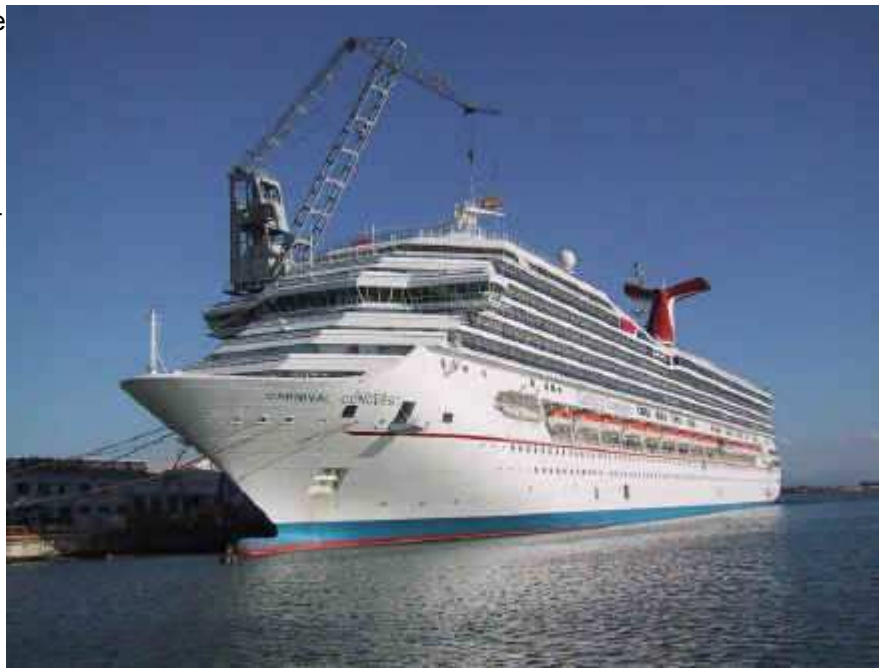
Marine Tests - Italy 2002

Executive Summary

DSE Tests were conducted aboard the Carnival

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 lead into the centre of the lowest deck to points of maximum acoustic confusion (from which no illuminated exit signs were visible but the sounds from many sounders were audible). They were asked to find exit doors – which they readily and quickly achieved, some 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 a second 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. The same group participated in both trials, however their cabin locations were changed and they were lead by a disorienting route in thick smoke to reduce the risk of learning. Amongst the group most were experts (e.g. trained crew) and many who were familiar with the test area – however their evacuation times showed them to have no advantage over those with no prior knowledge.

The DSE test 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.

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.

Background

Directional Sound Evacuation (DSE) technology is currently being proposed by the Administrations of UK and Germany to the IMO as an equivalent to Low Location Lighting (LLL).

Extensive trials were conducted under the supervision of the UK Administration in 2001 in Scotland aboard two RoRo ferries using demographically matched population samples recruited from the general public. These trials were most positive and showed DSE to be at least the equivalent to LLL in corridors and stairs. In addition those

trials investigated the use of DSE in open spaces, areas not currently covered by SOLAS regulations.

A number of questions have been raised at various IMO meetings regarding detailed aspects of implementation of DSE. Prior to the completion of the current IMO considerations for the granting of equivalence to LLL, it would be possible for early fitment of DSE using SOLAS II-2 regulation 17 “Alternative Design and Arrangements” however this can only be achieved with the support of many parties including Classification Societies, Administrations as well as Fire Safety Engineering Analysts. These parties have had limited opportunity to experience DSE technology and prior to these tests no demonstrations or trials had been conducted on a large passenger ship.

Carnival Corporation (via its membership of ICCL) and Fincantieri are participants on the IMO committees at which these questions were raised, have potential interest in early implementation and hence agreed to sponsor a series of tests aboard the vessel Carnival Conquest at Monfalcone at the same time as the handover inspection on Wednesday 16th and Thursday 17th October 2002. This allowed a number of participants from the US Coast Guard, Lloyds, RINA, MCA as well as representatives of Carnival, Costa, Holland America Line and others.

Feedback from these participants as well as analysis of data is included in this report.

Open public space – 9 deck atrium audibility test

Objective

To demonstrate that DSE can be successfully implemented in a complex acoustic environment such as an atrium where many DSE sounders would be active in the same space.

The challenge

SOLAS regulations do not regard the atrium as part of the escape route and therefore LLL is not required. On each deck within the atrium there are exits marked with illuminated exit signs to guide passengers out of the atrium into adjacent fire zones - to escape routes marked by LLL. However, in the event of smoke, these illuminated exit signs may become obscured and difficult to locate.

An atrium has a complex acoustic environment. For DSE technology to be applied successfully, it must be possible for passengers standing on the floor or on balconies to identify the exits which are accessible to them on their deck – despite the potential acoustic confusion created by the presence of multiple DSE sounders on other decks.
Furthermore the additional potential acoustic confusion of PA announcements and GA alarms needed to be assessed, together with the crew’s ability to communicate using radio handsets.

The test

The Carnival Conquest has an atrium that spans 9 decks. Of these, 7 decks have open access to the atrium and could be impacted by smoke within the atrium area.
As part of the handover inspection, a smoke evacuation test was carried out on Wednesday 16th October – for which the atrium was filled with theatrical smoke restricting visibility to approx 1-2 metres.

DSE sounders with output levels of between 92-98dbA were mounted at each of the 26 exits from the 7 decks of the atrium to adjacent fire zones or open decks. The atrium design is such that 20 of the DSE sounders were located on the lower three decks – each of which was audible individually during set-up to anyone

located on the three lower decks.

Since the vessel was in the course of handover, its decorative finishes were complete. To avoid damage to decor some of the DSE sounders were located adjacent to exit doors rather than vertically above the door handles.

The demo simulated the above confusing environment. Observers with normal hearing (according to the completed questionnaires) were taken into the smoke filled atrium and positioned on deck 3 (the lowest deck) at one of 4 locations. These locations were chosen due to their central position where a large number of sounders were audible from all three of the lower decks.

Participants were asked to identify exits from where they stood. After a few minutes, the DSE sounders were activated and participants asked to find their way to an exit – they were then free to walk around the test area and attempt to locate other exits. Whilst this was happening some test PA announcements were made, the General Alarm was activated and radio handset communication was tested.

Feedback from participants

Questionnaires have been received from many participants giving their reactions and experiences.

DSE system's effectiveness at locating exits

Most commented that they could not see an exit from their starting position, and none could see an illuminated exit sign.

Several commented that they were unsure from their starting position which of several sounders was closest, however after moving even a short distance they were immediately able to tell the difference between sounders and locate their nearest exit by following the loudest sound. Having located that exit they were able to move on and locate other exits nearby with surprising ease.

Many commented on the precision of the guidance provided by the sounders, the ease with which they could locate exits and the speed at which they could move - only needing to guard against tripping hazards since they knew where they were heading.

"it was surprisingly easy to locate the exit doors using the directional evacuation sound system. The only difficulties experienced were avoiding tripping hazards. The demonstration system was significantly more effective than the lighted exit signs. The direction of each door speaker was clearly discernable from a distance, whereas the exit signage was not."

"after my decision to move in one direction I found the exit door. I went back into the atrium and found all the exit doors"

"It was quite easy to go straight towards the loudest sounder - no doubts on the direction to choose, i.e. clear perception of exit location"

"once I moved I could make the difference between sounders that were close and could easily locate the one that was closer."

"It was interesting to understand how even hearing many sounds you could recognize where to go, I was able to reach exit doors quite fast."

"In the centre area of the Atrium I was not able to locate a sounder clearly. But when I walked some meter in one direction there was one sounder I could locate clearly. So I walked in that direction to find the exit. But also to find another exit was very helpful by walking (swimming) around and following the next loudest sounder."

"I walked around, trying not to trip over furniture, and easily made my way to the closest exit door. From there, I walked away from the located door until I acquired the sound of and found the next closest door. Repeating this

method, I located every exit on deck 3 and deck 4."

On the ability to hear the GA system (a pure tone 1800hz signal) in addition to the DSE sounders, there were mixed reactions – some had no problem, others could only just hear the alarm whilst others did not notice it at all.

On the ability to hear the PA announcements – some heard them, others did not.

Ability to locate exit door handles

There were several comments on the extreme precision with which the DSE sounders could be located. Since many of the sounders had been located to one side of the door (to avoid damage to décor in this test), several participants found themselves directly in front of a sounder but actually at the side of a door and thus unable to locate a door handle nearby.

Comment: Many of the doors were sliding pneumatic doors with recessed door handles. Some of these were at the centre (of very large double sliding doors) others were at the side. None of the doors in the test area had "push bar" panic door releases. Previous trials have shown it is important that the DSE sounder is located vertically above the handle.

Communication with radios – tests with handheld radios confirmed that communication was possible when in the test area. Naturally it was easier to communicate when standing away from the DSE sounders than when standing close to them.

Conclusions

DSE sounders were very effective in locating nearby exits even when many sounders were in operation in the same space. The direction of multiple exits could be located and the nearest identified without difficulty. By comparison illuminated exit signs were invisible until the participants were very close to the doors. The DSE system continued to operate well even when other sound distractions were present.

In this test PA and GA systems were deliberately operated at the same time as DSE and, whilst the DSE system was unaffected, neither the PA or GA systems were effective in the body of the atrium. The DSE sounders were at their maximum output levels and could perhaps have been adjusted to lower outputs. The PA/GA system, by contrast was set-up to meet the SOLAS regulations – minimum of 75dbA or 10db above ambient noise levels. In a real implementation, it would be necessary for the DSE system to be interrupted automatically in the event of an announcement. With regards to the GA it may be necessary to look at the priority of alarm sequence.

Radio handset communication was tested OK

Location of door handles in smoke is a problem. None of the door handles in the atrium had LLL marking their location. Where DSE sounders were to one side, the handles were hard to find.

Cabin evacuation test

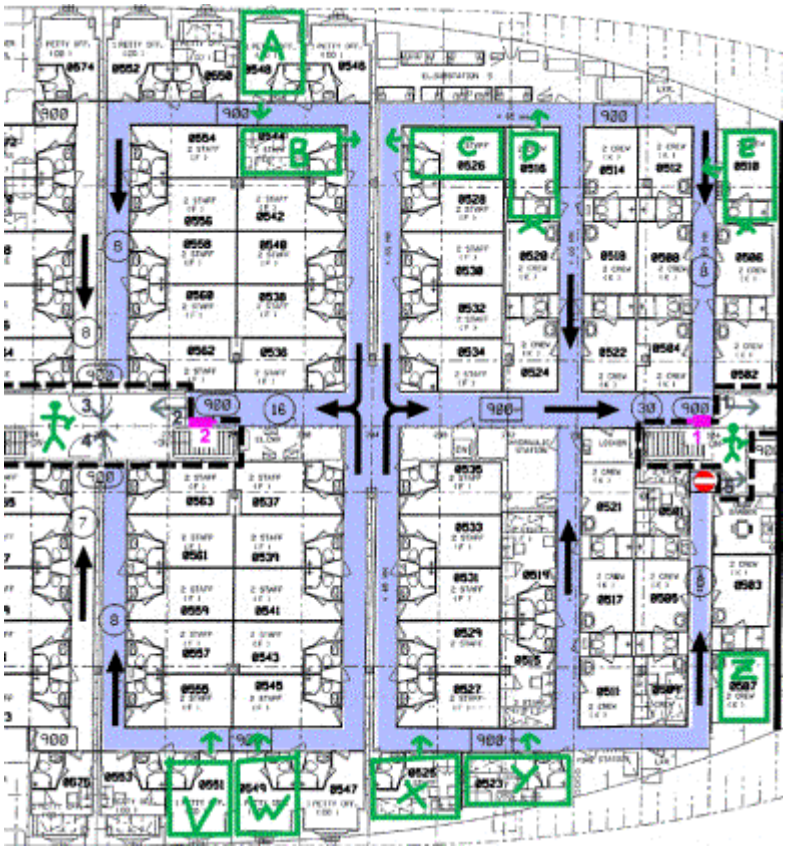
Objective – to compare LLL and DSE technologies in the evacuation of a complex cabin accommodation space on a large passenger ship.

The test

The Carnival Conquest has substantial accommodation for passengers and crew. The passenger accommodation is both sides of two long straight corridors running the length of the ship – this layout is not very challenging for a test. By contrast, the crew accommodation layout is complex and confusing and was thus ideal for a pair of identical tests – one using LLL the other DSE.

Many of the participants were familiar with the layout of the test area so special efforts were made to disorient

and confuse them. No layout plans were on the backs of the cabin doors, cabin door numbers were obscured and participants were lead through smoke filled corridors to a series of cabins situated in confusing locations (each with several possible choices of evacuation route). They waited whilst the corridors were completely filled with dense theatrical smoke simulating loss of vision caused by the attack of real smoke on the eyes (visibility about 0.5-1m). On PA announcement – they were asked to find their way out. After a short time – 30 seconds in the LLL test and 15 second in the DSE test, the GA alarms were started and ran to the end of the tests. In the DSE test, there was a PA announcement during the test to evaluate audibility.



In the first test the participants had the benefit of LLL. In the second test, the same people were guided to different cabins and asked to repeat the exercise this time using DSE for guidance (the LLL was switched off). Each participant had numbered vests and was observed using thermal imaging cameras. Observers at each exit logged their exit times. On completion of the tests, each participant completed a questionnaire to log their experiences.

The test area had five possible exits – two forward, three aft. One of the forward exits was blocked by a security guard simulating the exit being blocked by a fire. When participants arrived at that exit, they were instructed to find an alternative. This was to test the ability of LLL and DSE to trace back their route and find alternative exits.

Feedback from participants

33 participants took part. Of these, 32 completed questionnaires – their comments are shown in the enclosed Excel database file, originals are available for study.

LLL examples of very long journeys where far shorter exit routes were missed:

One participant - familiar with the layout - started from cabin V (aft stbd) followed the LLL forward around the complex layout eventually arriving at the blocked exit 5 – he then backtracked eventually emerging at the forward x-roads on the main corridor. Turning aft he finally exited after 275 seconds (4 m 35 s).

Another - also familiar with the layout - started from cabin B (aft port) crawled following LLL and eventually realised he had gone in a circle, finally exiting at door 1 well behind the other occupants of his cabin who had started after him (3 m 24s)

DSE experience

"*I was somewhat disoriented and I had no idea where I was located with respect to the entrance.*

I made my way to an exit using the directional sound evac system. This turned out to be very easy, as the loudest speaker led me directly to an exit. This exit, however, had been blocked. I then bactracked to a location where I could make out another speaker. I made my way to this speaker, making two turns at corridor

intersections, without any difficulty and exited the smoke-filled space.

This test again showed promise for this system. It simulated escape from a smoke-filled space, with practically no visibility and distracting noises, except for two details - the smoke was not toxic or unpleasant and the volunteers were not filled with panic. The directional sound evac speakers were highly effective under the test conditions."

Questionnaire analysis:

LLL test:

5 people (15%) could not see the LLL at all. Of those that did, 6 people (18%) felt the LLL did not provide assistance to an available exit. 25 people (78%) crouched or went down on hands and knees

DSE test:

All could hear the DSE sounders and all felt they guided them to an available exit.

24 people (75%) heard 2 or more sounders on their journey and all chose to go towards the loudest one.

11 people (34%) delayed their journey at some stage to understand the direction of the sound. Of these 7 heard one or more sounders, 2 were confused by the direction of the one they could hear, 1 saw an illuminated sign pointing the opposite way to the sounder direction! Of those that paused to find which way was the loudest sound, the video shows several of these incidents –typically this pause lasted ½ to 1 second.

25 participants (75%) heard the PA & GA alarms during the test – however 4 could only just hear them.

2 people (6%) went down on hands & knees on their way out – the rest remained standing – reason "no need".

Participants were asked to imagine if the smoke were real, which would they prefer to rely on to evacuate them to safety: 26 (84%) DSE only 2 (6%) LLL only 3 (10%) both

Note: The full text of questionnaire responses is contained in the Excel spreadsheet.

Evacuation times Analysis

Table 1	Everyone (32 participants)			"Knew layout" group (16)		
	LLL	**DSE**	**Saving**	**LLL**	**DSE**	**Saving**
Average Exit Time	135.7	60.5	55%	136.88	63.1	54%
Average shortest distance (metres)	20.1	20.6		19.5	20.5	
Average actual route distance	24.0	21.7		24.2	21.6	
% wasted travel distance vs. optimal	19%	5%		24%	5%	
Travel speed m/sec	0.18	0.36		0.18	0.34	
Numbers of people over 90 secs (exceeded survival time in smoke)	22	2		13	2	
% survived	**31.3%**	**93.8%**		19%	88%	
In real smoke which would you prefer?	6%	84%	10% both	0%	86%	14% both

Referring to table 1, the tests using DSE provided a saving in evacuation times of 55% compared to those with LLL.

In his discussions on evacuation Prof Ed Galea mentions that in real smoke, people are unlikely to survive more than 90 seconds due to poisonous gas inhalation. If this criteria were to be applied to the above test, with LLL only 10 of the group survived (31%) whereas with DSE the survival rate would have been tripled (94%).

Some analysis of net travel distance was possible with this test since the start and end points for each evacuation are known. Table 1 shows that with DSE a more efficient choice of route was taken (DSE guiding people to nearer exits) thereby reducing wasted travel distance. It is also possible to calculate the net travel speeds. However, through the questionnaires it is known that in some of the LLL evacuations, people took much longer journeys through significant diversions – so the data does not reflect best possible speeds of movement with the two technologies. The differences in time are, however comparable.

Note: The full data on evacuation times and cabin locations is contained in the Excel spreadsheet.

Video Analysis – human behaviour

The Thermal Image videos showed behaviour in the central corridor from either end.

LLL test
Most people crouched or stooped to see the LLL. The moment they stood upright they could no longer see and had to bend again. Movement is very slow and hesitant. A small group of participants reached the forward exit door 1 fairly quickly, from cabins D&E nearby, however they did not immediately exit. The video shows the group waiting near the exit door. (One had been confused and hadn't realised that they had to LEAVE the area. As a result another of the participants thought this a blocked exit and said "you'll have to go back" erroneously sending No 19 away from the door. This resulted in delay in exit for nos 3,4,19 and 25 whose exit times have been adjusted to reflect the time they first arrived at door 1. Eventually 8 arrived at the exit door and immediately opened it – clearing the misunderstanding). Very late in the test a disoriented participant emerged at the forward end of the corridor and came the whole way aft to exit from door 2.

DSE test
Speed of movement was much greater, with everyone walking upright – at a slow walking pace.
People emerging from side corridors and hearing two sounders often paused for a fraction of a second looking both ways to work out which sounder was loudest – then correctly turned towards the nearest exit.

Limitations of the data on evacuation times and speed

Clearly there are some key differences between these tests and the trials conducted in Scotland.

In these tests, the participants were "experts" - many trained in fire fighting and evacuation techniques. One observed difference was that in the LLL trials in Scotland (using a demographically correct sample from members of the general public), very few participants crawled or crouched down to observe the LLL. In these tests, most of the participants were trained to do this - and followed their training.

Although 25 people (78%) had been on the ship before, only 18 people (56%) were familiar with the layout of the test area. One admitted in his questionnaire that he knew exactly where he was in both tests, another had no numbered vest – so their results have been excluded. However, others that were familiar were sufficiently disoriented by the smoke and confusion techniques that they became severely disoriented during their evacuation with LLL – one going round a complete circuit of an accommodation block following the LLL. Analysis of those who were familiar, compared with those who were not, showed very little difference in their times (see table 1)– they were slightly slower in both tests than the average of the total group.

Re-use of the same sample participants. Clearly there was potential for participants to learn the layout from the first test and do better in the second. For this reason, all participants were arranged such that they did one test starting from Port cabins and the other from Starboard. Mostly these swaps also shifted the nearest exit from fore to aft or vice verse. Bearing in mind that most of the participants were observers from internationally recognised maritime organisations – their questionnaire comments provide a good check on whether they felt the second test was "too easy" because they already knew their way.

Other comments

One participant offered two opinions in the questionnaire on which research has already been done:

Participant's opinion	Research based comment
I think elderly / inexperienced PAX would move away because sound is frightening	This was tested in the Scottish trials with a large mixed age population recruited from the general public, including elderly people – no such reaction was observed.
DSE did not force me down. This was dangerous: 1. Low on floor less smoke & heat 2. No indication if you approach stairway or step with DSE 3. Evacuation speed is higher but this can cause people to bump or fall over each other what slows the process.	1. Whilst it is true that smoke rises when it is mixed with hot gases this is only true for a very short time. As the gases cool the smoke falls to fill the entire space (See Nieuw Amsterdam NTSB incident report) 2. This test area was flat with no steps. DSE can provide guidance to mark the start of stairs. 3. Previous trials have shown NO problems caused by people walking. Non-experts are extremely reluctant to crawl, indeed this LLL test showed the chaos that a mixture of crawling and walking can bring.

In the second test the smoke levels in the side corridors aft were slightly lower than in the first test due to smoke leakage problems – this affected a small number of the participants.

Communication tests

78% heard and understood the PA and GA messages when operating at the same time as DSE. The radio handset communication test was successful.

Conclusion

DSE allowed participants to evacuate 55% (75 secs) faster than LLL. The blocked exit test showed that DSE provided effective tracking to an alternative available exit, providing a 50% (88 secs) saving in exit time compared to LLL. Participants all heard and located the DSE sounders despite the distraction of simultaneous PA & GA announcements and 84% preferred Directional Sound only as a guidance system.