9-5) which ranges between zero and 1 regardless of what value ‘z’ gets. Therefore, it can be said that logistic regression by nature is a very good fit to describe probability.

$$f(z) = \frac{1}{1 + e^{-z}}$$

Equation 9-5

Moreover, Figure 9-28 demonstrates the logistic function graphically. The shape of the logistic function is very appealing because if ‘z’ is considered to represent input variables (independent variable e.g. exposure to noise) after certain level of ‘z’ it can been seen that the risk factor grows rapidly (between vertical dashed lines) and then remains more or less steady representing high risk or probability.

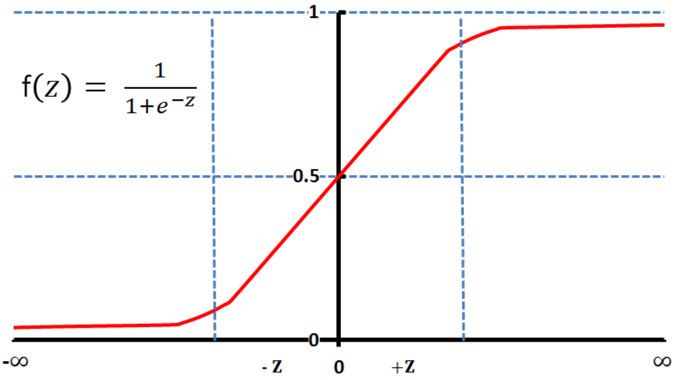


Figure 9-28: Graphical demonstration of logistic function

General form of a binomial logistic regression model can be seen in Equation 9-6 (Orme and Combs-Orme, 2009).

$$L_{(Dependent\ Variable=1)} = \ln\left[\frac{\hat{p}}{1-\hat{p}}\right] = a + B_1X_1 + B_2X_2 + \cdots + B_nX_n$$

Equation 9-6

In Equation 9-6, L represents logits of an event to happen where logits means natural log of odds. Slopes of independent variables X_1 to X_n are respectively B_1 to B_n where ‘a’ represent the intercept.

Since, the binomial logistic regression model estimates the logit of an event, in order to have more useful meaning the Equation 9-6 can be transformed to predict odds as shown in Equation 9-7.

$$odds = \frac{\hat{p}}{1-\hat{p}} = e^L = e^{[a+B_1X_1+B_2X_2+\cdots+B_nX_n]}$$

Equation 9-7

Then the odds in Equation 9-7 can be organised in a way to predict the probabilities as shown in Equation 9-8.

$$\hat{p} = \frac{1}{1 + e^{-L}} = \frac{1}{1 + e^{-[a + B_1 X_1 + B_2 X_2 + \cdots + B_n X_n]}}$$

Equation 9-8

Therefore, the parameters estimated from binomial logistic regression can be placed in the Equation 9-8 to achieve a model predicting probabilities of subjective human response (e.g. noise annoyance: annoyed, not annoyed).

9.5.3.2 Reorganisation of collected human response ratings

Binomial logistic regression is a modelling technique applicable to a dichotomous dependent variable. However, subjective response ratings collected through questionnaires had 5 ordinal categories (as shown in APPENDIX B). Therefore, in order to apply binomial logistic regression it was necessary to convert the five level ordinal response ratings (1-Not at all, 2-A little, 3-Moderately, 4-Very, 5-Very much) into two levels. Initially all types of annoyance (from 2-A little to 5-Very much) were combined together. However when the resulting models were evaluated it was observed that even for low levels of noise, the models were predicting high levels of discomfort or performance degrade. It is not wrong to say that there will always be some level of noise on board a ship which may influence some people to go for ‘a little’ category instead of ‘not at all’. Similarly, a person who is not sure about the annoyance is likely to choose ‘a little’ category rather than choosing ‘not at all’. Moreover, it may be possible that the participants psychologically reported a ‘little’ instead of ‘not at all’. Even though this statement is purely an assumption, there are supportive findings in literature about this issue. In a relevant research various evaluative phrases were tested and it was concluded that people tend to rate positive extreme more than negative extreme therefore not willing to assign themselves with negative descriptors (Bartram and Yelding, 1973, Friedman and Amoo, 1999). These observations can be supported with the observation that ‘a little' category was second most popular category selected by the respondents. Further details about these developed models can be found in APPENDIX G.

As a result, a new dichotomy was generated by pooling together the 3-Moderately, 4-Very and 5-Very much to represent the presence of discomfort or performance degrade. Therefore, the categories of all dependent response variables were converted into dichotomous as shown below;

- 'Not at all' and 'A little' to zero.
- 'Moderately', 'Very' and 'Very much' to one.

9.5.3.3 Binomial logistic regression results

In binomial logistic regression overall null hypotheses of all slopes equal to zero is needed to be tested (B1 = B2 = Bn = 0) which also means that all odds ratios equal to 1. This test is conducted to prove the significant relationships between the dependent and independent variables.

Maximum likelihood estimation is a method for estimating the parameters in a model. It is appealing to statisticians for fitting the logistic model due to the fact that it has no restrictions on the characteristics of independent variables (Kleinbaum and Klein, 2010). Therefore, for the binomial logistic regression modelling 'Likelihood ratio X^2 test' was used to test the overall null hypotheses in this section. 'Likelihood ratio X^2 test' follows chi distribution which has a degree of freedom equal to number of independent variables. After testing the overall null hypotheses the individual slopes of an independent variable was checked for being equal to zero (B_n = 0). In brief, 'likelihood ratio X^2 test' was used to test null hypotheses of both overall and individual slopes'.

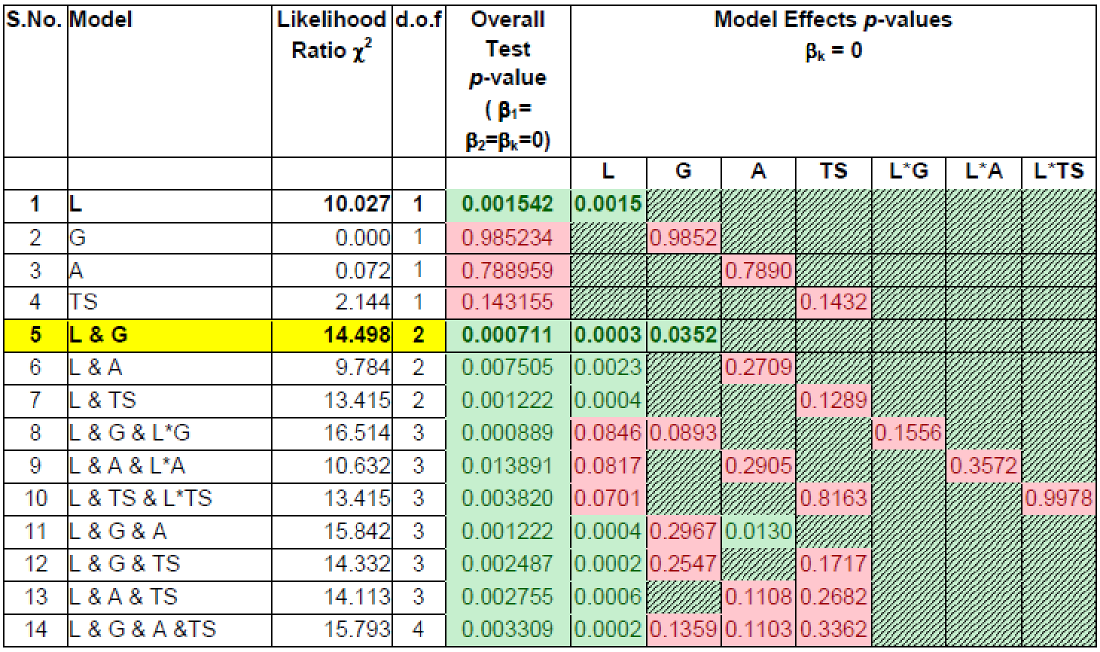
For the binomial logistic regression modelling, similar approach was used as ordinal logistic regressions. Dependent variables to be modelled for the comfort and performance models were selected in the 'Stage1 - Selection of informative variables' section. For each of those selected dependent variables (Table 9-3) a number of nested models were created and tested for significance in the SPSS

Statistics software package. Nested models are models which are special case of the other models. If there are only two models to compare, the bigger model can be named as a full model while the smaller one is called reduced model which can be achieved by setting certain parameters in a bigger model to 'zero'(Kleinbaum and Klein, 2010). In the case of this research numerous nested models were created with different number of variables in them. For each dependent variable the null hypotheses was tested in SPSS. The likelihood ratio chi-square which is the statistic builds on the likelihood of the data under the null hypothesis relative to the maximum likelihood (Howell, 2011) was used to test overall null hypotheses. On the other hand p statistic was used for both overall and individual slope tests. The independent (explanatory) variables used to create the nested models were; **L** (A-weighted noise level), **G** (Gender), **TS** (Time spent at the location) and Interaction terms of the three.

9.5.3.3.1 N2 – Noise Annoyance (Comfort)

Table 9-10 displays the summary of the hypotheses tests (green cells are depicting $p < 0.05$ for the test) for N2 (Noise Annoyance) binomial regression models

Table 9-10: Binomial regression hypotheses test - comfort subjective rating N2c



S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p*-value ($\beta_1=\beta_2=\beta_k=0$)	Model Effects *p*-values $\beta_k = 0$						
					L	**G**	**A**	**TS**	**L*G**	**L*A**	**L*TS**
1	**L**	**10.027**	**1**	**0.001542**	**0.0015**						
2	G	0.000	1	0.985234		0.9852					
3	A	0.072	1	0.788959			0.7890				
4	TS	2.144	1	0.143155				0.1432			
5	**L & G**	**14.498**	**2**	**0.000711**	**0.0003**	**0.0352**					
6	L & A	9.784	2	0.007505	0.0023		0.2709				
7	L & TS	13.415	2	0.001222	0.0004			0.1289			
8	L & G & L*G	16.514	3	0.000889	0.0846	0.0893			0.1556		
9	L & A & L*A	10.632	3	0.013891	0.0817		0.2905			0.3572	
10	L & TS & L*TS	13.415	3	0.003820	0.0701			0.8163			0.9978
11	L & G & A	15.842	3	0.001222	0.0004	0.2967	0.0130				
12	L & G & TS	14.332	3	0.002487	0.0002	0.2547		0.1717			
13	L & A & TS	14.113	3	0.002755	0.0006		0.1108	0.2682			
14	L & G & A &TS	15.793	4	0.003309	0.0002	0.1359	0.1103	0.3362			

Following conclusions can be drawn from Table 9-10:

- In No 1, the strongest relationship was observed between noise level (L) and the dependent variable N2 (Noise Annoyance)
- In No 5, the best model with two independent variables was observed which includes L (noise level) and G (gender) as independent variables. When compared to single independent variable in No 1, it can be seen that G (gender) contributes significantly (p= 0.0352, x^2 = 14.498-10.027 = 4.471, degree of freedom (d.o.f.) = 2-1 = 1)
- In No 8, best model with three independent variables was observed which include L (noise level), G (gender) and the interaction term L*G. However L*G is showing and insignificant contribution (p = 0.156, x^2 = 16.514-14.498 = 2.016, d.o.f. = 3-2 = 1) when compared to the best two independent variables model (No 5)
- In No 11, the best model with three independent variables without interaction terms can be seen. When compared to best two independent variable model (No 5) inclusion of A (Age) is showing insignificant contribution (p = 0.296, x^2 = 15.842-14.498 = 1.344, d.o.f. = 3-2 = 1)
- In No 14, the best model with four independent variables was observed, however, age (A) and time spent at the location (TS) appeared to be insignificantly contributing. When compared to best two independent variables model (x^2 = 15.793-14.498 = 1.295, d.o.f. = 4-2 = 2)

As a result, model No 5 with two independent variables (Noise level, Gender) was selected for N2 (Noise Annoyance). The model parameters were estimated in SPSS and an example is shown for N2 in Table 9-11. Hence, the selected binomial logistic regression model for N2, predicting mean logits is given by;

$$L_{N2-Noiee\ Annoyance} = -3.330 + 0.045L_{Aeq} - 0.525G$$

Equation 9-9

Equation 9-9 can be rearranged to estimate the mean probability of noise annoyance as below;

$$P_{(N2=yes)} = \frac{1}{1+e^{-L}} = \{1/(1+e^{-[-3.330+0.045L_{Aeq}-0.525G]})\}$$

Equation 9-10

Table 9-11: Parameter estimates table for the best N2 (Noise Annoyance) binomial logistic regression model with two independent variables

Parameter Estimates

			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-3.330	.6917	-4.686	-1.975	23.182	1	.000
LAeq	.045	.0131	.020	.071	11.996	1	.001
[Gender=1]	-.525	.2491	-1.014	-.037	4.450	1	.035
[Gender=0]	0^a	.	.	.	.	.	.
(Scale)	1^b						

Dependent Variable: Noise Annoyance

Model: (Intercept), LAeq, Gender

a. Set to zero because this parameter is redundant.

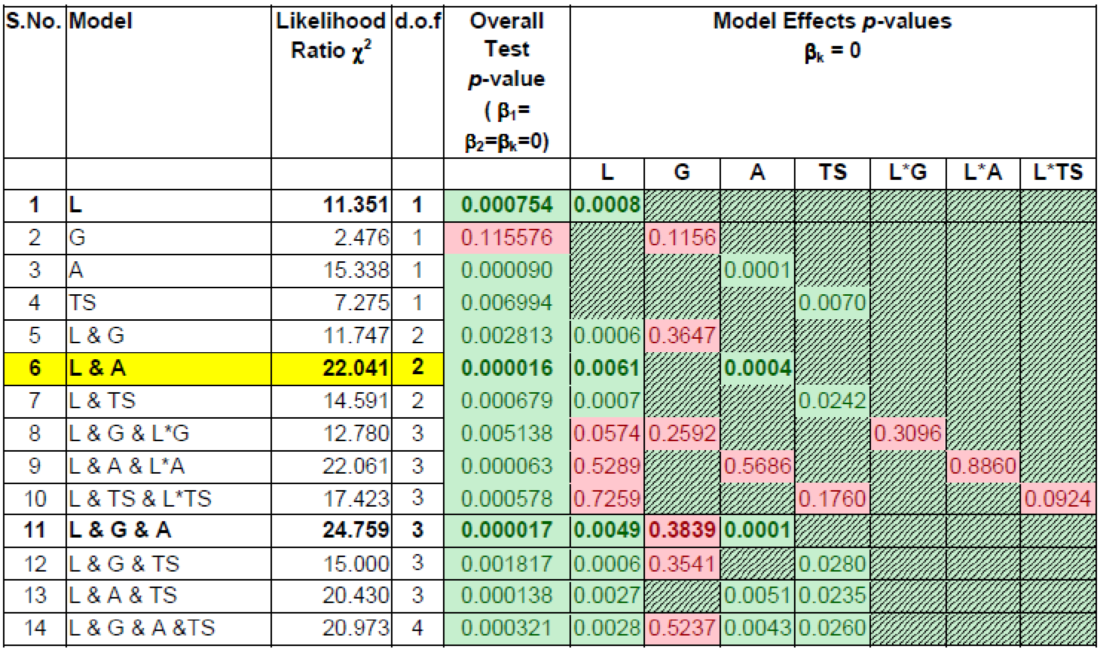
b. Fixed at the displayed value.

In Table 9-11 first column shows the intercept and the parameters that were included in the model. Second column shows that the coefficients of the parameters in the model.

9.5.3.3.2 O1 – Overall Feeling of Comfort (Comfort)

In Table 9-12 the summary of the hypotheses tests (green cells are depicting $p < 0.05$ for the test) are shown for N2 (Noise Annoyance) binomial regression models.

Table 9-12: Binomial regression hypotheses test - comfort subjective rating O1c



S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p*-value (β_1= β_2=β_k=0)	Model Effects *p*-values β_k = 0						
					L	**G**	**A**	**TS**	**L*G**	**L*A**	**L*TS**
1	**L**	**11.351**	**1**	**0.000754**	**0.0008**	▨	▨	▨	▨	▨	▨
2	G	2.476	1	0.115576	▨	0.1156	▨	▨	▨	▨	▨
3	A	15.338	1	0.000090	▨	▨	0.0001	▨	▨	▨	▨
4	TS	7.275	1	0.006994	▨	▨	▨	0.0070	▨	▨	▨
5	L & G	11.747	2	0.002813	0.0006	0.3647	▨	▨	▨	▨	▨
6	**L & A**	**22.041**	**2**	**0.000016**	**0.0061**	▨	**0.0004**	▨	▨	▨	▨
7	L & TS	14.591	2	0.000679	0.0007	▨	▨	0.0242	▨	▨	▨
8	L & G & L*G	12.780	3	0.005138	0.0574	0.2592	▨	▨	0.3096	▨	▨
9	L & A & L*A	22.061	3	0.000063	0.5289	▨	0.5686	▨	▨	0.8860	▨
10	L & TS & L*TS	17.423	3	0.000578	0.7259	▨	▨	0.1760	▨	▨	0.0924
11	**L & G & A**	**24.759**	**3**	**0.000017**	**0.0049**	**0.3839**	**0.0001**	▨	▨	▨	▨
12	L & G & TS	15.000	3	0.001817	0.0006	0.3541	▨	0.0280	▨	▨	▨
13	L & A & TS	20.430	3	0.000138	0.0027	▨	0.0051	0.0235	▨	▨	▨
14	L & G & A &TS	20.973	4	0.000321	0.0028	0.5237	0.0043	0.0260	▨	▨	▨

Following conclusions can be drawn from Table 9-12:

- In No 3, Age (A) is showing the strongest relationship with the dependent variable O1. However, in No 1 also Noise level (L) shows very strong relationship with the dependent variable. Understandable it is more preferable and informative to select Noise Level (L) for a single independent variable model.
- In No 6, best two independent variable model can be seen which includes L (noise level) and A (Age) as explanatory variables. Comparing this model to the selected noise level bases single independent variable model (No 1) it can be observed that the age (A) is contributing to the model significantly (p = 0.0004, x^2 = 22.041-11.351 = 10.69, d.o.f. = 2-1 = 1)
- In No 11, the best three independent variable model can be seen with the following variables; L (Noise level), G (Gender) and A (Age). When compared to the best two independent variable model (No 6), inclusion of gender (G) shows insignificant contribution (p = 0.3839, x^2 = 24.759 - 22.041= 2.718, d.o.f. = 3-2 = 1)
- Inclusion of other variables does not show any further improvement.

Therefore, the best binomial logistic regression model has the following two independent variables; Noise level (L) and Age (A). The parameters of this model, estimated using SPSS, are shown in Table 9-13.

Table 9-13: Parameter estimates table for the best O1 (Overall Feeling of Comfort) binomial logistic regression model with two independent variables

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval Lower	95% Wald Confidence Interval Upper	Hypothesis Test Wald Chi-Square	Hypothesis Test df	Hypothesis Test Sig.	Exp(B)	95% Wald Confidence Interval for Exp(B) Lower	95% Wald Confidence Interval for Exp(B) Upper
(Intercept)	-1.641	.7558	-3.123	-.160	4.716	1	.030	.194	.044	.852
LAeq	.033	.0126	.009	.058	6.958	1	.008	1.034	1.009	1.060
Age	-.023	.0067	-.036	-.010	11.854	1	.001	.977	.965	.990
(Scale)	1[a]									

Dependent Variable: Comfort Feelings

Model: (Intercept), LAeq, Age

a. Fixed at the displayed value.

Hence, mean logits for the selected binomial logistic regression model for O1, can be predicted by;

$$L_{O1c-Overall\ Feeling\ of\ Comfort} = -1.641 + 0.033L_{Aeq} - 0.023G$$

Equation 9-11

Equation 9-11 can be rearranged to estimate the mean probability as below;

$$P_{(O1c=yes)} = \frac{1}{1+e^{-L}} = \{1/(1+e^{-[-1.641+0.033L_{Aeq}-0.023G]})\}$$

Equation 9-12

9.5.3.3.3 N2 – Noise Annoyance (Performance)

The summary of the hypotheses tests (green cells are depicting p < 0.05 for the test) are shown in Table 9-14 for N2p (Noise Annoyance) binomial regression models.

Table 9-14: Binomial regression hypotheses test - performance subjective rating N2p

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p*-value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects *p*-values $\beta_k = 0$						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**21.077**	**1**	**0.000004**	**0.0000**						
2	G	6.473	1	0.010951		0.0110					
3	A	1.908	1	0.167220			0.1672				
4	TS	0.004	1	0.947240				0.9472			
5	L & G	21.400	2	0.000023	0.0000	0.5886					
6	**L & A**	**22.832**	**2**	**0.000011**	**0.0000**		**0.0412**				
7	L & TS	14.391	2	0.000750	0.0002			0.8484			
8	L & G & L*G	21.405	3	0.000087	0.1001	0.8686			0.9438		
9	L & A & L*A	22.896	3	0.000042	0.3852		0.4284			0.8005	
10	L & TS & L*TS	15.684	3	0.001316	0.3599			0.2515			0.2556
11	**L & G & A**	**23.723**	**3**	**0.000029**	**0.0001**	**0.3452**	**0.0290**				
12	L & G & TS	14.478	3	0.002321	0.0006	0.8875		0.7689			
13	L & A & TS	17.227	3	0.000635	0.0001		0.0531	0.6032			
14	L & G & A &TS	17.607	4	0.001473	0.0008	0.5380	0.0438	0.6486			

Observations from Table 9-14 are shared below:

- In No 1, it can be seen that Noise Level (L) is displaying the strongest link with the dependent variable N2p
- In No 6, best model with two independent variables (Noise Level and Age) can be seen. Compared to the best single independent variable model (No 1) it can be seen that age (A) is contributing significantly (p = 0.0412, x^2 = 22.832 - 21.077= 1.755, d.o.f. = 2-1 = 1)
- In No 11, best three independent variables model is observed with variables Noise Level (L), Gender (G) and Age (A). When this model is compared to the best two independent variable model (in No 6) it can be seen that inclusion of Gender (G) contributes insignificantly (p = 0.3452, x^2 = 23.723 - 22.832= 0.891, d.o.f. = 3-2 = 1)
- Inclusion of other variables did not improve the model fitness any further.

Single independent variable model (No 1) was selected over the two independent one(No 6) due to its simplicity and almost same fitness level. Therefore, the selected binomial logistic regression model has the independent variable; Noise level (L). The parameters of this model, estimated using SPSS, are shown in Table 9-15.

Table 9-15: Parameter estimates table for the best N2p (Noise Annoyance) binomial logistic regression model

Parameter Estimates

			95% Wald Confidence Interval		Hypothesis Test				95% Wald Confidence Interval for Exp(B)	
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.	Exp(B)	Lower	Upper
(Intercept)	-3.840	.7459	-5.302	-2.378	26.501	1	.000	.021	.005	.093
LAeq	.046	.0108	.025	.068	18.352	1	.000	1.048	1.026	1.070
(Scale)	1[a]									

Dependent Variable: Noise Annoyance

Model: (Intercept), LAeq

a. Fixed at the displayed value.

Thus, mean logits for the selected binomial logistic regression model for N2p, can be predicted by;

$$L_{N2p-Noise\ Annoyance} = -3.840 + 0.046L_{Aeq}$$

Equation 9-13

When Equation 9-13 is rearranged to predict the mean probability following can be achieved;

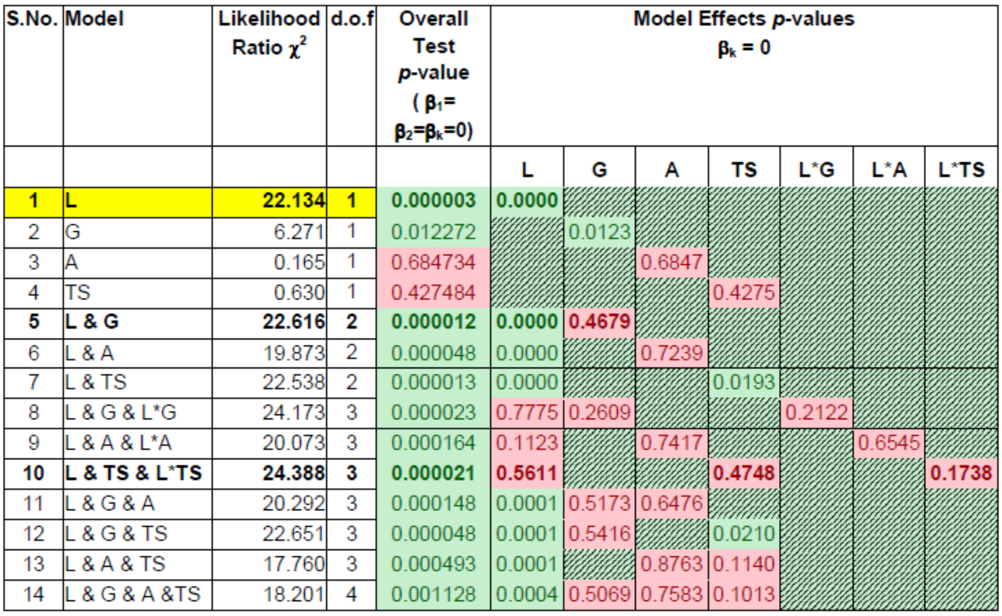
$$P_{(N2p=yes)} = \frac{1}{1+e^{-L}} = \{1/(1+e^{-[-3.840+0.046L_{Aeq}]})\}$$

Equation 9-14

9.5.3.3.4 N7 – Noise Quality Impairment (Performance)

Table 9-16 displays the summary of the hypotheses tests (green cells are depicting p < 0.05 for the test) for N7 (Noise Quality Impairment) binomial regression models.

Table 9-16: Binomial regression hypotheses test - performance subjective rating N7p



S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p*-value ($\beta_1=\beta_2=\beta_k=0$)	Model Effects *p*-values $\beta_k = 0$						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**22.134**	**1**	**0.000003**	**0.0000**	▨	▨	▨	▨	▨	▨
2	G	6.271	1	0.012272	▨	0.0123	▨	▨	▨	▨	▨
3	A	0.165	1	0.684734	▨	▨	0.6847	▨	▨	▨	▨
4	TS	0.630	1	0.427484	▨	▨	▨	0.4275	▨	▨	▨
5	**L & G**	**22.616**	**2**	**0.000012**	**0.0000**	**0.4679**	▨	▨	▨	▨	▨
6	L & A	19.873	2	0.000048	0.0000	▨	0.7239	▨	▨	▨	▨
7	L & TS	22.538	2	0.000013	0.0000	▨	▨	0.0193	▨	▨	▨
8	L & G & L*G	24.173	3	0.000023	0.7775	0.2609	▨	▨	0.2122	▨	▨
9	L & A & L*A	20.073	3	0.000164	0.1123	▨	0.7417	▨	▨	0.6545	▨
10	**L & TS & L*TS**	**24.388**	**3**	**0.000021**	**0.5611**	▨	▨	**0.4748**	▨	▨	**0.1738**
11	L & G & A	20.292	3	0.000148	0.0001	0.5173	0.6476	▨	▨	▨	▨
12	L & G & TS	22.651	3	0.000048	0.0001	0.5416	▨	0.0210	▨	▨	▨
13	L & A & TS	17.760	3	0.000493	0.0001	▨	0.8763	0.1140	▨	▨	▨
14	L & G & A &TS	18.201	4	0.001128	0.0004	0.5069	0.7583	0.1013	▨	▨	▨

Following conclusions were drawn from Table 9-16:

- In No 1, Noise level (L) is showing the strongest link with the dependent variable N7
- In No 5, best two independent variable model can be seen with variables Noise Level (L) and Gender (G). When compared to best single independent variable model (No 1), it can be seen that Gender (G) contributes insignificantly (p = 0.4679, x^2 = 22.616 - 22.134= 0.482, d.o.f. = 2-1 = 1)
- Also in No 7, second best two independent variable model can be seen with the variables Noise Level (L) and Time Spent at the Location (TS). Compared to best single independent model based on Noise Level(No 1), TS can be seen as contributing significantly. (p = 0.0193, x^2 = 22.538 - 22.134= 0.404, d.o.f. = 2-1 = 1). However the contribution is very low.
- In No 10, best three independent variable model is shown with the variables Noise Level (L), Time spent at the Location (TS) and the interaction factor of the two (L*TS). When compared to the single independent variable model (in No1) inclusion of TS and L*TS shows an improvement of x^2 = 24.388 - 22.134= 2.254 (d.o.f. = 3-1 = 2) however all the slopes become insignificant.
- No further improvement was observed through inclusion of more variables.

As a result of above observations a single independent variable model (No 1) was selected which has the independent variable; Noise level (L). The parameters of this model, estimated using SPSS, are shown in Table 9-17.

Table 9-17: Parameter estimates table for the best N7p (Noise Quality Impairment) binomial logistic regression model

Parameter Estimates

			95% Wald Confidence Interval		Hypothesis Test				95% Wald Confidence Interval for Exp(B)	
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.	Exp(B)	Lower	Upper
(Intercept)	-5.121	.8728	-6.831	-3.410	34.423	1	.000	.006	.001	.033
LAeq	.052	.0115	.030	.075	20.533	1	.000	1.053	1.030	1.077
(Scale)	1[a]									

Dependent Variable: Noise – quality impairment

Model: (Intercept), LAeq

a. Fixed at the displayed value.

As a result the mean logits for the selected binomial logistic regression model for N7p, are shown in Equation 9-15;

$$L_{N7p-Quality\ Impairment} = -5.121 + 0.052L_{Aeq}$$

Equation 9-15

Equation 9-15 can be rewritten to predict the mean probability;

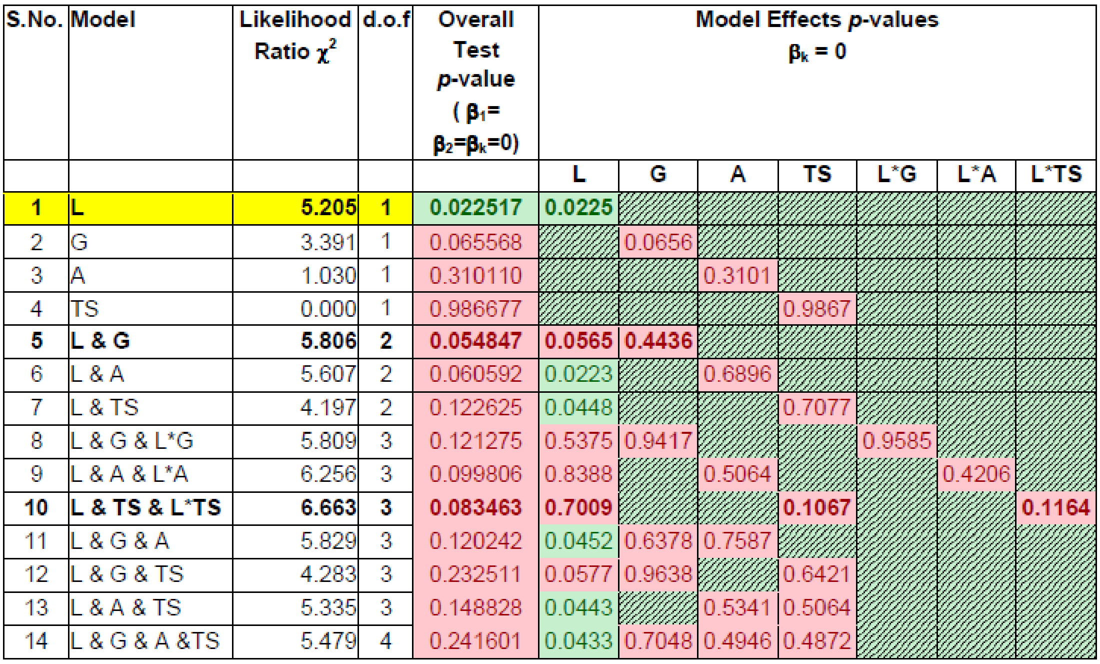
$$P_{(N7p=yes)} = \frac{1}{1+e^{-L}} = \left\{1/\left(1+e^{-[-5.121+0.052L_{Aeq}]}\right)\right\}$$

Equation 9-16

9.5.3.3.5 O1 – Overall Feeling of Wellbeing (Performance)

The summary of the hypotheses tests (green cells are depicting p < 0.05 for the test) are displayed in Table 9-18 for O1p (Overall Feeling of Wellbeing) binomial regression models.

Table 9-18: Binomial regression hypotheses test - performance subjective rating O1p



S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p*-value (β_1= β_2=β_k=0)	Model Effects *p*-values β_k = 0						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**5.205**	**1**	**0.022517**	**0.0225**						
2	G	3.391	1	0.065568		0.0656					
3	A	1.030	1	0.310110			0.3101				
4	TS	0.000	1	0.986677				0.9867			
5	**L & G**	**5.806**	**2**	**0.054847**	**0.0565**	**0.4436**					
6	L & A	5.607	2	0.060592	0.0223		0.6896				
7	L & TS	4.197	2	0.122625	0.0448			0.7077			
8	L & G & L*G	5.809	3	0.121275	0.5375	0.9417			0.9585		
9	L & A & L*A	6.256	3	0.099806	0.8388		0.5064			0.4206	
10	**L & TS & L*TS**	**6.663**	**3**	**0.083463**	**0.7009**			**0.1067**			**0.1164**
11	L & G & A	5.829	3	0.120242	0.0452	0.6378	0.7587				
12	L & G & TS	4.283	3	0.232511	0.0577	0.9638		0.6421			
13	L & A & TS	5.335	3	0.148828	0.0443		0.5341	0.5064			
14	L & G & A &TS	5.479	4	0.241601	0.0433	0.7048	0.4946	0.4872			

Following can be observed from Table 9-18:

- In No 1, Noise level (L) is showing the strongest link with the dependent variable N7
- When compared to single independent variable model (in No 1) the inclusion of inclusion of Gender (G) in No 5 appear to improve the model fitness (x^2 = 5.806 - 5.205= 0.601 d.o.f. = 2-1 = 1). However the overall test of P value is insignificant (P=0.054847)
- In No 10, similar situation is observed for the best three independent variable model. When compared to best single independent variable model (in No 1) inclusion of Time Spent at the Location (TS) and interaction term (L*TS) appear to improve the model fitness.(x^2 = 6.663 - 5.205= 1.458 d.o.f. = 3-1 = 2) However overall p value test result becomes insignificant.

Based on above observations, a single independent variable model (No 1) was selected which has the independent variable; Noise level (L). The parameters of this model were estimated using SPSS and displayed in Table 9-19.

Table 9-19: Parameter estimates table for the best O1p (Overall Feeling of Wellbeing) binomial logistic regression model

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
(Intercept)	-2.335	.6773	-3.662	-1.007	11.883	1	.001	.097	.026	.365
LAeq	.022	.0097	.003	.041	5.217	1	.022	1.023	1.003	1.042
(Scale)	1[a]									

Dependent Variable: Discomfort feeling

Model: (Intercept), LAeq

a. Fixed at the displayed value.

Using the parameters in Table 9-19 the mean logits for the selected binomial logistic regression model for O1p can be shown as in Equation 9-17

$$L_{O1p-Overall\ feeling\ of\ wellbeing} = -2.335 + 0.022L_{Aeq}$$

Equation 9-17

Equation 9-17 can be reformatted to predict the mean probability;

$$P_{(O1p=yes)} = \frac{1}{1+e^{-L}} = \{1/(1+e^{-[-2.335+0.022L_{Aeq}]})\}$$

Equation 9-18

9.5.3.4 Evaluation of binomial logistic regression models

Unlike the linear regression, logistic regression procedures do not have an exact counter part of summary measure such as adjusted R^2. A number of analogues R^2 measures available for logistic regression but there is no consensus on which one to use and they produce different results (DeMaris, 2004). Therefore, similar to ordinal logistic regression, following will be used to evaluate the fitness of the model to the sample data:

- Outliers (Index Plots of Leverages)
- Residuals (Index Plots of standardized deviance)
- Influence (Index Plots of Cook’s D.)

In statistics, leverage points are observations of extreme values in terms of the independent variables.

9.5.3.4.1 N2-Noise Annoyance (Comfort)

Figure 9-29 shows the index plot of leverages for the N2 (Noise Annoyance) binary logistic regression model. Cases with relatively high leverages are shown in squares.) It can be seen that there are 6 cases immediately visible for further consideration. When those extreme cases shown in squares investigated, it was found that all those people were located in high noise areas such as engine room. The people in case number 112 and 165 were exposed to A weighted noise level of 104 dB while people in cases 206 and 238 were exposed to 105 dB. Similarly, people in case number 226 and 322 were in a location with 97 dB(A). These people reported following noise annoyance ratings; case112: very, case165: very, case206: moderately, case226: moderately, case238: very much and case322: very. Since, annoyance ratings were also reported high accordingly, these cases were not considered to influence the binomial logistic regression significantly.

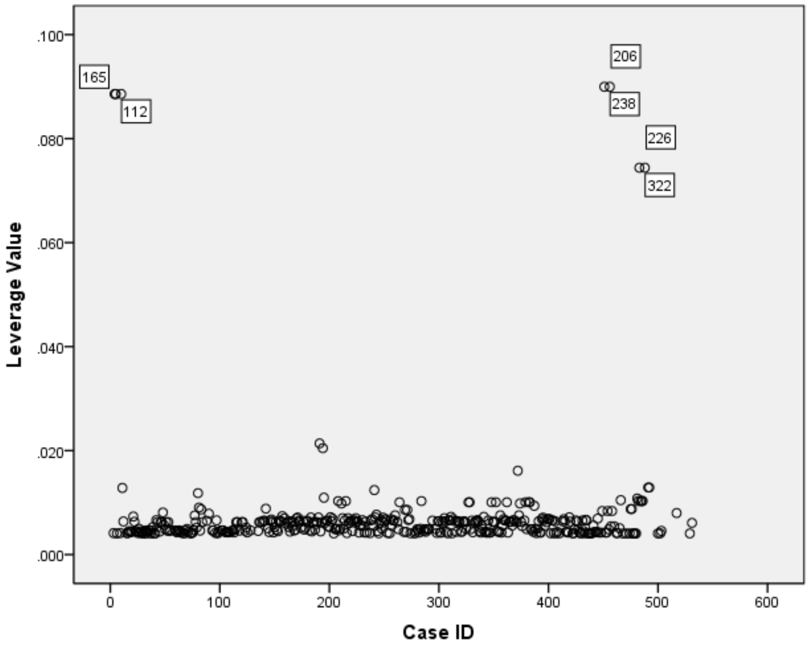


Figure 9-29: Index plot of leverage values for the binomial logistic model of N2.

Even though, there are no clear rules about identifying the large residuals (Scott and Freese, 2006) values less than -2 and more than +2 can be treated as large residuals and further investigated (Menard, 2002). Figure 9-30 displays the residuals for N2 (Noise Annoyance-Comfort) as standardized deviance residuals. There are no residual values of concern can be observed from the graph.

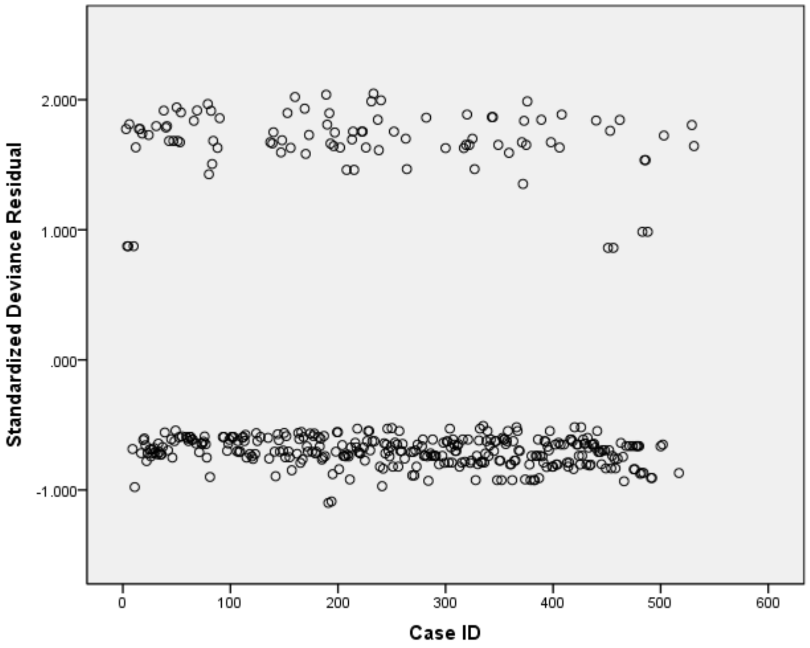


Figure 9-30: Index plot of standardized deviance residuals for the N2 (Noise Annoyance-Comfort) binomial logistic model.

According to Cohen *et al.* (2003) cases with a value of Cook’s D. of 1 or more may represent a problematic degree of influence by an individual case. For the dependent variable N2 (Noise Annoyance – Comfort) index plot of Cook’s D. is shown in Figure 9-31. As a result it can be observed that none of the cases are displaying problematic values.

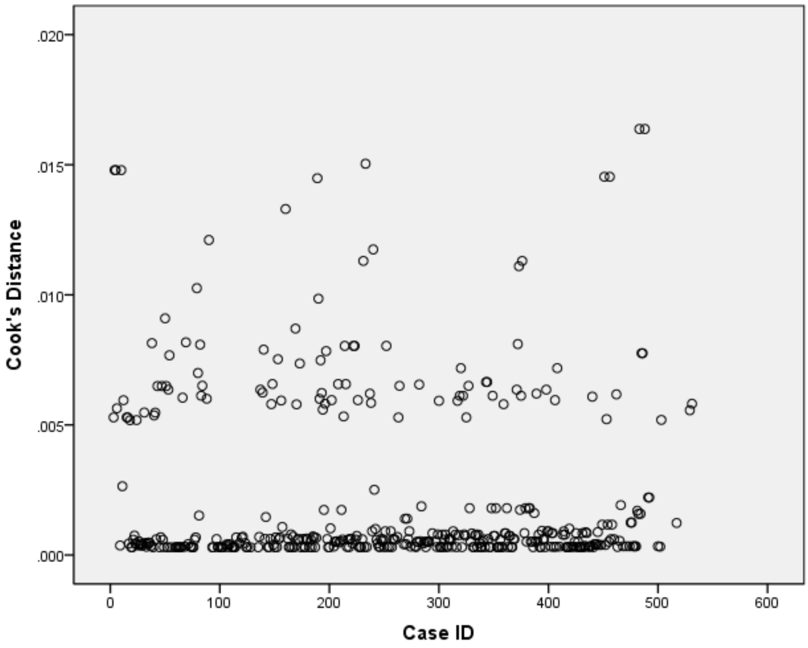


Figure 9-31: Index Plot of Cook's Distance for the N2 (Noise Annoyance - Comfort) binomial logistic model.

As a result, the observations of above graphs show that N2 (Noise Annoyance - Comfort) binomial logistic regression model is fitting well to the sample data.

9.5.3.4.2 O1-Overall Feeling of Comfort (Comfort)

Figure 9-32 shows the index plot of leverages for the O1c (Overall feeling of Comfort) binary logistic regression model. Cases with relatively high leverages are shown in squares.) It can be seen that, similar to the N2 (Noise Annoyance) there are 6 cases standing out to be further investigated. It was identified that in all these cases people were located in very noisy engine room. The people in case number 112, 165 and 366 were exposed to A weighted noise level of 104 dB while people in cases 206 and 238 were exposed to 105 dB. Similarly, people in case number 226 and 322 were in a location with 97 dB(A). However, almost all of the people in aforementioned case numbers reported existence of overall feeling of discomfort Therefore; these cases were not considered to influence the binomial logistic regressions significantly.

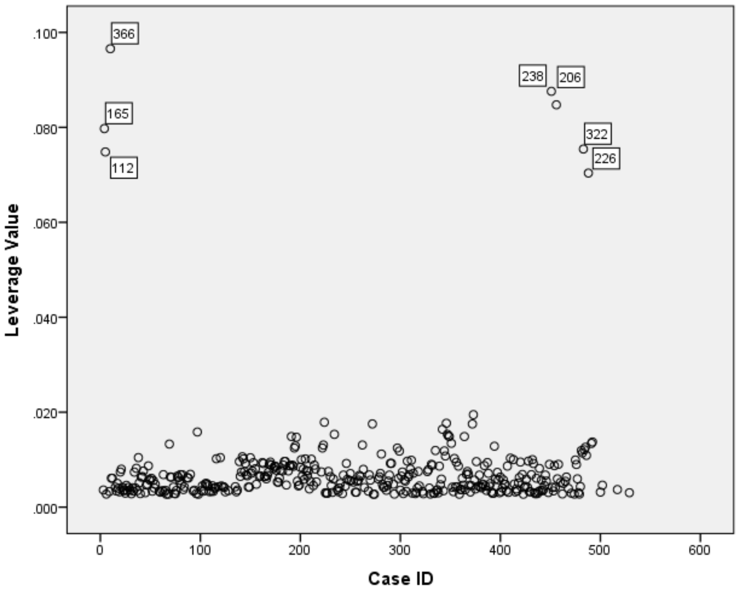


Figure 9-32: Index plot of leverage values for the binomial logistic model of O1c

Figure 9-33 shows the residuals for O1c (Overall Feeling of Comfort) as standardized deviance residuals. There are no residual values of concern (values less than -2 or greater than +2) can be observed from the graph.

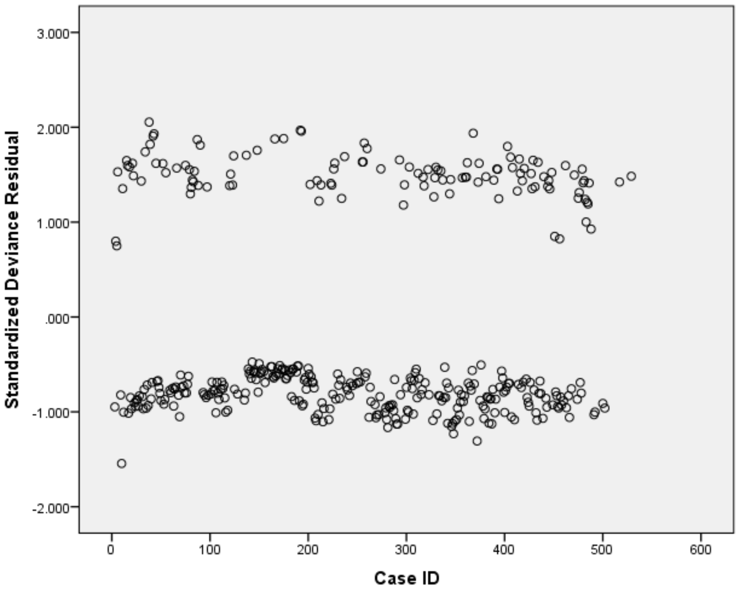


Figure 9-33: Index plot of standardized deviance residuals for the O1c binomial model.

Index plot of Cook's D. is shown in Figure 9-34. Even though Case no 366 stands out from the rest of the cases, none of the cases is showing a very strong influence on model parameters (cases with a Cook's D. of 1 or more). As a result, above graphs show that O1c (Overall Feeling of Comfort) binomial logistic regression model is fitting well to the sample data.

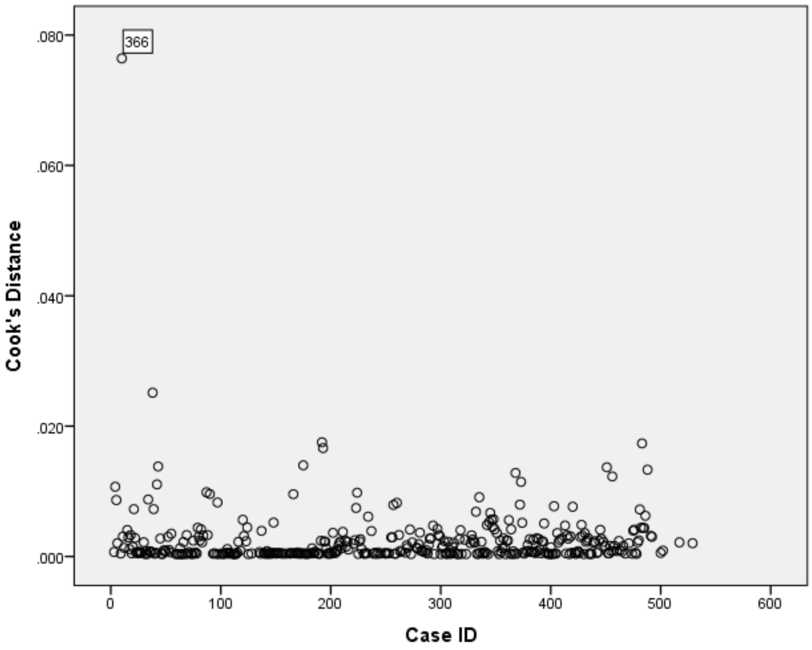


Figure 9-34: Index Plot of Cook's Distance for the O1c binomial logistic model.

9.5.3.4.3 N2-Noise Annoyance (Performance)

From Figure 9-35 it can be seen that, some cases have higher values than the rest. When these cases were investigated it was found that in almost all of them people were exposed to high levels of noise and also reported high noise ratings. Therefore, the aforementioned cases were not considered to influence the binomial logistic regression significantly.

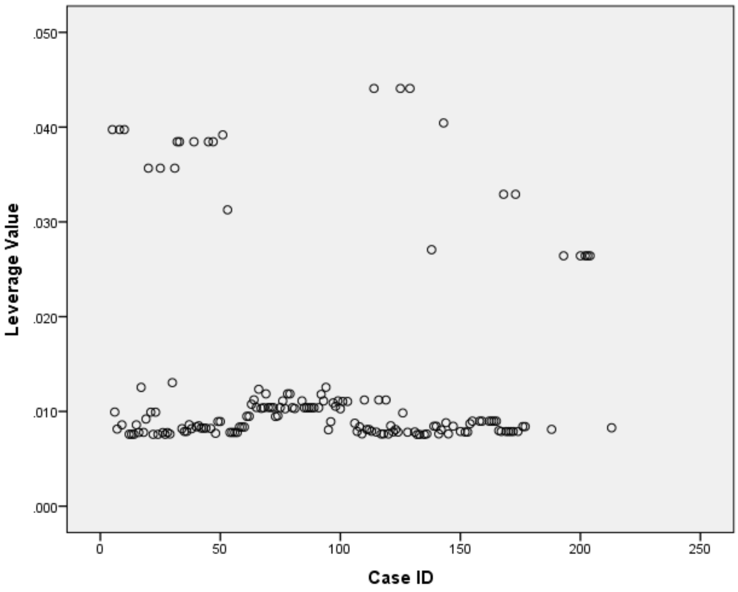


Figure 9-35: Index plot of leverage values for the binomial logistic model of N2p

Figure 9-36 shows the residuals for N2p (Noise Annoyance) as standardized deviance residuals. All values lie between the range of bigger than -2 or less than 2, thus no concerning cases were identified.

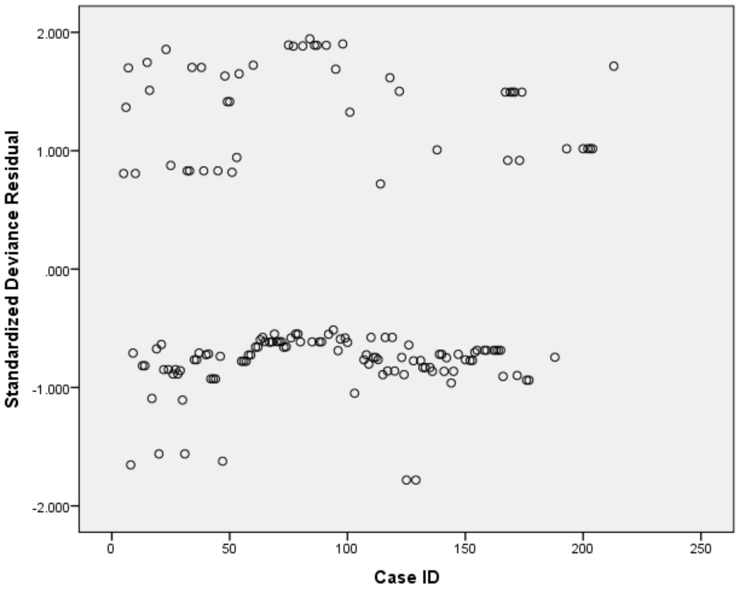


Figure 9-36: Index plot of standardized deviance residuals for the N2p binomial logistic model.

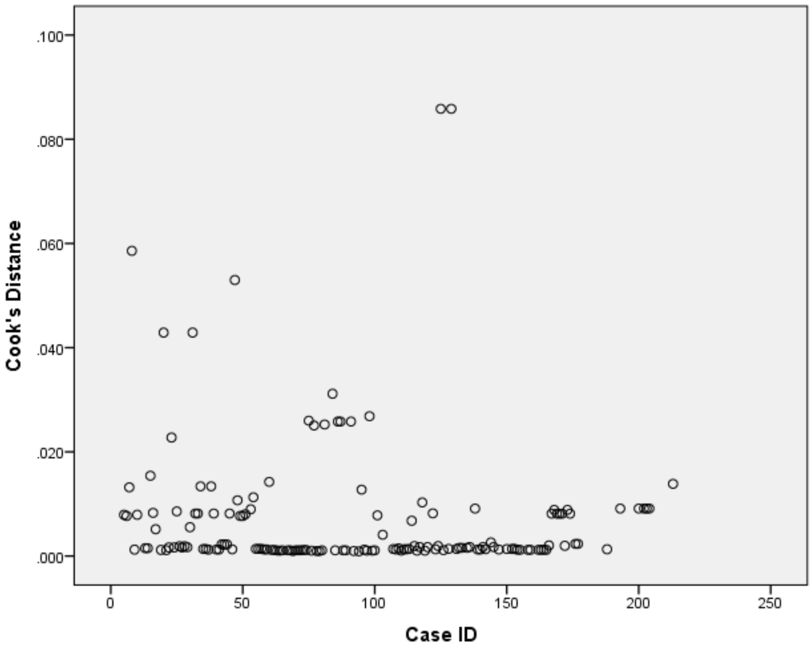


Figure 9-37: Index Plot of Cook's Distance for the N2p binomial logistic model.

Figure 9-37 shows the Index plot of Cook's D. None of the cases is showing a very strong influence on model parameters (cases with a Cook's D. of 1 or more).

As a result, analysis of index plots show that N2p (Noise Annoyance) binomial logistic regression model is fitting well to the sample data.

9.5.3.4.4 N7-Noise Quality Impairment (Performance)

Figure 9-38 shows that, there are some cases which have higher values than the rest. Further investigation shows that in these cases people were in very noisy areas such as engine room and accordingly reported high response ratings. Therefore, these cases were not considered to influence the binomial logistic regression at this stage.

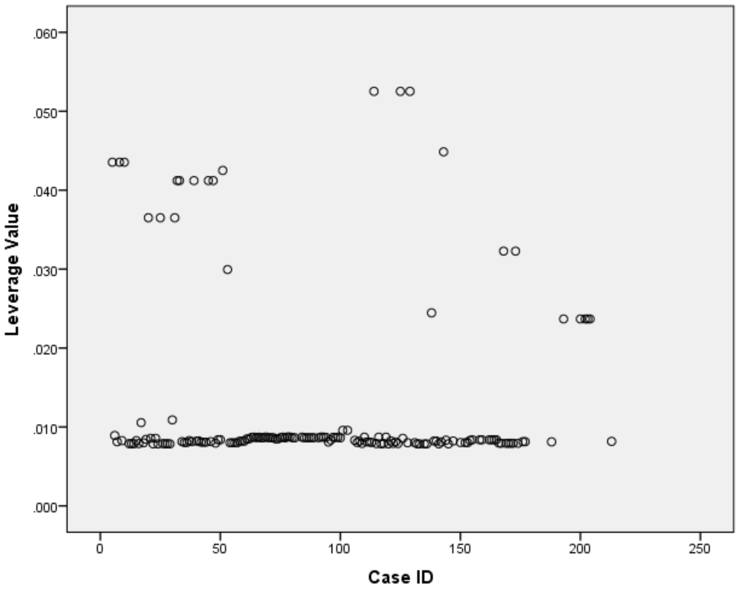


Figure 9-38: Index plot of leverage values for the binomial logistic model of N7p

Moreover, in Figure 9-39 the residuals for N7p (Quality impairment) was shown as standardized deviance residuals. All values lie between the range of bigger than -2 or less than 2, thus no concerning cases were identified.

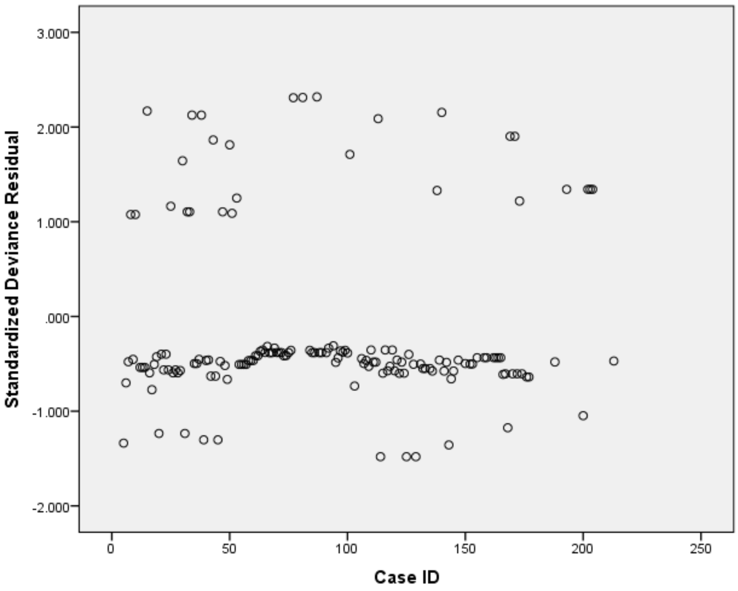


Figure 9-39: Index plot of standardized deviance residuals for the N7p binomial logistic model.

Finally, Index plot of Cook's D. in Figure 9-40 also shows that there are no cases which show strong influence on model parameters (Cook's D. of 1 or more).

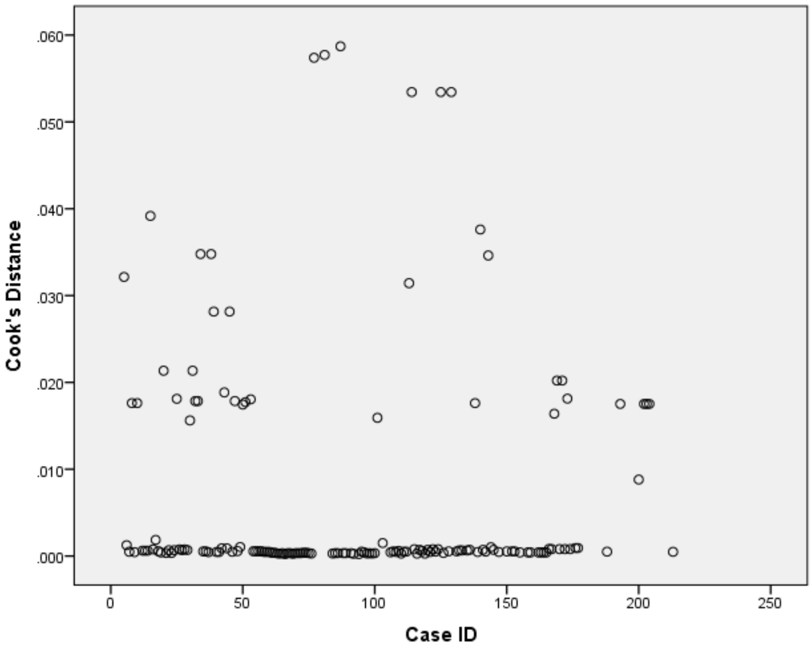


Figure 9-40: Index Plot of Cook's Distance for the N7p binomial logistic model.

Therefore, aforementioned index plots show that N7p (Quality impairment) binomial logistic regression model is fitting well to the sample data.

9.5.3.4.5 O1-Overall Feeling of Wellbeing (Performance)

Similar to the observations made for the previous models, for O1p (Overall feeling of wellbeing) as well some outstanding leverage values can be observed from Figure 9-41. However, as previously explained these high leverage cases represent high rating responses of people who are located in high noise areas (e.g. engine room, auxiliary room etc.) Therefore, at this stage these cases were not considered to be influencing the binomial logistic regression.

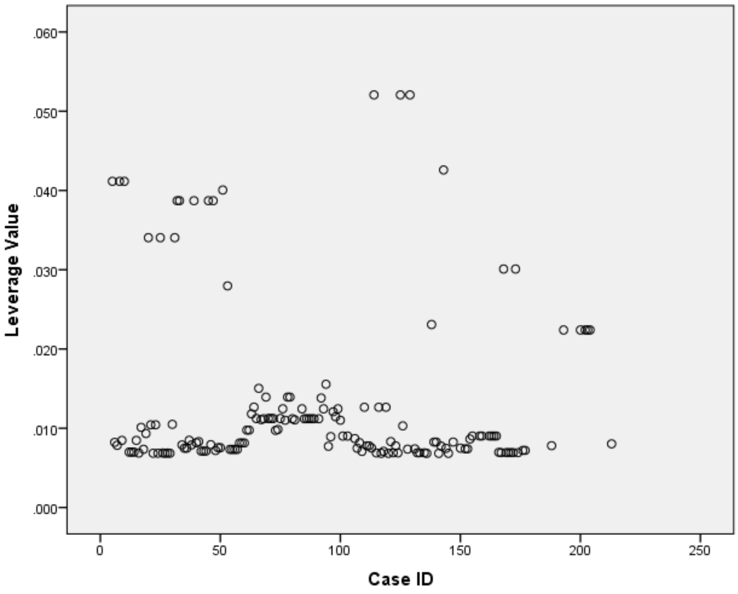


Figure 9-41: Index plot of leverage values for the binomial logistic model of O1p

Moreover, standardized Deviance Residuals were shown in Figure 9-42 which do not suggest any cases to be further investigated. (Larger than 2 smaller than -2)

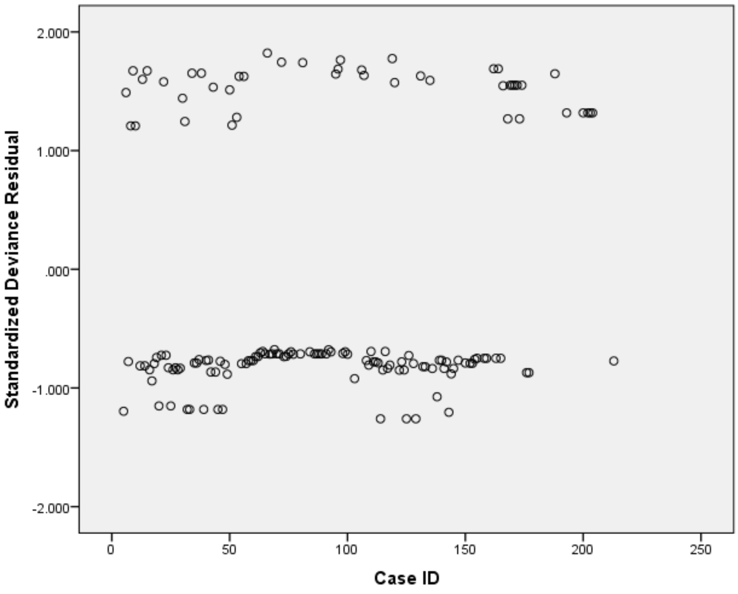


Figure 9-42: Index plot of standardized deviance residuals for the O1p binomial logistic model.

In Figure 9-43 the index plot of the Cook's Distance was displayed. As can be seen from Figure 9-43 that all cases have a value of Cook's Distance which is smaller than

0.4. Therefore, there are not any cases which may strongly influence the model parameters (Cook's D. of 1 or more).

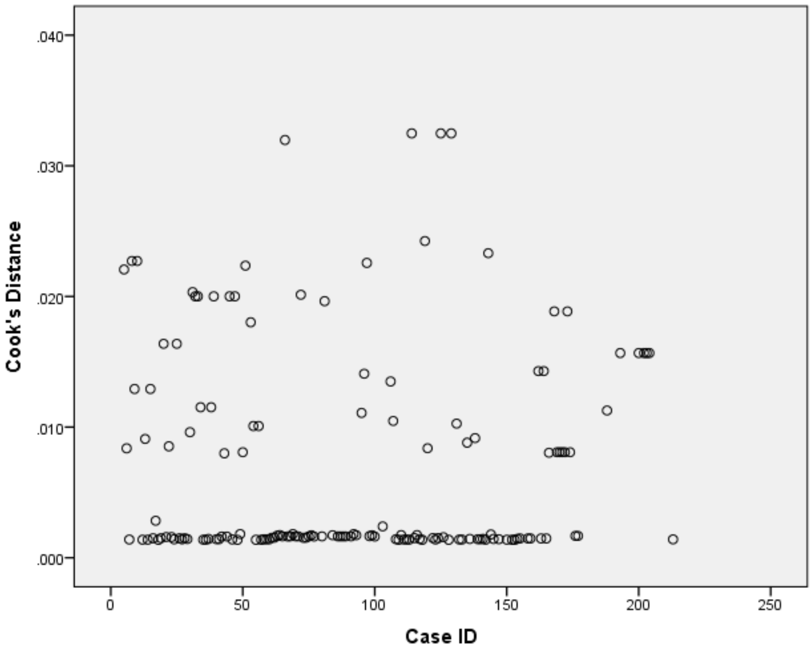


Figure 9-43: Index Plot of Cook's Distance for the O1p binomial logistic model

As a result, investigation of above graphs shows that O1p (Overall feeling of wellbeing) binomial logistic regression model is fitting well to the sample data.

9.5.4 Summary of developed binomial logistic regression models and probability plots

The dependent variables in binomial logistic regression models are dichotomous in nature. Therefore, given that, the demographic information (such as gender or age) and noise level (A weighted level) is known, the developed models (e.g. N2 Noise Annoyance in Equation 9-10) are designed to predict probability of a person getting discomforted or performance degraded on individual basis. Moreover, the probability estimated from the models also represents the proportion of the population likely to get discomforted or performance degraded on global basis.

As previously explained the general form of binomial logistic regression expression is shown below;

$$L_{(Discomfort\ OR\ Performance\ degrade=Yes)} = a_1 + B_1X_1 + B_2X_2 + \cdots + B_nX_n$$

Equation 9-19

Table 9-20: Overview of the developed models (overall p values and regression parameters)

Model	Variables in model	p	a_1	B_L	B_G	B_A	B_{TS}
COMFORT – NOISE							
N2c: Noise annoyance	L & G	0.00071	-3.330	0.045	-0.525		
O1c: Overall feeling of discomfort	L & A	0.00001	-1.641	0.033		-0.023	
PERFORMANCE – NOISE							
N2p: Noise annoyance	L	0.000004	-3.840	0.046			
N7p: Quality impairment	L	0.000003	-5.121	0.052			
O1pn: Overall feeling of wellbeing	L	0.022517	-2.335	0.022			

It is important to note the following;

- Overall hypotheses tests of all models show significant values ($P<0.05$ assumed significant)
- All models have either one or two variables, as a result the models are very simple to use.
- A weighted Noise level entered into all models as desired. Moreover Noise level is positively related to the dependent response variable which means when the noise level increase the human response will get worse.
- Gender (where 1-male 0-female) is only included into N2c (Noise Annoyance) in comfort models and it has a negative relationship with the

noise annoyance. Which means the odds for a male getting annoyed by a known noise level is $e^{-0.525}$ =0.592 times smaller than females.

- Age only included in to O1c (Overall feeling of discomfort) model and it is showing a negative relationship with the dependent response variable. This indicates when people get older they are less likely to get affected adversely in the same noise level.
- Finally, Time spent at location was not included into any model which is quite strange since in the literature there is evidence of such relationship (South, 2004).

The parameters in Table 9-20 can be fed into the Equation 9-19 to obtain the following desired models

- Comfort – Noise Annoyance Model:

$$P_{(N2c=yes)} = \frac{1}{1+e^{-L}} = \left\{1/\left(1+e^{-\left[-3.330+0.045L_{Aeq}-0.525G\right]}\right)\right\}$$

- Comfort – Noise Induced Overall Discomfort Feeling Model:

$$P_{(O1c=yes)} = \frac{1}{1+e^{-L}} = \left\{1/\left(1+e^{-\left[-1.641+0.033L_{Aeq}-0.023A\right]}\right)\right\}$$

- Performance – Noise Annoyance Model:

$$P_{(N2p=yes)} = \frac{1}{1+e^{-L}} = \left\{1/\left(1+e^{-\left[-3.840+0.046L_{Aeq}\right]}\right)\right\}$$

- Performance – Noise Induced Quality Impairment Model:

$$P_{(N7p=yes)} = \frac{1}{1+e^{-L}} = \left\{1/\left(1+e^{-\left[-5.121+0.052L_{Aeq}\right]}\right)\right\}$$

- Performance – Overall Feeling of Un-wellbeing Model:

$$P_{(O1p=yes)} = \frac{1}{1+e^{-L}} = \left\{1/\left(1+e^{-\left[-2.335+0.022L_{Aeq}\right]}\right)\right\}$$

Following graphs (Figure 9-44, Figure 9-45, Figure 9-46, Figure 9-47 and Figure 9-48) demonstrate the estimated probabilities from the developed binomial logistic regression models. The faded areas in the graphs indicate extrapolation.

From Figure 9-44, it can be observed that there is a nonlinear relationship between the noise level (A weighted) and the probability of getting annoyed by that noise level. It can also be observed that females are more likely to get annoyed when compared to males in same noise level.

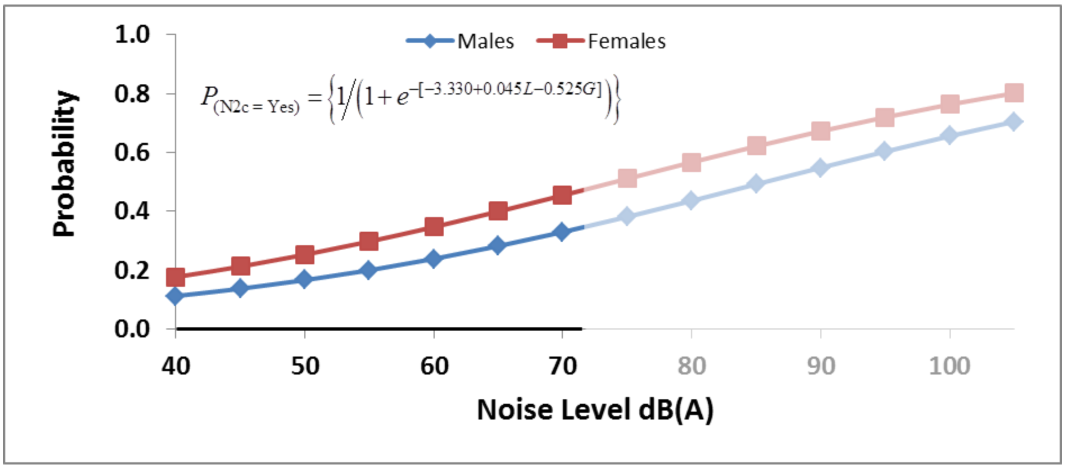


Figure 9-44: Comfort – Noise Annoyance Model

In Figure 9-45 the probabilities of overall feelings of discomfort is demonstrated in different age groups. It can be observed that there is also a nonlinear relationship between the noise levels and probability to feel overall discomfort. Age is also showing a moderate nonlinear impact on the probability of feeling discomfort.

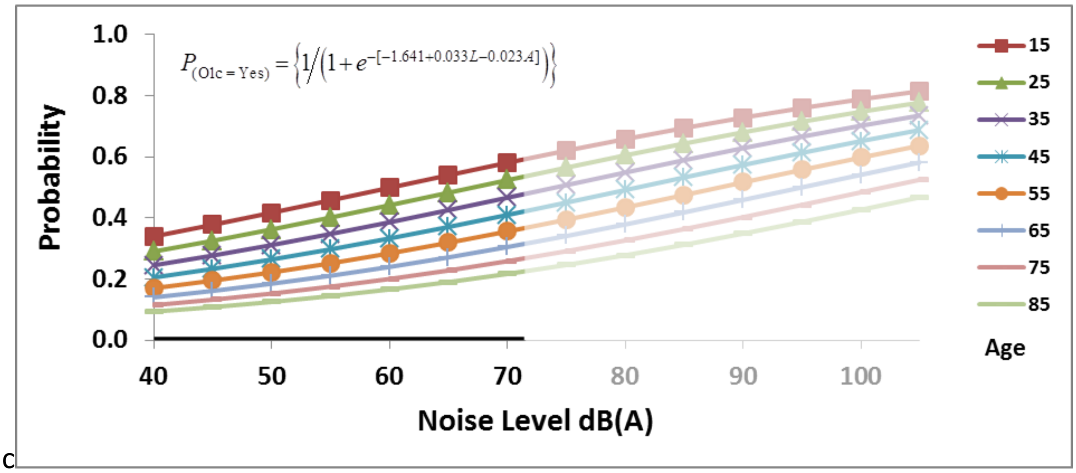


Figure 9-45: Comfort – Noise Induced Overall Feeling of Discomfort Model

Figure 9-46 displays the predicted probabilities of getting annoyed by the noise during the work which shows a nonlinear relationship with the noise levels.

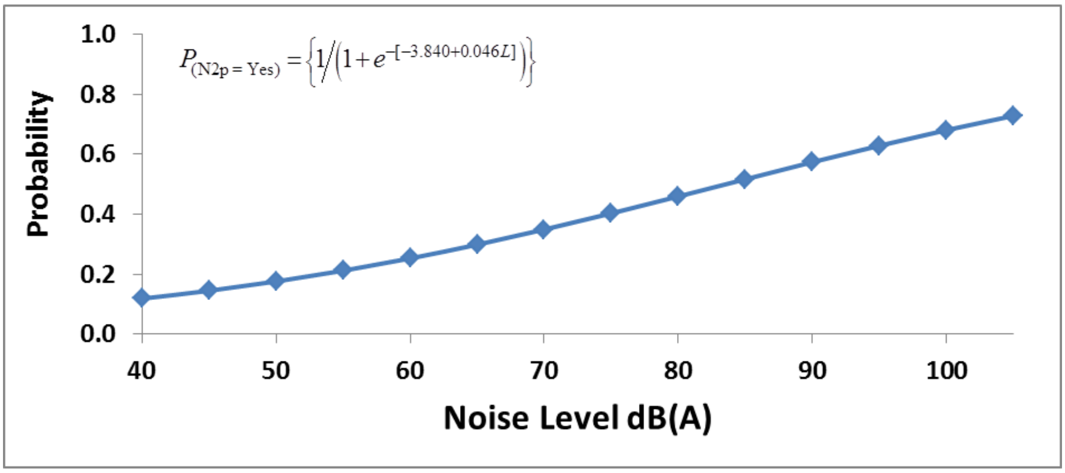


Figure 9-46: Performance – Noise Annoyance Model

Figure 9-47 demonstrates the probabilities of people getting work quality impaired due to noise in various noise levels. It can be observed that, very high noise levels can affect the crew on the quality of their job. This may be due to usage of personal protective equipment (PPE). Moreover, people may not be aware of noise effects on performance and therefore not directly relating their performance reduction or quality impairment to noise exposure.

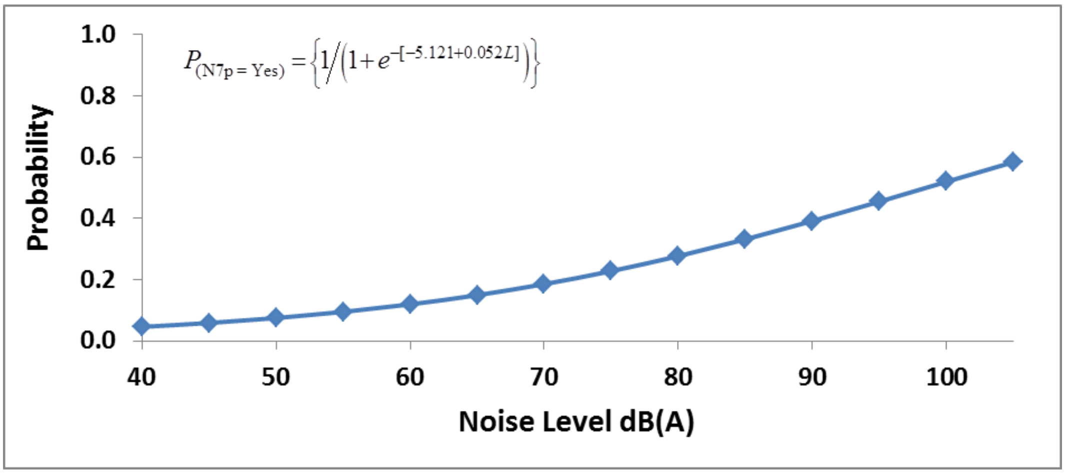


Figure 9-47: Performance – Noise Induced Quality Impairment Model

Finally, in Figure 9-48 the probabilities of not feeling well overall with respect to noise are shown. It can be seen that crew is very unlikely to get bad overall feeling of wellbeing even at very high noise levels. Again, this may be related to the consideration of PPE usage. However it is hard to comment on these low probabilities without further research.

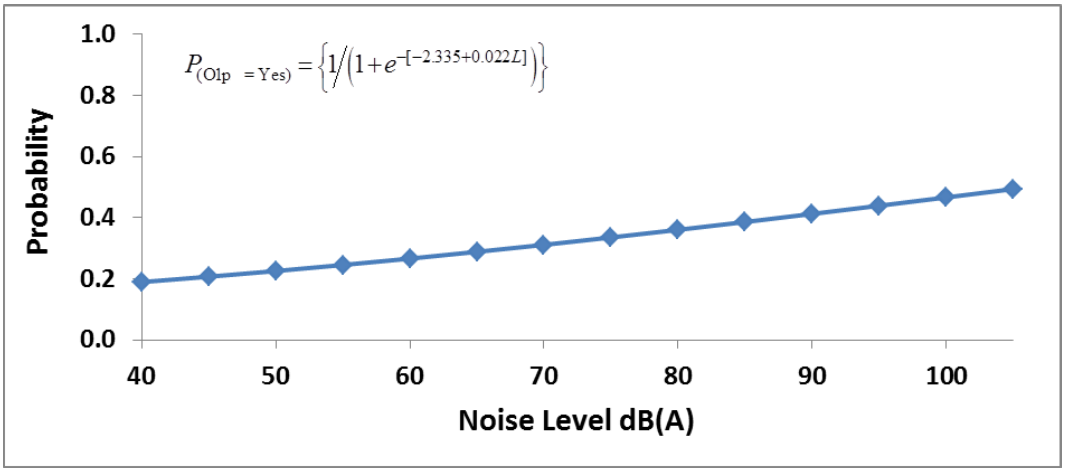


Figure 9-48: Performance – Overall Feeling of Unwellbeing

Figure 9-49 below shows the performance of the developed binomial logistic regression models. The percentages in the graph represent the correctly predicted human response which is calculated by checking the predicted human response by the model and observed response in the questionnaires. It can be seen that the least accurate model developed is able to predict 60 % of response correctly therefor the performance of the models are satisfactory and showing good fitness.

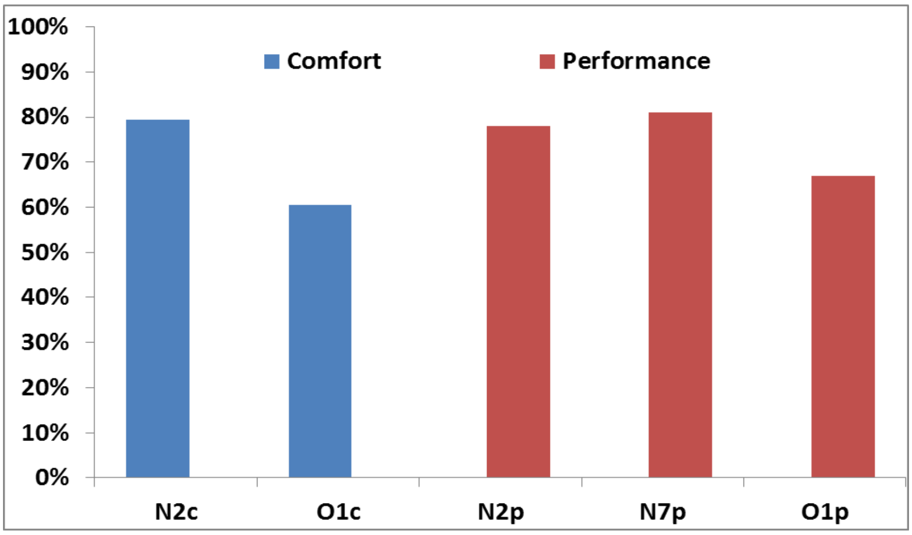


Figure 9-49: Performance of the Models

9.6 Chapter Summary

In this chapter several noise models have been developed focussing on comfort and performance and reported successfully. Collected human responses and demography together with the recorded noise levels were analysed and summarised statistically. Human response ratings to be modelled were selected via conducting variance analysis, correlation analysis as well as factor analysis. Similarly explanatory independent variables were selected by developing scatter plots to identify possible trends with noise etc. graphically. Then ANOVA analysis were conducted to find most relevant predictors

Initially multiple linear regression was studied but it was concluded that the relationships were not linear because, despite having statistically significant parameters, the best model developed was not able to explain more than 20% of variance. Then ordinal logistic regressions were visited but again the model finesses were not satisfactory.

Finally binomial logistic regressions were addressed and successful models were developed and duly reported under this chapter.

Chapter 10. PROPOSED HUMAN ORIENTED NOISE LIMITS AND DESIGN METHODOLOGY

10.1 Chapter Overview

In the previous chapters of this thesis the shortcoming of current regulatory framework was criticised as not considering the effects of noise exposure on crew wellbeing and performance. Therefore, this chapter through utilising the innovative human response models which were developed in Chapter 9 proposes new human-oriented noise criteria.

10.2 Introduction

The trend to reduce crew numbers on board ships together with the increased paperwork which was introduced by the adaptation of new regulations has increased the workload on board ships which in turn has resulted in greater levels of fatigue amongst the crew. According to the “Bridge Watchkeeping Safety Study” (MAIB, 2004b) fatigue is one of the most important factors leading to human error which has repeatedly been reported in the accident investigation reports of maritime casualties. As a result, it can be said that crew fatigue and comfort became more critical and recently been given more importance. The unique environmental conditions of ships also have an effect on the crew fatigue and the two stand out factors are motions and noise(Allen *et al.*, 2008). In previous chapters of this thesis the effects of noise on human comfort and performance was extensively researched and reported.

A review of the existing regulatory framework (Chapter 4) showed that the regulatory framework focuses on set noise limits for each compartment and/or aims to limit the total perceived acoustic power by the human on board. However, it was also evident that the regulatory framework was developed with a focus to protect human health from the hazardous effects of noise exposure. It can be seen that the limits set by the comfort class rules of classification societies are more stringent due to the fact that the target is not only to protect the health but also to maintain acceptable levels of comfort for passengers.

However, regulations fail to address the short and long term effects of noise exposure on the performance of crew on board. However, the research outcomes of this PhD study made it possible to take these factors into account and develop prototype human oriented noise criteria for ships.

10.3 Human Oriented Noise Limits

The proposal and development of new noise criteria for the ships is a comprehensive task which needs to be investigated by a multidisciplinary team to ensure its robustness. Hence, such proposals can only be developed by taking into account all legal, practical and scientific aspects of the matter while being committed to the process of arriving at consensus with the industry on the financial impacts of such criteria for the maritime sector. Therefore, the aim is to demonstrate a way that the developed human response models can be utilised to evaluate and improve the current regulations by changing the limits hence resulting in better human response. The approach of developing the human oriented noise criteria is explained in Figure 10-1.

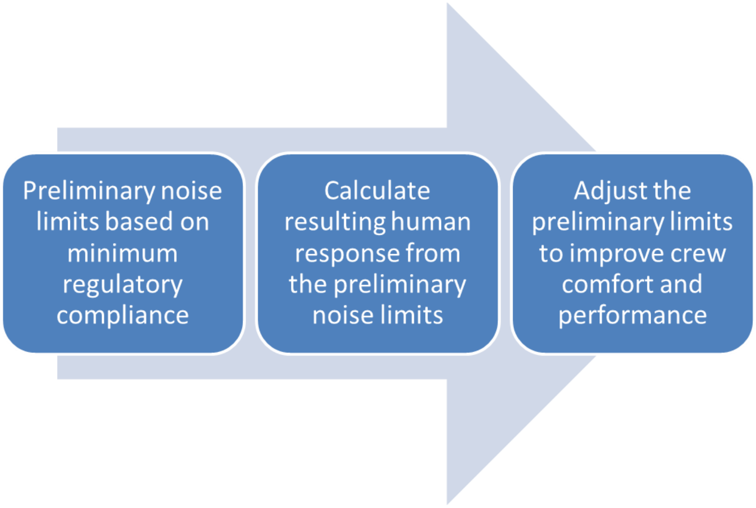


Figure 10-1: Approach for developing the prototype human oriented noise criteria

10.3.1 Preliminary Noise Limits

In Chapter 4 the noise related regulatory framework was extensively reviewed. It can be concluded that, even though there are many national and international norms applicable, the marine regulatory framework is heavily based on the IMO Noise Code which is recently updated and the new code is coming into force in July 2014. Since the IMO code is just updated, it was considered that the new IMO limits (given in Table 4-8) can be used as base line for the purpose of this section.

10.3.2 Resulting Human Response from the Preliminary Limits

The human response models developed in Chapter 9 (2 comfort and 3 performance models) were shown in Table 9-20. These models now can be utilised to assess the effectiveness of the updated IMO Noise Code. The aim of this part is to demonstrate the expected proportion of people likely to feel discomfort or performance degradation on a ship which is designed to meet the limits defined by IMO noise code. The amount of people likely to get annoyed is demonstrated in percentages in the tables. However, it is important to clarify what actually the percentages represent. After investigating the model outputs it was identified that some people were still reporting annoyance or performance drawbacks even when there is hardly any noise exist in the environment. Therefore, it was considered appropriate to exclude the probability of getting annoyed or performance degradation in low noise levels as this annoyance may not be directly related to noise. This noise annoyance at low noise levels may be due to many other reasons which influence people's satisfaction and view. As a result 40 dB(A) is considered as a baseline noise level and for any noise level above the baseline this is referred to as "extra" noise. Any annoyance/performance degradation percentages are calculated by deducting the baseline (at 40 dB(A)) probabilities of human response (annoyance and performance) from the actual human response probabilities at any noise level above 40 dB(A). This noise level was selected because it represents a typical silent office or library noise level, moreover, 'Night Noise Guidelines for Europe' also report that 40 dB was selected as the target of night noise guidelines (Hurtley, 2009). Therefore, the percentages in all tables demonstrate the annoyance/performance impairment on top of the base line annoyance/ performance impairment.

As explained before, along with the noise level at a location, comfort models also take into account the gender and the age of the population in order to calculate percentages of human response, while performance models do not. Therefore, in order to make the interpretation easier it was considered to run the comfort models for the average population. This was achieved by inputting 45 as an average age and inputting 0.5 for gender (originally 0: Female, 1: Male). Results are shown in Table 10-1 while Table 10-2 demonstrates the percentage of people who are likely to be annoyed or feel discomfort considering the age and gender differences.

Table 10-1: Comfort models applied on the new IMO Noise Code (average response)

Designation of rooms and spaces	dB(A)	N2c: Noise annoyance	O1c: Overall feeling of discomfort
Work spaces			
Machinery spaces	110	65.3%	51.7%
Machinery control rooms	75	30.3%	24.5%
Workshops	85	41.5%	32.7%
Non–specified work spaces (other work areas)	85	41.5%	32.7%
Navigation spaces			
Navigating bridge and chartrooms	65	19.6%	16.5%
Listening posts, incl. navigating bridge wings and windows	70	24.8%	20.5%
Radio rooms (with radio equipment operating but not producing audio signals)	60	14.8%	12.8%
Radar rooms	65	19.6%	16.5%
Accommodation spaces			
Cabin and hospitals	55	10.4%	9.2%
Messrooms	60	14.8%	12.8%
Recreation rooms	60	14.8%	12.8%
Open recreation areas (external recreation areas)	75	30.3%	24.5%
Offices	60	14.8%	12.8%
Service spaces			
Galleys, without food processing equipment operating	75	30.3%	24.5%
Serveries and pantries	75	30.3%	24.5%
Normally unoccupied spaces			
Spaces not specified	90	47.0%	36.8%

The following can be observed from Table 10-1;

- With current limits defined for the category “work spaces” especially for the sub category “machinery spaces” high annoyance (over 60%) and overall feeling of discomfort(over 50%) are expected to be observed.
- In navigational spaces annoyance and discomfort percentages are around 20% level.
- Accommodation spaces seem to result in less annoyance compared to other spaces changing from 10% to 15% with the exception of open recreation areas
- Noise levels defined for service spaces likely to cause 30% annoyance and 25% discomfort amongst the people occupying those spaces.

Table 10-2: Comfort models applied on the new IMO Noise Code with Age and Gender effects

		N2c: Noise annoyance		O1c: Overall feeling of discomfort								
Designation of rooms and spaces	dB(A)	Gender		Age								
		male	female	15	25	35	45	55	65	75	85	95
Work spaces												
Machinery spaces	110	63.6%	65.7%	49.9%	51.4%	52.1%	51.7%	50.4%	48.1%	45.1%	41.6%	37.6%
Machinery control rooms	75	26.9%	33.3%	28.0%	27.5%	26.2%	24.5%	22.4%	20.1%	17.7%	15.3%	13.0%
Workshops	85	37.9%	44.3%	35.5%	35.3%	34.4%	32.7%	30.5%	27.8%	24.9%	21.9%	19.0%
Non–specified work spaces (other work areas)	85	37.9%	44.3%	35.5%	35.3%	34.4%	32.7%	30.5%	27.8%	24.9%	21.9%	19.0%
Navigation spaces												
Navigating bridge and chartrooms	65	16.9%	22.2%	20.0%	19.2%	18.0%	16.5%	14.9%	13.1%	11.3%	9.7%	8.2%
Listening posts, incl. navigating bridge wings and windows	70	21.7%	27.7%	24.1%	23.4%	22.1%	20.5%	18.5%	16.5%	14.4%	12.3%	10.5%
Radio rooms (with radio equipment operating but not producing audio signals)	60	12.6%	17.0%	15.9%	15.1%	14.1%	12.8%	11.4%	10.0%	8.6%	7.3%	6.1%
Radar rooms	65	16.9%	22.2%	20.0%	19.2%	18.0%	16.5%	14.9%	13.1%	11.3%	9.7%	8.2%
Accommodation spaces												
Cabin and hospitals	55	8.7%	12.0%	11.8%	11.1%	10.2%	9.2%	8.2%	7.1%	6.1%	5.1%	4.3%
Messrooms	60	12.6%	17.0%	15.9%	15.1%	14.1%	12.8%	11.4%	10.0%	8.6%	7.3%	6.1%
Recreation rooms	60	12.6%	17.0%	15.9%	15.1%	14.1%	12.8%	11.4%	10.0%	8.6%	7.3%	6.1%
Open recreation areas (external recreation areas)	75	26.9%	33.3%	28.0%	27.5%	26.2%	24.5%	22.4%	20.1%	17.7%	15.3%	13.0%
Offices	60	12.6%	17.0%	15.9%	15.1%	14.1%	12.8%	11.4%	10.0%	8.6%	7.3%	6.1%
Service spaces												
Galleys, without food processing equipment operating	75	26.9%	33.3%	28.0%	27.5%	26.2%	24.5%	22.4%	20.1%	17.7%	15.3%	13.0%
Serveries and pantries	75	26.9%	33.3%	28.0%	27.5%	26.2%	24.5%	22.4%	20.1%	17.7%	15.3%	13.0%
Normally unoccupied spaces												
Spaces not specified	90	43.5%	49.5%	38.8%	39.0%	38.3%	36.8%	34.6%	31.9%	28.8%	25.5%	22.3%

- Normally unoccupied spaces section sets a high limit (90dB(A)) for the unspecified spaces, however it is not clear which spaces will fall under this section due to the vague description of the space and lack of guidance.
- However it was enforced by IMO that in spaces with noise levels exceeding 85 dB(A), suitable hearing protection should be used. So the resulting annoyance is likely to be different than the normal condition
- In order to take the effect of wearing hearing protectors in to account following table (Table 10-3) was prepared.

Table 10-3: Recalculated discomfort response in places where hearing protection is used

Designation of rooms and spaces	dB(A)	Attenuated noise Level in the ear dB(A)		N2c: Noise annoyance		O1c: Overall feeling of discomfort	
Work spaces		HP2	HP3	HP2	HP3	HP2	HP3
Machinery spaces	110	87	98.5	43.7%	55.6%	34.4%	43.5%
Workshops	85	62	73.5	16.7%	28.6%	14.3%	23.3%
Non–specified work spaces (other work areas)	85	62	73.5	16.7%	28.6%	14.3%	23.3%
Normally unoccupied spaces							
Spaces not specified	90	67	78.5	21.7%	34.2%	18.1%	27.4%

During preparation of these tables following assumptions were made;

- **A sophisticated hearing protection is assumed to be used:** From the practical experience gained through field trips and surveys applied to crew members, it can be confidently said that basic passive hearing protectors are in use on board ships. However, in order to demonstrate the best case scenario, in this calculations an NRR 30 (noise reduction rate) hearing protector is assumed to be used in the locations with noise level above 85 dB(A).
- **OHSA's attenuation calculation was used (HP2):** NRR supplied by the hearing protector manufacturer is normally based on C weighted noise level. However, if measurements are conducted in A-weighting and C weighted data is unavailable then the following correction can be made as suggested by OHSA;

Estimated exposure (dB(A)) = TWA (dB(A)) − [(NRR − 7)]

- **OHSA's correction factor is used (HP3):** According to OHSA, NRRs provided by manufacturers of hearing protection devices are obtained in laboratory conditions, and this noise protection will hardly be achieved in a real workspace environment. Therefore, in order to adjust the formula, OHSA strongly recommends a 50% correction factor as shown below;

$$\text{Estimated exposure } (dB(A)) = TWA(dB(A)) - [(NRR - 7) \times 50\%]$$

As it can be seen from Table 10-3 even the use of high rated hearing protectors was still unable to prevent the high levels of annoyance and discomfort.

In a similar way, performance models were used in order to demonstrate the proportion of people that are likely to get adversely affected by the noise limits defined in the updated IMO noise code. Results are shown in Table 10-4

Table 10-4: Performance models applied on the new IMO Noise Code

Designation of rooms and spaces	dB(A)	N2p: Noise annoyance	N7p: Quality impairment	O1pn: Overall feeling of wellbeing
Work spaces				
Machinery spaces	110	65.3%	60.0%	33.2%
Machinery control rooms	75	28.5%	18.2%	14.6%
Workshops	85	39.8%	28.6%	19.7%
Non–specified work spaces (other work areas)	85	39.8%	28.6%	19.7%
Navigation spaces				
Navigating bridge and chartrooms	65	18.0%	10.4%	9.9%
Listening posts, incl. navigating bridge wings and windows	70	23.1%	14.0%	12.2%
Radio rooms (with radio equipment operating but not producing audio signals)	60	13.4%	7.3%	7.7%
Radar rooms	65	18.0%	10.4%	9.9%
Accommodation spaces				
Cabin and hospitals	55	9.3%	4.9%	5.6%
Messrooms	60	13.4%	7.3%	7.7%
Recreation rooms	60	13.4%	7.3%	7.7%
Open recreation areas (external recreation areas)	75	28.5%	18.2%	14.6%
Offices	60	13.4%	7.3%	7.7%
Service spaces				
Galleys, without food processing equipment operating	75	28.5%	18.2%	14.6%
Serveries and pantries	75	28.5%	18.2%	14.6%
Normally unoccupied spaces				
Spaces not specified	90	45.5%	34.6%	22.3%

The following can be observed from the table;

- ‘Overall feeling of unwellbeing’ shows less variation between different noise levels, this is expected since there are other factors which contribute into overall feeling of discomfort. Therefore, it may be more logical to focus on the results of the other two models (N2p and N7p) especially Quality impairment model.
- Noise levels in ‘Navigation Spaces’ is likely to affect around 10% of population adversely while around 20% of people will feel annoyed.
- Below 10% quality impairment response is observed in ‘Accommodation spaces’ while noise annoyance likely to occur less than 15% of the population.
- Defined noise limits likely to cause slightly less than 20% of people to feel quality impaired as well as closed to 30% of population to feel annoyed.
- In ‘Workspaces’, the percentage of people likely to get quality impairment is 60% which is an outstanding value when compared to other locations
- As explained before, crew members are required to wear ear protection before entering high noise areas, so the results are recalculated for those areas shown in Table 10-5 below. It can be seen from the table that even with the hearing protection the percentage of population who are likely to get effected by the noise levels in machinery spaces is between 30% and 45%.

Table 10-5: Recalculated performance degradation in places where hearing protection is used

Designation of rooms and spaces	dB(A)	Attenuated noise Level in the ear dB(A)		N2p: Noise annoyance		N7p: Quality impairment		O1pn: Overall feeling of wellbeing	
Work spaces		**HP2**	**HP3**	**HP2**	**HP3**	**HP2**	**HP3**	**HP2**	**HP3**
Machinery spaces	110	87	98.5	42.1%	54.7%	30.9%	45.5%	20.7%	26.9%
Workshops	85	62	73.5	15.2%	26.8%	8.5%	16.9%	8.5%	13.9%
Non–specified work spaces (other work areas)	85	62	73.5	15.2%	26.8%	8.5%	16.9%	8.5%	13.9%
Normally unoccupied spaces									
Spaces not specified	90	67	78.5	20.0%	32.4%	11.7%	21.6%	10.8%	16.3%

10.3.3 Adjusted noise limits to improve the resulting human response and performance

Model results demonstrating the levels of discomfort and performance degradation based on the noise limits set by IMO have been discussed in previous part. However, similar to any other transport vehicle, due to the engines, moving parts and interaction they have with the environment, it is not possible to achieve complete silence on board a ship. Since, practically noise on board cannot be entirely eliminated, it is important to make an assumption to determine what are the acceptable proportions of people who will get adversely effected or discomforted. Then, the models can be run reverse to estimate what noise levels will result in those acceptable levels.

10.3.3.1 Interviews

In order to define the acceptable levels interviews have been conducted with 6 people who has specific expertise in maritime domain. The following demonstrates the background of experts who were interviewed.

- Maritime Transportation and Management Engineering
- Marine Engineering
- Naval Architecture.

Interviews were conducted in a structured way and following questions have been asked to each expert. Question 1 and Question 3 aimed to identify how important is the comfort and performance in each location defined in IMO noise code, while Question 2 and Question 4 aimed to capture the information to decide which models are more appropriate to be used to define limit discomfort and performance levels.

Table 10-6, Table 10-7, Table 10-8 and Table 10-9 shows the type of information collected by each question. The titles of each table contain the questions that were asked to interviewees.

Table 10-6: Question 1 - Below table shows the space groups on board a ship defined by IMO (International Maritime Organisation). Can you please rate how important it is to ensure the comfort of people in these spaces? (1 not important at all, 5 very important)

Designation of rooms and spaces	Circle as appropriate
Work spaces	
Machinery spaces	1 2 3 4 5
Machinery control rooms	1 2 3 4 5
Workshops	1 2 3 4 5
Non–specified work spaces (other work areas)	1 2 3 4 5
Navigation spaces	
Navigating bridge and chartrooms	1 2 3 4 5
Listening posts, incl. navigating bridge wings and windows	1 2 3 4 5
Radio rooms (with radio equipment operating but not producing audio signals)	1 2 3 4 5
Radar rooms	1 2 3 4 5
Accommodation spaces	
Cabin and hospitals	1 2 3 4 5
Mess-rooms	1 2 3 4 5
Recreation rooms	1 2 3 4 5
Open recreation areas (external recreation areas)	1 2 3 4 5
Offices	1 2 3 4 5
Service spaces	
Galleys, without food processing equipment operating	1 2 3 4 5
Serveries and pantries	1 2 3 4 5
Normally unoccupied spaces	
Spaces not specified	1 2 3 4 5

Table 10-7: Question 2 - Can you rank the following ship space categories based on the importance of comfort in these locations? (1 is most important – 5 is the least important)

Designation of rooms and spaces	Fill with appropriate number
Work spaces	
Navigation spaces	
Accommodation spaces	
Service spaces	
Normally unoccupied spaces	

Table 10-8: Question 3 - Can you please rate how important it is to ensure the good levels of human performance (e.g. attention, decision making, productivity etc.) in these spaces. (1 not important at all, 5 very important)

Designation of rooms and spaces	Circle as appropriate
Work spaces	
Machinery spaces	1 2 3 4 5
Machinery control rooms	1 2 3 4 5
Workshops	1 2 3 4 5
Non–specified work spaces (other work areas)	1 2 3 4 5
Navigation spaces	
Navigating bridge and chartrooms	1 2 3 4 5
Listening posts, incl. navigating bridge wings and windows	1 2 3 4 5
Radio rooms (with radio equipment operating but not producing audio signals)	1 2 3 4 5
Radar rooms	1 2 3 4 5
Accommodation spaces	
Cabin and hospitals	1 2 3 4 5
Mess-rooms	1 2 3 4 5
Recreation rooms	1 2 3 4 5
Open recreation areas (external recreation areas)	1 2 3 4 5
Offices	1 2 3 4 5
Service spaces	
Galleys, without food processing equipment operating	1 2 3 4 5
Serveries and pantries	1 2 3 4 5
Normally unoccupied spaces	
Spaces not specified	1 2 3 4 5

Table 10-9: Question 4 - Can you rank the following ship space categories based on the importance of human performance in these locations (1 is most important – 5 is the least important)

Designation of rooms and spaces	Fill with appropriate number
Work spaces	
Navigation spaces	
Accommodation spaces	
Service spaces	
Normally unoccupied spaces	

10.3.3.2 Results

The responses collected from the interviews then was analysed to identify the mean response for each location which was then converted to percentage of importance by comparing the mean response to the maximum rating in the scale (which in this case is 5 as shown in Table 10-6 and Table 10-8). Finally, the importance percentages were converted to comfort limits in percentages by subtracting them 100%. It needs to be noted that more complex methods can be developed to define such acceptable limits, however it is not in the context of this study to research and develop a method to define the acceptable performance and comfort limits. Therefore, the aforementioned method of converting expert feedback to limits has been followed in this study.

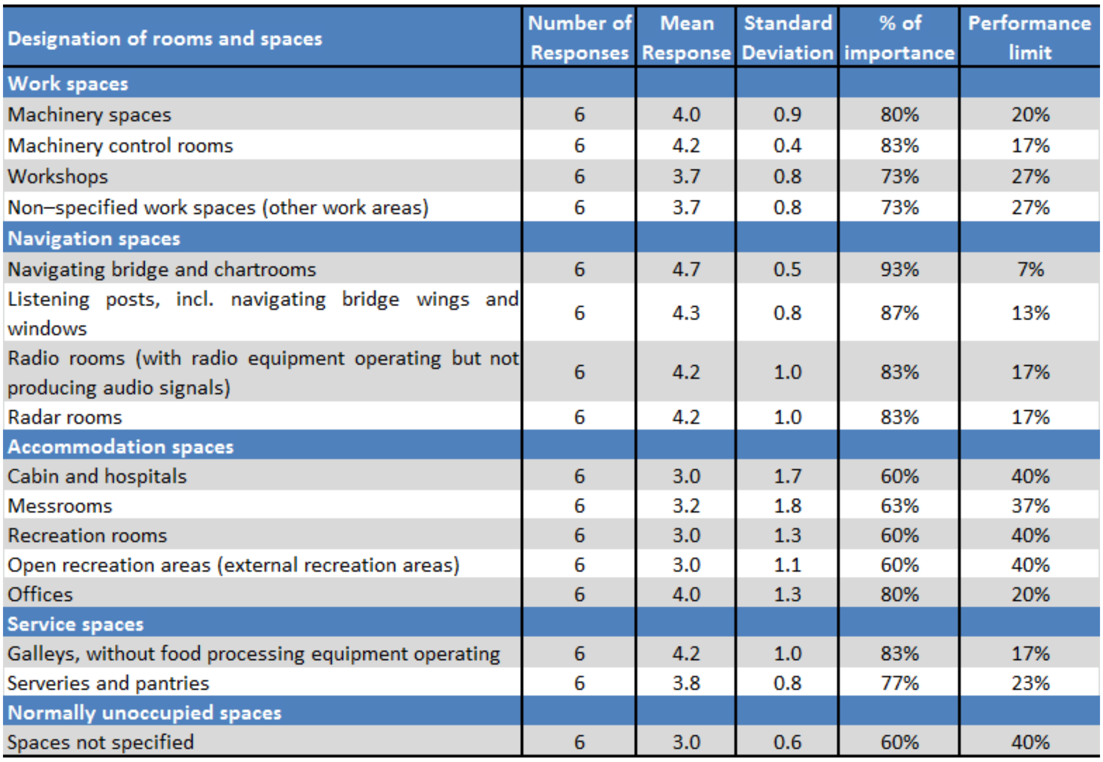
Table 10-10: Results for Question 1

Designation of rooms and spaces	Number of Responses	Mean Response	Standard Deviation	% of importance	Comfort limit
Work spaces					
Machinery spaces	6	2.7	1.4	53%	47%
Machinery control rooms	6	3.5	1.0	70%	30%
Workshops	6	3.7	1.5	73%	27%
Non–specified work spaces (other work areas)	6	2.5	0.5	50%	50%
Navigation spaces					
Navigating bridge and chartrooms	6	4.2	0.8	83%	17%
Listening posts, incl. navigating bridge wings and windows	6	3.8	1.2	77%	23%
Radio rooms (with radio equipment operating but not producing audio signals)	6	3.0	0.9	60%	40%
Radar rooms	6	3.7	1.0	73%	27%
Accommodation spaces					
Cabin and hospitals	6	4.8	0.4	97%	3%
Messrooms	6	4.5	0.5	90%	10%
Recreation rooms	6	4.3	0.5	87%	13%
Open recreation areas (external recreation areas)	6	3.7	0.8	73%	27%
Offices	6	4.3	0.8	87%	13%
Service spaces					
Galleys, without food processing equipment operating	6	3.7	1.8	73%	27%
Serveries and pantries	6	3.7	1.4	73%	27%
Normally unoccupied spaces					
Spaces not specified	6	2.7	0.8	53%	47%

Table 10-10 shows the summary responses collected for Question 1 together with the comfort limits based on these responses. The mean responses of participants (in column 3) for each location were converted to percentages in column 5. The comfort limits defined in the table means that a noise level needs to be defined for that location to ensure that, for example, in the worst case 30% of people in 'Machinery Control Rooms' should feel discomfort. Resulting comfort limits in Table 10-10 show that 'Cabins and Hospitals' have the most stringent requirement to ensure comfort, which makes total sense.

Similarly, Table 10-11 displays the summary of responses received for the Question 2 and resulting performance limits.

Table 10-11: Results for Question 3



Designation of rooms and spaces	Number of Responses	Mean Response	Standard Deviation	% of importance	Performance limit
Work spaces					
Machinery spaces	6	4.0	0.9	80%	20%
Machinery control rooms	6	4.2	0.4	83%	17%
Workshops	6	3.7	0.8	73%	27%
Non–specified work spaces (other work areas)	6	3.7	0.8	73%	27%
Navigation spaces					
Navigating bridge and chartrooms	6	4.7	0.5	93%	7%
Listening posts, incl. navigating bridge wings and windows	6	4.3	0.8	87%	13%
Radio rooms (with radio equipment operating but not producing audio signals)	6	4.2	1.0	83%	17%
Radar rooms	6	4.2	1.0	83%	17%
Accommodation spaces					
Cabin and hospitals	6	3.0	1.7	60%	40%
Messrooms	6	3.2	1.8	63%	37%
Recreation rooms	6	3.0	1.3	60%	40%
Open recreation areas (external recreation areas)	6	3.0	1.1	60%	40%
Offices	6	4.0	1.3	80%	20%
Service spaces					
Galleys, without food processing equipment operating	6	4.2	1.0	83%	17%
Serveries and pantries	6	3.8	0.8	77%	23%
Normally unoccupied spaces					
Spaces not specified	6	3.0	0.6	60%	40%

Performance limits defined in Table 10-11 shows that 'Navigating Bridge and Chartrooms' are most important location in terms of human performance. Therefore the noise limits should be defined to ensure that the proportion of people whose performance would get affected by noise would not exceed the 7%.

Once the limit values for comfort and performance have been developed, it was necessary to define for each location whether the crew comfort is more important or the performance.

Therefore, the responses received for the Question 2 and Question 4 have been analysed and mean responses have been obtained. Then, based on these responses the spaces were ranked according to the importance of comfort and performance in them. The results are showed in Table 10-12.

Table 10-12: Ranking results for Question 2 and Question 4

Designation of rooms and spaces	Number of Responses	Mean	Standard Deviation	Ranking
Comfort Ranking				
Accommodation spaces	6	1.80	0.8	1.0
Navigation spaces	6	1.83	0.8	2.0
Work spaces	6	3.00	1.4	3.0
Service spaces	6	3.80	0.4	4.0
Normally unoccupied spaces	6	5.00	0.0	5.0
Performance Ranking				
Navigation spaces	6	1.17	0.4	1.0
Work spaces	6	1.83	0.4	2.0
Service spaces	6	3.33	0.5	3.0
Accommodation spaces	6	4.17	1.0	4.0
Normally unoccupied spaces	6	4.50	0.5	5.0

Based on the importance ranking shown in Table 10-12 each space type has been compared to check in which ranking they scored highest. For 'Accommodation spaces' ranked number 1 in ranking based on comfort while ranked number 4 in performance ranking. This shows that in accommodation areas it is more important to ensure comfort than the performance. Therefore, for 'Accommodation Spaces' noise limits should be based on the outcomes of comfort models. Following the same methodology following have been concluded;

- For 'Navigation Spaces', 'Work Spaces' and 'Service Spaces' Performance models should be used to define limits
- For 'Accommodation Spaces' it is more appropriate to use comfort models
- Normally unoccupied spaces ranked number 5 in both ranking therefore both performance and/or comfort models can be applied.

As mentioned before, there are 2 comfort models (see Table 10-1) and 3 performance models (see Table 10-4) estimating different attributes of comfort.

When defining the new noise limits ‘Noise Annoyance’ model (N2c) was selected to represent comfort due to the fact that ‘Noise Annoyance’ will require more stringent noise limits to be complied with when compared to ‘Overall feeling of discomfort’ model (O1c). So if the limits are defined to satisfy the ‘Noise Annoyance’ model results then ‘Overall feeling of discomfort’ will automatically be satisfied. Moreover, there may be other possible factors which may contribute in ‘Overall feeling of discomfort’ along with noise; therefore, ‘Overall feeling of discomfort’ model is less relevant in this context.

On the other hand, ‘Quality impairment’ model (N7p) was selected to represent the performance models simply due to the fact that it better represents the performance and work quality when compared to the ‘Noise annoyance’ (N2p) and ‘Overall feeling of unwellbeing’ (O1pn) models.

Finally, the selected models (N2c and N7p) were run in reverse to obtain the noise limit values based on the defined maximum acceptable human annoyance and quality impairment levels. In Table 10-13 rows represent different space types while ‘model’ column shows which human response model was used in that space to calculate the percentages shown in ‘human response’ column. ‘Hearing protection’ column show whether the effect of hearing protectors are taken into account or not. ‘Human response limits’ column shows the limits (as defined in Table 10-10 and Table 10-11) for the maximum levels of adverse human response in each space type while the ‘new human oriented noise limits’ column shows the updated noise levels to ensure the resulting human annoyance and quality impairment does not exceed the set limits.

It can be seen that, for the space type ‘normally unoccupied spaces’ both ‘Quality impairment’ and ‘Noise annoyance’ models were utilised to decide the noise limit value. However, the required maximum noise level to comply with the 47% ‘Noise Annoyance’ limit was more stringent than the one in ‘Quality impairment’, so the final noise level defined is actually based on the ‘Noise Annoyance’ model.

Table 10-13: Final noise levels and corresponding human response

Designation of rooms and spaces	Model	Hearing Protection	Human Response limit	Human Response	New IMO limits dB(A)	New human oriented Limits dB(A)
Work spaces						
Machinery spaces	'Quality impairment' (N7p)	yes	20%	20%	110	100
Machinery control rooms	'Quality impairment' (N7p)	no	17%	16%	75	73
Workshops	'Quality impairment' (N7p)	yes	27%	8%	85	85
Non–specified work spaces (other work areas)	'Quality impairment' (N7p)	yes	27%	8%	85	85
Navigation spaces						
Navigating bridge and chartrooms	'Quality impairment' (N7p)	no	7%	7%	65	59
Listening posts, incl. navigating bridge wings and windows	'Quality impairment' (N7p)	no	13%	12%	70	68
Radio rooms (with radio equipment operating but not producing audio signals)	'Quality impairment' (N7p)	no	17%	7%	60	60
Radar rooms	'Quality impairment' (N7p)	no	17%	10%	65	65
Accommodation spaces						
Cabin and hospitals	'Noise Annoyance' (N2c)	no	3%	3%	55	45
Messrooms	'Noise Annoyance' (N2c)	no	10%	10%	60	54
Recreation rooms	'Noise Annoyance' (N2c)	no	13%	13%	60	58
Open recreation areas (external recreation areas)	'Noise Annoyance' (N2c)	no	27%	27%	75	72
Offices	'Noise Annoyance' (N2c)	no	13%	13%	60	58
Service spaces						
Galleys, without food processing equipment operating	'Quality impairment' (N7p)	no	17%	16%	75	72
Serveries and pantries	'Quality impairment' (N7p)	no	23%	18%	75	75
Normally unoccupied spaces						
Spaces not specified	'Quality impairment' (N7p) / 'Noise Annoyance' (N2c)	no	40% / 47%	35% / 47%	90	90

Form Table 10-13 the following can be observed;

- Even with the use of hearing protection the noise level defined by IMO is not enough to ensure the satisfactory levels of human performance. Moreover, it needs to be noted that calculations have been done by considering the hearing protection devices effectiveness as 100%, if OHSA's recommendation on the effectiveness of hearing protection devices (HP2) were applied, the resulting noise limit values would have been significantly lower therefore more stringent.
- In machinery spaces it can be seen that a 10 dB(A) decrease is needed to make the new IMO limits human oriented. Achieving lower noise levels in Engine Rooms, which is the main source of noise on board ships, can result significant reductions in rest of the locations as well.
- Experts rated the 'Navigating Bridge and Chartrooms' as the most important location of ship where human performance is critical for the safety of operations. Therefore, it is understandable that the quality impairment is not tolerated in this space. This resulted in a decrease of 6 dB(A) compared to the limit noise level defined by IMO.
- The other important location with a dramatic reduction in the limit level is 'Cabins and Hospitals' category. Due to the fact that crew members spend their time in their cabins to have a quality rest and recover from the fatigue and stress of their daily work, comfort of these cabins became extremely important. When human comfort is considered it appears that IMO's noise levels should be decrease by 10 dB(A).
- Similar noise reductions have been observed in other accommodation spaces in order to keep the noise annoyance levels below the defined limit.
- Finally, for some locations noise limits remained same for both IMO noise limits and the new human oriented limits as they appeared to be satisfactory to achieve the levels of comfort and performance for those spaces.

10.4 Human Oriented Ship Design for the Noise Levels

In the previous section it was shown that noise standards should consider human comfort and performance. Without a doubt when human performance and comfort concerns are also taken into account more stringent noise limits will be needed. In fact, the new Human Oriented Noise Criteria shown in Table 10-13 is more stringent than the recently updated IMO noise code and in some locations require 10 dB(A) noise reductions. Considering that previous noise code of IMO was not obligatory and the new noise code is coming into force in July 2014, it will not be wrong to say that there is an upcoming challenge for maritime industry. Especially on small ships complying with noise levels will be more challenging since the defined limits for some location types generally cannot be achieved without taking noise reduction measures (Nilsson, 1978). Therefore, it is expected that more importance will be given to noise at design stage.

Increased understanding on noise propagation and new methods for noise prediction together with the power of advanced computers, today noise concerns can easily be taken into account at the design stage. Designers can identify the problem areas; propose and test measures for mitigation or change the accommodation lay out to avoid non-compliance with regulations or contractual requirements. Considering the factors such as, amount of rework, space requirements for noise reduction measures, it is going to be very costly and hence less desirable to make changes after the ship is built (Andresen *et al.*, 1986).

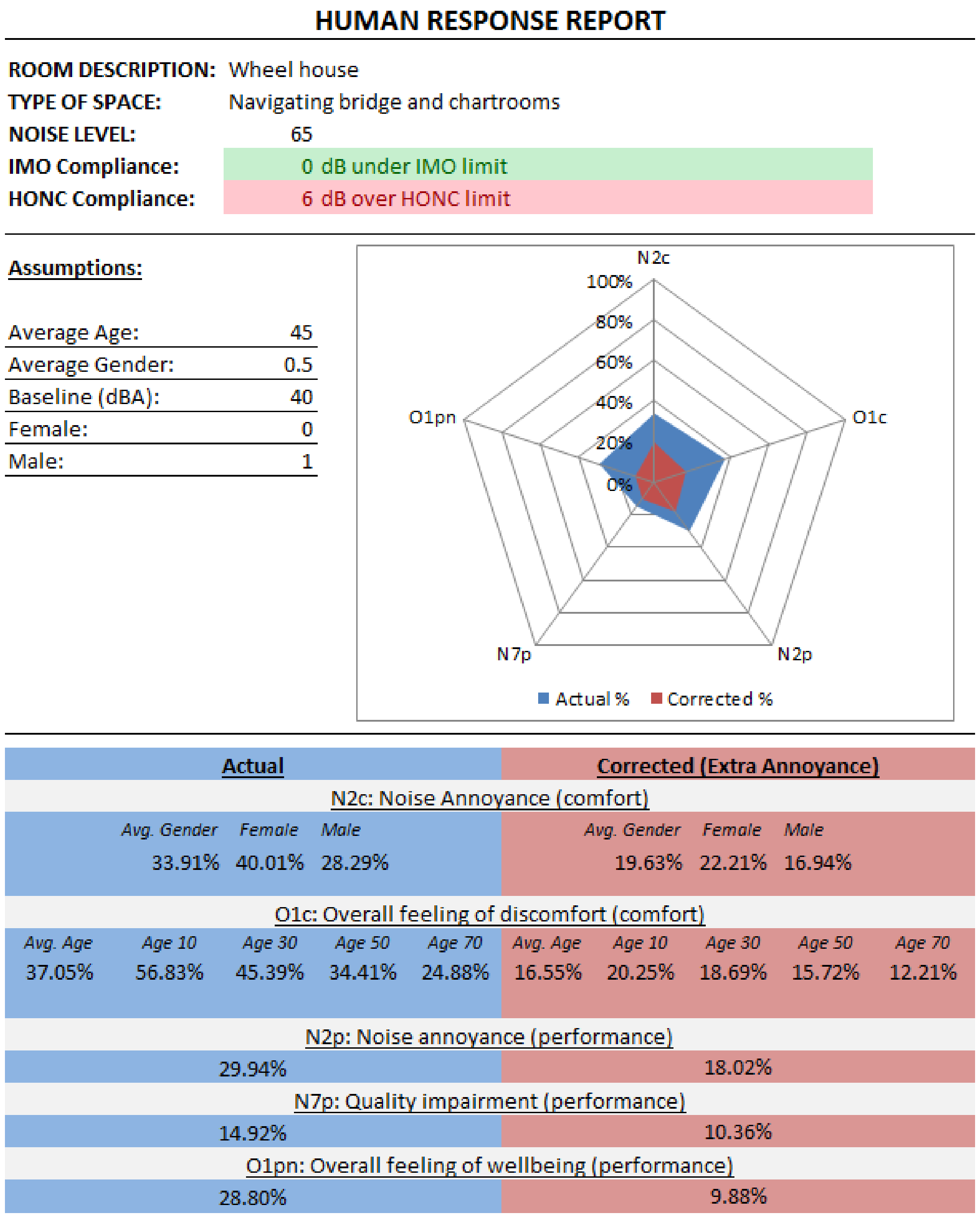
Due to all these practical and financial reasons it is becoming more popular to consider on board noise at the initial design stage. However, the biggest reason for why noise on-board a ship is a big concern for maritime industry is the human on-board. Therefore, considering that the health issues are already covered in the current noise regulations, wouldn’t it be nice to estimate at the design stage, the amount of people likely to get annoyed or perform worse due to the noise levels. Each ship is designed to operate in a certain condition to perform a certain operation; therefore, the operational needs will differ from one ship to the other.

For example, for a ferry running 30 minutes long short passages throughout the day whose crew can go and sleep on land is likely to be happy with only complying with noise code in terms of crew cabins while comfort in crew cabins can be a very important for a ship which runs long distance to allow proper rest of their crew members. On the other hand, for the aforementioned ferry it may be more important to ensure the performance and attention of officer in watch due to operating in a busy channel throughout the day while for the ship running operating in open sea the task of watch keeping may be cognitively less intensive.

Therefore, the performance and comfort of crew can be taken into account at design stage to ensure the operational needs. In order to address this need the developed models in this PhD study can be utilised at the design stage to estimate the human response to targeted noise levels. Hence, developed human response models were programmed in to a very simple excel program which can prepare a simple human response report for a location.

A snapshot of the human response report is shown in Figure 10-2. At the top of the human response report, location name and corresponding space type is shown followed by the compliance with the IMO's Noise Code and Human Oriented Noise Code (previously explained in this chapter). Then all 5 models developed in this PhD study were combined in a 'radar graph' to demonstrate the overall effect of targeted noise level for that location on the human. It needs to be noted that the graph is prepared based on the average values of age (45) and gender (0.5). Blue area in the graph represents the 'actual' human discomfort or annoyance while red area shows the 'extra' discomfort or annoyance ('extra' = 'actual' - discomfort/annoyance @ 40dB(A)). Also below the graph details of model results are shown.

The result shown in Figure 10-2 is for a wheel house. It can be seen that the 'noise annoyance' model (N2c) shows 19.63% of people are expected to get annoyed with this noise level and 'quality impairment' model (N7p) shows that performance of 10.36% of people will get affected by the noise level in wheel house.



HUMAN RESPONSE REPORT

ROOM DESCRIPTION:	Wheel house
TYPE OF SPACE:	Navigating bridge and chartrooms
NOISE LEVEL:	65
IMO Compliance:	0 dB under IMO limit
HONC Compliance:	6 dB over HONC limit

Assumptions:

Average Age:	45
Average Gender:	0.5
Baseline (dBA):	40
Female:	0
Male:	1

N2c: Noise Annoyance (comfort)

	Avg. Gender	Female	Male
Actual	33.91%	40.01%	28.29%
Corrected (Extra Annoyance)	19.63%	22.21%	16.94%

O1c: Overall feeling of discomfort (comfort)

	Avg. Age	Age 10	Age 30	Age 50	Age 70
Actual	37.05%	56.83%	45.39%	34.41%	24.88%
Corrected (Extra Annoyance)	16.55%	20.25%	18.69%	15.72%	12.21%

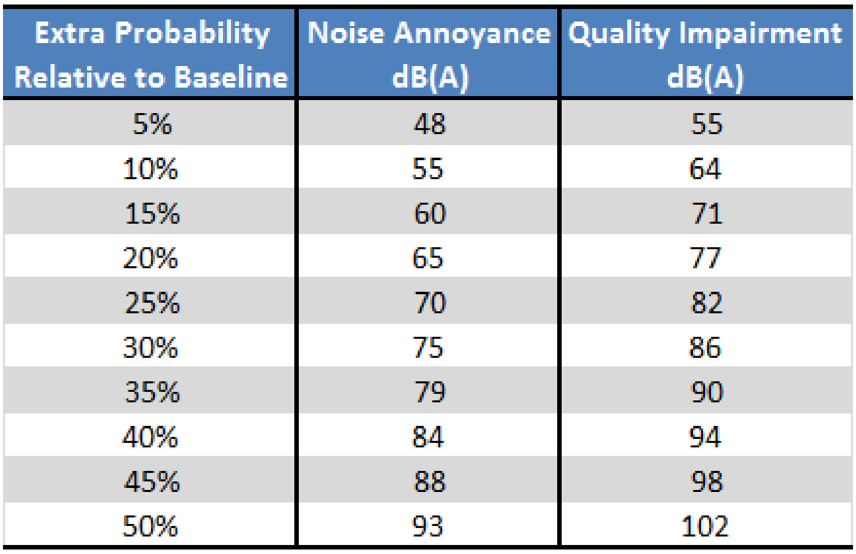
	Actual	Corrected (Extra Annoyance)
N2p: Noise annoyance (performance)	29.94%	18.02%
N7p: Quality impairment (performance)	14.92%	10.36%
O1pn: Overall feeling of wellbeing (performance)	28.80%	9.88%

Figure 10-2: Snapshot of a human response report

As mentioned before, if a ferry operating in a busy channel is concerned, then it can be said that the noise level of 65 dB(A) can be amended to ensure better crew performance and less discomfort.

Moreover, Table 10-14 shows the corresponding noise levels for specific percentage of people annoyed or impaired in their work by the noise. (Baseline = annoyance or quality impairment at 40 dB(A))

Table 10-14: Noise levels corresponding to human response levels (extra)



Extra Probability Relative to Baseline	Noise Annoyance dB(A)	Quality Impairment dB(A)
5%	48	55
10%	55	64
15%	60	71
20%	65	77
25%	70	82
30%	75	86
35%	79	90
40%	84	94
45%	88	98
50%	93	102

Therefore, Table 10-14 can be used as a scale which shows the noise levels depending on what percentage of people annoyed or impaired in their work is acceptable.

Designing a to ship minimum noise levels to achieve high human performance and comfort may result in safer and more efficient shipping, however eliminating noise problems on ships requires careful planning and careful engineering and of course it may come with an additional cost. Therefore human response models developed in this PhD study can be utilised at the initial design stage of a specific ship to do cost benefit analysis of improving human comfort and performance levels on board ships. This will lead to the safer and more efficient ship operations in accost effective manner.

10.5 Chapter Summary

In this chapter the use of developed human response models were demonstrated. In previous chapters it was identified that the noise limits defined by the regulatory bodies only consider the hazards of noise exposure in terms of human health and do not properly take into account the human performance and comfort. Hence, in this chapter as a case study the new IMO noise code was analysed with the developed human response models in order to demonstrate the levels of human annoyance and work impairment likely to occur on ships which complies with the code. Then, through expert feedbacks the comfort and performance requirements for each location were identified. Based on these comfort and performance needs, a new ‘human oriented noise code’ was introduced and levels were compared to the original noise criteria of IMO. Moreover, for a more cost effective approach, importance of addressing human response at the design stage of ships was discussed and a ship specific approach was proposed to be used by utilising the human response models developed in this thesis.

Chapter 11. DISCUSSIONS & FUTURE RECOMMENDATIONS

11.1 Chapter Overview

This chapter briefly explains a quick review of this PhD study and demonstrates the originality of the research outputs. Then the main contributions made to the discipline are also presented. Later, the limitations of the study are explained together with the potential improvement areas for future research.

11.2 A Quick Review of the Thesis and Its Originality

Historically, the main motivation towards improving the ship design has been the target of achieving more efficient ship operations through maximising the cargo capacity and minimizing the total energy consumption. On the other hand, in terms of safety improvements, mostly after major shipping disasters, the safety concerns and lessons learnt have been incorporated into the new ship design concepts and related norms to achieve safer ship design.

Therefore, it can be said that, the approach of the maritime sector when improving performance based ship design is proactive but when improving the safety based ship design is rather reactive in nature. While energy efficiency based ship design has been embraced by the industry through the potential financial gains to be achieved, safety being incorporated into design still lags behind in terms of implementation due to a lack of knowledge and awareness of the financial impacts safety can have.

Moreover, even though human performance problems are often related to shipping accidents, the integration of human factors to ship design has not been achieved effectively because of the underdeveloped knowledge of human factors in the maritime domain. Ship designers cannot effectively take into account the human element related considerations at design stage because the knowledge and tools which they should refer to has not yet been made available for the maritime domain.

In Chapter 2 of this thesis the concept of human factors was introduced and it was demonstrated that a wide range of theoretical branches of this topic exists. Therefore, the speciality of human factors in the maritime domain was reviewed, with the main influencers of human performance at sea discussed. After a careful review of these factors and considering that the main role of a naval architect is the design of the physical ship, it was decided that the focus should be on the environmental factors that affect the human on board ships. A careful investigation of the aforementioned environmental factors revealed that noise, as one of the major environmental factors that dominantly exist in shipboard environment, is being neglected. Hence, it was decided that this PhD study will address human factors in the maritime sector by focussing on noise issues on board ships.

Accordingly, in Chapter 4 noise related literature was further reviewed in detail. Different approaches adopted by other researchers from other sectors were investigated together with the existing models and regulatory framework. It was concluded that the effects of noise exposure on human is not only dependent on the physical quantities of noise but also related to other factors such as the nature of the task, duration of work and psychosocial factors. Therefore, the findings of different research studies were inconsistent which made them non-transferable between different domains. For that reason it was found necessary to design and conduct field studies in the application of controlled experiments to understand the effects of noise on crew on board ships.

In Chapter 6, noise exposure assessments on board tanker ships were conducted in order to investigate the regulatory compliance (i.e. protection of crew health) in terms of noise. Results showed values exceeding maximum allowed exposure levels which indicated the hearing of the crew was potentially under risk. Then, performance effects of noise were investigated (Chapter 7) through a controlled experimental study. A Peripheral Detection Task (PDT) was used to measure the vigilance performance while overall passage performance was assessed against a predefined ideal route. Results showed that noise has a significant adverse effect on human performance when compared to silent conditions.

The results obtained from the aforementioned studies indicated a need for the modelling of the human response to noise. In order to achieve that, first, human response data was collected in a structured way (Chapter 8) from ships through field studies. Then, through statistical modelling, a set of human response models in Chapter 9 were developed. The developed models were then utilised in the defining of a new human oriented noise criteria for ships.

11.3 Main Contribution of the Thesis

The main contribution of this PhD study is the development of human response models for noise on board ships. Similar response models exist in other sectors (as shown in Chapter 4) and are being utilised in the design and development of advanced air and surface transportation systems. However none have been developed for the unique application of the maritime domain. Therefore, the developed models in this thesis are a significant contribution to current knowledge in the discipline as they are the first human response models of noise that have been developed and applied to the maritime domain.

In order to collect the required human response data to noise, a data collection strategy was developed as explained in Chapter 8. This methodology is new in the maritime domain and can be followed by other researchers in order to validate the results of this study.

Effects of noise on crew performance were also investigated through application of an experimental study in a ship bridge simulator which was done for first time in the maritime domain. Results showed that, there is a significant relationship between noise exposure and human performance.

The main application of the developed models is considered to be in the human oriented design of ships which require a fundamental understanding of human response to noise on board ships. As ship designer needs reliable and practical methods for estimating the human response (comfort, performance, wellbeing etc.) resulting from the noise levels exist in the ship-board environment and understanding the trade-offs between the different noise levels and the way human on board a ship perceives them. Through utilising the derived human response curves (Figure 9-44, Figure 9-45, Figure 9-46, Figure 9-47 and Figure 9-48) designers can visualise the resulting human performance and comfort.

Moreover, a human oriented design criterion for noise was proposed based on the acceptable human response levels identified through questionnaires applied to experts. The proposed criteria can be used as a minimum requirement for ships to ensure acceptable levels of human response.

11.4 Achievement of Research Objectives

The research objectives defined in the Chapter 3 were achieved as shown in the following bullet points:

- The objective of reviewing the current literature and identifying the shortcomings of the current research has been achieved as reported in Chapter 4. It was identified that there is almost no research conducted focussing on the human response to noise on board ship environment. Review of the studies from other sectors revealed that results of both experimental and field studies are specific to the context that they are applied to. Therefore, it was observed that the findings of different studies contradicted each other. As a result, it was considered as necessary to study the human response to noise on ships. Review of existing models showed that human response cannot be only explained by the physical characteristics of the noise but also psychosocial factors should be considered. In terms of studying human performance, it was identified that the experimental studies provide more accurate results with regards to individual effects (through controlling other factors) of noise however more they are expensive and time consuming to conduct. Moreover, it is never possible to generate the real operating environment through experimental design. On the other hand, through field studies conducted on board ships during real operations, it is more likely to capture real human responses to the shipboard noise. When enough data is collected observations about the effect of noise on overall human response can be made confidently.

- The objective of reviewing current regulatory framework was also achieved. It was identified that the regulatory framework is only addressing the health effects of the noise while neglecting performance related effects which may become very important for the safety of shipping operations. Moreover, health of crew members of the ships which comply with the IMO's compartment based noise limits, were found to be under risk when noise exposure levels were considered and assessed against available norms. So an amendment in the compartment based noise limits was considered necessary.
- Another aim was to develop a framework which will be utilised to ensure the prevention of human being exposed to hazardous noise levels on board ships. This objective was also achieved successfully. However it needs to be mentioned that after the review of regulatory framework it was understood that there is a global understanding on the health effects of noise and regulatory framework well integrated these exposure response relationships into their rules. Therefore, complying with EU's recent Physical agents Directive was considered satisfactory for protecting seafarers' health from hazardous noise exposures. Accordingly a Noise Exposure Tool was developed to model the requirements of the aforementioned EU Noise Directive (please see Figure 6-6) which can be used to assess the crew members noise exposure values based on their work patterns even before they are exposed to noise.

- Moreover, as targeted, an experimental study was designed and conducted to investigate the effects of noise exposure in ship bridge simulators. The approaches of other experimental studies were carefully reviewed and all other factors which are likely to affect human performance other than the noise were tried to be neutralised. Well accepted experimental design techniques were used such as counterbalancing the experiment orders, limiting noise exposures, not informing the participants about the main aim of this study etc.). To the best knowledge of the author, these experiments were the first time that the performance effects of noise have been investigated in an environment resembling ship-board conditions and tasks. Furthermore, results of the experiments proved that there is a significant relationship between noise exposure and human performance.
- Collection of the required data for modelling human response was a very important task. There was a limited access to ships, therefore, it was important to conduct the data collection campaigns in a time effective way. To allow comparability of the data between different ships a predefined data collection and noise measurement structure were followed. The methodology followed for the data collection campaigns and collected data were reported in Chapter 8. Hence, if in future, similar human response assessments are wanted to be done, the methodology described in Chapter 8 can be followed as a guide.
- Selection of dependent variables (human responses) to be modelled were achieved through visiting following statistical analysis; (1) Analysis of variance; (2) Correlation Analysis, (3) Factor Analysis. Most meaningful (statistically) dependent variables were accordingly selected to be modelled as shown in Table 9-3.
- The key objective of this PhD study was to develop human response models to noise. This objective was also successfully achieved. Selected dependent variables, together with explanatory variables (age, gender, history of noise exposure etc.) tried to be modelled statistically. First, multiple linear

regressions were visited (as explained in Chapter 9 and in APPENDIX E) but statistical fitness of obtained models were not satisfactory. Then, ordinal logistic regressions were visited but again the developed models were not showing good fitness (APPENDIX F). Therefore, binomial logistic regressions were considered. However this required pooling together the 5 level ordinal human response data into 2 level dichotomous data. This trade-off resulted in models which cannot estimate the level of noise annoyance but probability of a person or whole community getting annoyed. The developed models were showing good statistical fitness and model performances can be found in Figure 9-49.

- Finally in order to achieve the objective of comparing models results to existing noise criteria, IMO's noise code was selected as a case and human response models were applied to the compartment based limits defined in the IMO's code. Then, through collecting expert opinions minimum acceptable comfort and performance levels of crew was identified. The noise limits were then amended to achieve minimum annoyance levels. Moreover, a simple to use excel tool (Figure 10-2) was coded which can be used as a design tool to visualise the human response to a noise level in a ship's compartment.

11.5 Limitations of the Developed Human Response Models

Simulation of a real life phenomenon through a mathematical model is a complicated issue and when the estimated phenomenon is a subjective human response then it becomes even more complex. Therefore, developed models include assumptions which were made at the development stage. Moreover, there were practical limitations or challenges experienced during the development of the models which are described in the bullet points below;

- Due to practical reasons, it was not possible to capture the noise exposure levels of people (e.g. with a dosemeter) on board ships. Instead, they were asked to provide their subjective feeling about a noise level in a specific location. Simultaneously, for the same location noise measurements were done over a period of 30 seconds and this noise level obtained was considered as remaining steady. However, even though exposure duration is likely to affect the resulting human response, the effect of exposure duration was neglected in this study.

- Moreover, some people may had more noise exposure (or different types of noise) during their stay in different compartments, and they may have already been annoyed which reflected their evaluation of current location in terms of noise annoyance. This situation was not possible to take into account due to practical reasons
- Some people did not specifically mention their exact location on the ships plan attached to the questionnaires instead they wrote down the name of the compartment they were in. For these people all measurements for that compartment were averaged instead of using the closest.
- It was necessary to record the noise spectra to allow testing of different noise ratings but in some measurements due to the functional limitation of the noise measurement device only A weighted noise levels were recorded. This limited the ability of modelling to include in different frequency weightings.
- Even though the type of noise can affect the human response (especially intermittent noise) the noise levels considered to be steady in this study.
- Statistically fit models were obtained through binomial logistic regressions which mean the developed human response models only predict the probability of getting annoyed by noise.
- As expected, noise level entered in every model. Some models also included explanatory variables such as age and gender (please see Table 9-20) which is in line with the previous research. However, there is strong evidence in the literature that exposure duration is a significant factor to take into account when dealing with human response to noise. However the developed models did not include exposure duration as a variable.

- Models developed in this PhD study is generic in nature which does not take into account the type of ships or location type. For example, without a doubt people will be less tolerant to noise in their cabins when compared to the recreational areas. Hence, the type of space (or type of the ship) that is will also have an influence on the resulting human response. However, achieving such models which include the aforementioned location or ship specific differences require substantial amount of human response data received from each location and ship type. Unfortunately the database generated in this study was not rich enough to take such effects into account.

11.6 Recommendations for future research

Based on the limitations explained in Section 11.5 following are the recommendations for the future researchers to further the research presented in this PhD study;

- Different noise weightings should be tested to see if a better representation of the human response can be achieved.
- Controlled experiments can be conducted in ship simulators to develop specific weighting factors to best represent human performance and annoyance.
- Inclusion of noise exposure duration to the models can improve the models. This requires a systematic data collection studies where each participant is observed and tracked.
- More field studies to collect human response data can be planned. So that, the models can be improved to include factors like location type. Once models include location types then the noise criteria for each location can be derived directly from the models
- Similarly, if more human response data can be obtained then ordinal logistic regressions can yield in statistically fit models. Hence, rather than the probability of a person getting annoyed by the noise level, how annoyed a person gets with the current noise level can also be predicted.

- Developed models can be combined with other models can become a part of a human oriented design framework which is required for ship design.
- Feasibility of the proposed standards should be tested with a new set of field data.
- Finally type of the noise (intermittent etc.) can also be included in to the models by conducting more measurement campaigns.

11.7 Chapter Summary

In this chapter, originality of the research and its contribution to the current literature was presented. The innovative human response models developed in this thesis was considered as a major contribution to the human factors research in the maritime domain. Developed models can be utilised by ship designers to understand the effect of noise levels on human wellbeing and performance on board ships. Therefore ships can be designed in a more human oriented way. Limitations of the developed human response models were discussed. Suggestions were made for the researcher who would like to further the research in this area.

Chapter 12. CONCLUSION

12.1 Chapter Overview

This chapter summarises the overall conclusions of this PhD study.

12.2 Conclusions

The research conducted in this PhD study researched the effects of noise on human performance and wellbeing on board commercial marine vessels. In this research study development of successful human response models to shipboard noise were achieved. The developed human response models are the first of an example available in maritime domain.

Following are bullet points summarise the overall concluding comments of the author;

- Assessments of current situation on board tanker vessels showed that crew members' (especially crew who work near engine areas) health under risk (Table 6-8 and Table 6-10). So more stringent noise limits should be enforced. Moreover, a noise exposure tool (Figure 6-6) was developed which can be used to predict the noise exposure levels of the crew based on their work patterns. In this was any hazardous noise exposure can be identified in advance and mitigations can be applied.
- Results of controlled experiments conducted in ship bridge simulators revealed the significant relationships between the noise exposure and human performance Following factors were found to have significant relationships with the noise exposure;
- It was also demonstrated that human response to noise is not only affected by physical characteristics of the noise but also individual differences of the human requires to be considered.
- Innovative human response models to noise were developed through binomial logistic regression. The models estimate the probability of an

individual to get annoyed by the given noise level for the maritime domain. Models, when applied at global level, can also predict the percentage of people likely to get annoyed or adversely affected by the noise on board ships.

- Both experimental research in a ship bridge simulator (Chapter 7), and the developed models (Chapter 9) proved that gender is influencing the human response to noise. Results show those females are more sensitive to noise than the male.
- Testing the developed human response models on the current noise standards show that, more stringent noise limits are needed to achieve desired levels of comfort and performance as defined in Chapter 10.

12.3 Chapter Summary

This chapter summarised the concluding comments of the author about this PhD study.

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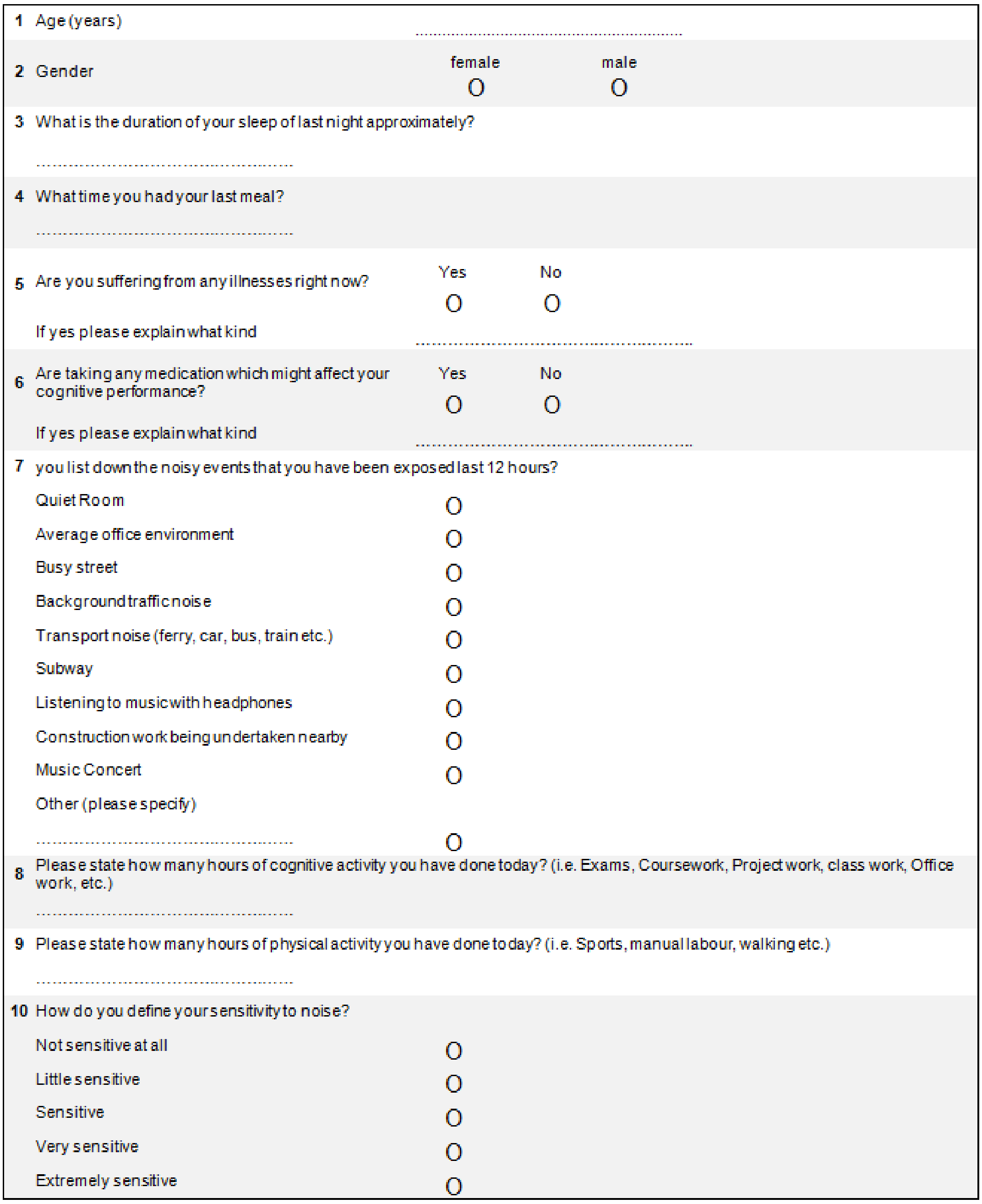
APPENDIX A

A-1: Questionnaire for Noise Experiments in Ship Bridge Simulators

PART A



1 Age (years) ....

2 Gender — female ○ male ○

3 What is the duration of your sleep of last night approximately?

....

4 What time you had your last meal?

....

5 Are you suffering from any illnesses right now? Yes ○ No ○

If yes please explain what kind ....

6 Are taking any medication which might affect your cognitive performance? Yes ○ No ○

If yes please explain what kind ....

7 you list down the noisy events that you have been exposed last 12 hours?

Quiet Room ○
Average office environment ○
Busy street ○
Background traffic noise ○
Transport noise (ferry, car, bus, train etc.) ○
Subway ○
Listening to music with headphones ○
Construction work being undertaken nearby ○
Music Concert ○
Other (please specify)
.... ○

8 Please state how many hours of cognitive activity you have done today? (i.e. Exams, Coursework, Project work, class work, Office work, etc.)

....

9 Please state how many hours of physical activity you have done today? (i.e. Sports, manual labour, walking etc.)

....

10 How do you define your sensitivity to noise?

Not sensitive at all ○
Little sensitive ○
Sensitive ○
Very sensitive ○
Extremely sensitive ○

PART B

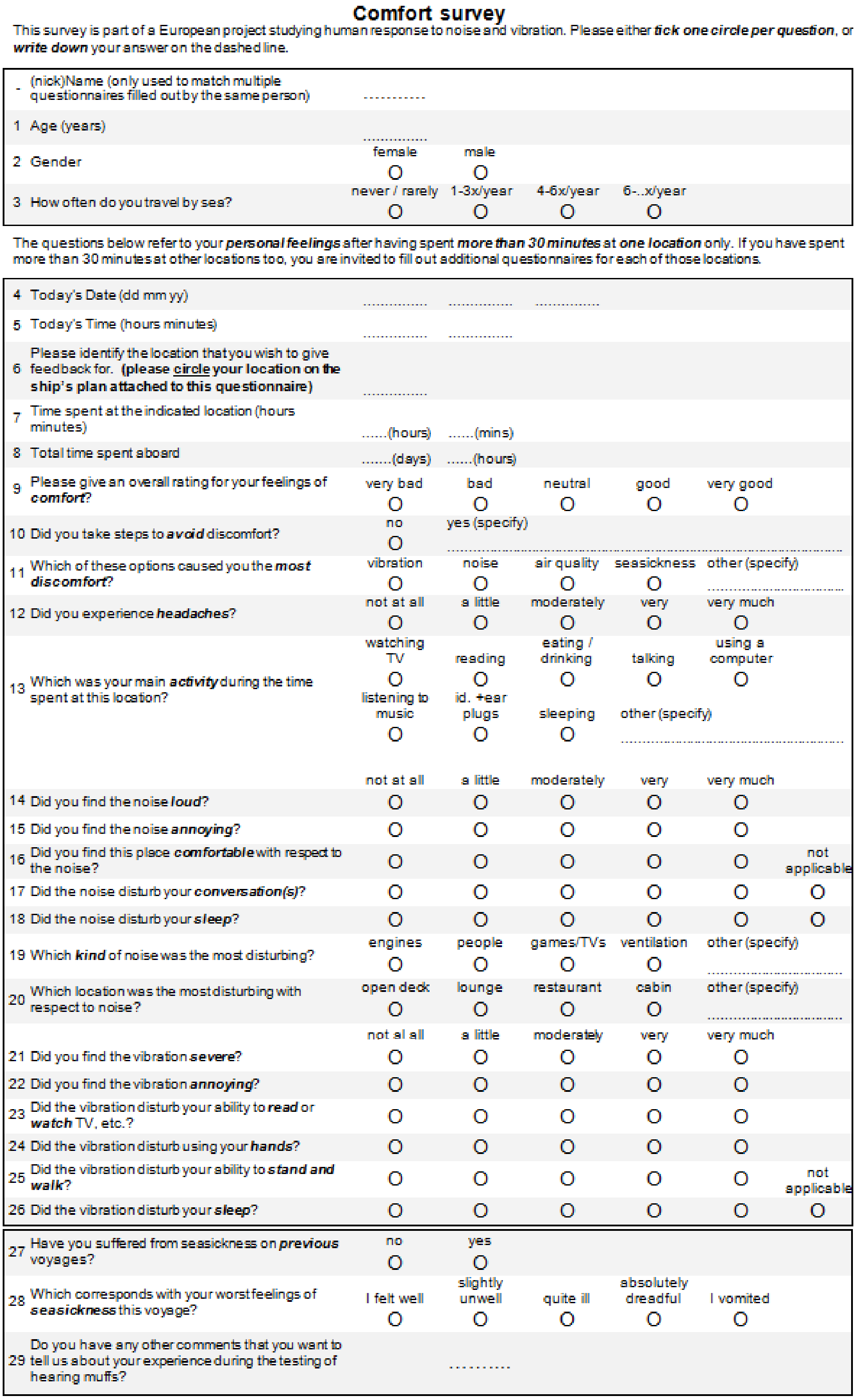
11	Which experiment set have you just completed?	Set 1 ○		Set 2 ○		Set 3 ○
		I totally disagree	Slightly disagree	Neutral	Slightly agree	Totally agree
12	During the Experiments I felt annoyed	○	○	○	○	○
13	During the Experiments I felt stressed	○	○	○	○	○
14	During the experiment (sometimes) I had difficulty to concentrate.	○	○	○	○	○
15	After the experiments I feel tired (the task was exhausting)	○	○	○	○	○

PART C

		Set 1	Set 2	Set 3	All the same
16	Which experiment set did you find easier to achieve? (Explain if possible)	○	○	○	○
17	Which experiment set did you find more annoying? (Explain if possible)	○	○	○	○
18	Which experiment set did you find more tiring? (Explain if possible)	○	○	○	○
19	Which experiment set did you find harder to concentrate? (Explain if possible)	○	○	○	○
20	Noise levels are likely to affect crew performance on board				
	I totally disagree	○			
	Slightly disagree	○			
	Neutral	○			
	Slightly agree	○			
	Totally agree	○			
21	In a real ship the crew will be exposing to the noise continuously rather than a short period of time (different than these experiments that you have joined). What effect do you think, being exposed to these noise levels in a continuous manner will have on crew performance?				

APPENDIX B

B-1: Comfort Survey



Comfort survey

This survey is part of a European project studying human response to noise and vibration. Please either ***tick one circle per question***, or ***write down*** your answer on the dashed line.

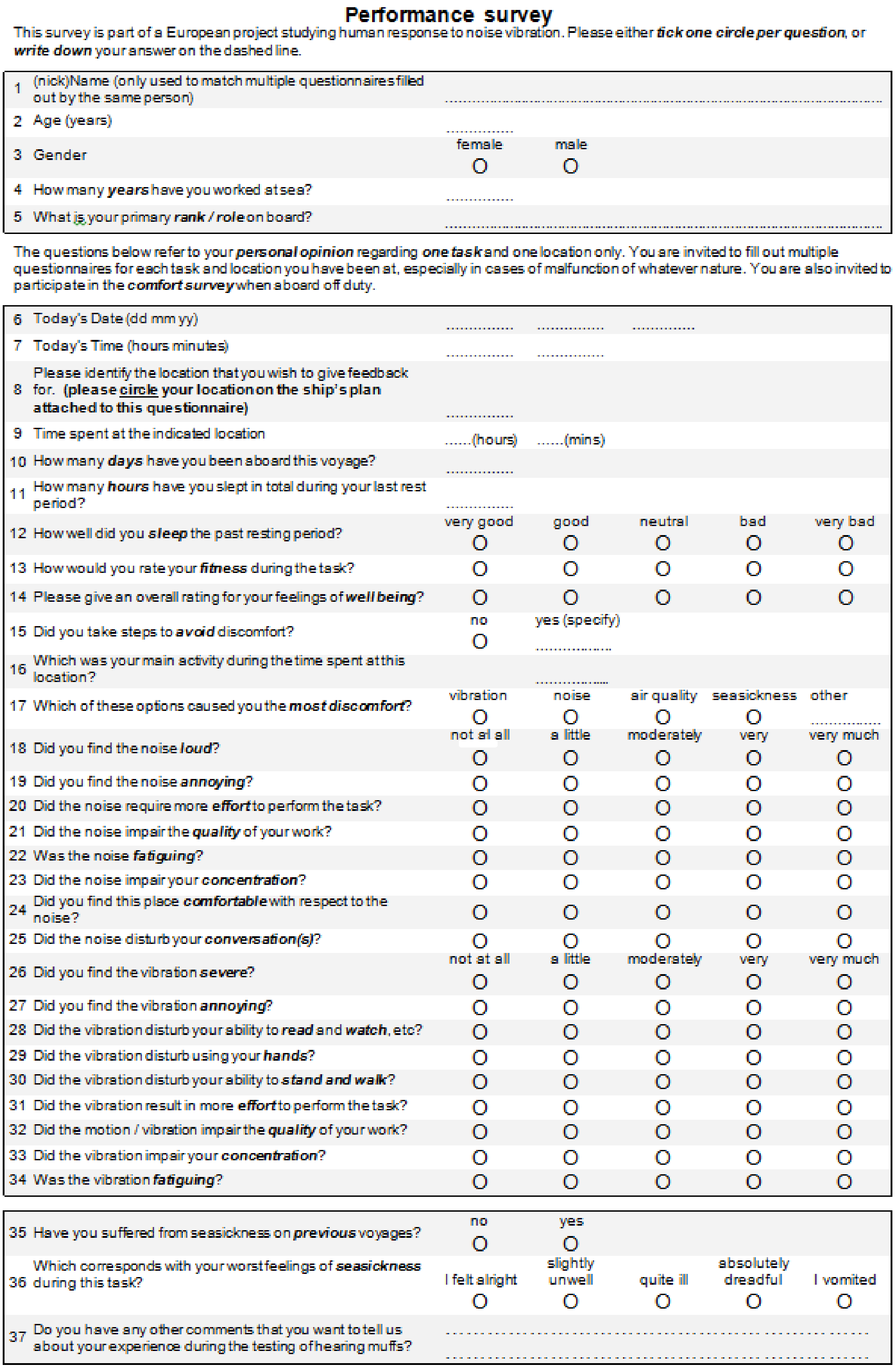
-	(nick)Name (only used to match multiple questionnaires filled out by the same person)	....					
1	Age (years)	....					
2	Gender	female ○	male ○				
3	How often do you travel by sea?	never / rarely ○	1-3x/year ○	4-6x/year ○	6-..x/year ○		

The questions below refer to your ***personal feelings*** after having spent ***more than 30 minutes*** at ***one location*** only. If you have spent more than 30 minutes at other locations too, you are invited to fill out additional questionnaires for each of those locations.

4	Today's Date (dd mm yy)	....	....	....			
5	Today's Time (hours minutes)	....	....				
6	Please identify the location that you wish to give feedback for. **(please circle your location on the ship's plan attached to this questionnaire)**	....					
7	Time spent at the indicated location (hours minutes)	......(hours)	......(mins)				
8	Total time spent aboard	.......(days)	......(hours)				
9	Please give an overall rating for your feelings of ***comfort?***	very bad ○	bad ○	neutral ○	good ○	very good ○	
10	Did you take steps to ***avoid*** discomfort?	no ○	yes (specify)				
11	Which of these options caused you the ***most discomfort?***	vibration ○	noise ○	air quality ○	seasickness ○	other (specify)	
12	Did you experience ***headaches***?	not at all ○	a little ○	moderately ○	very ○	very much ○	
13	Which was your main ***activity*** during the time spent at this location?	watching TV ○	reading ○	eating / drinking ○	talking ○	using a computer ○	
		listening to music ○	id. +ear plugs ○	sleeping ○	other (specify)		
		not at all	a little	moderately	very	very much	
14	Did you find the noise ***loud***?	○	○	○	○	○	
15	Did you find the noise ***annoying***?	○	○	○	○	○	
16	Did you find this place ***comfortable*** with respect to the noise?	○	○	○	○	○	not applicable
17	Did the noise disturb your ***conversation(s)***?	○	○	○	○	○	○
18	Did the noise disturb your ***sleep***?	○	○	○	○	○	○
19	Which ***kind*** of noise was the most disturbing?	engines ○	people ○	games/TVs ○	ventilation ○	other (specify)	
20	Which location was the most disturbing with respect to noise?	open deck ○	lounge ○	restaurant ○	cabin ○	other (specify)	
		not al all	a little	moderately	very	very much	
21	Did you find the vibration ***severe***?	○	○	○	○	○	
22	Did you find the vibration ***annoying?***	○	○	○	○	○	
23	Did the vibration disturb your ability to ***read*** or ***watch*** TV, etc.?	○	○	○	○	○	
24	Did the vibration disturb using your ***hands***?	○	○	○	○	○	
25	Did the vibration disturb your ability to ***stand and walk***?	○	○	○	○	○	not applicable
26	Did the vibration disturb your ***sleep***?	○	○	○	○	○	○

27	Have you suffered from seasickness on ***previous*** voyages?	no ○	yes ○			
28	Which corresponds with your worst feelings of ***seasickness*** this voyage?	I felt well ○	slightly unwell ○	quite ill ○	absolutely dreadful ○	I vomited ○
29	Do you have any other comments that you want to tell us about your experience during the testing of hearing muffs?		....			

B-2: Performance Survey



Performance survey

This survey is part of a European project studying human response to noise vibration. Please either ***tick one circle per question***, or ***write down*** your answer on the dashed line.

1	(nick)Name (only used to match multiple questionnaires filled out by the same person)	....				
2	Age (years)	....				
3	Gender	female ○	male ○			
4	How many ***years*** have you worked at sea?	....				
5	What is your primary ***rank / role*** on board?	....				

The questions below refer to your ***personal opinion*** regarding ***one task*** and one location only. You are invited to fill out multiple questionnaires for each task and location you have been at, especially in cases of malfunction of whatever nature. You are also invited to participate in the ***comfort survey*** when aboard off duty.

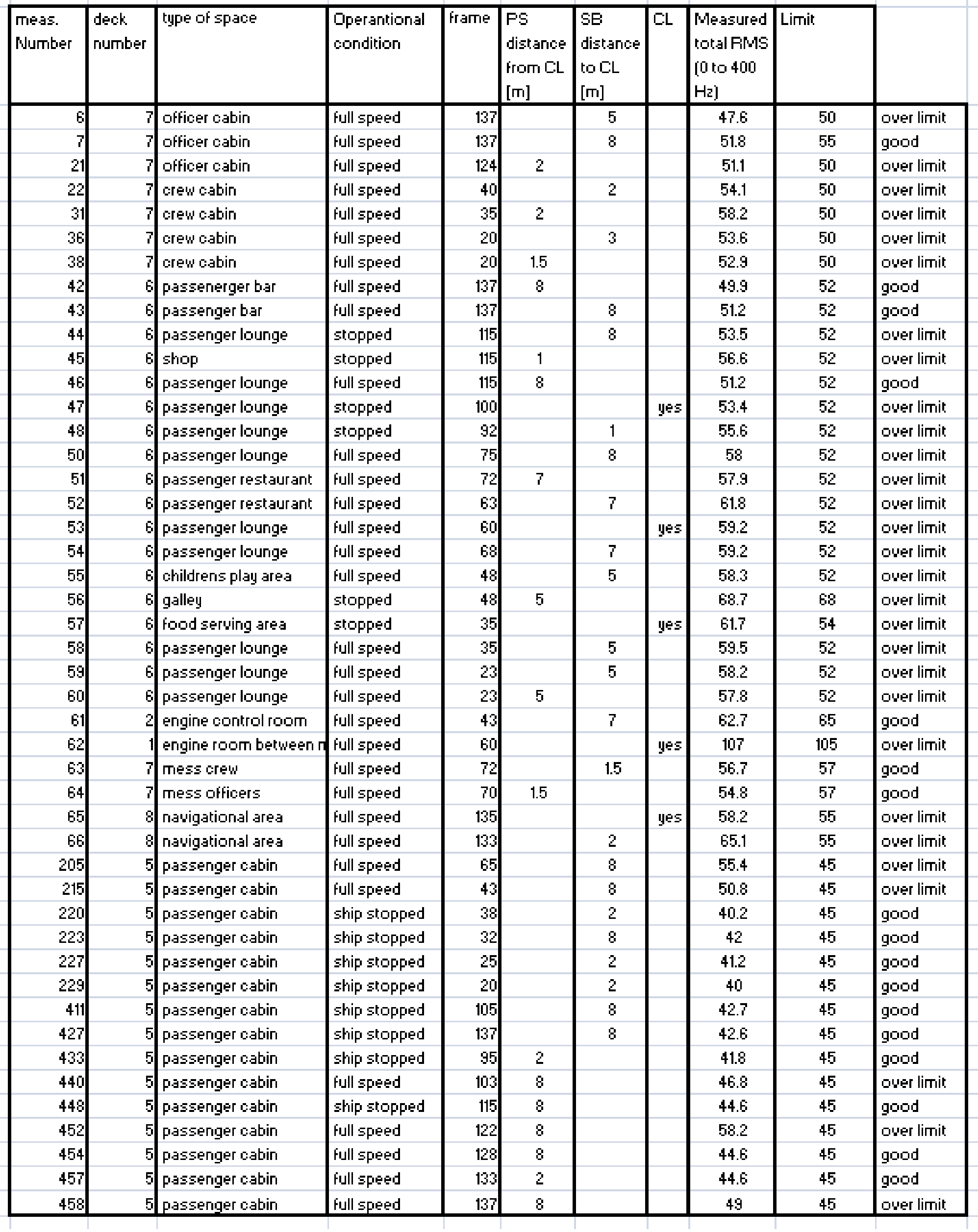
6	Today's Date (dd mm yy)	....	....	....		
7	Today's Time (hours minutes)	....	....			
8	Please identify the location that you wish to give feedback for. **(please circle your location on the ship's plan attached to this questionnaire)**	....				
9	Time spent at the indicated location	......(hours)	......(mins)			
10	How many ***days*** have you been aboard this voyage?	....				
11	How many ***hours*** have you slept in total during your last rest period?	....				
12	How well did you ***sleep*** the past resting period?	very good ○	good ○	neutral ○	bad ○	very bad ○
13	How would you rate your ***fitness*** during the task?	○	○	○	○	○
14	Please give an overall rating for your feelings of ***well being***?	○	○	○	○	○
15	Did you take steps to ***avoid*** discomfort?	no ○	yes (specify)			
16	Which was your main activity during the time spent at this location?		....			
17	Which of these options caused you the ***most discomfort***?	vibration ○	noise ○	air quality ○	seasickness ○	other ....
18	Did you find the noise ***loud***?	not at all ○	a little ○	moderately ○	very ○	very much ○
19	Did you find the noise ***annoying***?	○	○	○	○	○
20	Did the noise require more ***effort*** to perform the task?	○	○	○	○	○
21	Did the noise impair the ***quality*** of your work?	○	○	○	○	○
22	Was the noise ***fatiguing***?	○	○	○	○	○
23	Did the noise impair your ***concentration***?	○	○	○	○	○
24	Did you find this place ***comfortable*** with respect to the noise?	○	○	○	○	○
25	Did the noise disturb your ***conversation(s)***?	○	○	○	○	○
26	Did you find the vibration ***severe***?	not at all ○	a little ○	moderately ○	very ○	very much ○
27	Did you find the vibration ***annoying***?	○	○	○	○	○
28	Did the vibration disturb your ability to ***read*** and ***watch***, etc?	○	○	○	○	○
29	Did the vibration disturb using your ***hands***?	○	○	○	○	○
30	Did the vibration disturb your ability to ***stand and walk***?	○	○	○	○	○
31	Did the vibration result in more ***effort*** to perform the task?	○	○	○	○	○
32	Did the motion / vibration impair the ***quality*** of your work?	○	○	○	○	○
33	Did the vibration impair your ***concentration***?	○	○	○	○	○
34	Was the vibration ***fatiguing***?	○	○	○	○	○

35	Have you suffered from seasickness on ***previous*** voyages?	no ○	yes ○			
36	Which corresponds with your worst feelings of ***seasickness*** during this task?	I felt alright ○	slightly unwell ○	quite ill ○	absolutely dreadful ○	I vomited ○
37	Do you have any other comments that you want to tell us about your experience during the testing of hearing muffs?	....				

APPENDIX C

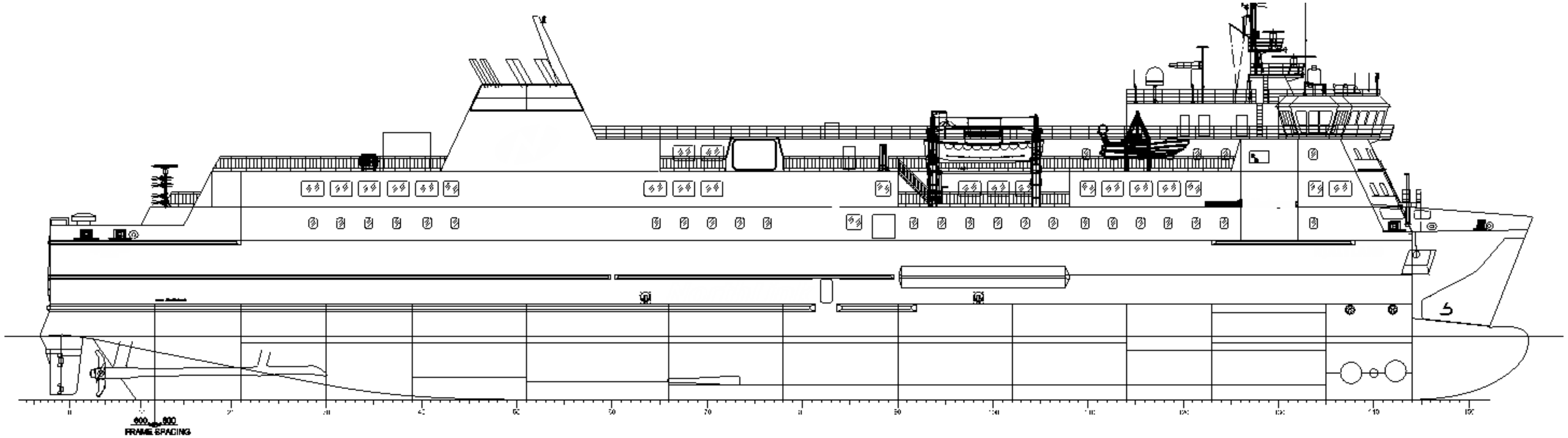
C-1: Summary of Noise Data

Following tables summarise the noise data collected from the Passenger 5 measurement campaign.

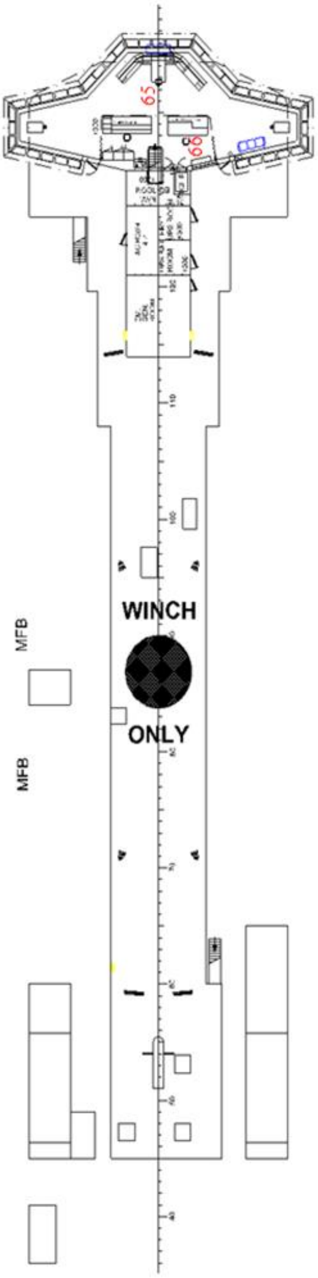


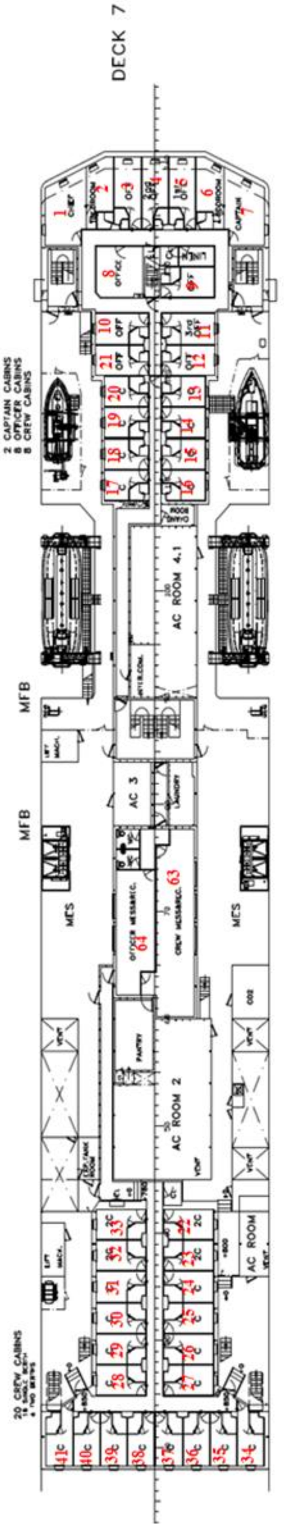
meas. Number	deck number	type of space	Operantional condition	frame	PS distance from CL [m]	SB distance to CL [m]	CL	Measured total RMS (0 to 400 Hz)	Limit	
6	7	officer cabin	full speed	137		5		47.6	50	over limit
7	7	officer cabin	full speed	137		8		51.8	55	good
21	7	officer cabin	full speed	124	2			51.1	50	over limit
22	7	crew cabin	full speed	40		2		54.1	50	over limit
31	7	crew cabin	full speed	35	2			58.2	50	over limit
36	7	crew cabin	full speed	20		3		53.6	50	over limit
38	7	crew cabin	full speed	20	1.5			52.9	50	over limit
42	6	passenerger bar	full speed	137	8			49.9	52	good
43	6	passenger bar	full speed	137		8		51.2	52	good
44	6	passenger lounge	stopped	115		8		53.5	52	over limit
45	6	shop	stopped	115	1			56.6	52	over limit
46	6	passenger lounge	full speed	115	8			51.2	52	good
47	6	passenger lounge	stopped	100			yes	53.4	52	over limit
48	6	passenger lounge	stopped	92		1		55.6	52	over limit
50	6	passenger lounge	full speed	75		8		58	52	over limit
51	6	passenger restaurant	full speed	72	7			57.9	52	over limit
52	6	passenger restaurant	full speed	63		7		61.8	52	over limit
53	6	passenger lounge	full speed	60			yes	59.2	52	over limit
54	6	passenger lounge	full speed	68		7		59.2	52	over limit
55	6	childrens play area	full speed	48		5		58.3	52	over limit
56	6	galley	stopped	48	5			68.7	68	over limit
57	6	food serving area	stopped	35			yes	61.7	54	over limit
58	6	passenger lounge	full speed	35		5		59.5	52	over limit
59	6	passenger lounge	full speed	23		5		58.2	52	over limit
60	6	passenger lounge	full speed	23	5			57.8	52	over limit
61	2	engine control room	full speed	43		7		62.7	65	good
62	1	engine room between	full speed	60			yes	107	105	over limit
63	7	mess crew	full speed	72		1.5		56.7	57	good
64	7	mess officers	full speed	70	1.5			54.8	57	good
65	8	navigational area	full speed	135			yes	58.2	55	over limit
66	8	navigational area	full speed	133		2		65.1	55	over limit
205	5	passenger cabin	full speed	65		8		55.4	45	over limit
215	5	passenger cabin	full speed	43		8		50.8	45	over limit
220	5	passenger cabin	ship stopped	38		2		40.2	45	good
223	5	passenger cabin	ship stopped	32		8		42	45	good
227	5	passenger cabin	ship stopped	25		2		41.2	45	good
229	5	passenger cabin	ship stopped	20		2		40	45	good
411	5	passenger cabin	ship stopped	105		8		42.7	45	good
427	5	passenger cabin	ship stopped	137		8		42.6	45	good
433	5	passenger cabin	ship stopped	95	2			41.8	45	good
440	5	passenger cabin	full speed	103	8			46.8	45	over limit
448	5	passenger cabin	ship stopped	115	8			44.6	45	good
452	5	passenger cabin	full speed	122	8			58.2	45	over limit
454	5	passenger cabin	full speed	128	8			44.6	45	good
457	5	passenger cabin	full speed	133	2			44.6	45	good
458	5	passenger cabin	full speed	137	8			49	45	over limit

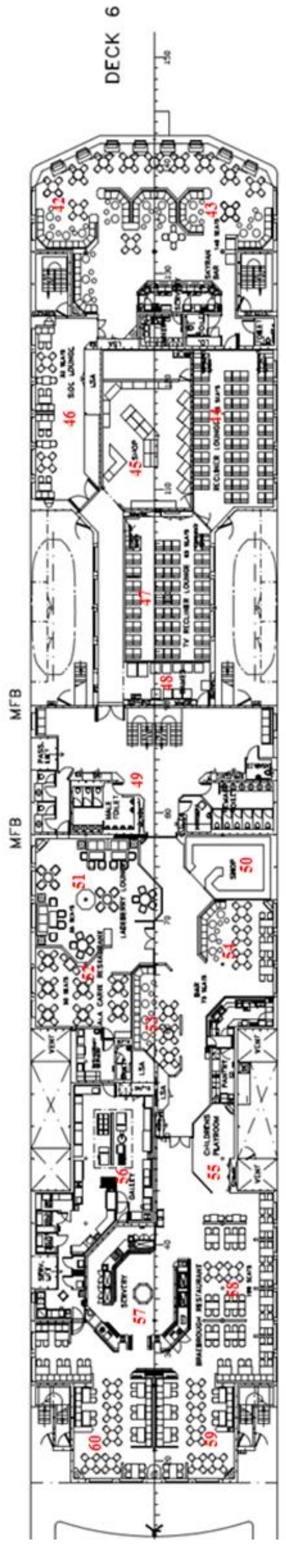
C-2: Sample Ship Plan



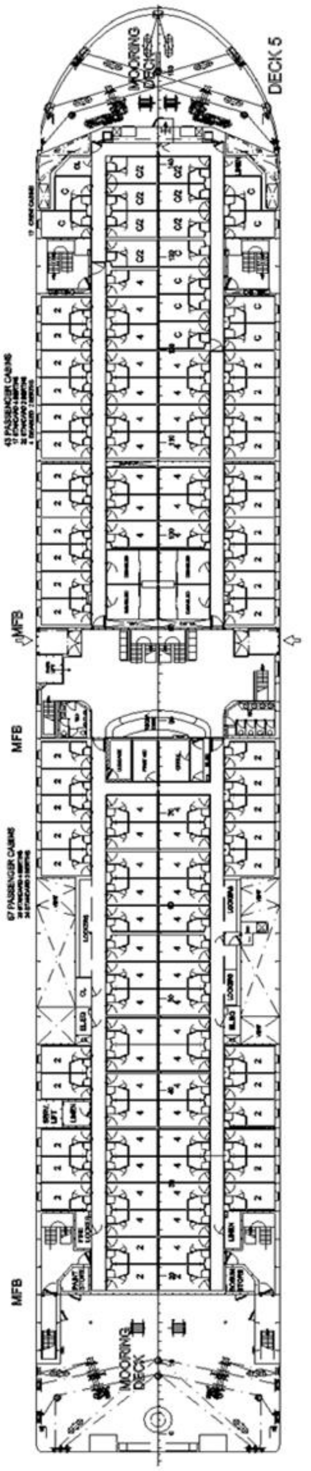
C-3: Measurement Positions

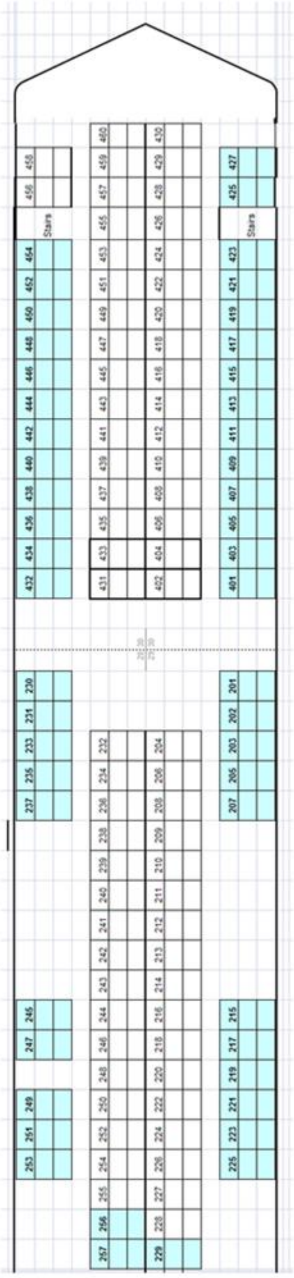




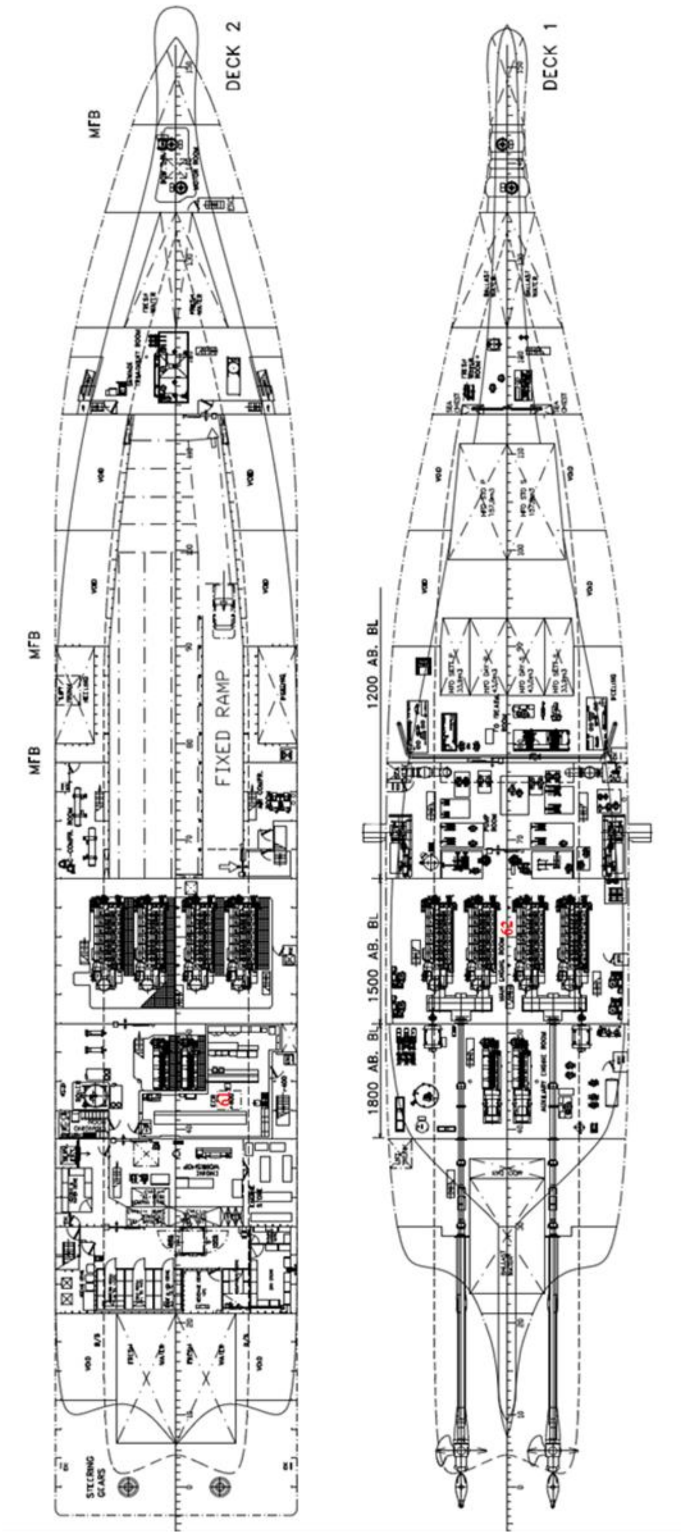


C-4: Measurement Positions



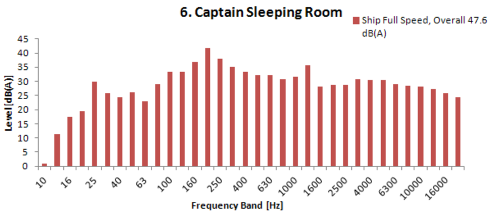


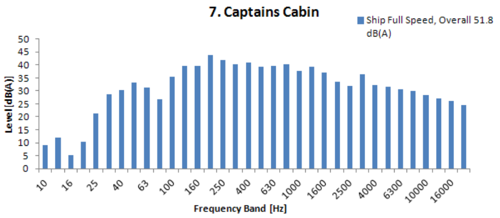
C-5: Measurement Positions

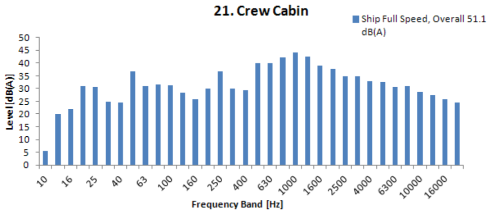


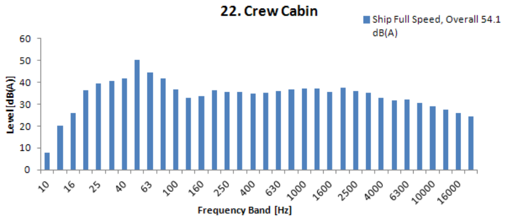
C-6: Noise Spectra

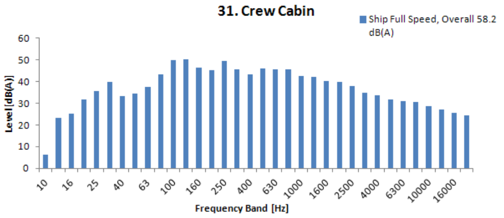
All the graphs below display the noise spectra for the corresponding measurement positions.

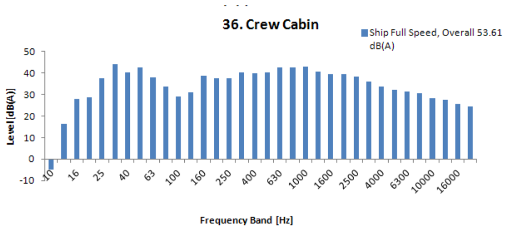

6. Captain Sleeping Room

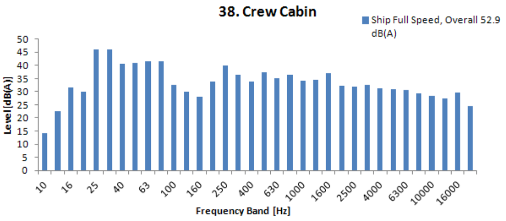

7. Captains Cabin

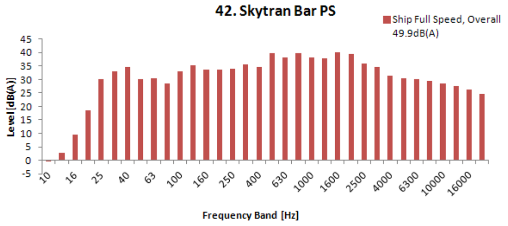

21. Crew Cabin

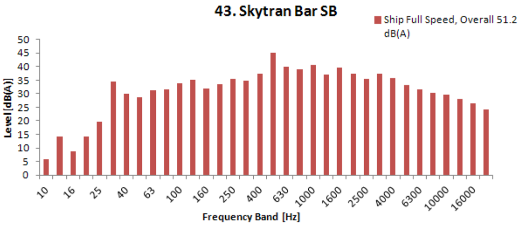

22. Crew Cabin

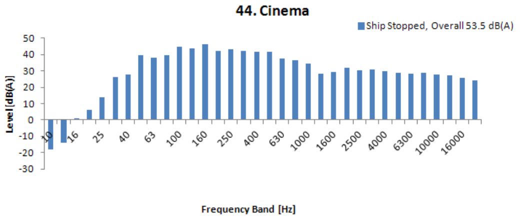

31. Crew Cabin

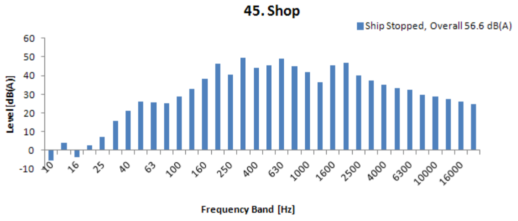

36. Crew Cabin

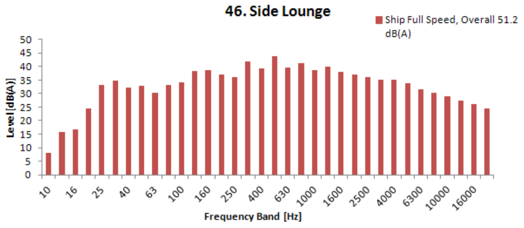

38. Crew Cabin

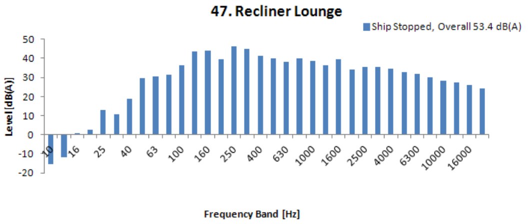

42. Skytran Bar PS

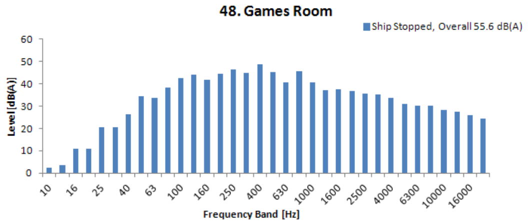

43. Skytran Bar SB

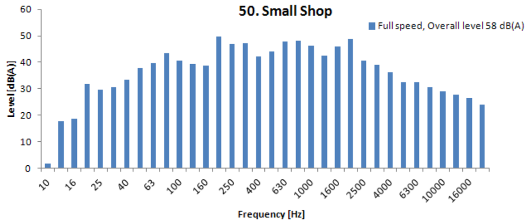

44. Cinema

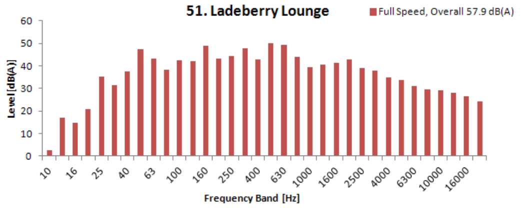

45. Shop

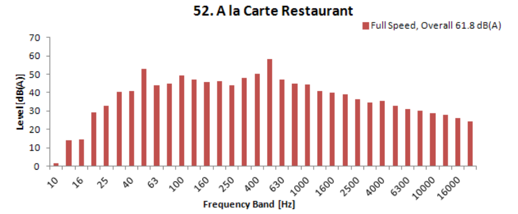

46. Side Lounge

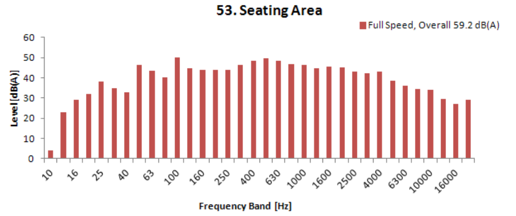

47. Recliner Lounge
Ship Stopped, Overall 53.4 dB(A)
Level [dB(A)]
50
40
30
20
10
0
-10
-20
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

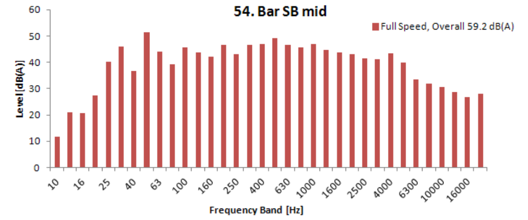

48. Games Room
Ship Stopped, Overall 55.6 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

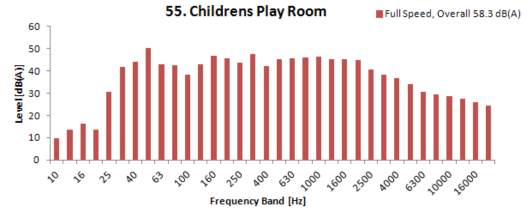

50. Small Shop
Full speed, Overall level 58 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency [Hz]

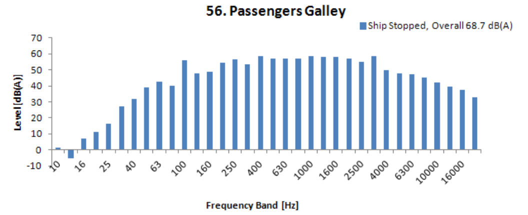

51. Ladeberry Lounge
Full Speed, Overall 57.9 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

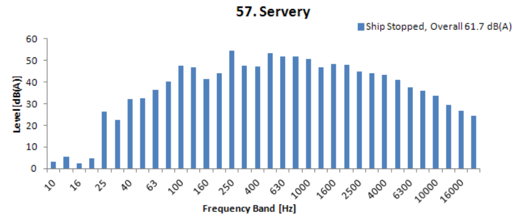

52. A la Carte Restaurant
Full Speed, Overall 61.8 dB(A)
Level [dB(A)]
70
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

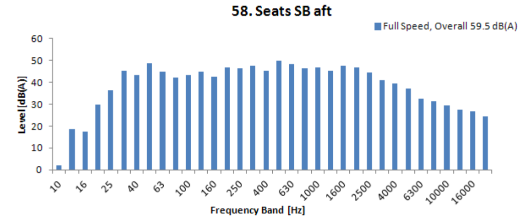

53. Seating Area
Full Speed, Overall 59.2 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

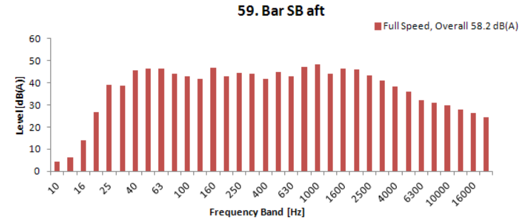

54. Bar SB mid
Full Speed, Overall 59.2 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

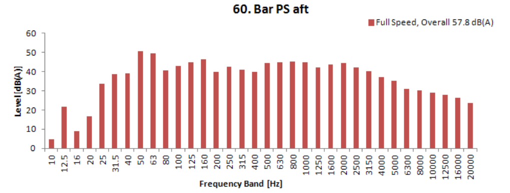

55. Childrens Play Room
Full Speed, Overall 58.3 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

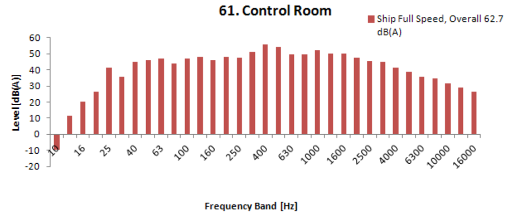

56. Passengers Galley
Ship Stopped, Overall 68.7 dB(A)
Level [dB(A)]
70
60
50
40
30
20
10
0
-10
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

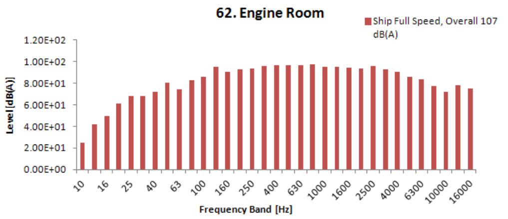

57. Servery
Ship Stopped, Overall 61.7 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

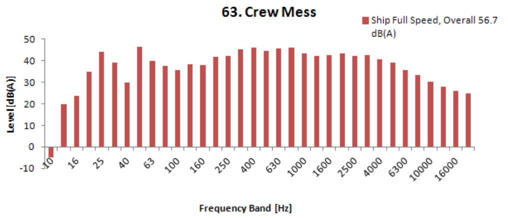

58. Seats SB aft
Full Speed, Overall 59.5 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

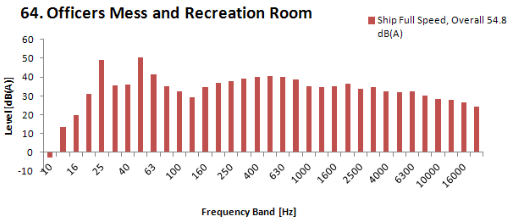

59. Bar SB aft
Full Speed, Overall 58.2 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

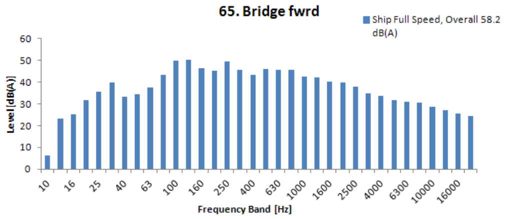

60. Bar PS aft
Full Speed, Overall 57.8 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
Frequency Band [Hz]

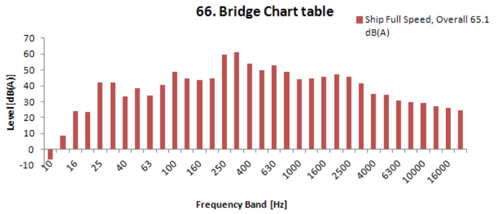

61. Control Room
Ship Full Speed, Overall 62.7 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
-10
-20
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

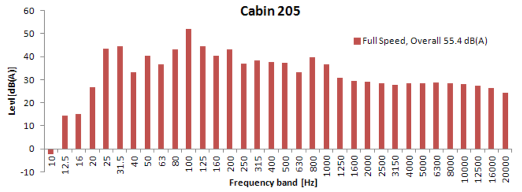

62. Engine Room
Ship Full Speed, Overall 107 dB(A)
Level [dB(A)]
1.20E+02
1.00E+02
8.00E+01
6.00E+01
4.00E+01
2.00E+01
0.00E+00
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

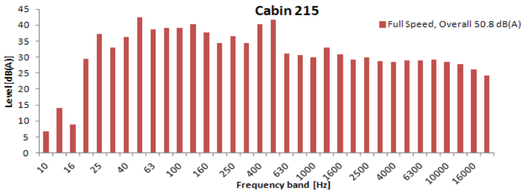

63. Crew Mess
Ship Full Speed, Overall 56.7 dB(A)
Level [dB(A)]
50
40
30
20
10
0
-10
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

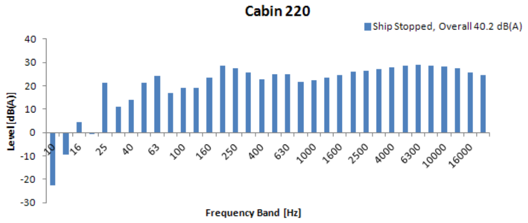

64. Officers Mess and Recreation Room
Ship Full Speed, Overall 54.8 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
-10
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

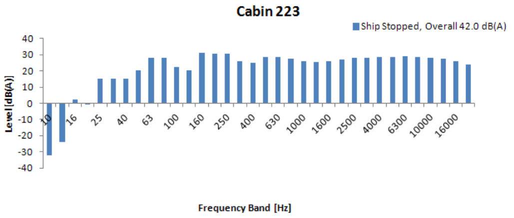

65. Bridge fwrd
Ship Full Speed, Overall 58.2 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

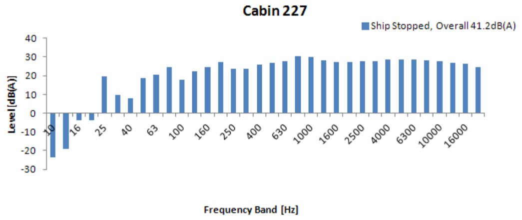

66. Bridge Chart table
Ship Full Speed, Overall 65.1 dB(A)
Level [dB(A)]
70
60
50
40
30
20
10
0
-10
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

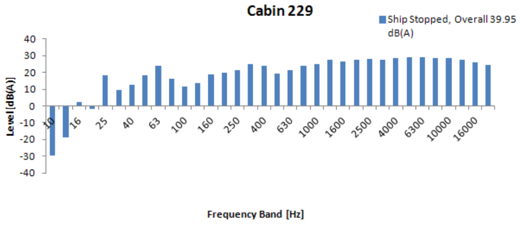

Cabin 205
Full Speed, Overall 55.4 dB(A)
Level [dB(A)]
60
50
40
30
20
10
0
-10
10
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
Frequency band [Hz]

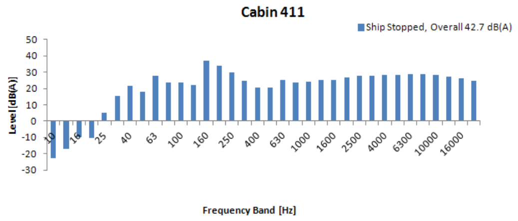

Cabin 215
Full Speed, Overall 50.8 dB(A)
Level [dB(A)]
45
40
35
30
25
20
15
10
5
0
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency band [Hz]

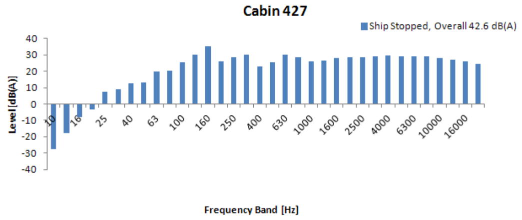

Cabin 220
Ship Stopped, Overall 40.2 dB(A)
Level [dB(A)]
40
30
20
10
0
-10
-20
-30
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

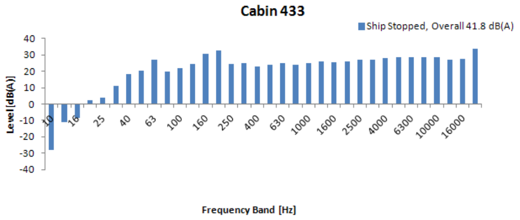

Cabin 223
Ship Stopped, Overall 42.0 dB(A)
Level [dB(A)]
40
30
20
10
0
-10
-20
-30
-40
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

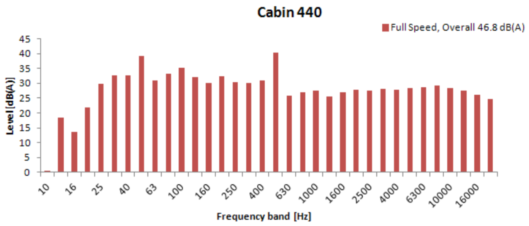

Cabin 227
Ship Stopped, Overall 41.2dB(A)
Level [dB(A)]
40
30
20
10
0
-10
-20
-30
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

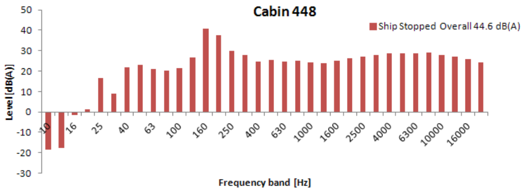

Cabin 229
Ship Stopped, Overall 39.95 dB(A)
Level [dB(A)]
40
30
20
10
0
-10
-20
-30
-40
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

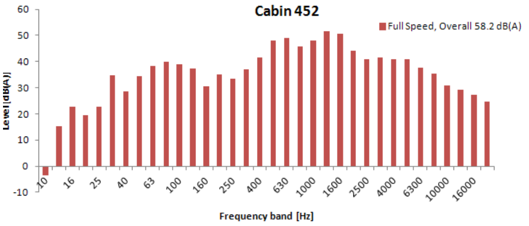

Cabin 411
Ship Stopped, Overall 42.7 dB(A)
Level [dB(A)]
50
40
30
20
10
0
-10
-20
-30
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

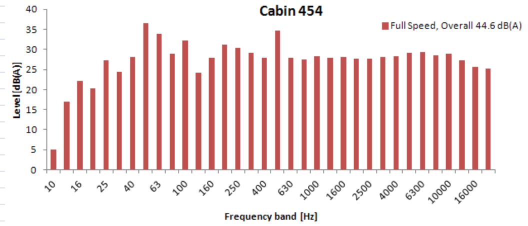

Cabin 427
Ship Stopped, Overall 42.6 dB(A)
Level [dB(A)]
40
30
20
10
0
-10
-20
-30
-40
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

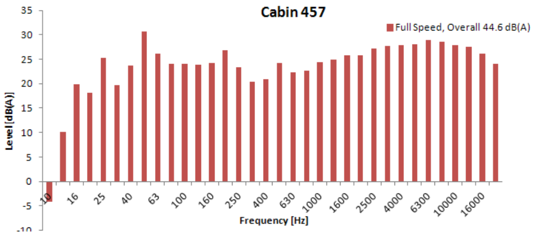

Cabin 433
Ship Stopped, Overall 41.8 dB(A)
Level [dB(A)]
40
30
20
10
0
-10
-20
-30
-40
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency Band [Hz]

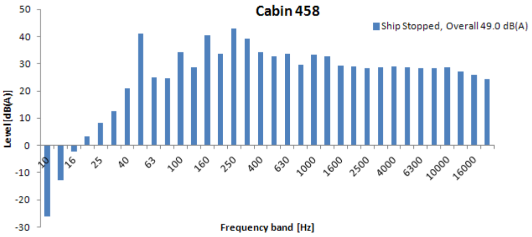

Cabin 440
Full Speed, Overall 46.8 dB(A)
Level [dB(A)]
0
5
10
15
20
25
30
35
40
45
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency band [Hz]


Cabin 448
Ship Stopped Overall 44.6 dB(A)
Level [dB(A)]
-30
-20
-10
0
10
20
30
40
50
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency band [Hz]


Cabin 452
Full Speed, Overall 58.2 dB(A)
Level [dB(A)]
-10
0
10
20
30
40
50
60
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency band [Hz]


Cabin 454
Full Speed, Overall 44.6 dB(A)
Level [dB(A)]
0
5
10
15
20
25
30
35
40
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency band [Hz]


Cabin 457
Full Speed, Overall 44.6 dB(A)
Level [dB(A)]
-10
-5
0
5
10
15
20
25
30
35
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency [Hz]


Cabin 458
Ship Stopped, Overall 49.0 dB(A)
Level [dB(A)]
-30
-20
-10
0
10
20
30
40
50
10
16
25
40
63
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Frequency band [Hz]

APPENDIX D

D-1: Output Tables for ANOVA (Comfort Questionnaires)

Results of ANOVA output tables from SPSS statistical software.

ANOVA

O1.Comfort Feelings - Age

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	29.750	3	9.917	11.906	.000
Within Groups	402.299	483	.833		
Total	432.049	486			

ANOVA

N2.Noise Annoyance - Age

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.165	3	1.055	.842	.471
Within Groups	606.311	484	1.253		
Total	609.475	487			

ANOVA

O1.Comfort Feelings - Gender

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11.127	1	11.127	13.010	.000
Within Groups	434.473	508	.855		
Total	445.600	509			

ANOVA

N2.Noise Annoyance - Gender

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.318	1	.318	.256	.613
Within Groups	632.444	508	1.245		
Total	632.763	509			

ANOVA

O1.Comfort Feelings - Exposure Time

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.827	4	.957	1.193	.313
Within Groups	307.111	383	.802		
Total	310.938	387			

ANOVA

N2.Noise Annoyance - Exposure Time

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.895	4	1.724	1.464	.212
Within Groups	447.354	380	1.177		
Total	454.249	384			

D-2: Output Tables for ANOVA (Performance Questionnaires)

ANOVA

O1.Wellbeing feelings - Age

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.651	2	.826	1.199	.304
Within Groups	129.511	188	.689		
Total	131.162	190			

ANOVA

N7.Noise – quality impairment - Age

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.302	2	.151	.124	.883
Within Groups	231.252	190	1.217		
Total	231.554	192			

ANOVA

N2.Noise – annoyance - Age

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.044	2	2.022	1.415	.245
Within Groups	265.765	186	1.429		
Total	269.810	188			

ANOVA

O1.Wellbeing feelings - Gender

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.090	1	3.090	4.345	.038
Within Groups	143.670	202	.711		
Total	146.760	203			

ANOVA

N7.Noise – quality impairment - Gender

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.345	1	5.345	4.355	.038
Within Groups	250.383	204	1.227		
Total	255.728	205			

ANOVA

N2.Noise – annoyance - Gender

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.240	1	7.240	5.074	.025
Within Groups	285.379	200	1.427		
Total	292.619	201			

ANOVA

O1.Wellbeing feelings - Exposure Time

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.543	4	.136	.230	.921
Within Groups	94.451	160	.590		
Total	94.994	164			

ANOVA

N7.Noise – quality impairment - Exposure Time

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.052	4	.513	.456	.768
Within Groups	182.127	162	1.124		
Total	184.180	166			

ANOVA

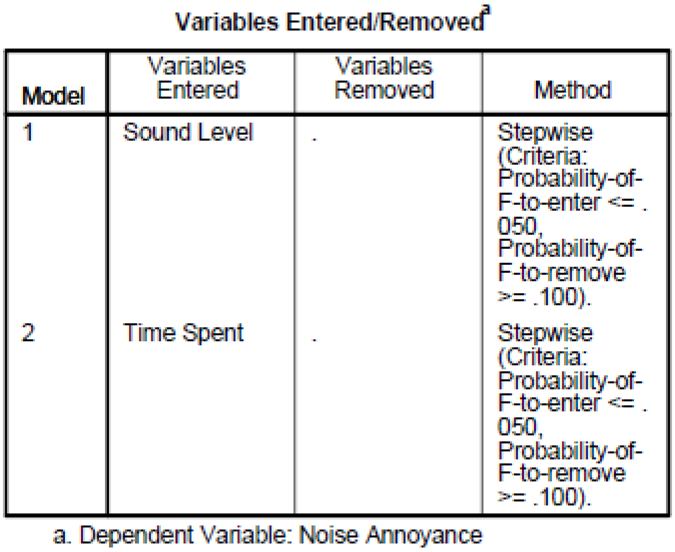
N2.Noise – annoyance - Exposure Time

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.186	4	.796	.597	.665
Within Groups	209.363	157	1.334		
Total	212.549	161			

APPENDIX E

E-1: Multiple Linear Regression Results - Comfort Data (N2)

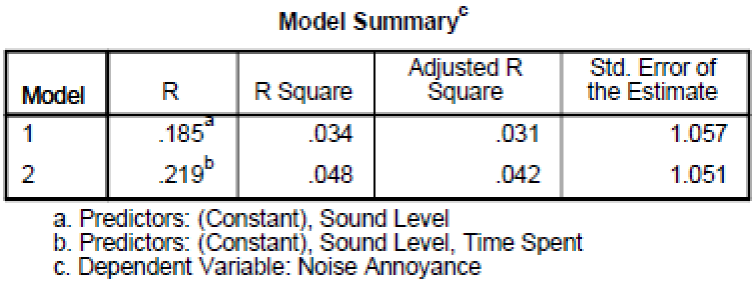
E-1.1: Tables



Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Sound Level	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	Time Spent	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

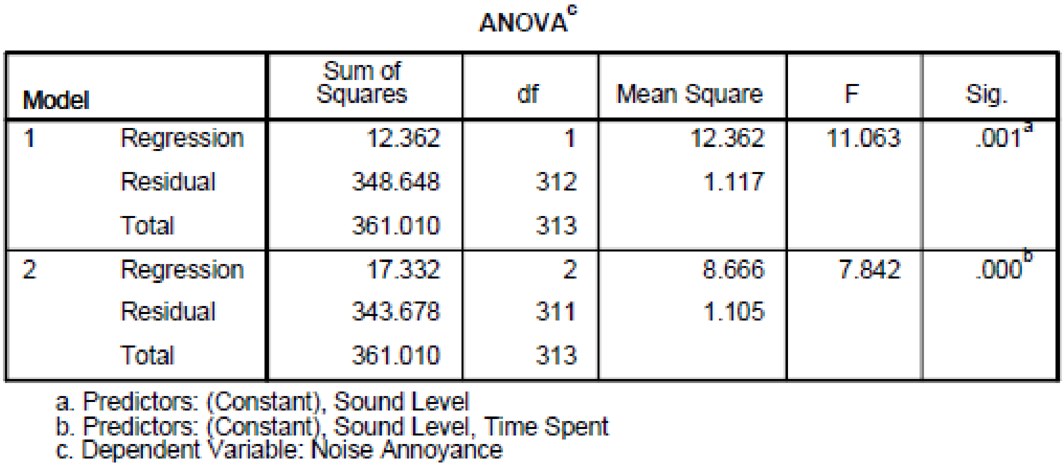
a. Dependent Variable: Noise Annoyance



Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.185[a]	.034	.031	1.057
2	.219[b]	.048	.042	1.051

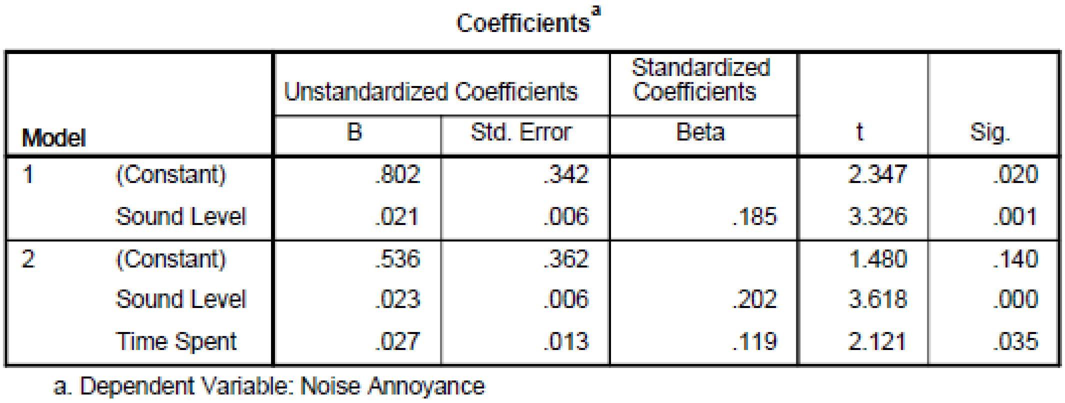
a. Predictors: (Constant), Sound Level
b. Predictors: (Constant), Sound Level, Time Spent
c. Dependent Variable: Noise Annoyance



ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12.362	1	12.362	11.063	.001[a]
	Residual	348.648	312	1.117		
	Total	361.010	313			
2	Regression	17.332	2	8.666	7.842	.000[b]
	Residual	343.678	311	1.105		
	Total	361.010	313			

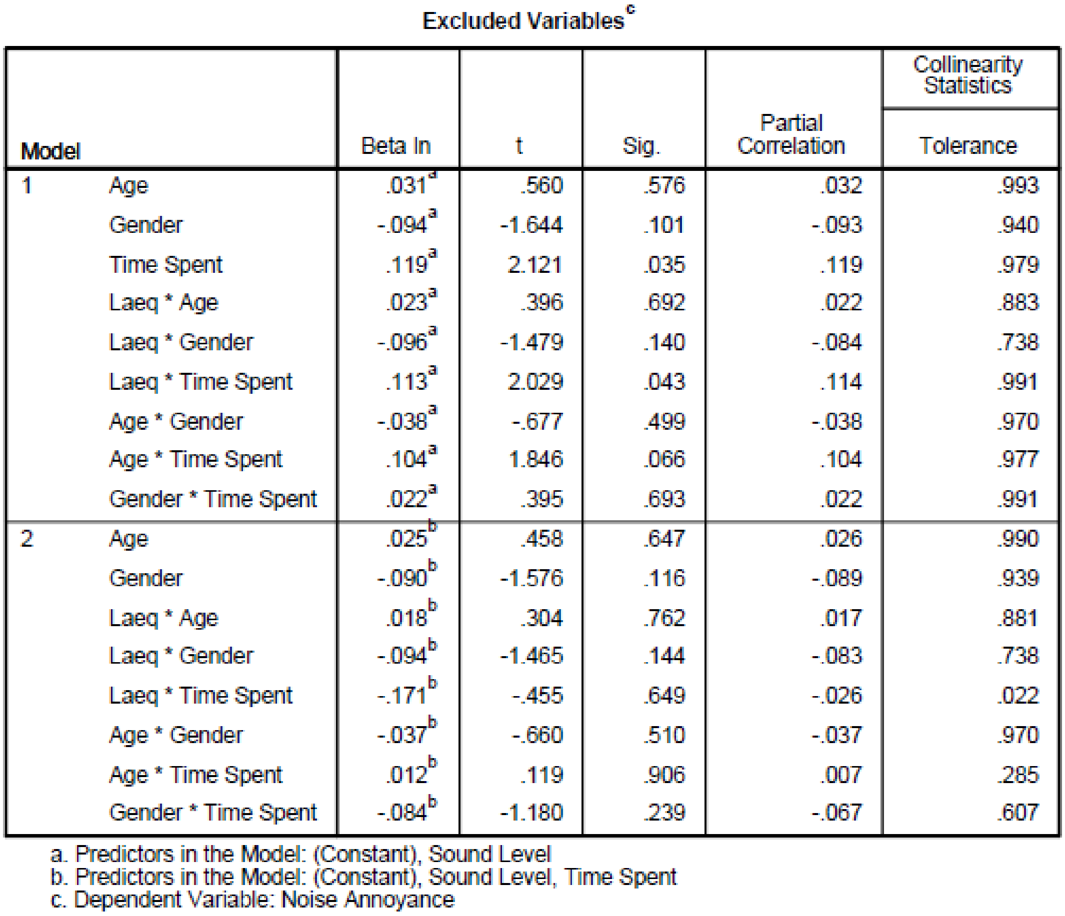
a. Predictors: (Constant), Sound Level
b. Predictors: (Constant), Sound Level, Time Spent
c. Dependent Variable: Noise Annoyance



Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.802	.342		2.347	.020
	Sound Level	.021	.006	.185	3.326	.001
2	(Constant)	.536	.362		1.480	.140
	Sound Level	.023	.006	.202	3.618	.000
	Time Spent	.027	.013	.119	2.121	.035

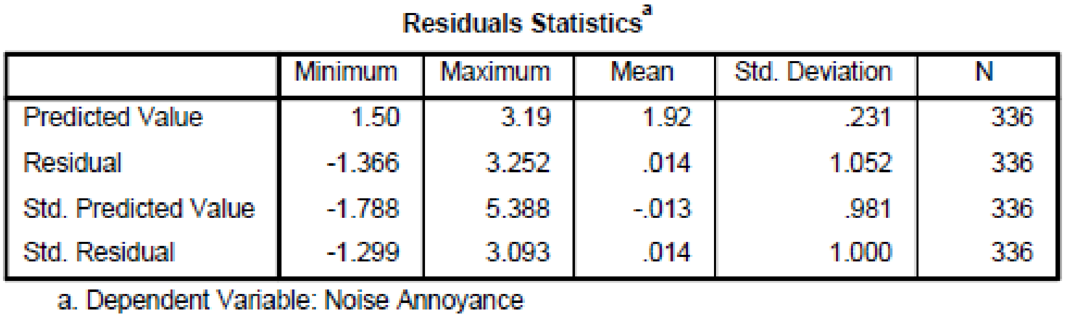
a. Dependent Variable: Noise Annoyance



Excluded Variables[c]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Age	.031[a]	.560	.576	.032	.993
	Gender	-.094[a]	-1.644	.101	-.093	.940
	Time Spent	.119[a]	2.121	.035	.119	.979
	Laeq * Age	.023[a]	.396	.692	.022	.883
	Laeq * Gender	-.096[a]	-1.479	.140	-.084	.738
	Laeq * Time Spent	.113[a]	2.029	.043	.114	.991
	Age * Gender	-.038[a]	-.677	.499	-.038	.970
	Age * Time Spent	.104[a]	1.846	.066	.104	.977
	Gender * Time Spent	.022[a]	.395	.693	.022	.991
2	Age	.025[b]	.458	.647	.026	.990
	Gender	-.090[b]	-1.576	.116	-.089	.939
	Laeq * Age	.018[b]	.304	.762	.017	.881
	Laeq * Gender	-.094[b]	-1.465	.144	-.083	.738
	Laeq * Time Spent	-.171[b]	-.455	.649	-.026	.022
	Age * Gender	-.037[b]	-.660	.510	-.037	.970
	Age * Time Spent	.012[b]	.119	.906	.007	.285
	Gender * Time Spent	-.084[b]	-1.180	.239	-.067	.607

a. Predictors in the Model: (Constant), Sound Level
b. Predictors in the Model: (Constant), Sound Level, Time Spent
c. Dependent Variable: Noise Annoyance

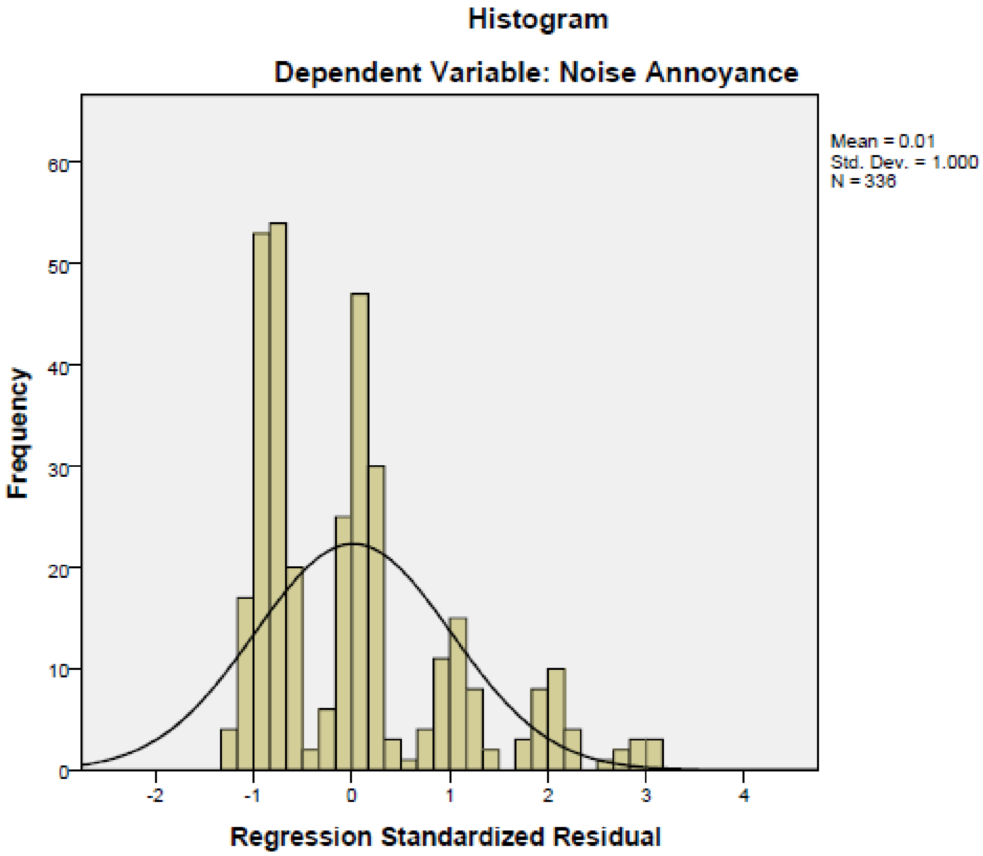


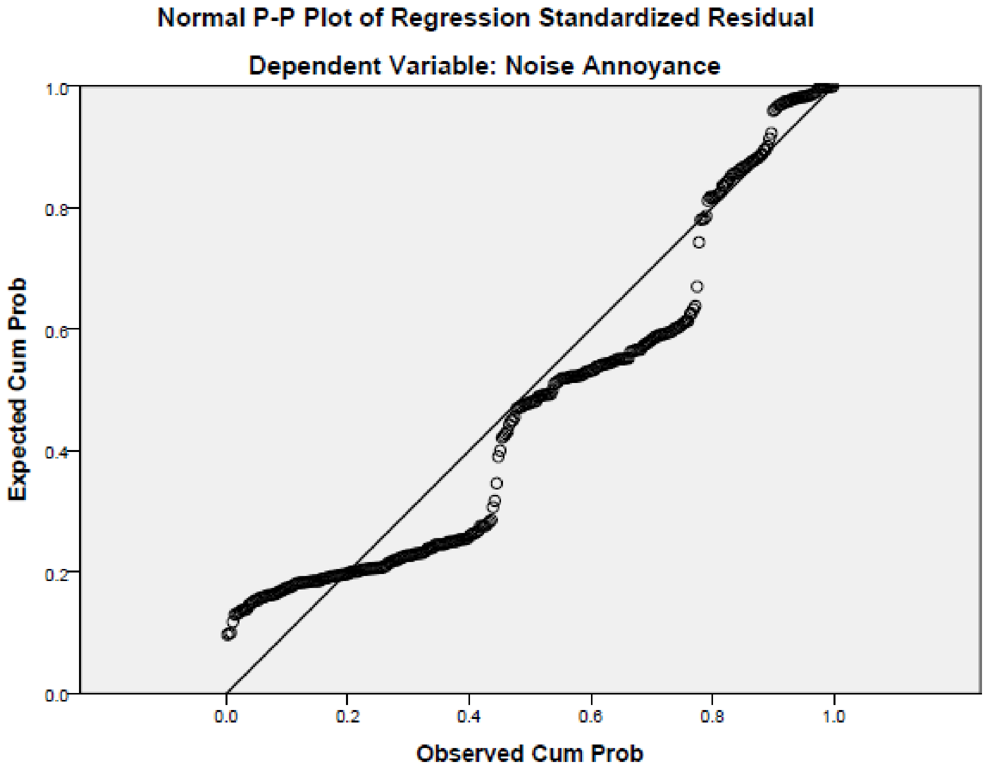
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.50	3.19	1.92	.231	336
Residual	-1.366	3.252	.014	1.052	336
Std. Predicted Value	-1.788	5.388	-.013	.981	336
Std. Residual	-1.299	3.093	.014	1.000	336

a. Dependent Variable: Noise Annoyance

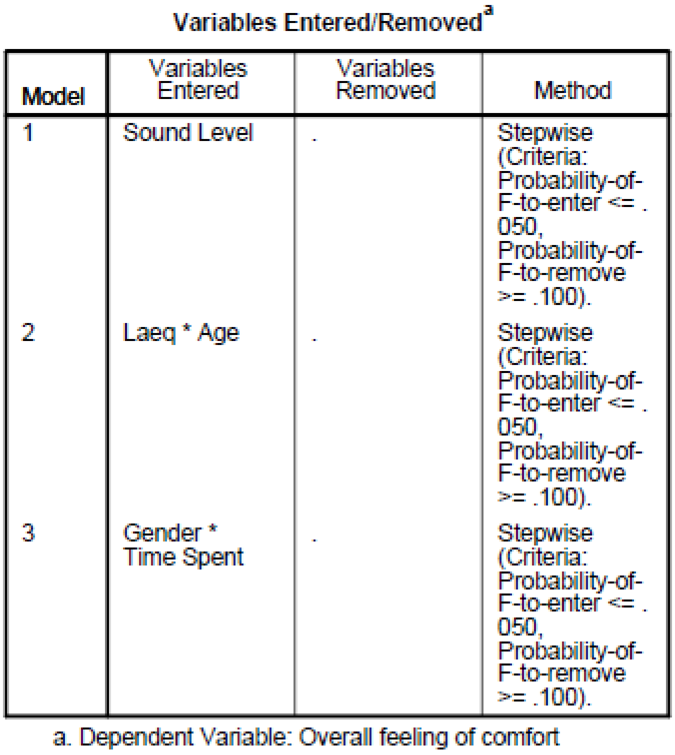
E-1.2: Charts


Histogram
Dependent Variable: Noise Annoyance
Mean = 0.01
Std. Dev. = 1.000
N = 336
Frequency
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Noise Annoyance
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob

E-2: Multiple Linear Regression Results - Comfort Data (O1)

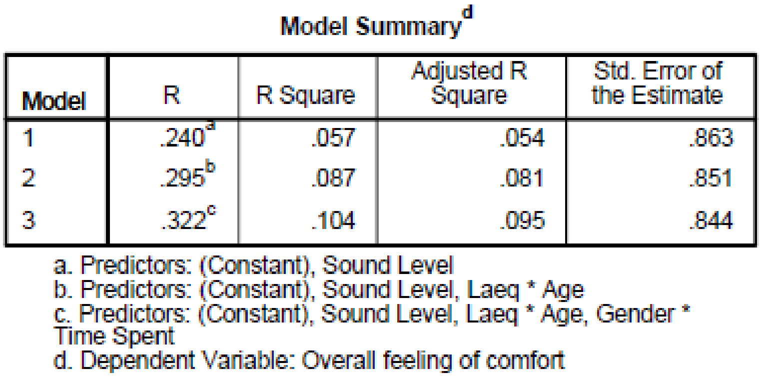
E-2.1: Tables



Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Sound Level	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	Laeq * Age	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
3	Gender * Time Spent	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

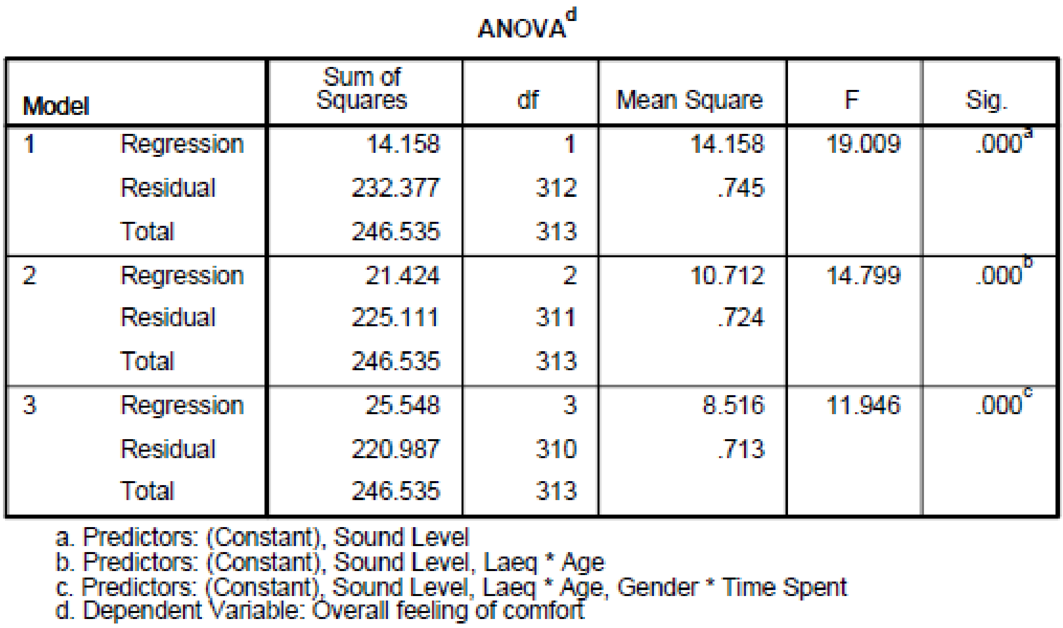
a. Dependent Variable: Overall feeling of comfort



Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.240[a]	.057	.054	.863
2	.295[b]	.087	.081	.851
3	.322[c]	.104	.095	.844

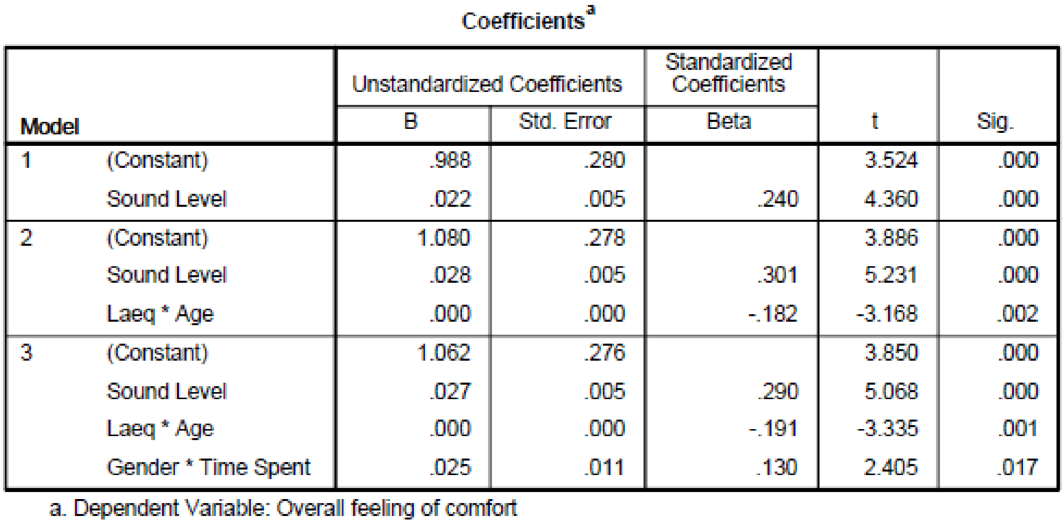
a. Predictors: (Constant), Sound Level
b. Predictors: (Constant), Sound Level, Laeq * Age
c. Predictors: (Constant), Sound Level, Laeq * Age, Gender * Time Spent
d. Dependent Variable: Overall feeling of comfort



ANOVA[d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14.158	1	14.158	19.009	.000[a]
	Residual	232.377	312	.745		
	Total	246.535	313			
2	Regression	21.424	2	10.712	14.799	.000[b]
	Residual	225.111	311	.724		
	Total	246.535	313			
3	Regression	25.548	3	8.516	11.946	.000[c]
	Residual	220.987	310	.713		
	Total	246.535	313			

a. Predictors: (Constant), Sound Level
b. Predictors: (Constant), Sound Level, Laeq * Age
c. Predictors: (Constant), Sound Level, Laeq * Age, Gender * Time Spent
d. Dependent Variable: Overall feeling of comfort



Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.988	.280		3.524	.000
	Sound Level	.022	.005	.240	4.360	.000
2	(Constant)	1.080	.278		3.886	.000
	Sound Level	.028	.005	.301	5.231	.000
	Laeq * Age	.000	.000	-.182	-3.168	.002
3	(Constant)	1.062	.276		3.850	.000
	Sound Level	.027	.005	.290	5.068	.000
	Laeq * Age	.000	.000	-.191	-3.335	.001
	Gender * Time Spent	.025	.011	.130	2.405	.017

a. Dependent Variable: Overall feeling of comfort

Excluded Variables[d]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Age	-.166[a]	-3.048	.002	-.170	.993
	Gender	.038[a]	.668	.505	.038	.940
	Time Spent	.073[a]	1.321	.187	.075	.981
	Laeq * Age	-.182[a]	-3.168	.002	-.177	.887
	Laeq * Gender	.050[a]	.777	.438	.044	.739
	Laeq * Time Spent	.087[a]	1.572	.117	.089	.990
	Age * Gender	-.021[a]	-.373	.709	-.021	.971
	Age * Time Spent	-.041[a]	-.741	.459	-.042	.977
	Gender * Time Spent	.119[a]	2.168	.031	.122	.989
2	Age	.308[b]	.716	.474	.041	.016
	Gender	.049[b]	.871	.385	.049	.937
	Time Spent	.083[b]	1.524	.128	.086	.977
	Laeq * Gender	.064[b]	1.017	.310	.058	.735
	Laeq * Time Spent	.096[b]	1.769	.078	.100	.987
	Age * Gender	.073[b]	1.184	.237	.067	.772
	Age * Time Spent	.048[b]	.785	.433	.045	.772
	Gender * Time Spent	.130[b]	2.405	.017	.135	.985
3	Age	.288[c]	.675	.500	.038	.016
	Gender	-.043[c]	-.634	.526	-.036	.622
	Time Spent	.004[c]	.064	.949	.004	.606
	Laeq * Gender	-.033[c]	-.430	.667	-.024	.494
	Laeq * Time Spent	.023[c]	.321	.748	.018	.589
	Age * Gender	-.011[c]	-.156	.876	-.009	.539
	Age * Time Spent	-.048[c]	-.654	.514	-.037	.534

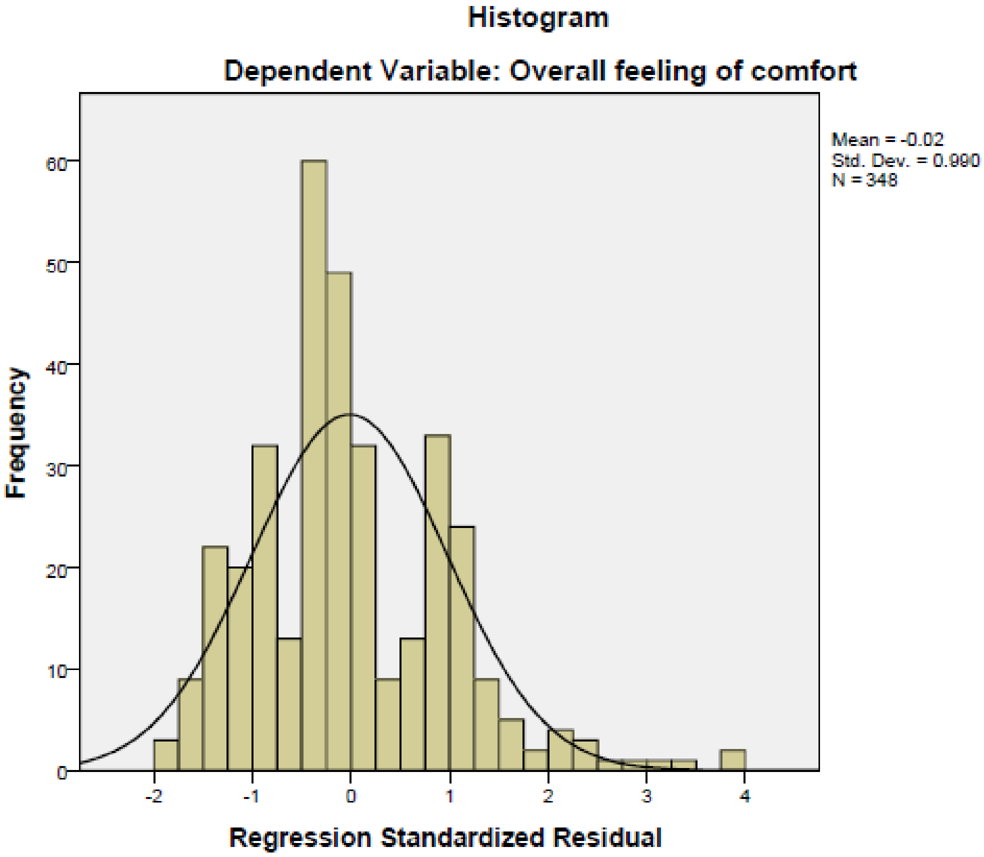
a. Predictors in the Model: (Constant), Sound Level
b. Predictors in the Model: (Constant), Sound Level, Laeq * Age
c. Predictors in the Model: (Constant), Sound Level, Laeq * Age, Gender * Time Spent
d. Dependent Variable: Overall feeling of comfort

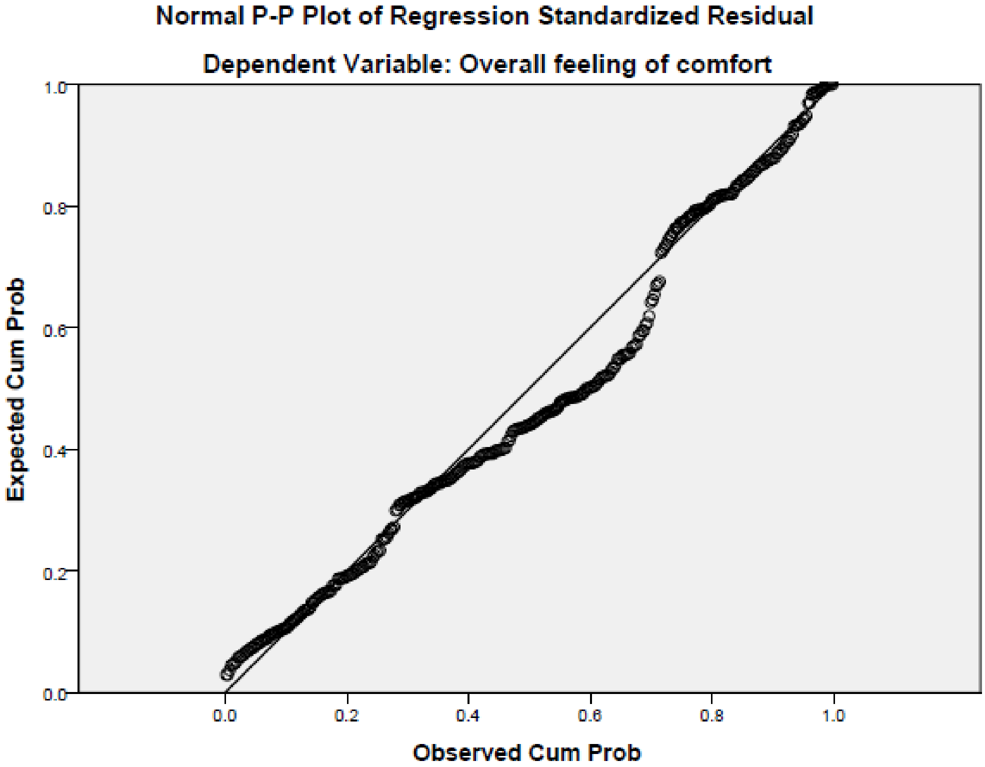
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.61	3.62	2.16	.292	348
Residual	-1.594	3.338	-.014	.836	348
Std. Predicted Value	-2.022	5.018	-.097	1.024	348
Std. Residual	-1.888	3.953	-.017	.990	348

a. Dependent Variable: Overall feeling of comfort

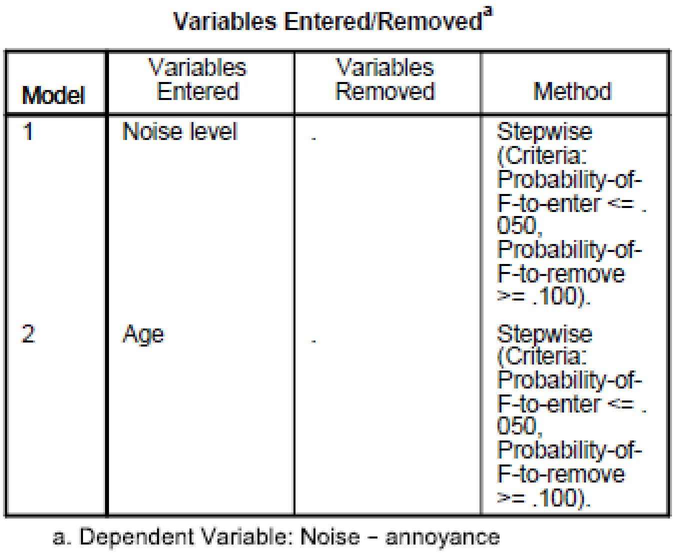
E-2.2: Charts


Histogram
Dependent Variable: Overall feeling of comfort
Mean = -0.02
Std. Dev. = 0.990
N = 348
Frequency
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Overall feeling of comfort
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob

E-3: Multiple Linear Regression Results - Performance Data (N2)

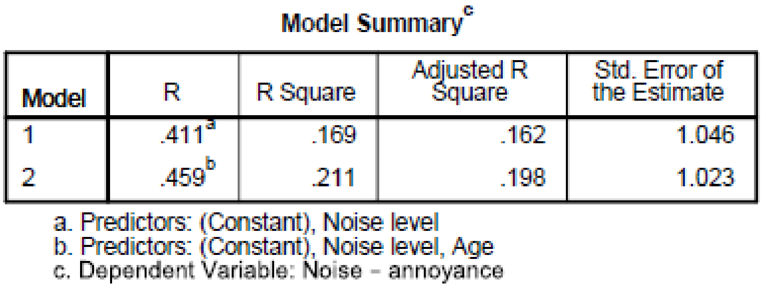
E-3.1: Tables



Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Noise level	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	Age	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

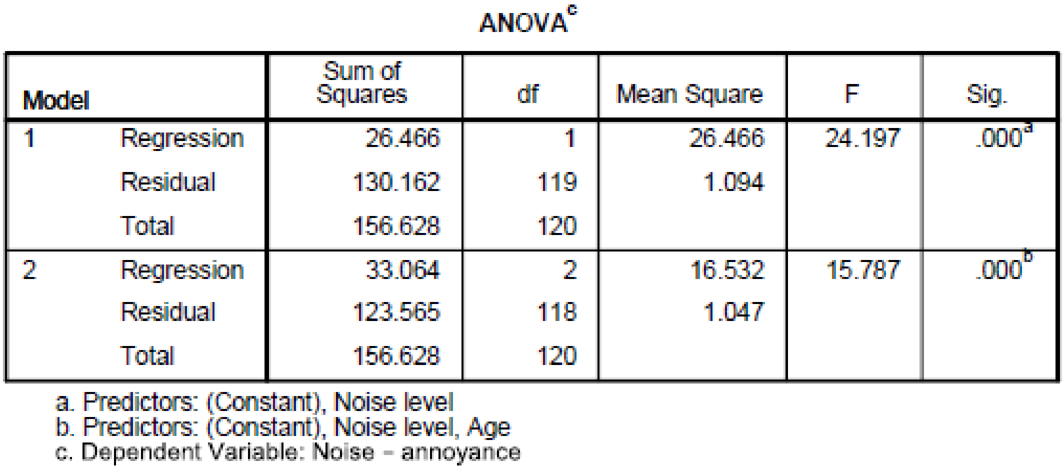
a. Dependent Variable: Noise – annoyance



Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.411[a]	.169	.162	1.046
2	.459[b]	.211	.198	1.023

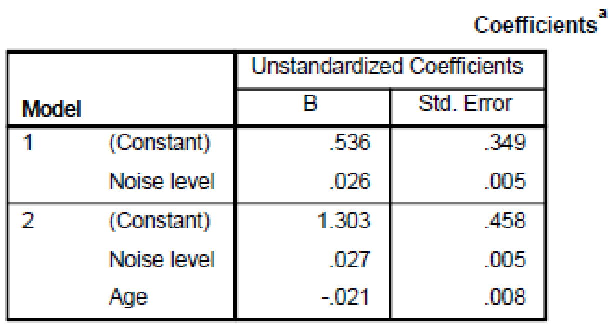
a. Predictors: (Constant), Noise level
b. Predictors: (Constant), Noise level, Age
c. Dependent Variable: Noise – annoyance



ANOVA[c]

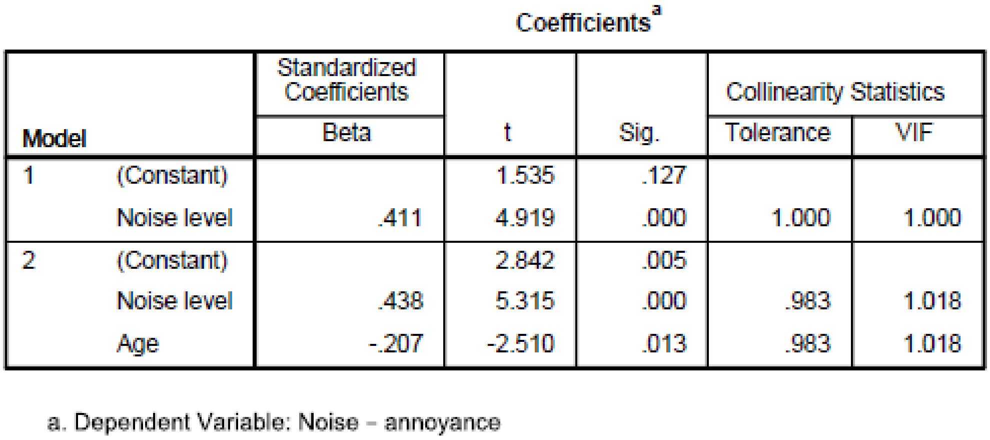
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	26.466	1	26.466	24.197	.000[a]
	Residual	130.162	119	1.094		
	Total	156.628	120			
2	Regression	33.064	2	16.532	15.787	.000[b]
	Residual	123.565	118	1.047		
	Total	156.628	120			

a. Predictors: (Constant), Noise level
b. Predictors: (Constant), Noise level, Age
c. Dependent Variable: Noise – annoyance



Coefficients[a]

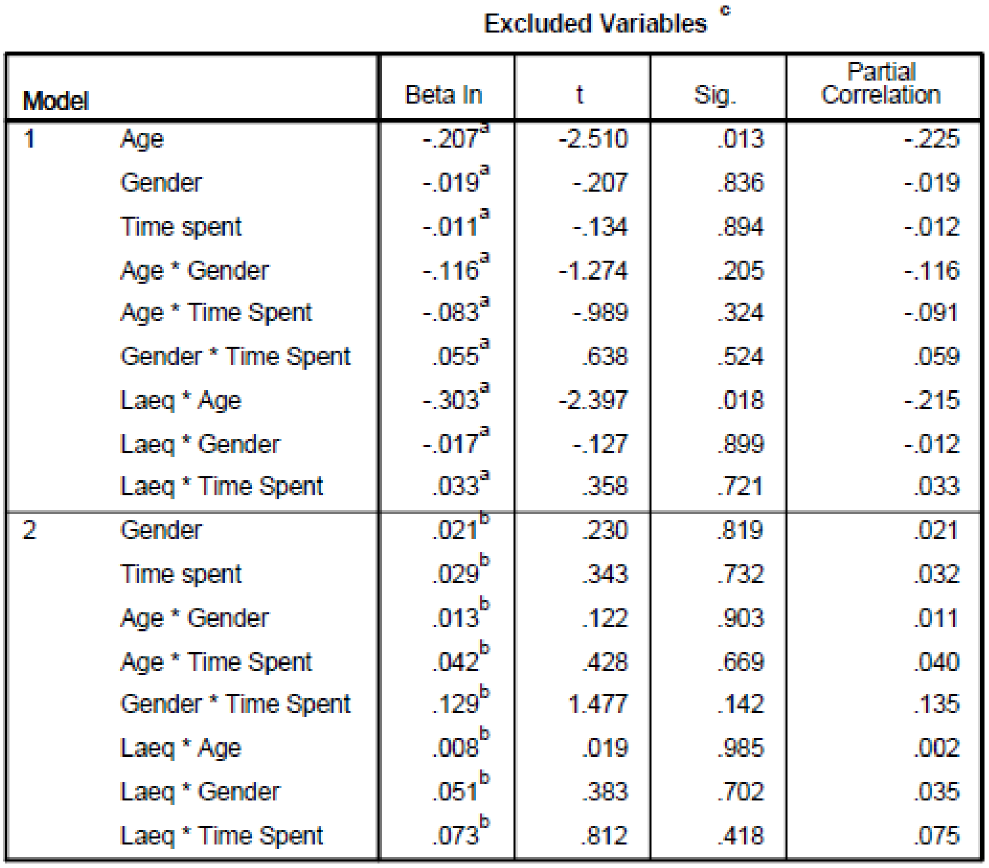
Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error
1	(Constant)	.536	.349
	Noise level	.026	.005
2	(Constant)	1.303	.458
	Noise level	.027	.005
	Age	-.021	.008



Coefficients[a]

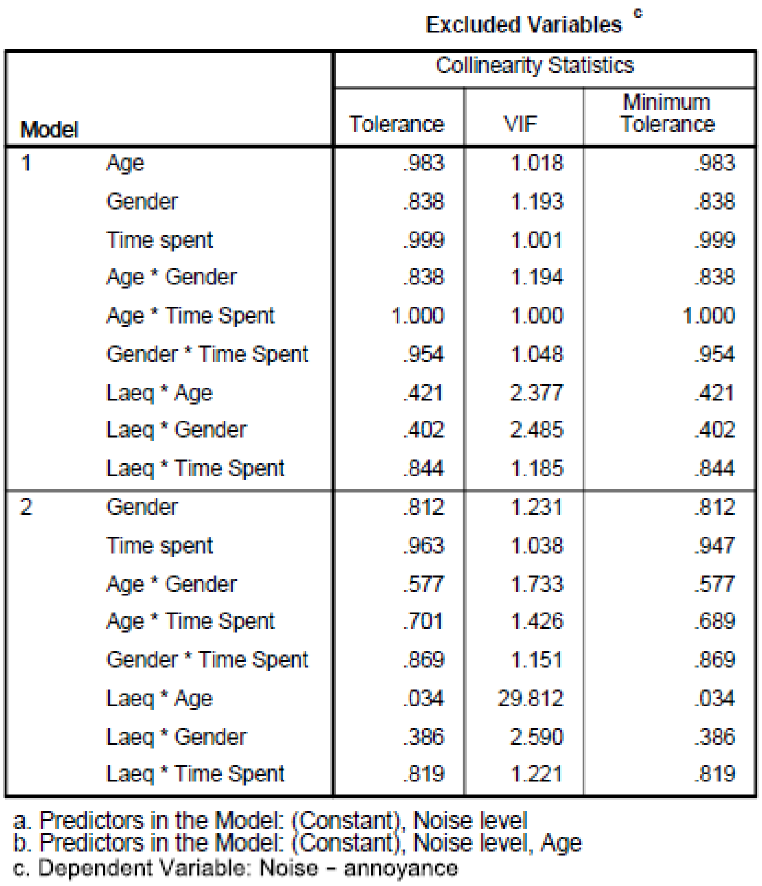
Model		Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)		1.535	.127		
	Noise level	.411	4.919	.000	1.000	1.000
2	(Constant)		2.842	.005		
	Noise level	.438	5.315	.000	.983	1.018
	Age	-.207	-2.510	.013	.983	1.018

a. Dependent Variable: Noise – annoyance



Excluded Variables [c]

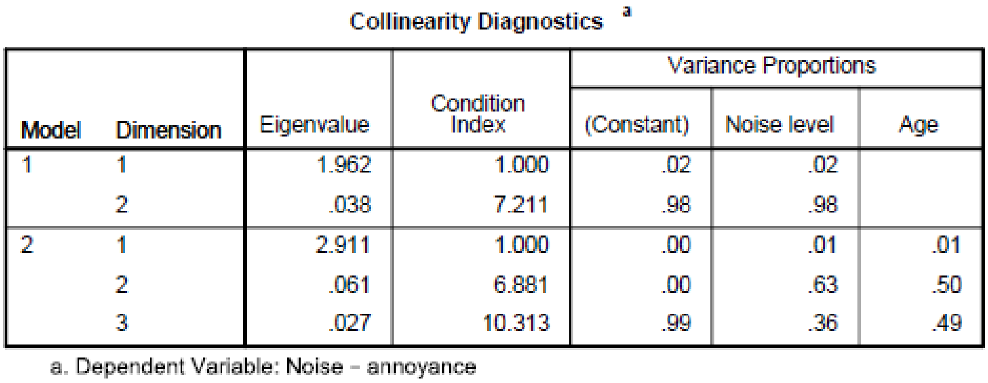
Model		Beta In	t	Sig.	Partial Correlation
1	Age	-.207[a]	-2.510	.013	-.225
	Gender	-.019[a]	-.207	.836	-.019
	Time spent	-.011[a]	-.134	.894	-.012
	Age * Gender	-.116[a]	-1.274	.205	-.116
	Age * Time Spent	-.083[a]	-.989	.324	-.091
	Gender * Time Spent	.055[a]	.638	.524	.059
	Laeq * Age	-.303[a]	-2.397	.018	-.215
	Laeq * Gender	-.017[a]	-.127	.899	-.012
	Laeq * Time Spent	.033[a]	.358	.721	.033
2	Gender	.021[b]	.230	.819	.021
	Time spent	.029[b]	.343	.732	.032
	Age * Gender	.013[b]	.122	.903	.011
	Age * Time Spent	.042[b]	.428	.669	.040
	Gender * Time Spent	.129[b]	1.477	.142	.135
	Laeq * Age	.008[b]	.019	.985	.002
	Laeq * Gender	.051[b]	.383	.702	.035
	Laeq * Time Spent	.073[b]	.812	.418	.075



Excluded Variables [c]

Model		Collinearity Statistics		
		Tolerance	VIF	Minimum Tolerance
1	Age	.983	1.018	.983
	Gender	.838	1.193	.838
	Time spent	.999	1.001	.999
	Age * Gender	.838	1.194	.838
	Age * Time Spent	1.000	1.000	1.000
	Gender * Time Spent	.954	1.048	.954
	Laeq * Age	.421	2.377	.421
	Laeq * Gender	.402	2.485	.402
	Laeq * Time Spent	.844	1.185	.844
2	Gender	.812	1.231	.812
	Time spent	.963	1.038	.947
	Age * Gender	.577	1.733	.577
	Age * Time Spent	.701	1.426	.689
	Gender * Time Spent	.869	1.151	.869
	Laeq * Age	.034	29.812	.034
	Laeq * Gender	.386	2.590	.386
	Laeq * Time Spent	.819	1.221	.819

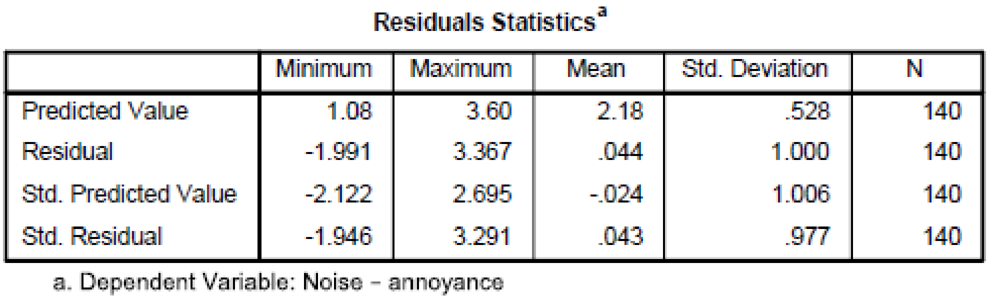
a. Predictors in the Model: (Constant), Noise level
b. Predictors in the Model: (Constant), Noise level, Age
c. Dependent Variable: Noise - annoyance



Collinearity Diagnostics [a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions		
				(Constant)	Noise level	Age
1	1	1.962	1.000	.02	.02	
	2	.038	7.211	.98	.98	
2	1	2.911	1.000	.00	.01	.01
	2	.061	6.881	.00	.63	.50
	3	.027	10.313	.99	.36	.49

a. Dependent Variable: Noise - annoyance

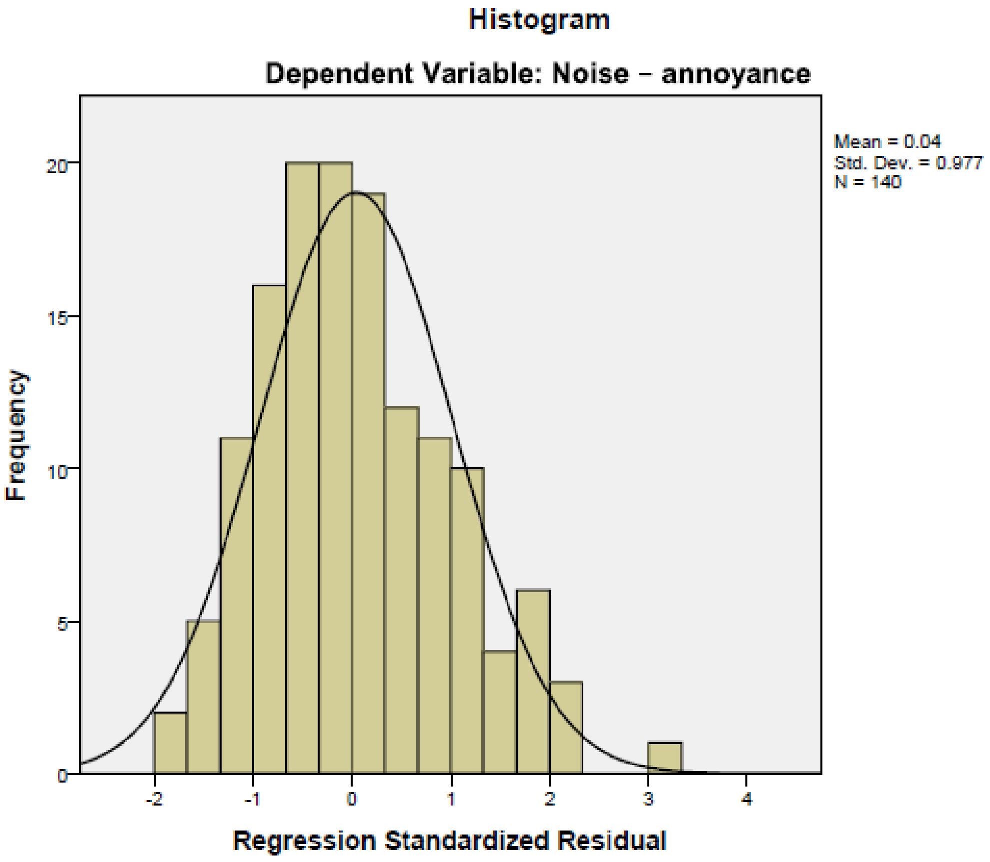


Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.08	3.60	2.18	.528	140
Residual	-1.991	3.367	.044	1.000	140
Std. Predicted Value	-2.122	2.695	-.024	1.006	140
Std. Residual	-1.946	3.291	.043	.977	140

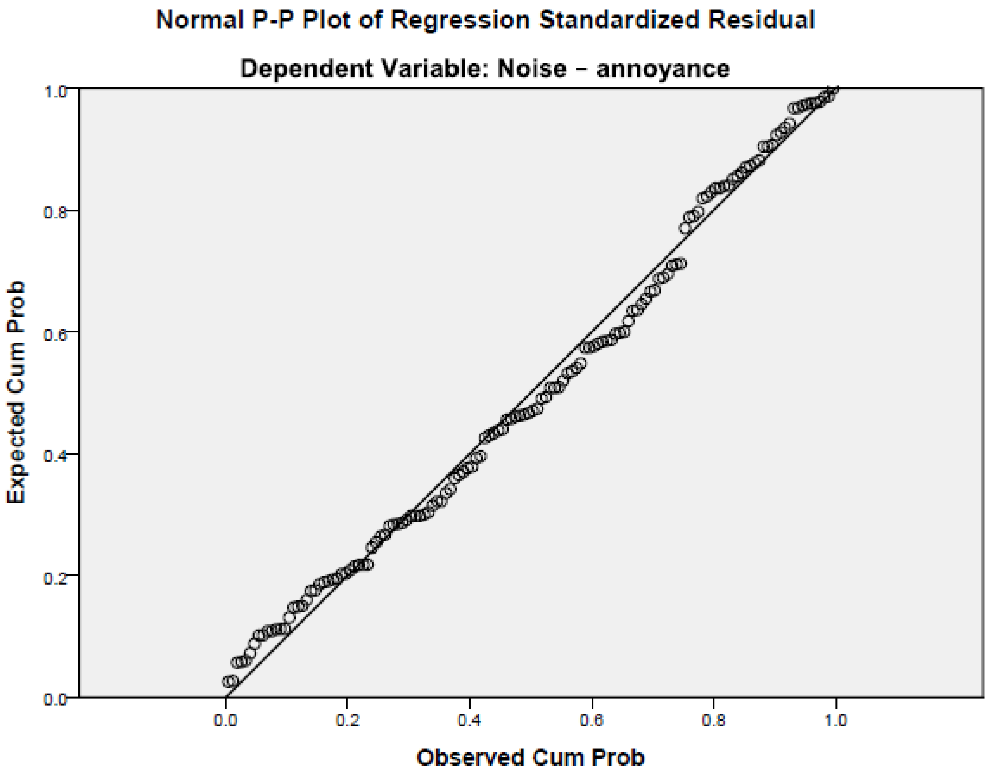
a. Dependent Variable: Noise - annoyance

E-3.2: Charts



Histogram

Dependent Variable: Noise – annoyance

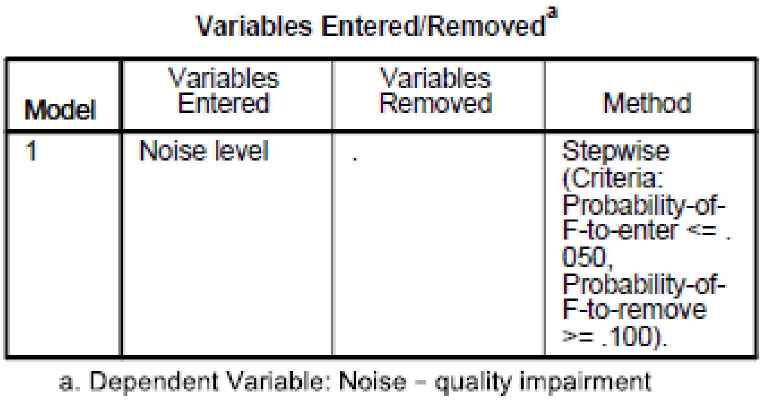


Normal P-P Plot of Regression Standardized Residual

Dependent Variable: Noise – annoyance

E-4: Multiple Linear Regression Results - Performance Data (N7)

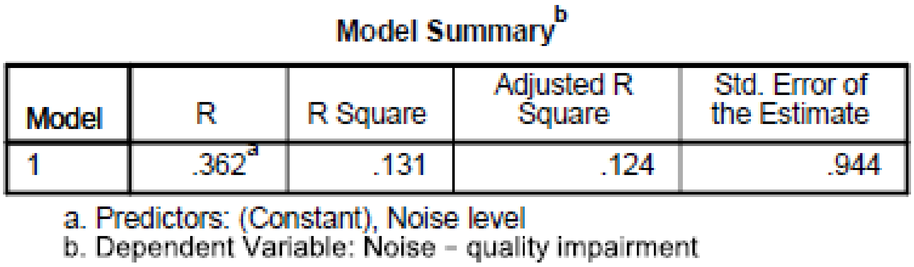
E-4.1: Tables



Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Noise level	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

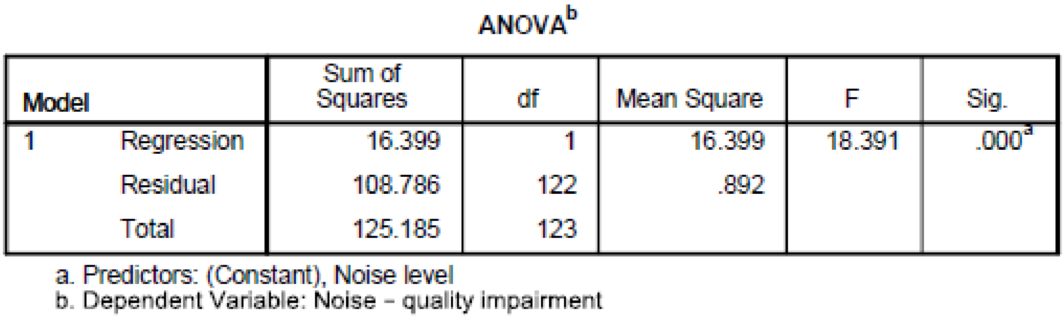
a. Dependent Variable: Noise – quality impairment



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.362[a]	.131	.124	.944

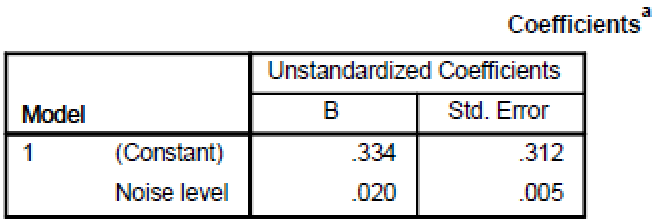
a. Predictors: (Constant), Noise level
b. Dependent Variable: Noise – quality impairment



ANOVA[b]

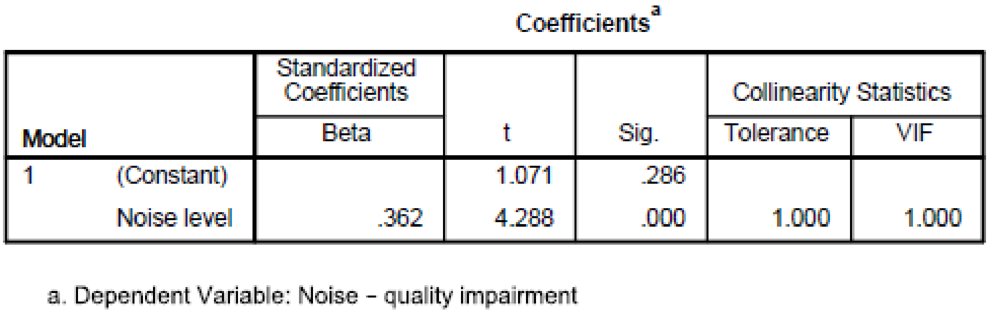
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16.399	1	16.399	18.391	.000[a]
	Residual	108.786	122	.892		
	Total	125.185	123			

a. Predictors: (Constant), Noise level
b. Dependent Variable: Noise – quality impairment



Coefficients[a]

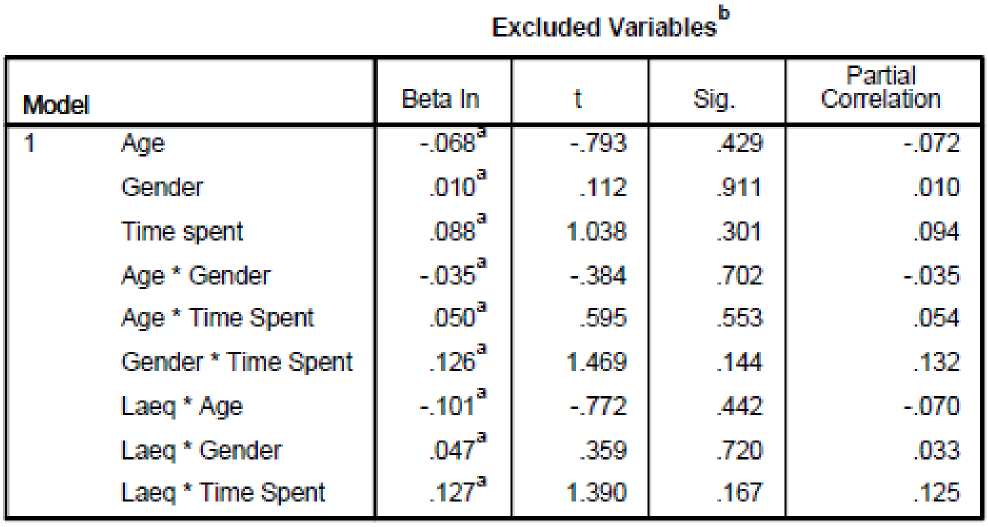
Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	.334	.312
	Noise level	.020	.005



Coefficients[a]

Model		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		Beta			Tolerance	VIF
1	(Constant)		1.071	.286		
	Noise level	.362	4.288	.000	1.000	1.000

a. Dependent Variable: Noise – quality impairment



Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation
1	Age	-.068[a]	-.793	.429	-.072
	Gender	.010[a]	.112	.911	.010
	Time spent	.088[a]	1.038	.301	.094
	Age * Gender	-.035[a]	-.384	.702	-.035
	Age * Time Spent	.050[a]	.595	.553	.054
	Gender * Time Spent	.126[a]	1.469	.144	.132
	Laeq * Age	-.101[a]	-.772	.442	-.070
	Laeq * Gender	.047[a]	.359	.720	.033
	Laeq * Time Spent	.127[a]	1.390	.167	.125

Excluded Variables[b]

Model		Collinearity Statistics		
		Tolerance	VIF	Minimum Tolerance
1	Age	.979	1.021	.979
	Gender	.863	1.159	.863
	Time spent	.998	1.002	.998
	Age * Gender	.859	1.165	.859
	Age * Time Spent	1.000	1.000	1.000
	Gender * Time Spent	.958	1.044	.958
	Laeq * Age	.414	2.416	.414
	Laeq * Gender	.411	2.432	.411
	Laeq * Time Spent	.843	1.187	.843

a. Predictors in the Model: (Constant), Noise level
b. Dependent Variable: Noise – quality impairment

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Noise level
1	1	1.962	1.000	.02	.02
	2	.038	7.217	.98	.98

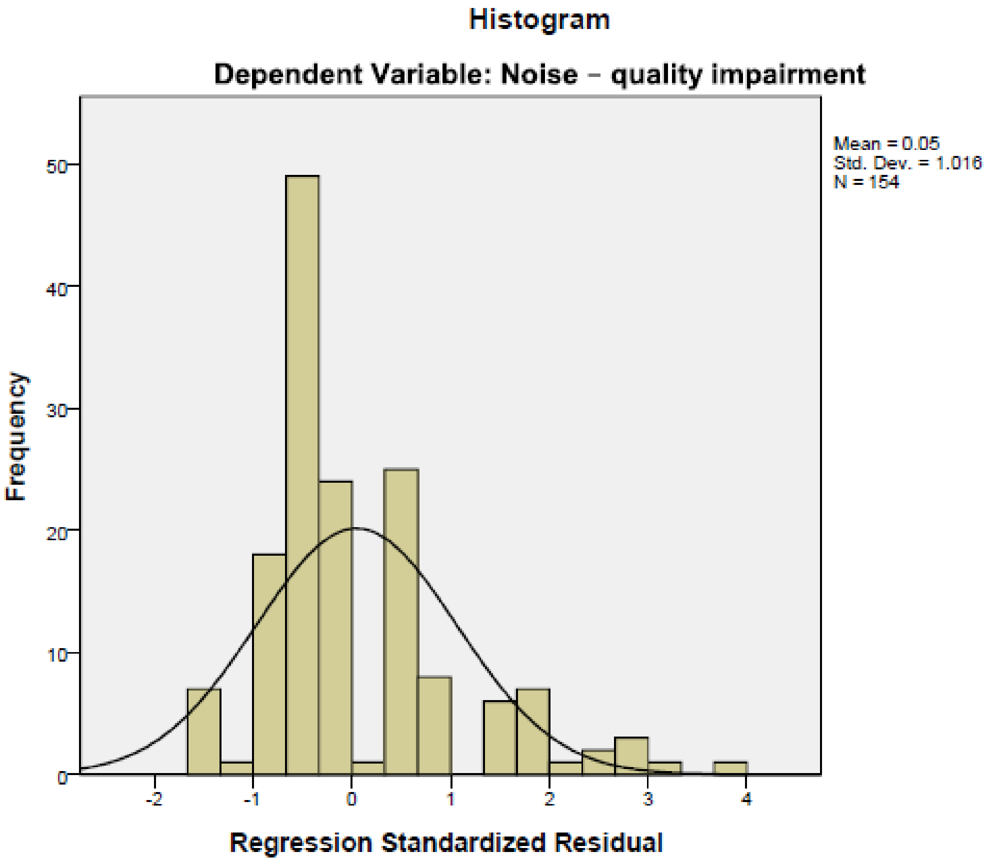
a. Dependent Variable: Noise – quality impairment

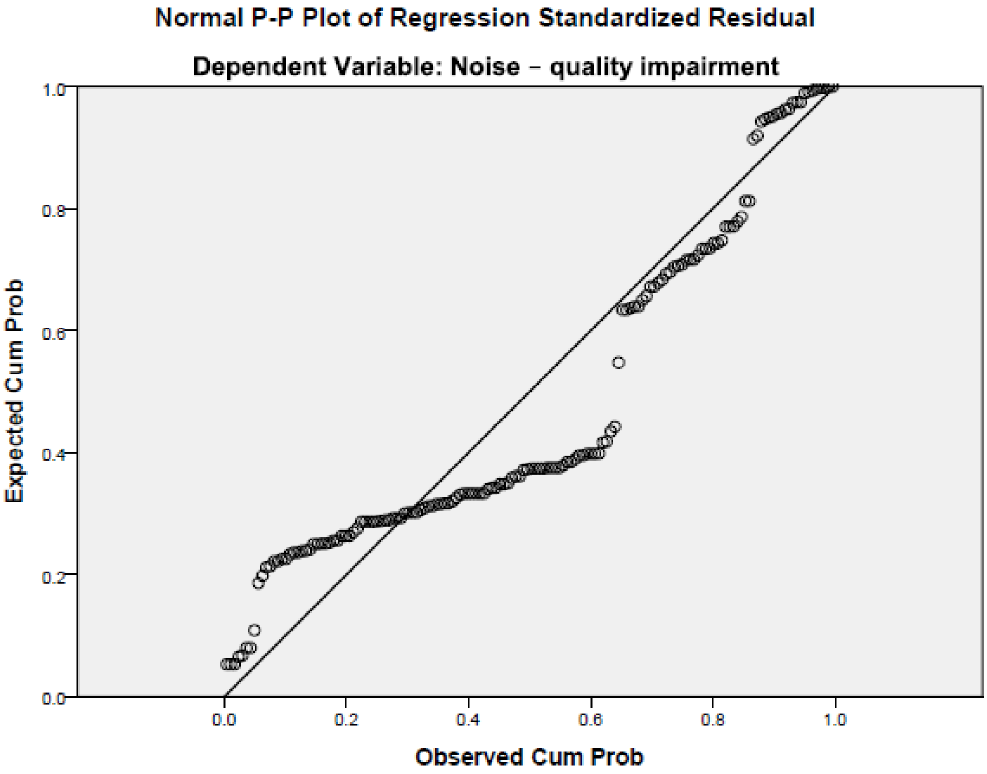
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.14	2.53	1.63	.351	154
Residual	-1.526	3.689	.044	.959	154
Std. Predicted Value	-1.325	2.479	.012	.961	154
Std. Residual	-1.616	3.907	.046	1.016	154

a. Dependent Variable: Noise – quality impairment

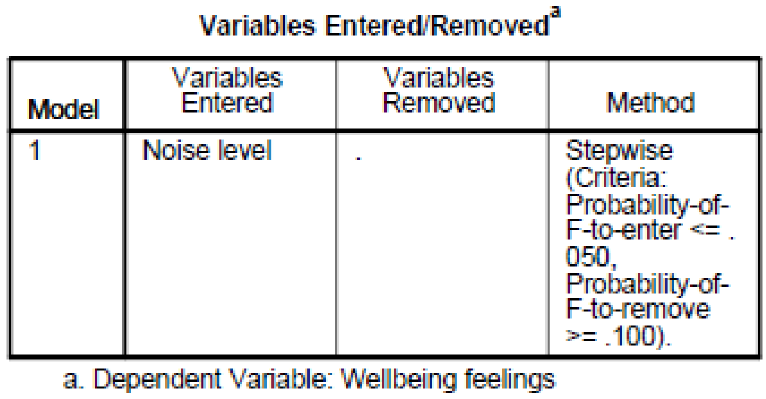
E-4.2: Charts


Histogram
Dependent Variable: Noise – quality impairment
Mean = 0.05
Std. Dev. = 1.016
N = 154
Frequency
0
10
20
30
40
50
-2
-1
0
1
2
3
4
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Noise – quality impairment
Expected Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob

E-5: Multiple Linear Regression Result - Performance Data (O1)

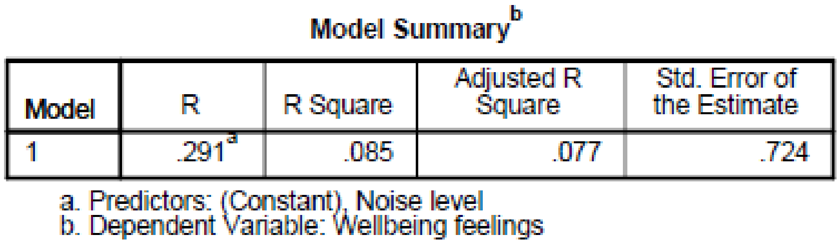
E-5.1: Tables



Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Noise level	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

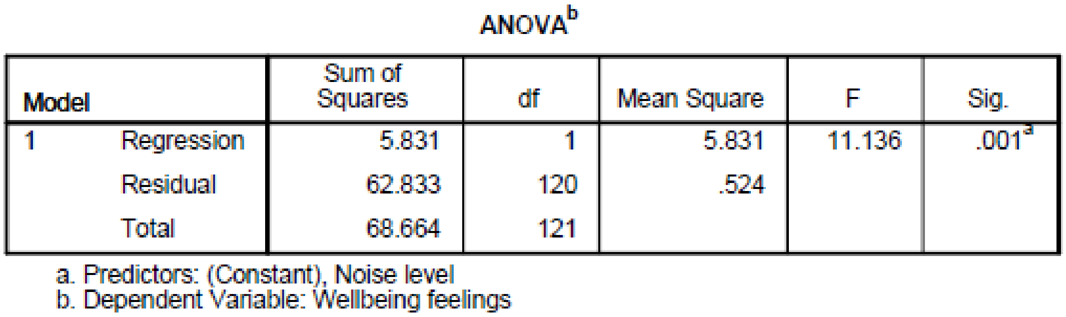
a. Dependent Variable: Wellbeing feelings



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.291[a]	.085	.077	.724

a. Predictors: (Constant), Noise level
b. Dependent Variable: Wellbeing feelings



ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.831	1	5.831	11.136	.001[a]
	Residual	62.833	120	.524		
	Total	68.664	121			

a. Predictors: (Constant), Noise level
b. Dependent Variable: Wellbeing feelings

Coefficients[a]

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	1.423	.239
	Noise level	.012	.004

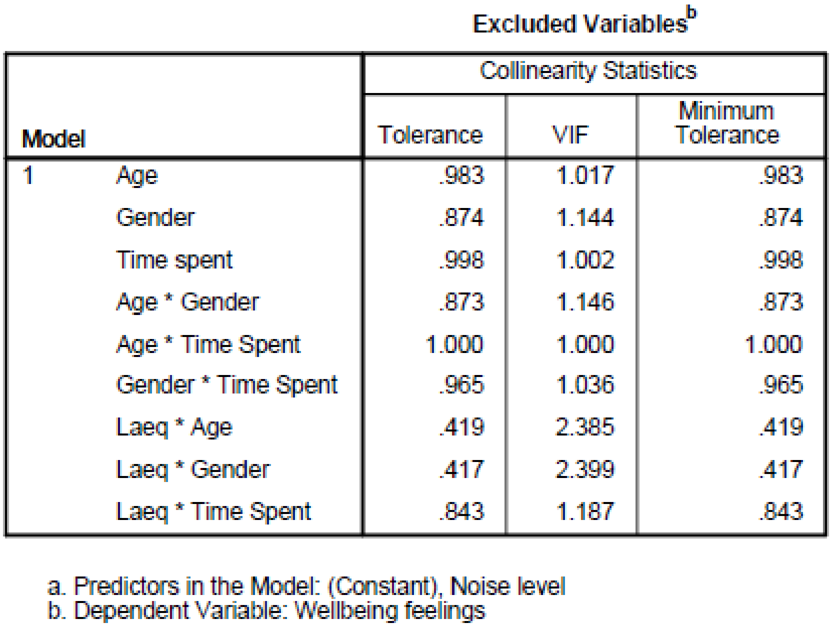
Coefficients[a]

Model		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		Beta			Tolerance	VIF
1	(Constant)		5.959	.000		
	Noise level	.291	3.337	.001	1.000	1.000

a. Dependent Variable: Wellbeing feelings

Excluded Variables[b]

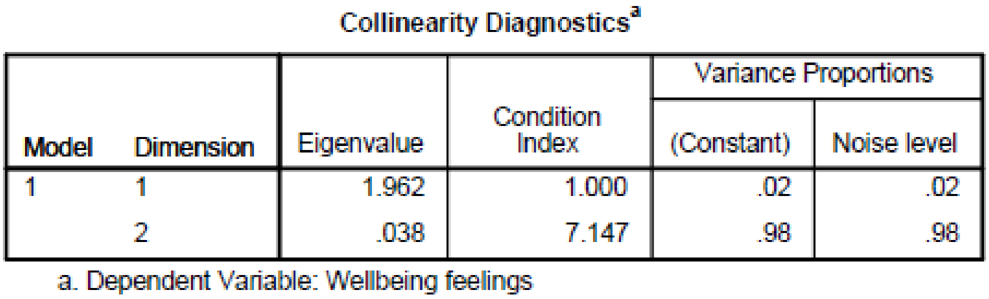
Model		Beta In	t	Sig.	Partial Correlation
1	Age	-.014[a]	-.161	.873	-.015
	Gender	.042[a]	.450	.653	.041
	Time spent	-.051[a]	-.584	.561	-.053
	Age * Gender	.031[a]	.331	.741	.030
	Age * Time Spent	-.041[a]	-.472	.638	-.043
	Gender * Time Spent	.049[a]	.554	.581	.051
	Laeq * Age	.036[a]	.267	.790	.024
	Laeq * Gender	.060[a]	.442	.659	.041
	Laeq * Time Spent	.014[a]	.148	.882	.014



Excluded Variables[b]

Model		Collinearity Statistics		
		Tolerance	VIF	Minimum Tolerance
1	Age	.983	1.017	.983
	Gender	.874	1.144	.874
	Time spent	.998	1.002	.998
	Age * Gender	.873	1.146	.873
	Age * Time Spent	1.000	1.000	1.000
	Gender * Time Spent	.965	1.036	.965
	Laeq * Age	.419	2.385	.419
	Laeq * Gender	.417	2.399	.417
	Laeq * Time Spent	.843	1.187	.843

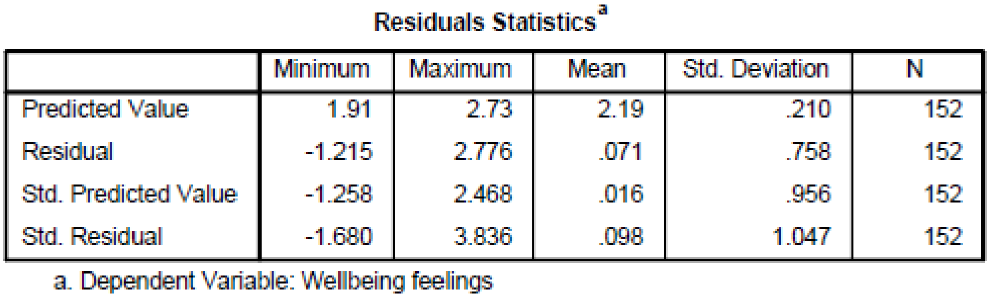
a. Predictors in the Model: (Constant), Noise level
b. Dependent Variable: Wellbeing feelings



Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Noise level
1	1	1.962	1.000	.02	.02
	2	.038	7.147	.98	.98

a. Dependent Variable: Wellbeing feelings

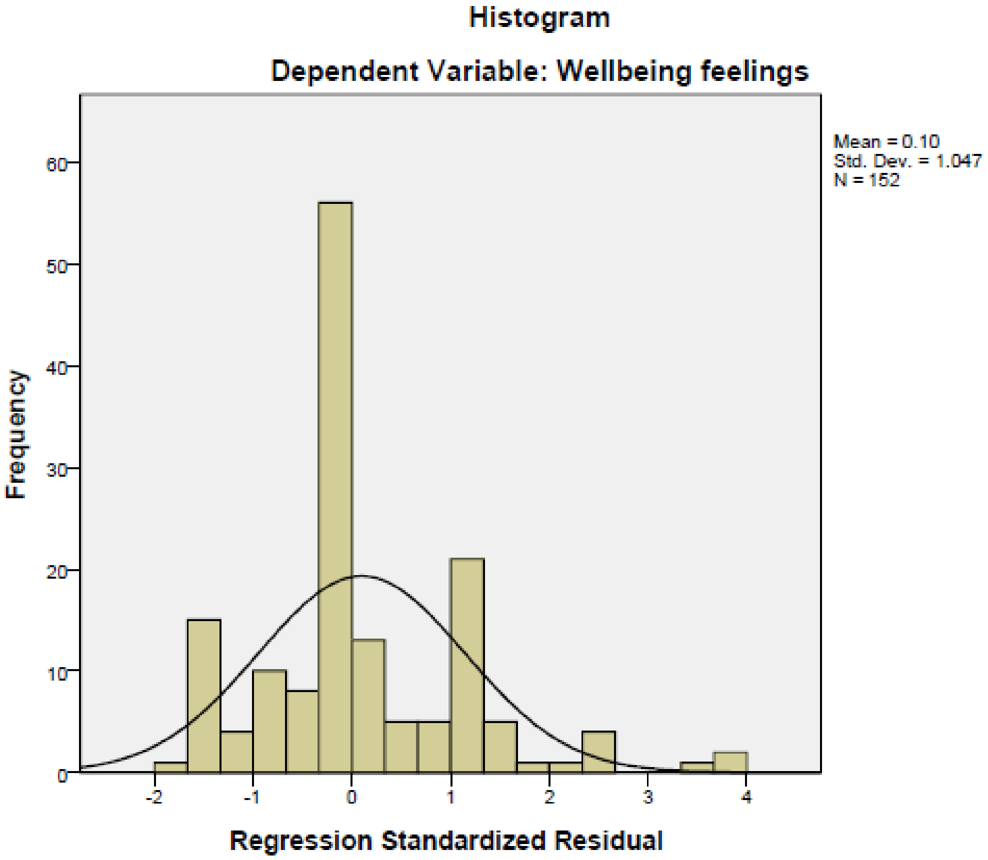


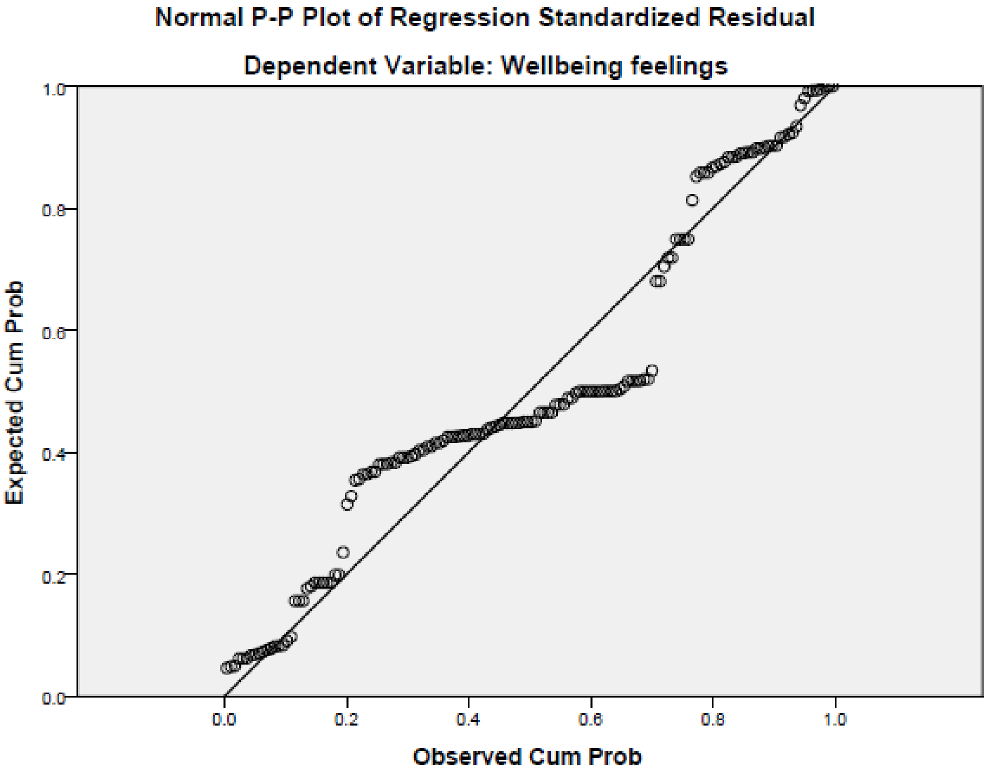
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.91	2.73	2.19	.210	152
Residual	-1.215	2.776	.071	.758	152
Std. Predicted Value	-1.258	2.468	.016	.956	152
Std. Residual	-1.680	3.836	.098	1.047	152

a. Dependent Variable: Wellbeing feelings

E-5.2: Charts


Histogram
Dependent Variable: Wellbeing feelings
Mean = 0.10
Std. Dev. = 1.047
N = 152
Frequency
0
10
20
30
40
50
60
-2
-1
0
1
2
3
4
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Wellbeing feelings
Expected Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob

APPENDIX F

The hypotheses tests tables shown below with the selected models highlighted in it. Moreover parameter estimates tables for the developed ordinal logistic regression models are also shown below (generated in SPSS)

F-1: Hypotheses Tests Tables

ORDINAL REGRESSION HYPOTHESES TEST - COMFORT SUBJECTIVE RATING N2

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p*-value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects *p*-values $\beta_k = 0$						
					L	**G**	**A**	**TS**	**L*G**	**L*A**	**L*TS**
1	**L**	**11.449**	**1**	**0.0007**	**0.0007**						
2	G	0.666	1	0.4143		0.4143					
3	A	2.451	1	0.1175			0.1175				
4	TS	3.441	1	0.0636				0.0636			
5	**L & G**	**18.156**	**2**	**0.0001**	**0.0001**	**0.0073**					
6	L & A	11.739	2	0.0028	0.0014		0.3378				
7	L & TS	16.259	2	0.0003	0.0002			0.0316			
8	**L & G & L*G**	**20.390**	**3**	**0.0001**	**0.0419**	**0.0633**			**0.1350**		
9	L & A & L*A	11.741	3	0.0083	0.3176		0.9328			0.9662	
10	L & TS & L*TS	16.482	3	0.0009	0.0188			0.4294			0.6369
11	L & G & A	19.844	3	0.0002	0.0002	0.0037	0.3718				
12	L & G & TS	19.246	3	0.0002	0.0001	0.0611		0.0611			
13	L & A & TS	14.372	3	0.0024	0.0004		0.7450	0.0788			
14	**L & G & A &TS**	**17.967**	**4**	**0.0013**	**0.0001**	**0.0460**	**0.8392**	**0.1342**			

ORDINAL REGRESSION HYPOTHESES TEST - COMFORT SUBJECTIVE RATING O1

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p*-value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects *p*-values $\beta_k = 0$						
					L	**G**	**A**	**TS**	**L*G**	**L*A**	**L*TS**
1	L	22.932	1	0.000001679	0.0000						
2	G	13.538	1	0.000233781		0.0002					
3	**A**	**32.494**	**1**	**0.000000012**			**0.0000**				
4	TS	4.143	1	0.041802705				0.0418			
5	L & G	24.317	2	0.000005243	0.0000	0.1265					
6	**L & A**	**48.238**	**2**	**0.000000000**	**0.0001**		**0.0000**				
7	L & TS	23.215	2	0.000009097	0.0000			0.0584			
8	L & G & L*G	24.819	3	0.000016846	0.0075	0.6178			0.4788		
9	L & A & L*A	48.413	3	0.000000000	0.1272		0.7975			0.6765	
10	L & TS & L*TS	25.461	3	0.000012367	0.1951			0.2284			0.1340
11	**L & G & A**	**51.972**	**3**	**0.000000000**	**0.0006**	**0.1110**	**0.0000**				
12	L & G & TS	23.555	3	0.000030935	0.0000	0.3387		0.0511			
13	L & A & TS	36.430	3	0.000000061	0.0000		0.0001	0.0283			
14	**L & G & A &TS**	**38.330**	**4**	**0.000000096**	**0.0001**	**0.1766**	**0.0000**	**0.0221**			

ORDINAL REGRESSION HYPOTHESES TEST - PERFORMANCE SUBJECTIVE RATING N2

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p* -value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects *p* -values $\beta_k = 0$						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**28.322**	**1**	**0.000000103**	**0.0000**						
2	G	5.092	1	0.024031711		0.0240					
3	A	4.166	1	0.041240798			0.0412				
4	TS	0.056	1	0.813343885				0.8133			
5	L & G	28.236	2	0.000000739	0.0000	0.7289					
6	**L & A**	**32.713**	**2**	**0.000000079**	**0.0000**		**0.0117**				
7	L & TS	20.459	2	0.000036085	0.0000			0.9975			
8	L & G & L*G	28.252	3	0.000003215	0.0243	0.9512			0.8982		
9	L & A & L*A	32.741	3	0.000000365	0.1899		0.3868			0.8673	
10	L & TS & L*TS	22.958	3	0.000041202	0.2593			0.1280			0.1139
11	**L & G & A**	**33.906**	**3**	**0.000000207**	**0.0000**	**0.2747**	**0.0069**				
12	L & G & TS	20.298	3	0.000147225	0.0000	0.8763		0.9936			
13	L & A & TS	25.543	3	0.000011889	0.0000		0.0095	0.8222			
14	**L & G & A &TS**	**26.058**	**4**	**0.000030803**	**0.0000**	**0.4729**	**0.0071**	**0.7963**			

ORDINAL REGRESSION HYPOTHESES TEST - PERFORMANCE SUBJECTIVE RATING N7

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p* -value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects *p* -values $\beta_k = 0$						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**19.906**	**1**	**0.000008137**	**0.0000**						
2	G	3.864	1	0.049334084		0.0493					
3	A	1.662	1	0.197393173			0.1974				
4	TS	0.017	1	0.896021124				0.8960			
5	L & G	19.914	2	0.000047395	0.0001	0.5972					
6	**L & A**	**20.404**	**2**	**0.000037089**	**0.0000**		**0.1143**				
7	L & TS	19.746	2	0.000051548	0.0000			0.0933			
8	**L & G & L*G**	**21.275**	**3**	**0.000092294**	**0.6996**	**0.2878**			**0.2433**		
9	L & A & L*A	20.421	3	0.000138857	0.2137		0.7607			0.8984	
10	L & TS & L*TS	20.675	3	0.000122960	0.1699			0.6365			0.3351
11	L & G & A	20.947	3	0.000107970	0.0001	0.4613	0.0904				
12	L & G & TS	20.218	3	0.000152940	0.0001	0.6883		0.0639			
13	L & A & TS	20.188	3	0.000155206	0.0000		0.0554	0.1022			
14	**L & G & A &TS**	**21.287**	**4**	**0.000277796**	**0.0002**	**0.2945**	**0.0340**	**0.0802**			

ORDINAL REGRESSION HYPOTHESES TEST - PERFORMANCE SUBJECTIVE RATING O1

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p* -value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects *p* -values $\beta_k = 0$						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**9.659**	**1**	**0.001884193**	**0.0019**						
2	G	4.324	1	0.037574492		0.0376					
3	A	0.709	1	0.399728848			0.3997				
4	TS	0.013	1	0.909608310				0.9096			
5	**L & G**	**11.327**	**2**	**0.003469592**	**0.0111**	**0.1921**					
6	L & A	9.856	2	0.007242170	0.0018		0.9619				
7	L & TS	8.909	2	0.011625418	0.0041			0.4755			
8	L & G & L*G	11.330	3	0.010070955	0.2883	0.7857			0.9632		
9	L & A & L*A	11.692	3	0.008516340	0.5967		0.1875			0.1754	
10	**L & TS & L*TS**	**12.995**	**3**	**0.004647702**	**0.7739**			**0.0325**			**0.0432**
11	L & G & A	11.571	3	0.009009062	0.0101	0.1904	0.7629				
12	L & G & TS	9.503	3	0.023300015	0.0140	0.4511		0.4525			
13	L & A & TS	9.793	3	0.020410906	0.0032		0.9379	0.4582			
14	**L & G & A &TS**	**10.221**	**4**	**0.036864645**	**0.0092**	**0.5129**	**0.8327**	**0.4894**			

F-2: Parameter Estimates Tables

The general form of the ordinal governing expression is:

$$L_{(\text{Very much})} = t_1 - \left[B_1 X_1 + B_1 X_2 + \cdots + B_n X_n \right]$$
$$L_{(\text{Very much}\backslash\text{Very})} = t_2 - \left[B_1 X_1 + B_1 X_2 + \cdots + B_n X_n \right]$$
$$L_{(\text{Very much}\backslash\text{Very}\backslash\text{Moderately})} = t_3 - \left[B_1 X_1 + B_1 X_2 + \cdots + B_n X_n \right]$$
$$L_{(\text{Very much}\backslash\text{Very}\backslash\text{Moderately}\backslash\text{A little})} = t_4 - \left[B_1 X_1 + B_1 X_2 + \cdots + B_n X_n \right]$$

F-2.1: Ordinal Regression Parameters - Comfort Subjective Rating N2

Parameter Estimates

Parameter		B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
				Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Threshold	[N2r=1]	-5.194	.6087	-6.387	-4.001	72.801	1	.000	.006	.002	.018
	[N2r=2]	-4.045	.5614	-5.145	-2.945	51.907	1	.000	.018	.006	.053
	[N2r=3]	-3.065	.5369	-4.117	-2.012	32.585	1	.000	.047	.016	.134
	[N2r=4]	-1.520	.5199	-2.539	-.501	8.544	1	.003	.219	.079	.606
Laeq		-.040	.0100	-.060	-.021	16.172	1	.000	.961	.942	.980
[Gender=1]		.517	.1933	.139	.896	7.166	1	.007	1.678	1.149	2.451
[Gender=0]		0[a]	.	.	.	.	.	.	1	.	.
(Scale)		1[b]									

Dependent Variable: Noise Annoyance

Model: (Threshold), Laeq, Gender

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

F-2.2: Ordinal Regression Parameters - Comfort Subjective Rating O1

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Threshold [O1r=1]	-4.925	.7519	-6.399	-3.451	42.899	1	.000	.007	.002	.032
[O1r=2]	-3.798	.6847	-5.140	-2.456	30.770	1	.000	.022	.006	.086
[O1r=3]	-1.806	.6386	-3.058	-.554	7.999	1	.005	.164	.047	.574
[O1r=4]	.446	.6399	-.809	1.700	.485	1	.486	1.562	.446	5.474
Laeq	-.038	.0108	-.059	-.016	12.119	1	.000	.963	.943	.984
[Gender=1]	-.328	.2062	-.732	.076	2.530	1	.112	.720	.481	1.079
[Gender=0]	0[a]	.	.	.	.	.	.	1	.	.
Age	.031	.0057	.020	.043	29.801	1	.000	1.032	1.020	1.044
(Scale)	1[b]									

Dependent Variable: Comfort Feelings

Model: (Threshold), Laeq, Gender, Age

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

F-2.3: Ordinal Regression Parameters - Performance Subjective Rating N2

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Threshold [N2r=1]	-5.291	.9708	-7.194	-3.388	29.707	1	.000	.005	.001	.034
[N2r=2]	-3.606	.8711	-5.313	-1.898	17.130	1	.000	.027	.005	.150
[N2r=3]	-2.541	.8332	-4.174	-.908	9.302	1	.002	.079	.015	.403
[N2r=4]	-.726	.8108	-2.315	.863	.802	1	.370	.484	.099	2.370
LAeq	-.050	.0097	-.069	-.031	26.759	1	.000	.951	.933	.969
Age	.036	.0143	.008	.064	6.219	1	.013	1.036	1.008	1.066
(Scale)	1[a]									

Dependent Variable: Noise Annoyance

Model: (Threshold), LAeq, Age

a. Fixed at the displayed value.

F-2.4: Ordinal Regression Parameters - Performance Subjective Rating N7

Parameter Estimates

Parameter		B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
				Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Threshold	[N7r=1]	-6.923	.9342	-8.754	-5.092	54.911	1	.000	.001	.000	.006
	[N7r=2]	-5.241	.7619	-6.734	-3.747	47.312	1	.000	.005	.001	.024
	[N7r=3]	-4.337	.7045	-5.718	-2.956	37.891	1	.000	.013	.003	.052
	[N7r=4]	-3.203	.6504	-4.478	-1.929	24.259	1	.000	.041	.011	.145
LAeq		-.042	.0096	-.060	-.023	19.056	1	.000	.959	.941	.977
(Scale)		1[a]									

Dependent Variable: Noise – quality impairment

Model: (Threshold), LAeq

a. Fixed at the displayed value.

F-2.5: Ordinal Regression Parameters - Performance Subjective Rating O1

Parameter Estimates

Parameter		B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
				Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Threshold	[O1r=1]	-5.821	.8701	-7.526	-4.116	44.761	1	.000	.003	.001	.016
	[O1r=2]	-4.666	.7258	-6.088	-3.243	41.322	1	.000	.009	.002	.039
	[O1r=3]	-2.710	.6367	-3.958	-1.462	18.114	1	.000	.067	.019	.232
	[O1r=4]	.352	.6065	-.836	1.541	.337	1	.561	1.422	.433	4.669
LAeq		-.028	.0090	-.045	-.010	9.412	1	.002	.973	.956	.990
(Scale)		1[a]									

Dependent Variable: DisPERFORMANCE feeling

Model: (Threshold), LAeq

a. Fixed at the displayed value.

APPENDIX G

Here in this section the results of binomial logistic regressions with following dichotomy are presented.

- Not at all' to zero.
- 'A little', 'Moderately', 'Very' and 'Very much' to one.

G-1: Hypotheses Tests Tables

BINOMIAL REGRESSION HYPOTHESES TEST - COMFORT SUBJECTIVE RATING N2

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p* -value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects *p* -values $\beta_k = 0$						
					L	**G**	**A**	**TS**	**L*G**	**L*A**	**L*TS**
1	L	6.171	1	0.012983651	0.0130						
2	G	1.658	1	0.197903384		0.1979					
3	**A**	**6.268**	**1**	**0.012290340**			**0.0123**				
4	TS	1.854	1	0.173362144				0.1734			
5	**L & G**	**11.798**	**2**	**0.002741905**	**0.0037**	**0.0131**					
6	L & A	10.215	2	0.006051952	0.0240		0.0509				
7	L & TS	8.670	2	0.013104890	0.0073			0.0984			
8	L & G & L*G	12.695	3	0.005343646	0.0761	0.2119			0.3435		
9	L & A & L*A	10.594	3	0.014134311	0.9383		0.4020			0.5378	
10	L & TS & L*TS	9.772	3	0.020609573	0.0215			0.2091			0.2938
11	**L & G & A**	**16.504**	**3**	**0.000893649**	**0.0073**	**0.0429**	**0.0103**				
12	L & G & TS	13.310	3	0.004011712	0.0020	0.1232		0.0264			
13	L & A & TS	9.821	3	0.020151210	0.0123		0.1395	0.1701			
14	L & G & A &TS	14.049	4	0.007139469	0.0040	0.0368	0.1487	0.1982			

BINOMIAL REGRESSION HYPOTHESES TEST - COMFORT SUBJECTIVE RATING O1

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test *p* -value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects *p* -values $\beta_k = 0$						
					L	**G**	**A**	**TS**	**L*G**	**L*A**	**L*TS**
1	**L**	**19.913**	**1**	**0.000008106**	**0.0000**						
2	G	19.809	1	0.000008559		0.0000					
3	A	37.054	1	0.000000001			0.0000				
4	TS	0.271	1	0.602649405				0.6026			
5	L & G	28.931	2	0.000000522	0.0007	0.0013					
6	**L & A**	**43.759**	**2**	**0.000000000**	**0.0012**		**0.0000**				
7	L & TS	18.884	2	0.000079334	0.0000			0.3334			
8	L & G & L*G	31.231	3	0.000000760	0.0018	0.2496			0.1294		
9	L & A & L*A	44.237	3	0.000000001	0.1157		0.8555			0.4893	
10	L & TS & L*TS	19.230	3	0.000245088	0.0035			0.4890			0.5565
11	**L & G & A**	**53.519**	**3**	**0.000000000**	**0.0224**	**0.0000**	**0.0010**				
12	L & G & TS	24.310	3	0.000021521	0.0003	0.2609		0.0158			
13	L & A & TS	30.057	3	0.000001343	0.0001		0.0005	0.2548			
14	L & G & A &TS	36.906	4	0.000000188	0.0025	0.0076	0.0002	0.2024			

BINOMIAL REGRESSION HYPOTHESES TEST - PERFORMANCE SUBJECTIVE RATING N2

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test p-value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects p-values $\beta_k = 0$						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**13.604**	**1**	**0.000225679**	**0.0002**						
2	G	2.151	1	0.142433043		0.1424					
3	A	3.897	1	0.048360944			0.0484				
4	TS	0.287	1	0.592062992				0.5921			
5	L & G	13.498	2	0.001171810	0.0011	0.8486					
6	**L & A**	**15.571**	**2**	**0.000415783**	**0.0003**		**0.0720**				
7	L & TS	9.769	2	0.007561514	0.0018			0.9196			
8	L & G & L*G	13.537	3	0.003608320	0.0436	0.8220			0.8444		
9	L & A & L*A	15.792	3	0.001250656	0.7830		0.3990			0.6377	
10	L & TS & L*TS	11.328	3	0.010078991	0.6846			0.2149			0.2119
11	**L & G & A**	**16.190**	**3**	**0.001036669**	**0.0027**	**0.0567**	**0.4313**				
12	L & G & TS	9.664	3	0.021652573	0.0037	0.9968		0.8748			
13	L & A & TS	12.697	3	0.005338993	0.0014		0.0434	0.8301			
14	**L & G & A &TS**	**12.928**	**4**	**0.011633360**	**0.0060**	**0.6311**	**0.0381**	**0.8335**			

BINOMIAL REGRESSION HYPOTHESES TEST - PERFORMANCE SUBJECTIVE RATING N7

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test p-value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects p-values $\beta_k = 0$						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**13.301**	**1**	**0.000265335**	**0.0003**						
2	G	2.552	1	0.110139126		0.1101					
3	A	2.739	1	0.097946638			0.0979				
4	TS	0.024	1	0.877177806				0.8772			
5	L & G	13.508	2	0.001165987	0.0013	0.6018					
6	**L & A**	**16.027**	**2**	**0.000330895**	**0.0002**		**0.0428**				
7	L & TS	12.929	2	0.001557625	0.0005			0.3642			
8	L & G & L*G	14.447	3	0.002355483	0.7368	0.3857			0.3326		
9	L & A & L*A	16.234	3	0.001015214	0.1753		0.9133			0.6492	
10	L & TS & L*TS	12.932	3	0.004786580	0.1053			0.8543			0.9597
11	**L & G & A**	**16.706**	**3**	**0.000812165**	**0.0016**	**0.0320**	**0.4100**				
12	L & G & TS	13.447	3	0.003762605	0.0016	0.2563		0.7094			
13	L & A & TS	16.682	3	0.000821594	0.0002		0.0188	0.2281			
14	**L & G & A &TS**	**17.979**	**4**	**0.001245672**	**0.0017**	**0.2547**	**0.0106**	**0.1759**			

BINOMIAL REGRESSION HYPOTHESES TEST - PERFORMANCE SUBJECTIVE RATING O1

S.No.	Model	Likelihood Ratio χ^2	d.o.f	Overall Test p-value ($\beta_1 = \beta_2 = \beta_k = 0$)	Model Effects p-values $\beta_k = 0$						
					L	G	A	TS	L*G	L*A	L*TS
1	**L**	**9.470**	**1**	**0.002088109**	**0.0021**						
2	G	1.802	1	0.179431335		0.1794					
3	A	0.066	1	0.797193625			0.7972				
4	TS	0.158	1	0.691239585				0.6912			
5	L & G	10.334	2	0.005700291	0.0141	0.3256					
6	**L & A**	**10.530**	**2**	**0.005169793**	**0.0015**		**0.3015**				
7	L & TS	9.306	2	0.009534568	0.0049			0.2775			
8	L & G & L*G	10.614	3	0.014005427	0.1315	0.7062			0.5968		
9	**L & A & L*A**	**13.523**	**3**	**0.003632127**	**0.2495**		**0.0636**			**0.0836**	
10	L & TS & L*TS	9.632	3	0.021964289	0.5872			0.4644			0.5676
11	L & G & A	12.496	3	0.005864787	0.0187	0.2096	0.1609				
12	L & G & TS	10.357	3	0.015759851	0.0275	0.2696		0.2697			
13	L & A & TS	10.662	3	0.013704320	0.0029		0.2908	0.5197			
14	**L & G & A &TS**	**12.409**	**4**	**0.014552997**	**0.0227**	**0.1861**	**0.1890**	**0.5080**			

G-2: Parameter Estimates Tables

The general form of the binomial governing expression is:

- $L_{(\text{Any level of discomfort = yes})} = a_1 + B_1 X_1 + B_1 X_2 + \cdots + B_n X_n$

G-2.1: Binomial Regression Parameters - Comfort Subjective Rating N2

Parameter Estimates

			95% Wald Confidence Interval		Hypothesis Test				95% Wald Confidence Interval for Exp(B)	
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.	Exp(B)	Lower	Upper
(Intercept)	-.690	.8152	-2.287	.908	.716	1	.398	.502	.102	2.480
Laeq	.035	.0144	.007	.064	6.083	1	.014	1.036	1.007	1.066
Age	-.012	.0060	-.024	.000	4.043	1	.044	.988	.976	1.000
[Gender=1]	-.568	.2237	-1.007	-.130	6.453	1	.011	.566	.365	.878
[Gender=0]	0[a]	.	.	.	.	.	.	1	.	.
(Scale)	1[b]									

Dependent Variable: Noise Annoyance

Model: (Intercept), Laeq, Age, Gender

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

G-2.2: Binomial Regression Parameters - Comfort Subjective Rating O1

Parameter Estimates

			95% Wald Confidence Interval		Hypothesis Test				95% Wald Confidence Interval for Exp(B)	
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.	Exp(B)	Lower	Upper
(Intercept)	.049	1.2015	-2.306	2.404	.002	1	.968	1.050	.100	11.065
Laeq	.045	.0217	.003	.088	4.388	1	.036	1.047	1.003	1.092
Age	-.037	.0074	-.051	-.022	24.584	1	.000	.964	.950	.978
[Gender=1]	.861	.2622	.347	1.374	10.775	1	.001	2.365	1.414	3.953
[Gender=0]	0[a]	.	.	.	.	.	.	1	.	.
(Scale)	1[b]									

Dependent Variable: Comfort Feelings

Model: (Intercept), Laeq, Age, Gender

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

G-2.3: Binomial Regression Parameters - Performance Subjective Rating N2

Parameter Estimates

			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-2.041	.8867	-3.779	-.303	5.296	1	.021
LAeq	.046	.0147	.017	.075	9.863	1	.002
(Scale)	1[a]						

Dependent Variable: Noise Annoyance

Model: (Intercept), LAeq

a. Fixed at the displayed value.

G-2.4: Binomial Regression Parameters - Performance Subjective Rating N7

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-1.522	.9059	-3.298	.254	2.823	1	.093
LAeq	.037	.0105	.016	.057	12.201	1	.000
Age	-.034	.0171	-.068	-.001	3.958	1	.047
(Scale)	1[a]						

Dependent Variable: Noise – quality impairment

Model: (Intercept), LAeq, Age

a. Fixed at the displayed value.

G-2.5: Binomial Regression Parameters - Performance Subjective Rating O1

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-2.135	1.6833	-5.434	1.164	1.608	1	.205
LAeq	.072	.0302	.012	.131	5.620	1	.018
(Scale)	1[a]						

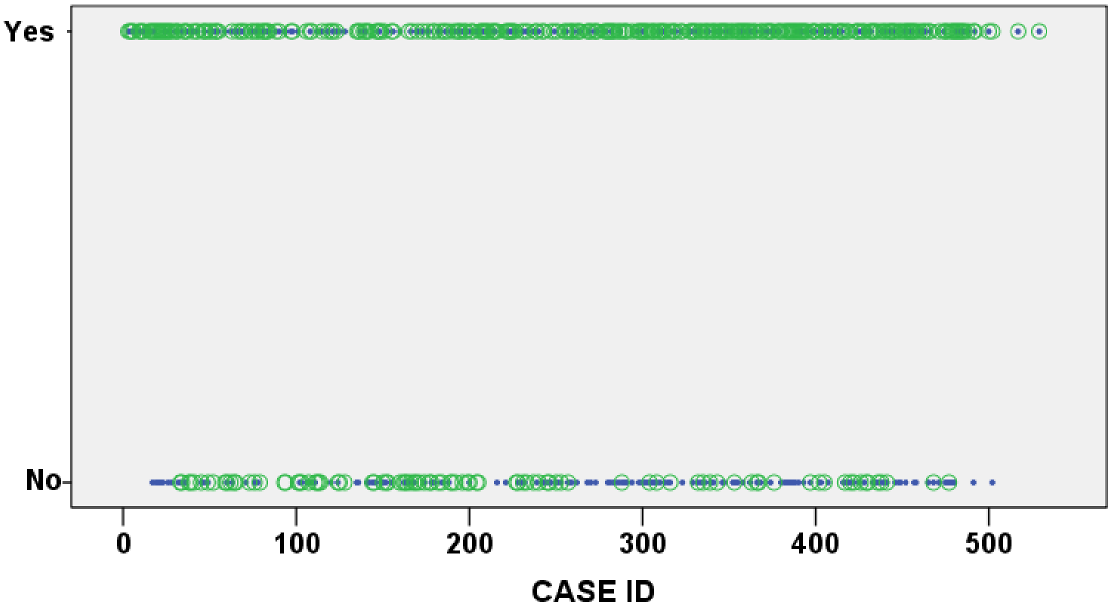
Dependent Variable: Discomfort feeling

Model: (Intercept), LAeq

a. Fixed at the displayed value.

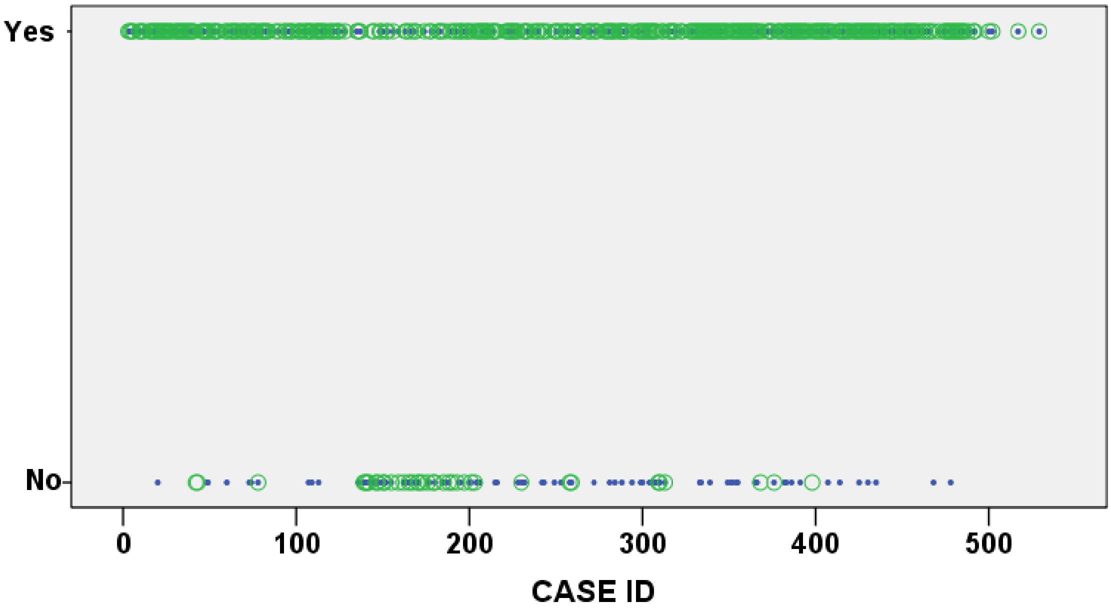
G-3: Index Plots of Predicted and Observed Comfort Subjective Ratings

G-3.1: Comfort Subjective rating N2



Predicted (circle) and observed (dot)

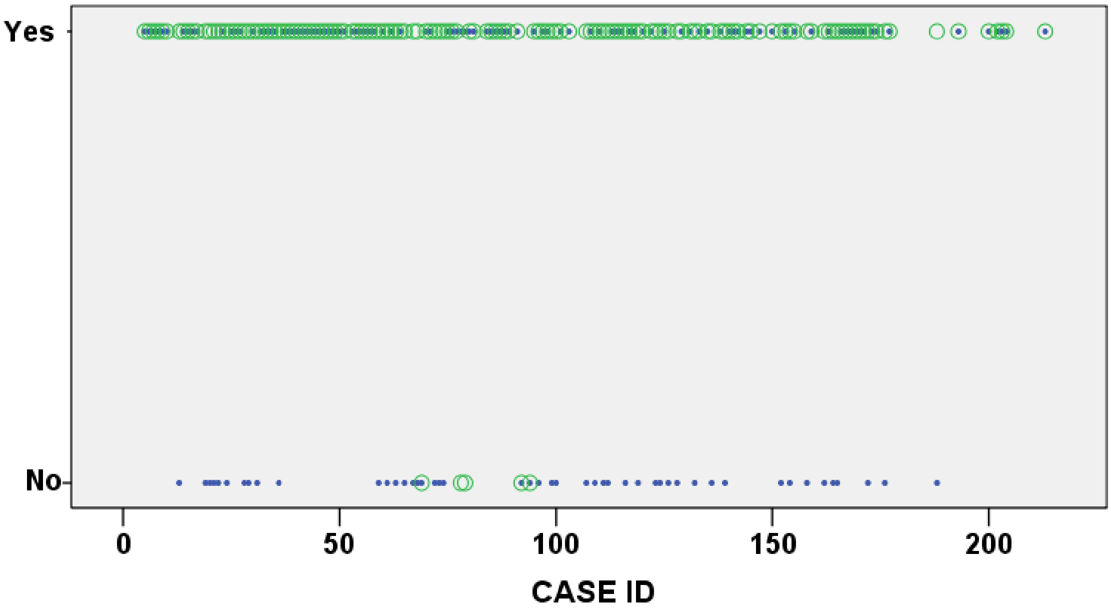
G-3.2: Comfort Subjective Rating O1



Predicted (circle) and observed (dot)

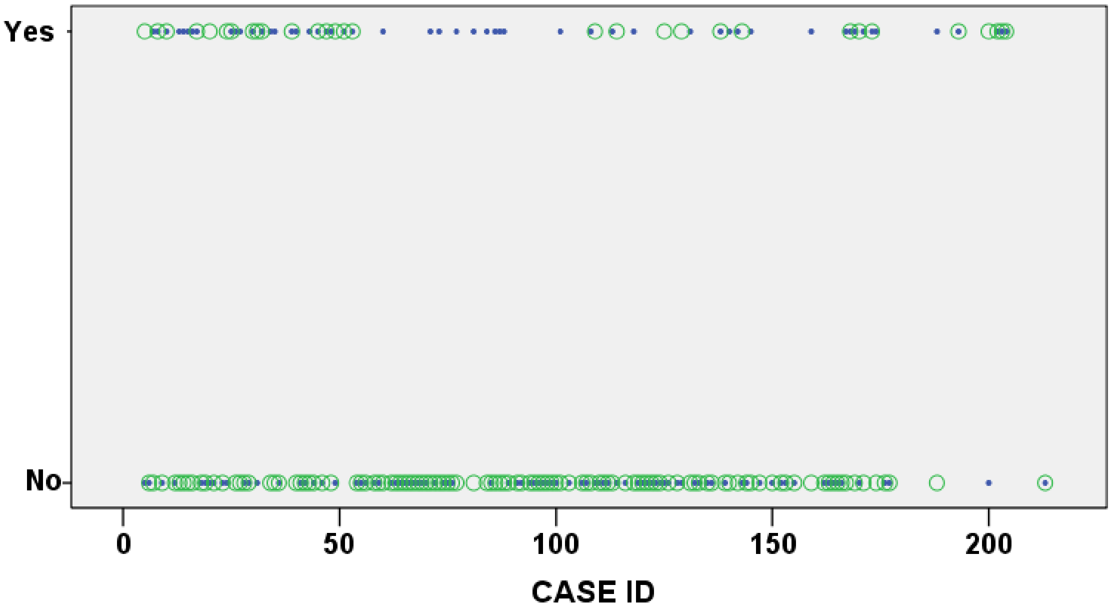
G-4: Index Plots of Predicted and Observed Performance Subjective Ratings

G-4.1: Performance subjective rating N2



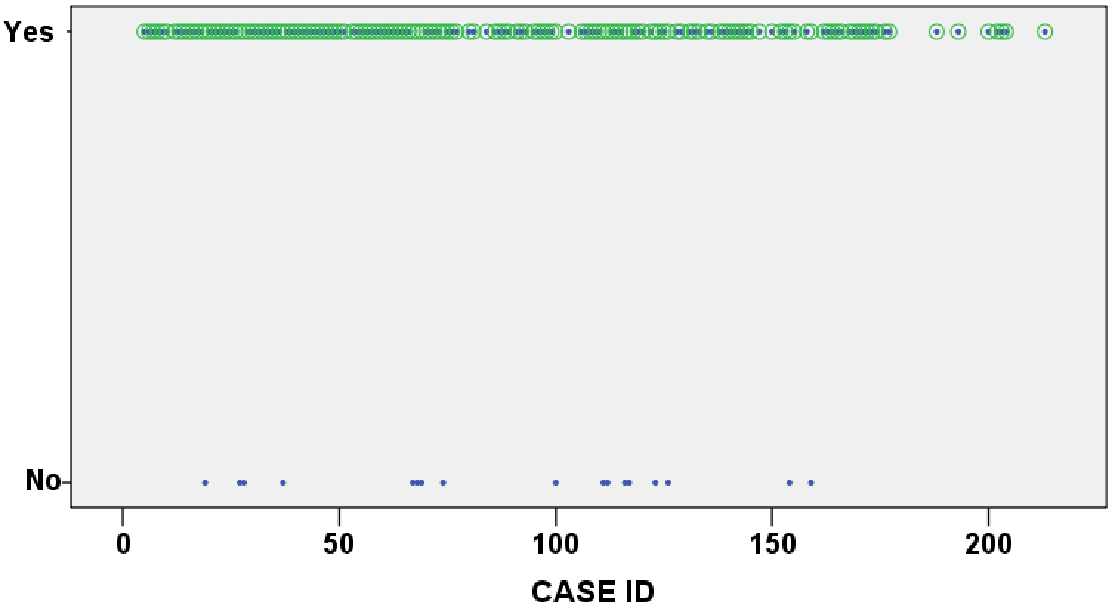
Predicted (circle) and observed (dot)

G-4.2: Performance subjective rating N7



Predicted (circle) and observed (dot)

G-4.3: Performance subjective rating O1



Predicted (circle) and observed (dot)

G-5: Summary and Conclusion

This section gives hypotheses test summaries of the binomial regressions on all selected subjective ratings. The general form of the binomial governing expression is:

$$L_{(\text{Any level of discomfort = yes})} = a_1 + B_1 X_1 + B_1 X_2 + \cdots + B_n X_n$$

Table below lists which variables are in the best regression models as well as the regression parameters for each model.

Overview of which variables are in the best binomial regression models. Also given are the overall test p-value and the regression parameters.

Model	Variables in model	p	a_1	B_L	B_G	B_A	B_{TS}
COMFORT – NOISE							
N2c: Noise annoyance	L & G & A	0.00089	-0.690	0.035	-0.568	-0.012	
O1c: Overall feeling of discomfort	L & G & A	0.0000	0.049	0.045	0.861	-0.037	
PERFORMANCE – NOISE							
N2p: Noise annoyance	L	0.00023	-2.041	0.046			
N7p: Quality impairment	L & A	0.00033	-1.522	0.037		-0.034	
O1pn: Overall feeling of unwellbeing	L	0.0021	-2.135	0.072			

The following can be observed from above table:

- Overall hypotheses tests for the parameters of all models are displaying highly significant values (at a 0.05 level).
- All models have A-weighted noise level included. Futhermore, exposure level is positively related (all B_L coefficients positive) to noise discomfort as well as noise induced performance degradation. Thus, with increasing noise levels, people are more likely to get discomfort and experience performance degradation. This observation is in line with existing literature and can intuitively be guessed.
- **Gender** is only included in the models for discomfort due to noise annoyance (N2c) and overall feeling of discomfort in noisy environments (O1c), with B_G coefficients opposite in sign:
- Gender is showing a negative relationship with noise annoyance (N2c). According to the coding used (1-males), the odds of getting annoyed by a given noise level are ($e^{-0.568}$ =) 0.567 times smaller for males than females.
- Overall feeling of discomfort in noise environment (O1c) is displaying a positive relationship with gender. The odds of feeling discomfort in a given noise environment are ($e^{0.861}$=) 2.36 times greater for males than females.
- **Age** is included in almost all of the models, with B_A coefficients always negative, displaying a negative relationship with noise (N2c) as well as performance degradation (N7p). This means, people are less likely to get annoyed / degrade work performance with increasing age. This may not be surprising as the human sensors for noise degrade with aging, leading to less discomfort / disruption in work.
- **Time spent at location** (or exposure time) did not enter in any of the models.