DIRECTIONAL SOUND EVACUATION - AN IMPROVED SYSTEM FOR WAY GUIDANCE FROM OPEN SPACES AND EXIT ROUTES ON SHIPS

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SUMMARY

Directional Sound Evacuation technology offers an additional or alternative evacuation way guidance that has been shown to considerably improve exit times. “Audible exit signs” positioned at carefully chosen locations guide people along escape routes including up or down stairs. They can also guide people out of public spaces - which today represent an increasing proportion of modern ship designs, have no evacuation aids effective in smoke and are not covered by SOLAS escape route regulations.

The UK Government's Maritime & Coastguard Agency has recently completed an extensive series of independent tests with University of Strathclyde in which over 400 volunteers participated in trials simulating accommodation, corridors and stairs as well as open spaces with and without smoke. In these trials improvements of up to 75% were achieved in smoke, and as much as 35%in perfect visibility. Following these trials, the Governments of UK and Germany have proposed Directional Sound Evacuation to the IMO for approval within SOLAS regulations as an alternative to Low Location Lighting and mandatory in public spaces.

AUTHOR’S BIOGRAPHIES

Professor Deborah Withington has studied directional sound for over 15years, first at the Institute of Medical Research in London, then in her own laboratories at the University of Leeds. She is a member of the American Neuroscience Association, Brain Research Association, European Neuroscience Association, Physiological Society, British Society of Audiology and a member of the Academy of Expert Witnesses. She has published nearly 50 articles in peer reviewed journals, and numerous book chapters.

Mike Lunch is Managing Director of Sound Alert Technology plc, developers of Directional Sound Evacuation systems. He is a member of the UK delegation in the IMO’s Large Passenger Ship Safety working group. Prior to Sound Alert he had twenty years in the IT business where he was Vice President of Toshiba’s European laptop PC business and latterly Managing Director of IBM’s PC business in the UK.

1. INTRODUCTION

Research on survivors of evacuation incidents has shown that finding the nearest available exit is the most important determinant of survival. It is therefore essential that individuals be guided to available exit routes in the least possible time. To achieve this and ensure balanced exit usage individuals must assisted to identify and find their optimal exits using the most effective sensory information.

Given that vision is the primary sense it is understandable that the majority of emergency exit aids, such as lighting, signage and photo-luminescent guidance strips are all visual aids. However the assistance given by visual aids may be reduced or rendered totally ineffective in a smoke filled environment.

2. EVACUATION CONSIDERATIONS

Behavioural studies have repeatedly shown that the most natural instinct in the event of an evacuation is to leave by the same route used for entry since this route is known. Frequently these exits are neither the quickest nor the most appropriate. People fail to notice nearby exits, and in some cases walk straight past visible fire exits. During evacuation the circulation routes used for normal everyday movement may encounter higher population flows than they were designed for. This results in overcrowding and a slowing down of the evacuation process.

The visual clutter of information and advertising signage may seriously impair identification of an optimal exit route, even in normal visibility. In some instances the nearest exit may not be visible and at present there is nothing to draw attention to it.

The process of evacuating a large passenger ship is a complex one, not least because it involves the management of a high population density on a moving platform. The design and layout of ships, often with narrow confined corridors and very few external reference points, can create difficulties in passenger orientation since most will be unfamiliar with the environment

When evacuating a ship while at sea, vessel motion is a factor that affects both mobility and way-finding abilities. When subjected to motion, the brain is occupied with maintaining balance while moving hence the ability to process information and make judgement is impaired, consequently way-finding abilities decrease. Motion sickness and nausea are results of visual/vestibular mismatch, (sensation of movement with no visual evidence) which reduces mental awareness. Sound localisation is primarily, a subconscious task and as such does not add to the burden of visual/vestibular mismatch. In view of this the use of directional sound may be more suitable as a guidance aid onboard ships.

Data from the UK Building Research Establishment show that well illuminated visual signage is unusable at a distance greater than 1.5m in dense smoke. There are many examples of evacuations through smoke in which the inability to find exits has resulted in multiple fatalities.

In April 1990 a fire onboard the ferry SCANDINAVIAN STAR killed 158 passengers. Many deaths occurred in passageways close to emergency exits and in cabins. Many survivors claimed that it was impossible to see the emergency exits in the smoke filled corridors. The Norwegian Fire Research Laboratory performed a series of evacuation trials on a reconstructed section of the SCANDINAVIAN STAR using the original emergency signage. It was found that 40% of test subjects failed to find the emergency exit. They either passed it, or tried to exit through the wrong door. In their summary the Norwegian researchers stated, *"We do know that emergency lighting and marking signs do not help to distribute people among the evacuation routes available."*

Norwegian Official Report NOR 1991:1E on the SCANDINAVIAN STAR Disaster stated, *"The committee recommends that a requirement be introduced that audible signals with a sound that clearly distinguishes them from the alarm bells be installed by the exit doors in escape routes on board passenger ships, as directions for escape in conditions of reduced visibility"*.

Thankfully, fires on passenger ships where passengers have to evacuate from or via smoke-filled spaces are rare. Experience in the use of low-location lighting in emergency situations is therefore limited.

However, an incident reported by the Unites States Coast Guard to IMO raised some doubts concerning its effectiveness in smoke. On 23 May 2000 a fire broke out on the Nieuw Amsterdam:

"By the time the passenger re-entered the corridor, it had become filled with smoke. Crouching to move along the corridor, the passenger became disoriented and was eventually found by a crewmember and taken to safety. The ship's electroluminescent low-location lighting system was in operation"

Survival time in smoke is another critical factor. Studies by Purser in the USA and Geir Jensen in Norway have shown that endurance in toxic smoke may be as little as 50 - 90 seconds. In a real ship fire, it is probable that evacuation into the next Main Vertical Zone would take people into their nearest place of safety – which is likely to be a distance of just 20 metres. However speed of movement would be critical for survival.

3. THE TECHNOLOGY

Sound is used in emergency evacuations to provide an "alarm" which merely alerts people to an imminent danger. Irrespective of whether this information is provided by conventional alarm tones or through voice messaging these give no information concerning the direction to, or location of, the nearest exits. These alarms are positioned to alert as wide an area as possible but even if they were placed over exit doors they would still be very difficult to locate quickly. To understand why these devices would not suffice as exit locators, it is necessary to describe how we locate sounds in space to an accuracy of 2-4 degrees.

For accurate localisation the brain has to decode three types of sound cues, which individually convey only limited amounts of spatially ambiguous information. The first two are known as *binaural* cues as they make use of the fact that we have two ears separated by the width of our head. A sound that emanates from either side of the midline of the head will arrive first at the ear closest to it and will also be louder. It is this difference in path length that forms the basis for binaural processing. Unfortunately, there are further complications with binaural cues. Firstly, the brain is very sensitive to the phase of an incoming waveform at frequencies below 1 kHz, so interaural time differences (the time difference between each ear, ITDs) are only really applicable at frequencies below this threshold. In addition, for the loudness differences (or interaural intensity differences, IIDs) to work the source must emit a sound that has frequency components with wavelengths smaller than the diameter of the head (about 3 kHz and above). The use of these two types of cue is known as the "duplex" theory and was proposed by Lord Rayleigh as long ago as 1906.

There are further problems however as the ITD and IID are virtually identical for sounds emanating either directly in front of or behind the head. To solve this ambiguity, the auditory system uses a third type of cue, the spectral cue for localisation. These spectral cues are provided by the way in which the external ear, or pinna, modifies the spectrum of the received sound such that some frequencies are attenuated whilst others are amplified.

To provide complete localisation knowledge, information from all three cues must be combined. For a sound to be accurately located it must contain as much of the audible frequency range as possible (20-20000 Hz). This is 'broadband' sound and can most easily be described as the sound of a rushing river or waterfall. Neither conventional alarms nor speech, which are narrowband frequencies, will work as directional sound aids.

4. DEVELOPMENT OF THE TECHNOLOGY

The principles of localization of sound have been understood by scientists for many years, however the concept of using an sound pattern optimised for localization specifically to identify direction was innovative when Professor Withington proposed this as part of her research at Leeds University in 1994. This innovative idea technology was patented and a spin off company formed to refine the technology into practical and commercially viable applications. The first directional sound evacuation experiments took place in 1997 in a TV studio at Leeds University where a thermal imaging camera tracked volunteers trying to find their way out of a dark room. Using DSE, a volunteer got out in just 15 seconds walking directly to the exit as compared to up to 1 minute and 50 seconds feeling around the walls.

A long succession of development trials and tests lead to the system being used in buildings such as Munich International Airport as well as now being examined by the aircraft industry as a means to improve aircraft evacuation. Sound Alert Technology has funded the development of this technology from its own resources – encouraged by the enthusiasm and support of the Maritime & Coastguard Agency (MCA) and Maritime Industry in the UK. It is now being proposed by UK and Germany's Administrations to IMO for equivalence to LLL meanwhile several shipyards and owners are keen to use the technology to improve life safety with early installations.

5. MARINE TRIALS

A series of marine trials were devised by Strathclyde University and the MCA and performed onboard two CalMac ro-ro vessels in June and October 2001.

360 volunteers for the trials were recruited from the local population and represented ages from 17–67 of both genders. Each trial endeavoured to obtain an evenly distributed age range and some included both hearing and visually impaired subjects.

For safety reasons smoke used in the trials was theatrical rather than real smoke. Theatrical smoke provides the visual disability associated with real smoke but not the toxic effects. The gases in real smoke cause a reflex closing and watering of the eyes consequently vision is almost immediately impaired and may be totally disabled.

Evacuation times were recorded, thermal-imaging cameras were used to enable further analysis and all participants completed questionnaires related to their particular trial. In smoke evacuation times were reduced by over 50%, in some trials as much as 75% - in clear visibility up to 35% saving was achieved.

In October 2002 a further set of tests were conducted aboard the Carnival Conquest shortly before delivery. The 9 deck atrium was filled with theatrical smoke and equipped with DSE sounders on all 26 exits, 20 of which were on the lower three decks – this created a potentially confusing acoustic environment. Participants were taken to points of maximum acoustic confusion - from which no illuminated exit signs were visible but the sounds from many sounders were audible. They readily and quickly found the nearest exits and then walked around the three lower decks of the atrium, locating door after door. Many remarked on the precision with which sounders could be located

In another series of tests, participants were put into cabins within a complex crew accommodation area filled with smoke. They evacuated the area in two tests, one using LLL, the other using DSE. DSE showed a reduction of 55% in average evacuation time compared to LLL – people moved faster with more confidence also saving time through using more direct routes. . The PA & GA systems were operated in both sets of tests and had no impact on the DSE's effectiveness.

Asked to imagine they were evacuating in real smoke, 84% of participants indicated they would prefer to rely solely on DSE compared to 6% on LLL and 10% on both.

Full details of the trails, thermal image footage, evacuation data and analysis are included on a CD published by the MCA, which can be ordered by email: webmaster@directionalsoundevacuation.com

MCA's Conclusions (observers of the trials) as submitted in their paper to IMO's FP46 committee in February 2002:

The results of the trials appear to be conclusive in that under the given conditions and acknowledged limitations of trial evacuations there is a clear benefit in the use of sound as an aid to guidance. In trials using smoke it was evident that there was little reliance on LLL since in 3% density smoke lighting assistance was not visible.

Analysis of the results of trials in which the benefits of directional sound and LLL may be directly compared indicate that in both smoke and no-smoke conditions directional sound offers at least an equivalent level of safety to that of LLL.

Open public spaces are not considered to constitute an escape route and consequently LLL is not required under the SOLAS convention.

Open public spaces are becoming an increasing popular feature of cruise ships and ferries. Existing IMO SOLAS regulations regarding means of escape do not adequately address the need to provide escape guidance from these areas. If LLL were to be made a requirement in open public spaces it is likely to be so distant from the *majority of passengers that in a smoke filled situation it would never be located. Under these conditions the only solution to the guidance of passengers in an evacuation is an audible directional alarm.*

6. GERMANY & UK PROPOSALS TO IMO

In May 2002 the UK and German Administrations, having observed the trials, proposed DSE to the IMO for equivalence to Low Location Lighting within SOLAS regulations. Details of the formal proposals to IMO and supporting documents are contained on the MCA's sponsored web site:
www.directionalsoundevacuation.com

7. APPROVALS STATUS

The UK and Germany's proposal for DSE to be granted equivalence to Low Location Lighting within SOLAS is being considered by the specialist sub-committees of IMO. This procedure is lengthy and detailed and inevitably may take some time. In the meantime DSE can be proposed and fitted as an alternative to Low Location Lighting within the SOLAS regulations using the provisions of regulation 17 of SOLAS 2-II. This regulation makes provision for "Alternative Design and Arrangements" to be examined and approved – subject to suitable fire safety engineering and risk analysis.

8. INNOVATIVE FEATURES AND CONTRIBUTION TO IMPROVEMENT IN SHIP SAFETY

The use of broadband directional sound allows passengers and crew to locate the direction of evacuation routes even in a smoke filled ship when other way finding aids dependent on vision are ineffective. In addition, even in perfect visibility, DSE technology draws attention to exit routes, which may otherwise be obscured due to visual clutter such as fruit machines in casinos and retail merchandising signs in shopping malls. Independent Trials have shown that evacuation times are improved as much as 75% in smoke and 35% in perfect visibility compared to existing Low Location Lighting technology. The DSE system consists of a series of sounders located at exits and on stairways along the exit route. The DSE system is capable of being integrated as an extension to the existing PA/GA system of passenger ships thereby enabling a more effective, lower cost and lower maintenance way-guidance solution than current Electro-Luminescent Low Location Lighting systems.

9. LEGAL IMPLICATIONS

In a number of judgements the American courts have ruled that the Americans with Disabilities Act 1990 (ADA) does apply to passenger ships. The American Council for the Blind (ACB), in a resolution passed in July 2002 voted to press for mandatory fitment of DSE to all passenger vessels operating in or visiting the United States. Since that time, the ACB's legal council has given a Legal Opinion that DSE is applicable not only to ADA Title II (which prohibits discrimination on the basis of disability by public entities) but also to ADA Title III (which prohibits discrimination on the basis of disability by public accommodations and requires places of public accommodation and commercial facilities to be designed, constructed, and altered in compliance with the accessibility standards established by the act). DSE provides a way guidance system that can assist an owner meet his obligations under these stringent regulations.

10. SYSTEM DESIGN CONSIDERATIONS

Vessels are divided into Fire Zones each of max 48 metres length. Fire zones are served by dedicated or shared staircases.

Staircases in atriums are not considered to be part of an evacuation route – evacuation within an atrium would always be back into the normal deck space on each level – thence to one of two or more alternative evacuation routes. The embarkation deck is the deck from which survival craft or Marine Evacuation Systems (MES) would be entered. The assembly stations are mostly on the embarkation deck. Movement of passengers from assembly station to survival craft or MES will always be under crew control. Thus pre-planned evacuation routes will always direct passengers on the assembly station deck and from upper or lower decks to the assembly station via stairwells.

Design of DSE systems takes into account possible exit routes and position of sounders to avoid conflict. The system is designed to provide route guidance to at least two exits – so that if an exit is blocked, sounders can be followed to find an alternative exit.

In long corridors, fire doors are closed remotely when there is a General Alarm (GA) to control spread of smoke. DSE sounders are installed on either side of these doors to attract passengers out of their fire zone and into the next one.

Passengers not already on the assembly station deck use stairways to travel both up and down to reach the assembly station deck. "Up" and "down" DSE guidance tones are used to send passengers the correct way, this supplemented by normal signage at both normal and low level. The DSE system provides a guided route in the stairwell – even if it were to be filled with smoke.

Open public spaces are becoming an increasing popular feature of cruise ships and passenger ferries – as many as three decks are devoted to Public Spaces on large cruise ships today. Existing SOLAS regulations regarding means of escape do not adequately address the need to provide escape guidance from these areas. In smoke filled conditions sufficient to obscure illuminated exit signs, there is no evacuation guidance afforded to passengers. The installation of DSE should be mandatory in these spaces where no suitable alternative can be demonstrated. Recent tests in Italy have shown that a large number of DSE sounders can operate successfully in the same space – without conflict. Normal conversations and radio communication were also possible.

11. POSSIBLE TYPES OF INSTALLATION

11.1 EXTENSION TO EXISTING OR NEW ANALOGUE PA/GA (PUBLIC ADDRESS) SYSTEMS

The conventional PA/GA system can be extended to provide DSE system functionality, (see Fig. 1) by adding "another message"; the directional sound pulses. Additional amplifiers and loops feed an additional set of loudspeakers placed at Exit nodes along the evacuation route. In this way the management of hierarchy of sounds can be handled within the existing PA/GA system to ensure no conflict between PA, GA, DSE and normal background music (BGM) sound signals. Similarly the cabling, installation, emergency electrical supply, redundancy and circuit monitoring would be to established SOLAS practise. Installation would use two loops (a & b) in each fire zone to ensure redundancy; alternate directional sounders being on each of the loops. This would be the preferred method for early installations since the technology is proven, type approved components and systems exist, installation is well understood and SOLAS already has relevant regulations covering its arrangement:

- DSE Sounders are extension to PA/GA System - normal 100v line
- Additional Control Amplifiers & DSE Tone circuitry – per Fire Zone
- Each Circuit (Tone, Amp and loops) can only handle one tone
- Additional tones (Up & Down tones for stairs) require additional circuits.
- 2 Independently wired loops for each circuit (a/b) in addition to PA/GA loops
- PA/ GA controller automatically handles hierarchy of sound signals – only one signal at a time, top three would override all entertainment systems on board to reduce risk of acoustic conflict (as today's PA/GA):

1. PA announcements from Master
2. General Alarm
3. DSE
4. Normal Background Music functions

- Use existing switch panel on bridge for triggering by fire zone or all together (option)

11.2 FREE STANDING SYSTEM

It is possible to design a new free standing system to trigger the DSE sounders – however such a system would require original design, class approvals and manufacture. These systems are required to deliver the same performance requirements and conform to the same Safety, Fire Protection and Electrical requirements as PA/GA systems within SOLAS today. Land based systems today use 24 volt powered directional sounders linked to Fire Detection Systems and automatically triggered.

11.3 EXTENSION TO DIRECT ADDRESSABLE DIGITAL PA/GA SYSTEM

This new digital technology has many advantages in PA/GA systems since it allows each speaker to be addressed individually. When it is commercially available to the marine industry, DSE may be fully incorporated within, and be only one facet of, an all-encompassing sound distribution system for the entire ship. Intelligent evacuation guidance with dynamic route changing will then be an option.

Detailed guidance for location of DSE sounders is contained in the "draft ISO standard" for arrangement of DSE aboard ships. A copy of this updated draft document can be found on the web site: www.directionalsoundevacuation.com

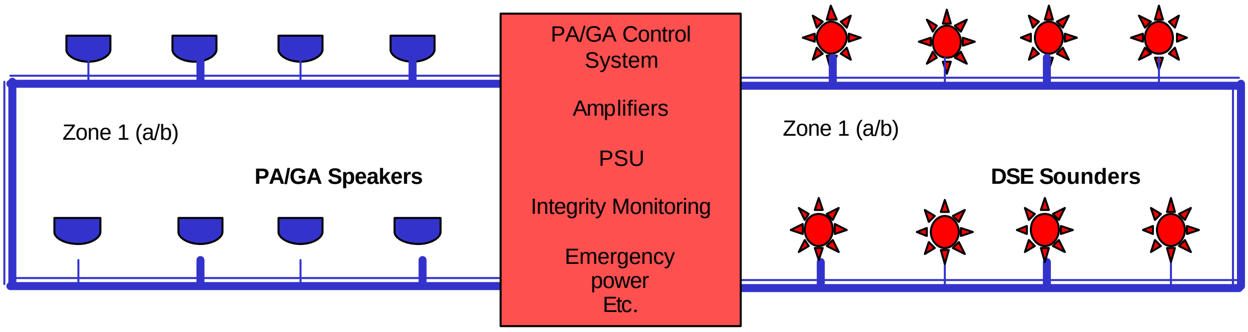

Figure 1: DSE Installation using Analogue PA/GA System

A performance based specification for Directional Sounders is being developed by the British Standards Institution. The current version of this specification – PAS41:2003 has just been published by BSI and can be found on the MCA's sponsored website:
www.directionalsoundevacuation.com

12. INSTALLATION AND SURVEY

During commissioning, the installation is tested to ensure that the sounders provide adequate sound levels at all points along an exit route. At least two sounders are to be audible at all points leading to alternative exit routes at levels of a minimum of 75dbA and at least 10dbA above ambient noise levels.

If a route ends with a corridor from which there is only one exit, only the sounder at that exit need be audible beyond the point at which you enter that route. If that exit is not viable a passenger would have no choice but to back track along the route, and when he arrives at a point of decision (i.e. where there is a choice of route to go) he must at that point be able to hear another sounder to guide him to an alternative exit. The exact location, direction and volume of sounders can be critical for their effective operation. The "draft ISO standard" and PAS41:2003 provides guidance on the siting and choice of sounders according to the location and area of coverage required.

The "draft ISO standard" calls for each sounder to have the capability to be independently isolated to allow for testing. This also allows for the possibility of disabling it manually in an emergency to avoid guiding passengers into danger – however use in this way this would be an operational matter – and should not be a mandatory item within the SOLAS regulations.

The "draft ISO standard" indicates how the sound levels must be tested for each sounder and records kept for audit purposes. A certificate of compliance must be issued.

Regular tests of the system's effectiveness will be required as well as periodic full surveys. Weekly abandon ship drills and fire drills not only satisfy the need for regular testing but also ensure passengers become familiar with the sound and the principle of DSE. The "draft ISO standard" contains proposals in this area.

13. OPERATION

The DSE system, in its initial implementations, would be manually triggered by the crew in response to a situation in which evacuation is deemed necessary. Evacuation could be by Fire Zone or the entire vessel dependant on the circumstances. Naturally the DSE system is intended to be complementary to the role of the crew in guiding passengers to safety – however in the event that smoke engulfs a vessel, the DSE system would still be able to provide way-guidance even when crew are unable to assist. The system is designed to avoid conflict of audible messages a hierarchy of sound signals is already established within today's PA/GA systems, and DSE can be managed to ensure that each audible signal – announcement, GES or DSE is broadcast in a clear and intelligible manner.

14. CONCLUSIONS

The DSE system offers for the first time an effective way guidance system for open public spaces. In addition, DSE offers superior performance to the Low Location Lighting systems specified today in corridors and stairs.
Recent court judgements concerning the Americans with Disabilities Act have shown that there maybe an exposure for passenger ship-owners operating within or visiting USA unless they fit DSE systems to accommodate the blind of visually impaired.

15. ACKNOWLEDGEMENTS

The assistance of Caledonian McBrayne Ferries, Carnival Corporate Construction, Fincantieri Shipbuilders together with the University of Strathclyde, University of Greenwich, University of Leeds and the Maritime & Coastguard Agency is gratefully acknowledged for their provision of facilities and participation in marine evacuation trials.

The MCA's sponsored web site contains independent research on Directional Sound Evacuation carried out on Aircraft, Buildings and Ships as well as an archive of papers submitted to IMO proposing DSE as equivalent to Low Location Lighting:
www.directionalsoundevacuation.com

Sound Alert Technology also has a web site that contains information on the wider applications of DSE outside the maritime industry, further information on the technology and a bibliography of further references:
www.soundalert.com