

Bridge Officer Decision Support tool

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ABSTRACT: Vessel's stability, operation performance and safety depend on her load condition. During the design phase only a few load conditions are verified and therefore much responsibility relies on who is operating the vessel and therefore is prone to human error. This paper intends to present a software tool that aims to increase safety during operation by monitoring load condition, checking stability and strength criteria, and estimating vessel's performance in regular intervals to provide a clarified scenario. Additionally, if flooding occurs, the software includes a decision support tool that advises on how to manage fluids in order to increase vessel's stability depending on the load condition previous to damage.

1 INTRODUCTION

Handling a ship in transit, while maneuvering in shallow waters or channels, during operations or in case of damage, requires a solid knowledge of the platform, her capabilities, professional experience and specific training. Today, amongst shipping companies and navies all around the world, crew numbers are becoming smaller, they are less experienced, and crew replacement occurs more often.

On the other hand, today's technology allows information to be assessed more easily, so such problems can be minimized if these tools are smartly used. Following this reasoning, this paper presents a Decision Support Tool (DST) that is currently being developed for the Bridge Officer as the responsible for the vessel operation, safety of navigation and monitoring the vessel's stability, *i.e.* how the vessel relates with the surrounding medium.

The proposed tool is based on the fact that weight distribution influences vessel's stability, structural integrity, performance, and overall safety. Therefore, by monitoring the vessel's load condition, it makes possible to check her stability criteria and determine up-to-date operational characteristics in frequent intervals, turning the vessel's operation simpler and less prone to human error.

In case of damage, it becomes even more significant to have up to date knowledge of the ship's load condition since every action done to increase her stability must have it into account, or her ability to survive can be drastically reduced.

In the next sections, a small review of the influences taken into consideration to develop this work

are presented, followed by the DST concept analysis and finally the presentation of its implementation.

2 STATE OF THE ART

Since the first Safety of Life at Sea convention of 1914 (SOLAS), several deterministic and probabilistic criteria for stability have arisen, such as the the International Maritime Organization (IMO) code of 1993 IMO (1993), or the new probabilistic approach of SOLAS 2009 IMO (2009), and also military criteria, most of them developed from Sarchin and Goldberg (1962).

During ship design and construction only a few load conditions are checked against the criteria, since it is virtually impossible to check all possible load conditions and liquid cargo distributions in the tanks. Therefore, during operation, the responsibility to check intermediate load conditions is the master's responsibility. For that purpose, stability calculators, that simulate conditions inputted by the user are available aboard most cargo vessels

Among these calculators, the United States Navy produced Flooding Casualty-Control Software (FCCS) (Plumley (2009)). It is probably one of the more complete ones, that can:

- evaluate the ship attitude, hydrostatic, stability and strength status;
- model the ship's loads;
- evaluate the effects of flooding on stability;
- evaluate ship's strength in case of flooding or structural damage;
- send out warnings and advise if stability or strength criteria fail;

- evaluate stability and bottom reaction forces during vessel stranding.

Nevertheless, the safety of the ship's operation is not only concern with stability, but also depends on how the vessel is operated by the crew (House (2007)), and on her maneuverability, seakeeping and interaction characteristics (Barrass (2004)). Particularly, only in recent years has maneuverability become subjected to IMO resolutions as in IMO (1987) and IMO (2002). Further, for seakeeping and interaction we have no knowledge of any existing safety criteria, though there are several references suggesting ship motion limits, such as Graham (1990), and on how to calculate interaction effects, as in Barrass (2004) and Millward (1990). For the purpose of monitoring the ship's operational characteristics we have no knowledge of any available tool.

3 DECISION SUPPORT TOOL MODEL

This work, as previously mentioned, intends to propose a decision support tool (DST) to support vessel's operation and emergency reaction, and it's basic structure is presented in figure 1. This tool is composed of four separate modules with the following purposes:

- monitor the vessel's loading condition by automatically controlling the tanks' loads;
- verify at regular intervals, or as demanded, stability and structural criteria;
- provide decision support for reaction in case of damage;
- estimate the vessel's operational performance, limitations and maneuvering characteristics.

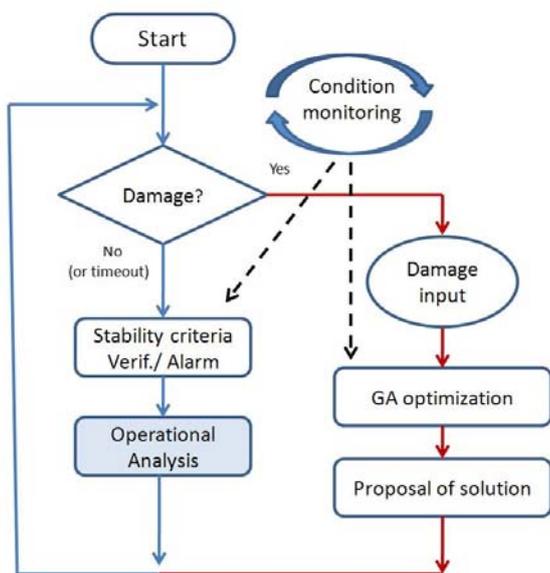


Figure 1. Bridge officer DST fluxogram.

This software follows a similar approach of the FCCS software, but differs from it by being able to estimate the load condition automatically, by being able to provide some data on the ship's performance, and by having implemented an optimization model using Genetic Algorithms to manage ballasting and fluid transfer correctly upon damage occurrence, as discussed in Martins and Lobo (2011).

In order to explain the software better, in the next sections, each software "task" is going to be dealt with separately.

3.1 Load condition estimate

The load condition monitoring is done by visual reading of the draught marks at the beginning of the journey and then by monitoring automatically at regular intervals the tanks' fluid capacity sensors using an OPC standard interface (Schleipen (2008)) available through the platform management system. The time interval introduced is 5 minutes. However, in future we intend to increase this period, if possible.

Further there is also the possibility for the user to introduce his own load condition in a separate routine and then go ahead with any analysis he wishes to do.

3.2 Stability criteria and strength criteria monitoring

Stability and strength criteria are checked every time load condition is monitored, by stand alone routines that can be replaced by any other implementation of different criteria as required for the vessel.

At the moment, the stability criteria for warships presented in Sarchin and Goldberg (1962) are implemented, which include intact stability criteria and damaged stability criteria for a damage length of any two consecutive watertight compartments with no regards for decks.

As far as structural criteria is concerned, for the load condition in question, still water bending moment and shear forces are compared with the ones used for the ship's design, which depend upon which classification society rules were used, or upon the International Association of Classification Societies Unified Requirement (IACS (2007)).

3.3 Operational analysis

The load condition also affects vessel's behaviour, seaworthiness, and manoeuvring as mentioned in several references such as Inoue, Hirano et al. (1981). Our aim is to present up-to-date values of

the manoeuvring data mentioned in IMO (1987), complemented with interaction data.

Based on sea trials data required by IMO (2002), complemented with some other trials (most of them turning trials) it is possible to provide some evaluation about:

- manoeuvring characteristics with the present load conditions;
- current distances travelled from current speed up to full stop following emergency stop or coastal stop procedure;
- autonomy at current speed and using economic speed from that time onwards;
- maximum squat values and canal width and depth limits from which interaction may be expected, using Barrass (2004).

In order to estimate hydrostatic coefficients from sea trials data, an optimization process similar to the one mentioned in Viviani, Bonvino et al. (2007) was used.

Nevertheless, in order to provide the data required for navigation planning (figure 2) we intend to implement a neural network architecture that will be trained with data collected while the ship manoeuvres under different weather conditions, with different load conditions, and with different depth limitations (open waters, restricted waters or confined channels). This prediction method has already been validated both by Moreira and Soares (2003) and Martins and Lobo (2007).

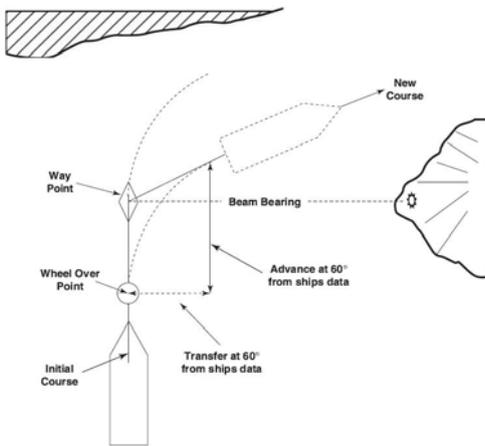


Figure 3. Navigation plan of turning in restricted waterways (adapted from reference House (2007)).

3.4 Damage input

The objective of the “damage mode” capability (implemented in separate routines) is to support the user’s decision on how to manage fluid loads in case of flooding and to advise on how to attribute drainage equipment to the damaged areas.

Obviously, the decision must take into account all tanks’ levels at that time, the damage location and its dimensions in order to calculate the sea water inflow rate, and how the flood spreads.

Knowing all of these, of which only the damage location and dimensions is required to be a user’s input, a Decision Support Tool (DST) can be built upon the software that is being discussed.

This DST is basically an optimization model with tank levels and watertight compartments flooding level as input variables, aiming to maximise stability and minimize response time, while complying with several constraints, such as damage stability criteria and limit bending moments to the ones supported by the actually built structure. Next section will be dedicated only to this matter.

4 SHIP SURVIVABILITY UNDER DAMAGE AS AN OPTIMIZATION PROBLEM

Finding a course of action to increase stability of a damaged ship by managing fluids, by flooding compartments, pumping water out, etc., can be seen as a complex optimization problem whose fluxogram is presented in figure 3 and whose solution can be achieved using Genetic Algorithms as is explained in more detail in Martins and Lobo (2011).

From now on we are going to present the mathematical formulation that characterizes the optimization problem.

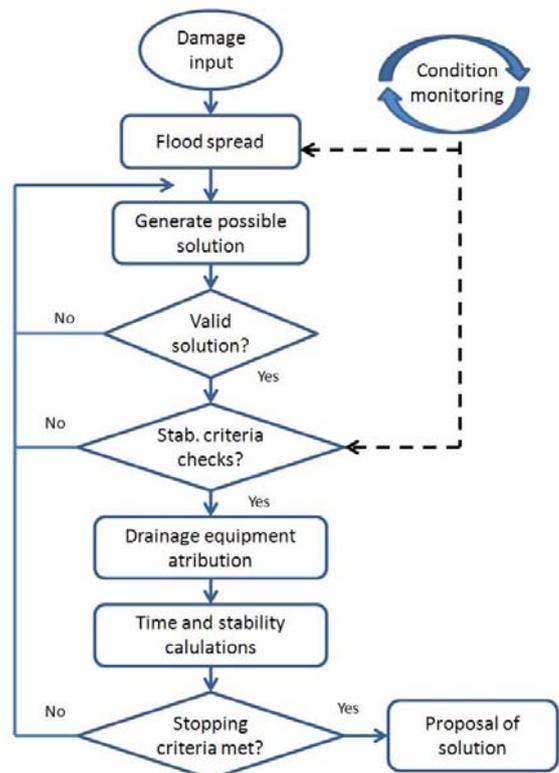


Figure 3. Flooding response optimization problem.

Input variables

As mentioned before, the input variables are the ones that characterise the problem, *i.e.* vessel's characteristics and damage characteristics. So, the following variables can be defined:

Δ	LCG	TCG	VCG	ship's light displacement, and correspondent centre of gravity position;
	HY			hull form;
	LK			ship's cross curves;
	TK			internal tank subdivision and capacity tables;
	HY			watertight compartments subdivision, dimensions and characteristics;
	SK			solid weights and correspondent centre of gravity position;
	Q_i			damage inflow rate calculated from its position and dimensions.

4.2 Decision variables

The fluid level (weight) that is inside each tank and watertight compartment, as well as drainage equipment attribution, are going to be the decision variables. Therefore:

$C_i(TK_i)$	fluid tanks' levels, where i identifies the different tanks;
$C_i(WC_i)$	watertight compartment flood levels where i identifies the different compartments;
WQ_i	watertight compartment drainage flow rate dependent upon the attributed equipment.

4.3 Auxiliary variables

From the previous variables it is possible to calculate the initial load condition (LC_0) and, as the journey continues, the different load conditions by the change of fluids within the tanks change $C_i(TK)$ while the solid cargo is considered to be unaltered, so that for a given instant in time:

$$LC_t = f(LC_0, C_i(TK_i)) \quad \text{for } t > 0 \quad (1)$$

where f is a known function.

4.4 Constraints

The first major constraint is to ensure that stability and strength criteria are met, whose values can be calculated using the current load condition and flooded watertight compartments data, that are complemented with some other:

1. Stability criteria mathematical representation:

$$ST_i(LC_0, C_i(TK_i)) > 0 \quad \wedge \quad ST_d(LC_0, C_i(TK_i), C_i(WC_i)) > 0 \quad \text{for } t > 0 \quad (2)$$

2. Tanks and watertight compartments are filled/flooded from 0 to 98% of their total capacity

$$0\% < C_i(TK_i) < 98\% \quad (3)$$

$$0\% < C_i(WC_i) < 98\%$$

3. Fresh water tanks must have the same amount of water or less (sea discharge) since no ballast was considered to fill them up

$$\sum_{i \in FO} C_{t_2}(TK_i^{FW}) \leq \sum_{i \in FO} C_{t_1}(TK_i^{FW}) \quad (4)$$

where t_1 is the time when damage occurs and t_2 is some time after.

4. Fuel can be changed between tanks but it can't be discharged overboard

$$\sum_{i \in FO} C_i(TK_i^{FO}) = \text{constant} \quad (5)$$

5. Lub oil and miscellaneous tanks are not changed

$$C_i(TK_i^{LO \cup M}) = \text{constant} \quad \forall i \in LO \cup M \quad (6)$$

6. When one of two compartments with a cross-flooding pipe connecting each other is flooded, so is the other

$$C_i(WC_j) > 0 \Rightarrow C_i(WC_{j^*}) > 0 \quad (7)$$

where j and j^* are two compartments connected by a cross-flooding pipe

7. No watertight compartments that were not flooded due to damage are going to be flooded

$$C_{t_1}(WC_i) = 0 \Rightarrow C_{t_2}(WC_i) = 0 \quad (8)$$

where t_1 is the time when damage occurs and t_2 is some time after.

8. Only if drainage flow of the available equipment is bigger than the flow of water ingress, is equipment used to drain the compartment

$$(WQ_i) > Q_i \quad (9)$$

9. Only if damage stability criteria are met after drainage, is equipment used to drain the compartment

$$\lambda_j(WC_i) = 1 \Rightarrow ST_d(LC_0, C_i(TK_i), C_i(WC_k)) > 0 \quad (10)$$

where j identifies the equipment and WC_k corresponds to a set of flooded compartments that don't include WC_i .

4.5 Cost function

As mentioned before, the aim of the problem is to increase vessel's survivability rapidly in case of damage. So the cost function has to be developed taking into account:

- how far the results of the damage stability criteria calculations were from their limits;
- how much time does it take to drain the flooded compartments;
- how much time does it take to ballast tanks or to go ahead with the fluid change between tanks;

each one of these are measured by a value which is then multiplied by a scale factor, in order to make their magnitudes comparable, and finally weighted according to the importance the user gives to each one. This can be translated into expression (11) that is intended to maximize:

$$k_1 [ST_d(LC_t)] + k_2 \left[\sum_{i \in WC} \frac{1}{Q_i - WQ_i} \right] + k_3 \left[\sum_{i \in TK} \frac{C_i(TK_i^B) - C_{t-1}(TK_i^B)}{TQ} \right] \quad (11)$$

where k_1, k_2, k_3 are scale/ weight factors, t is the time corresponding to the solution implementation, and $t-1$ is the time corresponding to damage.

5 BRIDGE OFFICER SUPPORT SYSTEM IMPLEMENTATION

The decision support tool software was developed using MATLAB, which not only enables the user to work in a friendly environment (see figures 4 to 6), but also includes several libraries of which the OPC library, the genetic algorithms library and the neural networks library were used.

Having used a modular and flexible implementation, there are several routines that can work as standalone, or can be called at different stages of the

program. This allows easy adaptation to other ships, simplified debugging, and makes the addition of different methods of calculation and further development easier.

Ships data are stored in a structure type variable, and the program starts by reading the input file of arbitrary loads, and begins reading sensor data via OPC. Once the interaction starts, the user is presented with figure 4, where we can see several ship parameters (upper left), weight distribution and still water bending moment (upper right), maneuvering data (lower left), righting arms curves (lower center), and the state of the alarms (lower right).

Additional information can be accessed from the menu on the top of the window, although in normal operation that is not required and criteria will be checked autonomously.

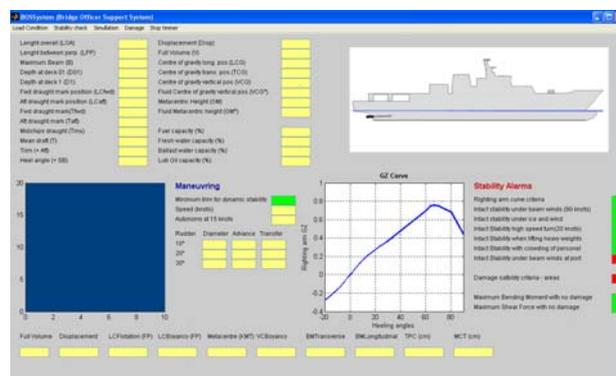


Figure 4. Main interface window.

The system is also capable to run simulations for a given condition once the user introduces the tank filling percentage (%) and solid cargo distribution. The methods used are the same as in the automatic mode. However, once the simulator is turned off, all simulation related data is lost (figure 5).

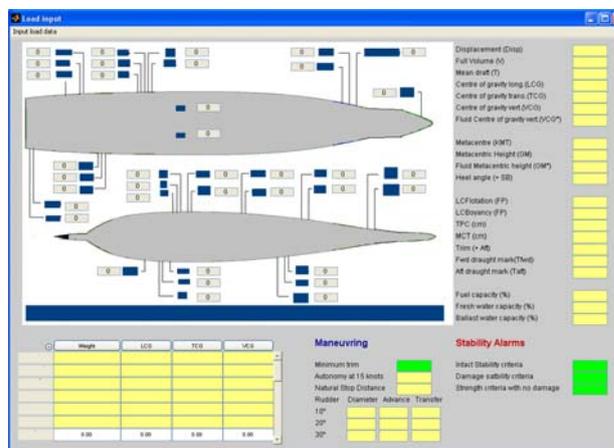


Figure 5. Simulation interface window (watertight subdivision and tank identification was erased).

In case of damage, in order for the optimization process to start, the user has to select the damage position and characteristics making use of the interface window presented in figure 6.

At that moment in time ($t = 0$) the load condition previous to damage is read, and how the flood is going to spread is checked by identifying all accesses (doors, hatches) and ventilation conducts that are opened from the flooding compartment.

The optimization process is done using genetic algorithms in two steps. In the first step 20 initial candidate solutions are built up changing ballast tank levels and after only three iterations (80 damage stability calculations done in about 1 minute) a first proposal for immediate action, including the attribution of drainage equipment is presented.

After that the best obtained solution, together with the initial set of candidate solutions, are once again used as an input for the genetic algorithm, in order to refine the results presented.

Figure 6 presents the improvement on the proposed solution given by the GA implementation for a scenario where a given area of the ship was flooded.

As we can see, in this case, the genetic algorithm converged very rapidly to the final solution (we formalized the problem as a minimization problem so lower fitness means better stability). It is also clear that the two step generations method is significantly better than the other.

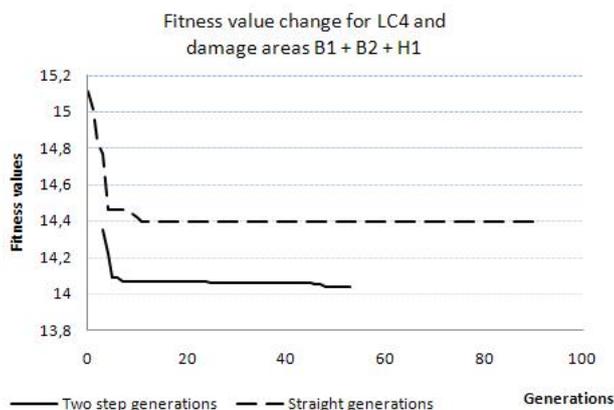


Figure 6. Genetic algorithms progress comparison of two methods for a given damage situation

6 CONCLUSIONS

A decision support tool for the bridge officer was presented, which provides up-to-date information on stability and strength, maneuvering data and other performance characteristics, during current operation.

On the other hand, the system recommends the best course of action in case of damage, by suggesting which tanks to flood or empty. Simulation tests

show that our approach to this problem provides good solutions in a very short time.

We feel that the system developed can significantly improve safety at sea.

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