Application of Vessel TRIAGE for a Damaged Passenger Ship

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ABSTRACT

Several recent flooding emergencies on passenger ships have pointed out the need to quickly get a better assessment of the survivability onboard a damaged ship. Advanced time-domain flooding prediction methods can be used to quickly get an assessment of progressive flooding and stability of the damaged ship. This paper presents an approach for using the Vessel TRIAGE method to display the severity of the damage case on the basis of flooding prediction results. The application is demonstrated with a collision damage case of a large passenger ship.

Keywords: *damage stability, progressive flooding, decision support*

1. INTRODUCTION

Investigations of recent accidents have clearly shown that there is a need for a decision support system on board the ships, e.g. *MIT (2013)* and *MAIB (2015)*. The most important information this system should provide, is the severity of the flooding case and the probable development of it. This information must be provided in a way that is easy to understand and easy to communicate further.

The IMO has recognized this need and SOLAS currently requires all new passenger ships to be equipped with a damage stability computer for providing the master with operational information on the residual damage stability of the ship after a flooding casualty. In the recently revised guidelines, *IMO (2016a)*, however, the residual damage stability output is defined in way of presenting the residual GZ curve and floating position information. Judging the severity of the flooding case and the survivability of the people on board, based on GZ curve data, requires interpretation, and is neither instantly intuitive nor easily communicable to other involved people on the accident scene.

The first approach to a decision support based on time-domain prediction was presented by *Ruponen et al. (2012)*. Recently, also *Varela et al. (2014)* have presented a similar concept for decision support based on progressive flooding calculation and virtual reality.

Vessel TRIAGE is a method for assessing and communicating the safety status of a vessel in distress situation, *Nordström et al. (2016)*. The concept for a decision support system, based on the Vessel TRIAGE method, for flooding emergencies was introduced by *Pennanen et al. (2015)*. The first approach for determination of the color coding was presented by *Ruponen et al. (2015)*, based on time-domain flooding prediction results. The present study reviews the applied methodology for a flooded passenger ship, and a new approach is introduced to account the flooding extent is respect to the size of the ship. Finally, a short case study with a collision damage to a large passenger ship is also presented.

2. VESSEL TRIAGE

Vessel TRIAGE is a method for assessing and communicating the safety status of vessels in maritime accidents and incidents. The method is intended for use by both vessels and maritime emergency responders to assess whether the subject vessel can provide a safe environment for the people onboard.

The method is currently under consideration for further testing its adequacy in search and rescue operations by the IMO Sub-Committee on Navigation, Communication and Search and Rescue

(IMO, 2016b). A detailed description of the method is given by *Nordström et al. (2016)*.

The method expresses the safety status of the vessel in terms of a Vessel TRIAGE category. There are four categories: GREEN, YELLOW, READ and BLACK (see Fig. 1). However, the category BLACK is not relevant for decision support onboard the damaged ship since in that case the ship has already been lost.

Initially it was suggested by *Ruponen et al. (2015)* to represent vulnerability as a real value between 0.0 and 1.0. However, based on the Vessel TRIAGE methodology, it is more simplified and practical to consider only color codes. Thus the total survivability color code is the worst of the color codes for the separate threat factors.

3. THREAT FACTORS FOR A DAMAGED PASSENGER SHIP

Heeling and Stability

Even with a small heel angle the risk of capsizing can be significant if the stability of the ship is not good enough. Thus heeling has been a primary safety indicator since the early decision support system concepts, *Lee et al. (2005)*.

GREEN	YELLOW	RED	BLACK
Vessel is safe and can be assumed to remain so	Vessel is currently safe, but there is a risk that the situation will get worse	Level of safety has significantly worsened or will worsen and external actions are required to ensure the safety of the people aboard	Vessel is no longer safe and has been lost
GENERAL SITUATION	GENERAL SITUATION	GENERAL SITUATION	GENERAL SITUATION
- The situation aboard is stable. Although the vessel may have been damaged by the accident, this damage does not threaten its seaworthiness or the people aboard. - The damage to the vessel has been assessed. It is highly unlikely that the damage will spread or get worse. - The vessel still protects the people aboard against the prevailing conditions.	- Damage to the vessel might affect its seaworthiness or the full extent of the damage has not as yet been determined. - Internal damage control measures and rescue operations have not been completed. Damage control is possible with reasonable resources available to carry out the proper measures. - Damage to the vessel may pose a direct or indirect threat to the people aboard.	- The vessel is significantly damaged, affecting its seaworthiness, and there is a threat to the people aboard. - A fire, leak or other damages to the vessel are not under control and escalation is highly likely. - The vessel no longer protects the people aboard against the prevailing conditions. - Major external resources are required.	- The vessel is capsized, broken, sunk, burnt or otherwise damaged so badly that it no longer provides protection to the people aboard against the prevailing conditions (that is, the vessel has totally lost its seaworthiness). - Even if the vessel is still completely or partly afloat, it is no longer safe to work aboard, even to save human lives.

Figure 1: Vessel TRIAGE categories: definitions and description of general situation, *Nordström et al. (2016)*

The s-factor in SOLAS II-1 Part II-1 Reg. 7 is applied:

$$s_{final} = K \cdot \left(\frac{GZ_{\max}}{0.12} \cdot \frac{range}{16} \right)^{\frac{1}{4}} \qquad (1)$$

where GZ_{max} is limited to 0.12 m and *range* to 16°. The effect of the heel angle ϕ is accounted with the coefficient:

$$K = \sqrt{\frac{15° - \phi}{15° - 7°}} \qquad (2)$$

when the heeling angle is between 7° and 15°. If the heeling exceeds 15° the effective s-factor is taken as zero. This is supported by the SOLAS requirement to be able to lower the lifeboats with heeling up to 15°.

The *range* is limited to the angle, where the first unprotected opening is immersed. Only real unprotected openings above the bulkhead deck should be considered in order to avoid too conservative approach that limits the reserve buoyancy of the hull. On the other hand, if no limitation of the range is used, the results could be too optimistic.

The suggested color coding for stability of a damaged ship for Vessel TRIAGE is presented in Table 1. The change from YELLOW to RED is taken rather conservatively based on Eq. (2) so that a heel angle of 10° will result in RED. On the other hand, GZ_{max} < 0.05 m will trigger RED even if heeling is less than 7°. Color GREEN is possible only if heel is less than 7° and the ship has sufficient stability range and GZ_{max}.

Also alternative threshold values can be considered, but the present approach has been selected based on the current SOLAS requirements.

Table 1: Suggested Vessel TRIAGE color coding for stability

GREEN	small heeling and good stability, $s_{final} = 1.0$
YELLOW	increased risk due to heel and/or decreased stability: $0.8 \leq s_{final} < 1.0$
RED	large heeling and/or decreased stability: $s_{final} < 0.8$

Extent of Flooding

The extent of flooding can be measured as the number of WT compartments with floodwater. However, the problem is that this needs to be scaled to the size of the ship, *Ruponen et al. (2015)*. From the Vessel TRIAGE color coding point of view, the GREEN is the simplest case since the Safe Return to Port regulation forms a solid background; GREEN is possible only if flooding is limited to a single WT compartment, although e.g. *Vassalos (2007)* suggested green color and safe return to port also for more extensive damages if stability is good and all systems are available.

The criterion for a change between YELLOW and RED is more complex. A simple approach for this problem is to use floodable length curves. In order to ensure some conservativeness, constant permeability of 0.95 may be used. The curves need to be calculated for a range of draft and trim values, and linear interpolation can be used to calculate the floodable length for the actual loading condition before flooding.

The flooding extent coefficient is:

$$F_{ext} = \frac{L_{flood}}{FL(x_{flood})} \qquad (3)$$

where L_{flood} is the length of flooded compartments, x_{flood} is the longitudinal center of this length and $FL(x)$ is the interpolated floodable length function at the relevant initial floating position.

The suggested Vessel TRIAGE color code for flooding extent is presented in Table 2 and illustrated in Fig. 2 for different flooding extents along with the floodable length curve. In practice the suggested threshold F_{ext} > 1.0 means that the color code is changed from YELLOW to RED if there is a risk of progressive flooding to undamaged compartments through flooding of the bulkhead deck.

Table 2: Suggested Vessel TRIAGE color coding for flooding extent

GREEN	flooding is limited to a single WT compartment
YELLOW	more than one WT compartment is flooded but $F_{ext} \leq 1.0$
RED	Flooding extent exceeds floodable length, $F_{ext} > 1.0$

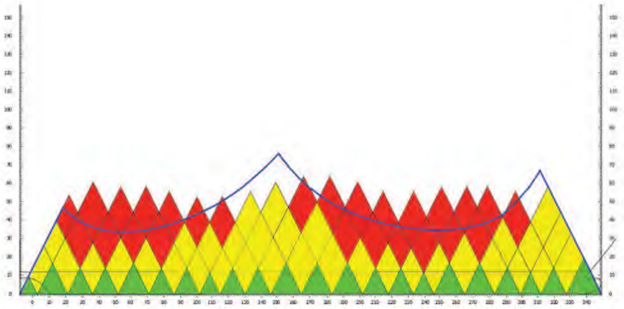

Figure 2: Example of color coding for flooding extent based on the floodable length curve.

This representation with triangles is very similar to the vulnerability analysis presented in *Jasionowski (2011)*. However, the exclusion of longitudinal and horizontal watertight subdivision may result in too conservative results, since e.g. the double bottom is not considered at all.

Evacuation

The Vessel TRIAGE methodology does not consider evacuation of the ship as a separate threat factor. However, the heeling and stability of the ship are very tightly linked with the available evacuation time, *Bles et al. (2002)*. A simplified approach for evaluating an approximate required evacuation time by using the predicted development of heel angle was presented by *Ruponen et al. (2015)*.

4. EXAMPLE OF APPLICATION

Damage Scenario

Sample calculations were done for a 125 000 GT large passenger ship design, originally developed for the EU FP7 project FLOODSTAND. The studied case is a collision damage on starboard side (SB) in the aft ship. Two WT compartments are breached, but in the aft one the breach is very small, Fig. 3. There is also an open WT door, resulting in progressive flooding to a third compartment. However, this door is successfully closed 10 min after the collision, and before water starts to flow through the door.

The reference data is first calculated with a time-domain flooding simulation, *Ruponen (2014)*. The time histories of measurement data for the flood level sensors are then generated based on the amounts of floodwater and the floating position in the reference results. This data is then used as input for automatic breach detection and prediction of progressive flooding, *Ruponen et al. (2015)*.

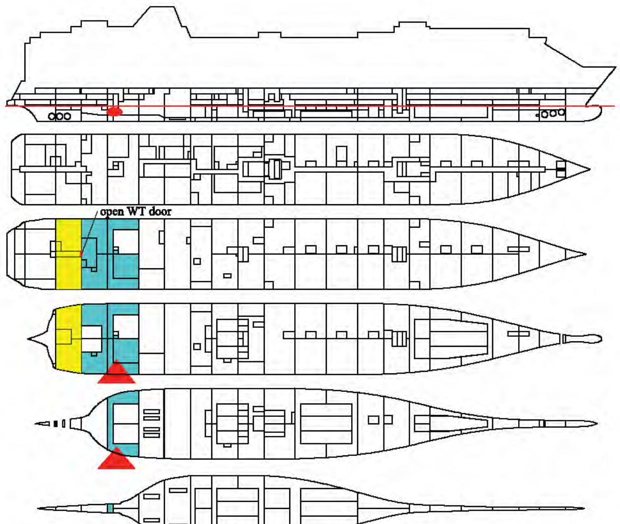

Figure 3: Damage scenario, with initially open WT door that is closed before flooding progresses to the undamaged compartment

For the analysis of the Vessel TRIAGE color coding, the worst predicted condition within the next 80 min (i.e. the required evacuation time).

Results

Initially flooding is detected only in one WT compartment since the inflow to the aft damaged compartment is very slow. Consequently the color code is GREEN since the maximum predicted heel angle is less than 7°, Fig. 4. This information is available within 5 min after the damage.

The second prediction, started 5 min after collision, accounts also flooding in the aft damaged WT compartment, where the inflow of water is much smaller. The WT door is still open, and therefore, the prediction results in progressive flooding to a third compartment. The predicted flooding extent exceeds the interpolated floodable length, and thus the color code is changed to RED, Fig. 5. The updated results are available about 8 min after damage.

The prediction that starts after the open WT door has been successfully closed, 10 min after damage, results in color code YELLOW since flooding is now limited to two compartments and heeling is predicted to be less than 7°, Fig. 6.

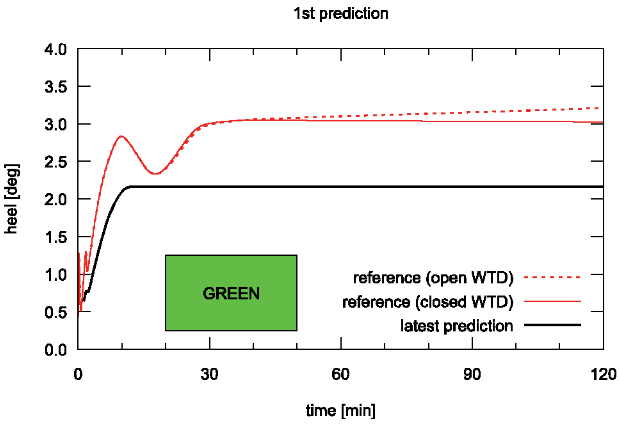

Figure 4: Results of 1st prediction flooding prediction

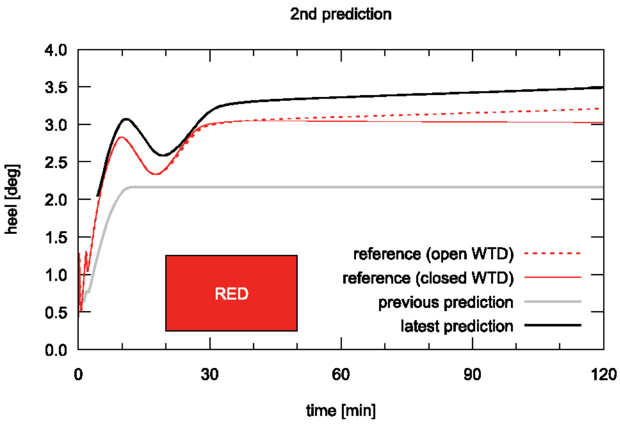

Figure 5: Results of 2nd prediction flooding prediction

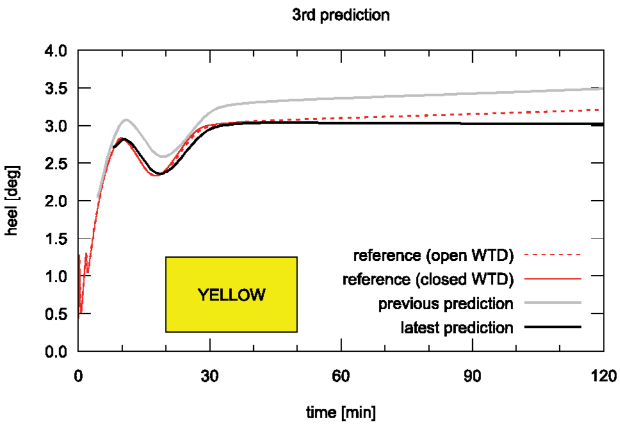

Figure 6: Results of 3rd prediction flooding prediction

5. CONCLUSIONS

Heeling angle is the most dominant component of the "s-factor" for assessing the Vessel TRIAGE color coding for damage stability. In practice this means that the color code for the threat factor stability/listing is changed from GREEN to YELLOW when heel exceeds 12°, and to RED when heel exceeds 15°. So the color YELLOW is possible only in very limited conditions. On the other hand, the proposed approach for accounting the threat factor for flooding extent, based on the pre-calculated floodable length curves triggers the code YELLOW immediately, when flooding is detected (or predicted to spread) in two or more compartments. The result is considered to be suitably conservative, meaning that the color GREEN is only shown in cases, where the ship will certainly survive the damage, and the color RED means that evacuation and abandonment may be necessary. This is in line with the definitions for Vessel TRIAGE.

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