Decision Support for Crisis Management and Emergency Response

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ABSTRACT

Decision support systems for onboard use are many and varied. Primary role of such systems is to alleviate burden of processing of ship and environment data and ultimately to help crew in making informed decisions. Effectiveness of such processing could not be more important than during crises situations. This article presents with a prototype of an ergonomic decision support function for provision of advisory to the crew for enhancing their instantaneous preparedness for response to a distressed flooding situation. It is argued that automated inculcation of crew preparedness is the most effective tool for avoiding and managing crises, should they occur.

KEYWORDS

Crises management, emergency response, decision support, stability, survivability, flooding.

INTRODUCTION

Technological advances in computing hardware over the last decades have facilitated solution of many problems in ever decreasing amount of time. However, the progress in technical calculus, involving modelling based on the fundamental physical laws, has been just as significant, and despite the availability of very powerful computers, many cases of numerical approximations to reality remain impractical to compute.

It is for this reason that advanced prognosis have only had limited success in proliferating the field of instantaneous decision support.

Although highly advanced computerised safety management systems (SMS), have found accelerated support, their advisory functionality are mostly limited to detection only, with more sophisticated prognosis capabilities remaining at prototyping and development stages.

Such prototype simulation approaches available for use in prognosis comprise a range of phenomena such as (a) flooding progression, modelled through various but direct solution to conservation of momentum laws, Papanikolaou et al, 2000, Schreuder 2008, de Kat 2002, Jasionowski 2001, Petey 1988, or through quasi-static iterative approximations, e.g. Varela et al, 2007; (b) structural stress evolution under flooding, Bole, 2007, (c) mustering process, Vassalos et al, 2001, Piñeiro et al, 2005, (d) fire and smoke spread, Guarin et al 2004, and other.

Some of the reasons inhibiting their more wide use for decision support arise due to a series of practical problems in addition to sheer computational effort, such as the following:

- Each of these processes may vary at any instant of time due to changing conditions.
- The input is subject to considerable uncertainty.
- For any set of input information the outcome is random due to computational and modelling uncertainties as well as due to random nature of environmental or process conditions themselves.
- Each may be seriously influenced by decision choices.

These would imply that the projection functionality would be iterated for a range of uncertain conditions of either of the scenarios occurring as well as for a range of decision options, so that the best choice can be identified with controllable degree of confidence.

This, in turn, implies that the computational task of scenario projection in real time in support of decision making will likely remain a serious challenge, as most of these analyses require substantial amount of processing time, usually measured in hours.

This is in contrast to real life cases of casualty scenarios, which in many occasions evolve in a matter of minutes, during which decisions could prove critical. The following recent casualties can be viewed to elaborate the issue.

MV Estonia, 1994, 852 fatalities

852 human lives were lost when the passenger Ro-Ro ferry MV Estonia sank on the night of 27/28th of September 1994 in the Baltic Sea, while on route between Tallinn, Estonia, and Stockholm, Sweden, Bergholtz at all 2008, Jasionowski et al 2008. The notable observation is that most of the 137 survivors are those that reacted fast, within the first approximate 10-20 minutes into the casualty.

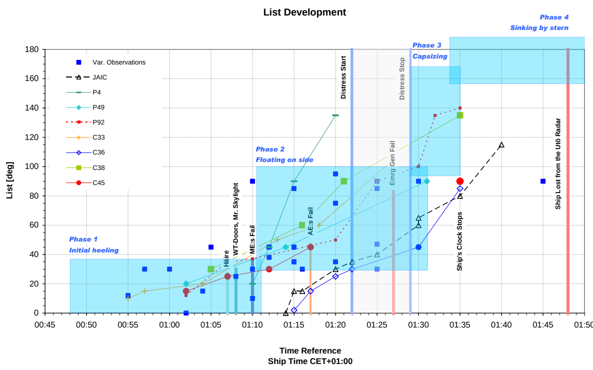

Figure 1 MV Estonia, statements by survivors on the heel angle experienced during abandonment, Bergholtz at all 2008.

Perhaps if crew were aware of what “to expect” they could have reacted quicker to casualty or averted it in the first place.

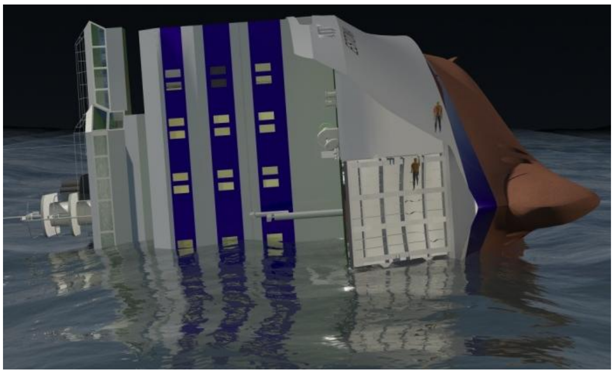

Figure 2 MV Estonia, Jasionowski et al 2008. At some instant two survivors managed to climb down the closed ramp, using its stiffening arrangement and abandon the ship. Heel angle 93deg.

Monarch of The Seas, 1998, no fatalities

According to the accident report by Paulsrud et al 2003, “At about 0130 hours, …, the Monarch of the Seas raked the Proselyte Reef at an approximate speed of 12 knots without becoming permanently stranded”. Subsequently, “At 01:35 hours and owing to the water ingress, all watertight doors were closed from the bridge …” and “At 01:47 hours the general emergency signal, seven short and one long blast, was given …”. See Figure 3.

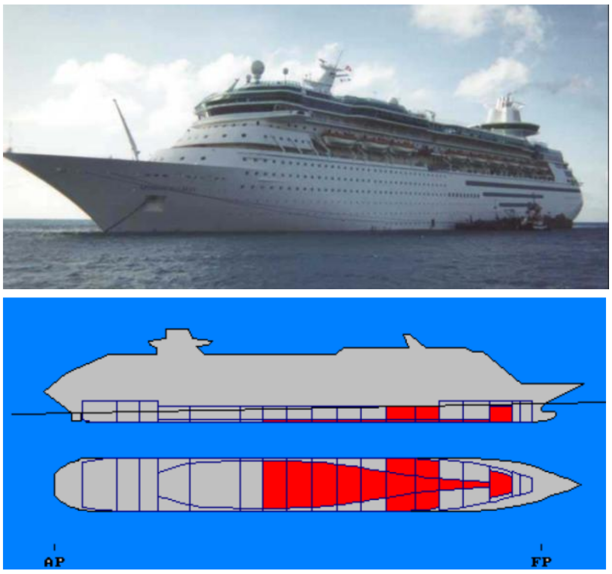

Figure 3 Monarch of the Seas, actual casualty in 1998 and flooding extent, Paulsrud et al 2003.

It appears that it took the crew 5minutes to decide about closure of water tight doors (WTD), and 17 minutes to inform the persons onboard of the casualty. Whilst this accident resulted in no fatalities, it should be clear that this time might as well not have been available, was the damage more severe. Decisions before as well as during every minute of the accident could have proven far more critical to this accident. A decision support system might have informed the crew if the situation is critical or not, and in this particular scenario it would have need to have been shown as moderate or perhaps not critical, after the watertight doors closure.

Of note is the fact that even though importance of WTD closure is identified in the report as critical, none of the ultimately recommended 20 safety actions, nor the pointed 20 lessons to be learned, mentioned issue of ship watertight integrity explicitly, highlighting only importance of SMS (Safety Management System) procedures.

Rockness, 2004, 18 fatalities

On the 19 of January 2004 the Antigua & Barbuda flagged cargo vessel MV 'Rocknes' capsized within a number of minutes in a strait south of Bergen, Norway, resulting in 18 fatalities, see Figure 4. At the time, the ship was loaded with stones and pebbles that were to be delivered in Emden, Germany.

Figure 4 MV Rocknes, actual casualty in 2004, Jasionowski et al 2005.

The crew had perhaps 2-3 minutes into the casualty, for making their minds up on what, or if, any action was to be taken, as the rate of ship capsize was very high, see Figure 5. Perhaps all these lives could have been saved if the crew was informed at all times of the vulnerability of the vessel to any flooding extent that was feasible, allowing them to react instantly at the first sign of distress.

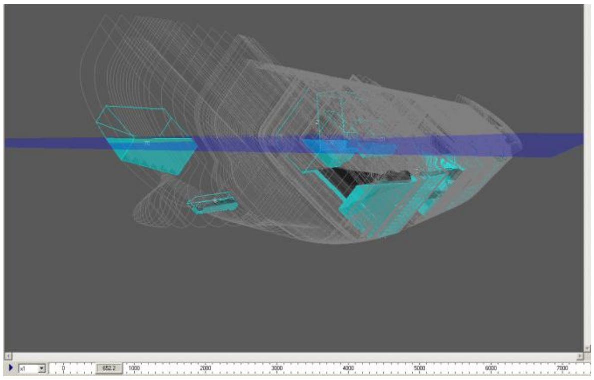

Figure 5 MV Rocknes, numerical reconstruction when heeling to 42 degrees during capsize process. The vessel capsizes in 2 minutes. Visible in a light blue colour are the intact ship free surface tank loads as well as compartments flooded due to damage, Jasionowski et al 2005.

It can be seen that decisions for crises management in either of these different ship scenarios would need to be made virtually within first vital minutes from the very instant of loss of watertight integrity.

Indeed, it could be argued, that even more effective would have been for the crew to know beforehand the crises occurring, as to how to react to the situation.

This is the principle, in the search of which the VLog functionality has been developed as a possible ergonomic solution for sustaining the crew's preparedness for response to a crises situation, as described next.

VULNERABILITY LOG (VLog)

Vulnerability Log, or VLog for short, is hereby proposed to be the functionality to inform the crew at all times on the instantaneous vulnerability state of the vessel, considering its actual loading conditions, the environmental conditions and the actual watertight integrity conditions. The vulnerability is proposed to be measured by means of the probability that a vessel might capsize within given time when subject to any feasible flooding scenario.

Since before casualty occurs it is impossible to guess what kind of damage a ship might suffer, it seems plausible that the crew is made aware of what actually “can” happen, and if it did, what impact on the ship it can have? They would immediately be able to infer how critical a situation evolving is and hence what possible actions to follow.

Such impact will of course vary from a flooding case to a flooding case, and subject to what condition the vessel operates at, at which environment and what is the watertight integrity status. All these must, therefore, be considered.

The following framework outline, see equations (1) and (2), is all that is required to provide with this functionality, whereby VLog refers to F_T logged continuously in real ship-operation time.

$$F_T(Hs) = \sum_j p_j \cdot F_{T|*}(Hs, j) \qquad (1)$$

Where:

$$F_{T|*}(Hs, j) = 1 - \left(1 - \Phi\left(\frac{Hs - H_{crit,j}}{\sigma}\right)\right)^{\frac{t}{30}} \qquad (2)$$

$$Hs_{crit,j} = 4 \cdot \frac{GZ_{\max,j}}{0.12} \cdot \frac{Range_j}{16} \qquad (3)$$

$$\sigma_r(Hs_{crit,j}) = 0.039 \cdot Hs_{crit,j} + 0.049 \qquad (4)$$

More details of the model itself can be found in Jasionowski 2006a and 2007, and Tagg 2002. It is hereby referred to as a framework, as even though extremely straightforward, its essential details as well as its uncertainty measures are all under research and development. However, it is sufficient to demonstrate and then explain how the VLog functionality would work in practice, including giving practical interpretations of F_T as well as $F_{T|*}$.

CASE STUDY

A case of MV Estonia is hereby used to demonstrate the VLog functionality. Loading condition at the time of the loss of the vessel in 1994 were used, see Table 1 and Figure 6.

Table 1 MV Estonia, ship particulars.

L_{bp}	137.4m
B	24.2m
Displacement	11,930 [m^3]
Draught mean	5.39m
Trim	0.435m aft
GM	1.17m
KG	10.62m

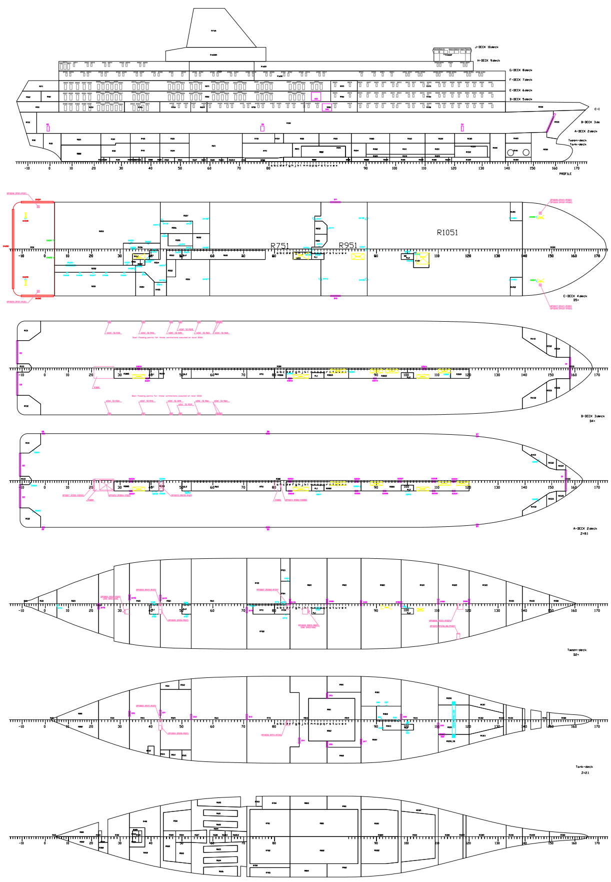

Figure 6 The GA of MV Estonia assumed for numerical modelling.

The following figures are presented to allow for interpretation of the VLog functionality.

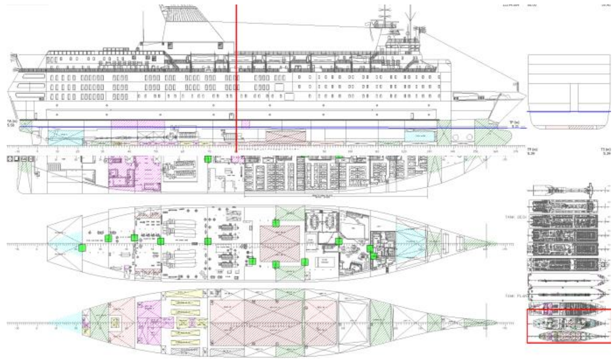

Figure 7 Ergonomic communication interface, model of MV Estonia, screenshot of watertight doors (WTD) closure status, green indicates "closed", red "opened".

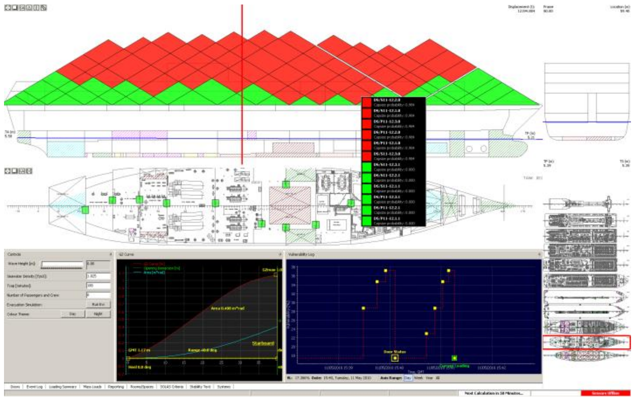

Figure 8 Vulnerability information, screenshot of the colour-coded values of $F_{T|*}\left(3hrs|Hs=0m, j\right)$ for each of the $j=1\ldots1368$ flooding cases, each represented by a "diamond", as well as $F_T\left(3hr|0m\right)=17.38\%$ of ship overall vulnerability, all logged down at **15:40:06** hours (example time marked by the yellow square at 15hrs 40min 06seconds). For overlapping "diamonds" (e.g. multiple penetration or vertical extent for the same length of flooding case), the worst cases are shown.

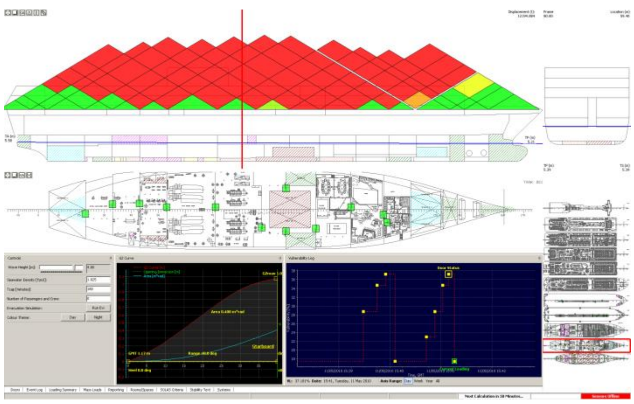

Figure 9 Screenshot of the colour-coded values of $F_{T|*}\left(3hrs|Hs=4m, j\right)$ for each of the flooding cases, ship vulnerability $F_T\left(3hr|4m\right)=37.18\%$ (purple window), logged down at **15:41:09** hours (example time marked by the yellow square at 15hrs 41minutes 09seconds). The green coloured "diamonds" indicate $F_{T|*}=0\%$, and red $F_{T|*}=100\%$. GZ curve and draught marks shown for the ship in intact condition. Sea state Hs manual input shown in the left lower corner.

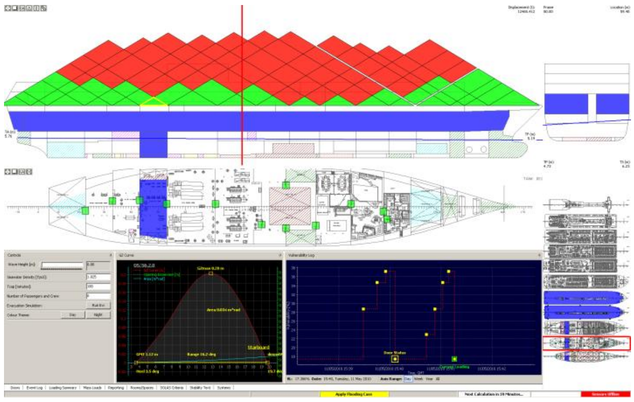

Figure 10 Flooding extent for damage case j=702, DS/S6.2.0, (diamond/triangle in yellow frame), with corresponding GZ curve logged at **15:40:06**, see Figure 8. Ship vulnerability $F_T\left(3hr|0m\right)=17.38\%$. Note that draught marks correspond to ship condition of the most recent log at 15:41:16.

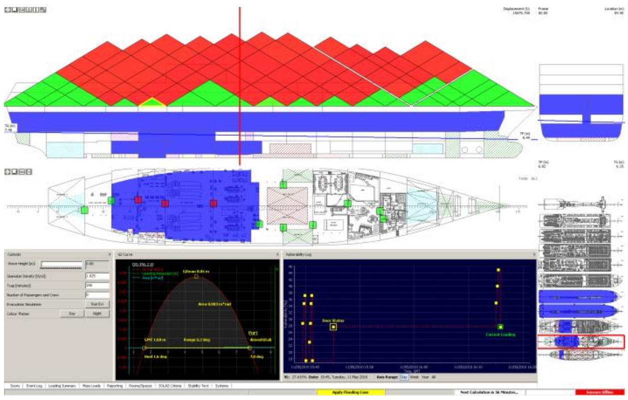

Figure 11 Flooding extent for damage case j=702, DS/S6.2.0, (diamond/triangle in yellow frame), with corresponding GZ curve logged at **15:45:09**, ship vulnerability $F_T\left(3hr|0m\right)=27.61\%$. Note the three watertight doors, #216, #217 and #218, on the tank deck opened with the ensuing impact on the flooding extent. Note again Hs=0m.

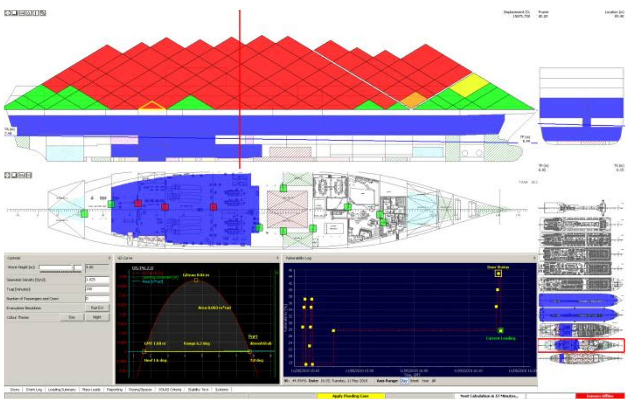

Figure 12 Flooding extent for damage case j=702, DS/S6.2.0, (diamond/triangle in yellow frame), with corresponding GZ curve logged at **16:15:28**, ship vulnerability $F_T\left(3hr|4m\right)=44.93\%$. Note Hs=4m.

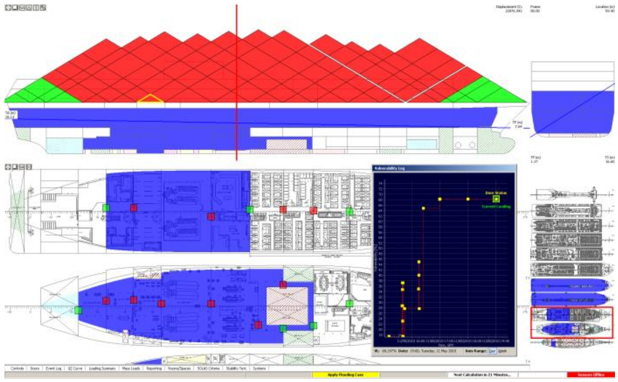

Figure 13 Flooding extent for damage case j=702, DS/S6.2.0, (diamond/triangle in yellow frame), with corresponding GZ curve logged at **19:00:30**, ship vulnerability $F_T\left(3hr|4m\right)=68.24\%$. Note Hs=4m and many WTD opened. Very likely state of the vessel on the night of the ship loss in September 1994.

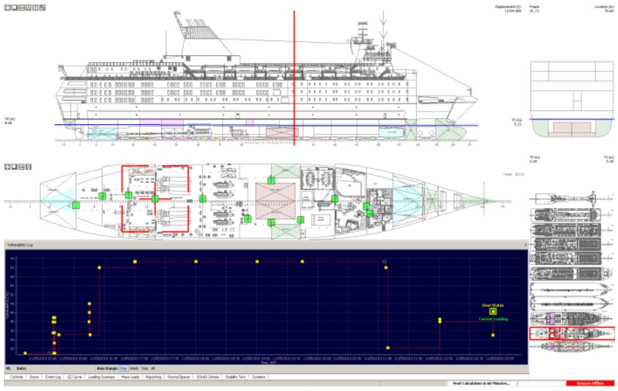

Figure 14 Sample of 8 hours vulnerability log (VLog).

The above figures should suffice to demonstrate the principle of the proposed VLog functionality for decision support, as discussed next.

DISCUSSIONS

The first element worth mentioning is the interpretation of "vulnerability". As mentioned earlier, ship vulnerability to flooding is proposed to be measured by means of the probability that an event of ship capsizing within given period of time occurs, subject to status assumptions.

For a flooding scenario resulting to final floating attitude, it is expected that ship's residual stability will be sufficient to sustain its functional attitude for a level of environmental excitation. The relationship between residual stability and the environment has been derived in project HARDER, as reported in Tagg 2002, and as given here by equation (3). It has subsequently been shown in the project SAFEDOR, Jasionowski at al 2006a, 2006b, 2007, that this relationship can be used to describe stochastic nature of ship capsize for any given environment, and that it can be marginalised for all feasible flooding scenarios.

Thus, for an example of a specific flooding case j, a vulnerability of $F_{T|*}\left(3hrs|Hs=2m,j\right)=40\%$ recorded in a given instant of time, implies probability of 40% that a ship may capsize in 3 hours, when subject to specific environmental conditions of Hs=2m. In other words, should the vessel suffer 10 accidents involving **exactly** flooding extent j, and each time at sea state of Hs=2m, it would be expected to observe 4 capsizes within less than 3 hours. This vulnerability can be derived for any feasible flooding extent for given ship design, and it can be conveyed to the crew in an ergonomic manner by means of colour coding, see the colourful "diamonds" in either of Figure 8 to Figure 13.

Furthermore, the vulnerability can be "averaged" for all flooding cases with "weights" corresponding to likelihood of any flooding extent occurring, in the marginalisation process. Thus, an example of an overall vulnerability of $F_T\left(3hr|4m\right)=70\%$, indicates probability of 70% that a ship may capsize in 3 hours, when subject to specific environmental conditions of Hs=4m and for any among the many feasible flooding extents a ship might suffer. In other words, should the vessel suffer 10 accidents involving **any** flooding extent, and each time at sea state of Hs=4m, it would be expected to observe 7 capsizes within less than 3 hours. This "overall" vulnerability can be derived periodically for given ship conditions and conveyed to the crew in an ergonomic manner as a time-log, see Figure 14.

It can be noted in Figure 14 the "enormity" of the extent to which operation can have on the ship's instantaneous vulnerability, that is its ability to sustain stable attitude when subject to loss of watertight integrity. The vulnerability can increase from some 18% to nearly 70%, for the sample study cases used. The various conditions leading to this dramatic variation can again be found from Figure 8 to Figure 13.

The variation in time reflects changes to ship loading conditions, environment conditions Hs, as well as watertight integrity through opening of watertight doors.

The very process of logging in time of quantified and meaningful measure of vulnerability allows for auditing of the "goodness" of the operation. Such information, easily inferable from typical on-board computer display, allows for development and sustaining of understanding on what to expect, should flooding casualty occur.

For instance, given the vulnerability of MV Estonia on the night of the loss as shown in Figure 13, it can easily be seen that the vessel is extremely likely to capsize due to flooding.

The fact that specific type of flooding which is thought to have happened on the night of the casualty is not taken into account in cases used in Figure 13 is immaterial. The crew would not know what was happening exactly, but given projections as shown in Figure 13 with vulnerability of 70%, it would be instantly obvious that immediate action is required at the first sign of problems. More importantly, the crew might have taken greater vigil, were they aware of how vulnerable their ship can be, and how this can be managed through their own actions.

ON-GOING WORK

The framework for vulnerability assessment given above by models (1) and (2) is very simple. However, it appears to serve as a very informative model for use in the context of decision making. It reflects fundamentals of physical processes governing ship stability in waves and explicitly acknowledges uncertainty of such predictions by exploiting probability theory. Therefore, research efforts are ongoing to establish and verify practicalities of the principles of the proposed functionality, as well as to assess impact of all engineering approximations that are to be used in application of the proposed model. Many such aspects are under study, with key focus on uncertainty in the widest sense, pertaining to its both aleatory as well as epistemic types. Example impact of treatment of actual tank loads in assessing stability, effects of damage character, relative importance of transient flooding stages, accuracy of physical experimentation used as basis data, or simple elements such as effect of computational speed on functionality of the whole proposition, or ergonomics of the conveying techniques used. The prime objective is to find solution acceptable for wider industrial application.

CONCLUSIONS

This article outlined a concept of an active through-life decision support and crises management principle. The key feature is provision of ergonomic information to the crew on the instantaneous ship vulnerability to flooding.

Such information allows the crew to have notion at all times on ships capacity to cope with any feasible flooding scenario, and thus allows for making informed and instant decisions on how to respond with mitigating actions at the first sign of distress.

Most importantly, the crew can take precautionary actions at any time of the ship operation to knowingly reduce vulnerability to the lowest levels possible for a particular ship design.

Therefore, crew preparedness for response to distressed situation can be promoted at all times.

ACKNOWLEDMENTS

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