Fishing Vessel Stability Assessment System

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ABSTRACT

Fishing is at the front of the maritime sector in accidents and ship losses, which are usually caused by stability loss and its associated problems. The crews of the vessels do not usually know how to deal with these situations and are unable to properly evaluate the risks their ships are undertaking. This is the problem we have tried to address, that is, how to create a system that can act as an assistant to crews of fishing vessels and provide information on their level of stability any given moment, in a very easy, clear and understandable way, independently from the training level of the user. Such a system is presented in this work: it is able to deal with the main causes of ship instability for the majority of ship loading conditions, presenting the stability information in a very understandable manner. Finally, the ease of operation of the system is demonstrated through an analysis of its usability, the results of which are also presented here.

KEY WORDS

Fishing vessels; stability; decision support; guidance systems

1. INTRODUCTION.

Fishing represents a contribution of 0.2% of the Spanish Gross Domestic Product and employs about 70.000 people. Although this number is not very high, fishing has a distinctly regional character and its GDP contribution in highly dependent zones can reach values of close to 15% (Pena et al., 2009). In Spain, Galicia, with more than half of the Spanish fishing fleet and workers, is the region where the fisheries sector has more relevance.

Despite the relatively small percentage of employment it provides, fishing is one of the sectors with more industrial accidents. In Galicia, fishing accounts for a very high number of fatal accidents during the working day, only behind the construction sector (MTI, 2009). Worldwide, in the US fishing ranks as second in industrial accidents, while in Great Britain fishing is the most dangerous activity (Womack, 2002).

Taking the case of Galicia as representative of Spain and analyzing the data on fatal industrial accidents (Artai, 2001; Xunta, 2007), it can be seen that most of the casualties happen because of vessel related accidents (or maritime accidents) and among them, losses due to stability problems (capsizing or large heeling) account for half, mainly in vessels of small and medium length (below 24 meters).

Figure 1 a. Number of Galician fishermen casualties. 1991- 2006 period. Source: Xunta de Galicia. Consellería de Pesca.

Figure 1 b. Cause of maritime accidents of Galician fishing vessels. 1991- 2006 period. Source: Xunta de Galicia. Consellería de Pesca.

Fishing is carried out in a highly hostile environment and there are lots of situations where economic pressure causes the work to be carried out in dangerous conditions, putting the fleet and crew at risk. These accidents can be caused by many factors, although they are usually triggered by a succession of them. Anyway, the main cause of these accidents is the lack of awareness of the level of risk that a vessel and its crew are taking during navigation, usually caused by deficient training and scarce information of the crew, especially in vessels of medium and small lengths.

Stability related accidents are the ones with more casualties. This is because these accidents occur suddenly, in a very short time, which is not enough for allowing the crew to reach safety or to use life saving devices and also because these accidents frequently imply the loss of the vessel. Within the high heterogeneity of the fishing fleet, a fundamental division may be made according to ship length: lengths of more and less than 24 meters. This differentiation establishes the application field of the international safety criteria and crew training.

Observing the statistics, it can be appreciated that accidents in ships of more than 24 meters in length caused by stability problems are fewer than in the case of ships of less than 24 meters, due to the fact that large ships present better conditions for sailing in adverse weather than small ships. Additionally, crews of large ships are better trained and have a higher capability to understand and deal with ship stability. They can objectively assess the risk in every loading condition and properly use the means available onboard to carry out these tasks (MEF, 2000).

It seems obvious that small and medium length vessel skippers are able to evaluate, even in a subjective way, the stability of their ships in a given situation. However, these evaluations are based on their previous experience, that normally doesn´t include stability related accidents. Thus, they have difficulties assessing a possible reduction in stability that can lead to a dangerous situation. This fact, coupled with the need of fishing at all costs and as much as possible, that implies sailing in unfavourable weather conditions and with high degrees of overloading, leads to reductions in stability that, together with other occasional factors, cause the accidents. These occasional factors are very diverse, but not ensuring weathertightness or deficient cargo stowage are among the most frequent ones. In any case, an ignorance of the real risk that is being undertaken can be appreciated (U.S.Coast Guard, 1999). However if the skipper had the information or training to asses this situation objectively, the scenario would change dramatically.

Although this problem is internationally accepted, few solutions have been adopted, going from simple manuals for skippers and owners of small fishing vessels (Gudmundsson, 2009) to onboard systems, which can be accessed by the crew.

The advantages and disadvantages of each option have been studied in order to design and develop an alternative system. This system is based on a number of basic requirements, including ease of use, understanding and installation, low cost of installation and life cycle, quick operation and the capacity of dealing with different sailing conditions and stability failures.

2. PROPOSED STABILITY ASSESSMENT SYSTEM

2.1. BACKGROUND

Nowadays, the stability requirements of fishing vessels of more than 24 meters of length are included in the Torremolinos International Protocol (IMO, 1993), adopted by the European Union in 1997 and modified in 1999 (CUE,1998; CUE,1999). For smaller vessels, the national authorities are responsible of imposing other stability requirements. In the Spanish case, these requirements are included in the Real Decreto 543/207 (MEF, 2007). Vessels of less than 12 meters must carry out stability evaluations according to ISO 12217 standards (AENOR, 2002; AENOR, 2003). These criteria are based on the analysis in still water condition of the righting lever (GZ) curves of the ship and also on the initial metacentric height. But they do not take into account the sea state in which a given vessel could safely sail (that depends, apart from its stability levels, on its size among other parameters) or the possible effects of dynamical instabilities (where ship speed, heading and other parameters should be considered). A detailed description of the drawbacks and deficiencies of these criteria and possible alternatives for taking into account the effects of sea state and dynamic issues can be found in (Womack, 2005, Deakin, 2006 and Deakin, 2010).

However, and although more adequate stability criteria are under study by IMO, the current regulatory way of evaluating the stability of a ship is by ensuring the fulfilment of these requirements (Wolfson, 2004).

At sea, the only way fishermen are able to know if they are complying with these criteria (which, as indicated, do not ensure the safety of the vessel) is through the use of the “Stability Book”. This book only contains four stability conditions, in which the aforementioned regulatory requirements are validated and includes a stability condition calculation procedure. This procedure is confusing and time consuming, always considering that the skipper has enough training to understand the instructions. As a result, and if available (it is only compulsory on ships of more than 12 meter length), the Stability Book is not frequently used by the crew (Wolfson, 2004). Still, in most cases, experience is the only way of evaluating the stability levels of the ship.

It has been accepted by the sector that one of the main factors contributing to these stability related accidents is this ignorance of the stability situation of the vessel, and some work has been carried out in order to try to solve this matter.

In (Wolfson, 2004) a detailed analysis of the current state of the art in this field is presented, observing four different alternatives. In Norway, the skippers use an A4 poster with a colour code and a general description of the places where cargo can be situated, identifying safe, medium and high risk situations. In the U.S., a loading matrix is proposed (Womack, 2002), including a more detailed evaluation of risk, taking in account the loading case and weather conditions. It is more complete than the previous alternative, but when the vessel has a large number of tanks and compartments the matrix can be complex and difficult to understand. A third option is used in Canada and implements the loading matrix in an onboard computer application, also considering roll and pitch motions, that triggers an alarm when some limits are exceeded. Finally, the

Icelandic approach evaluates the risk based on the stability problems caused by braking waves, combining meteorological predictions with an onboard roll motion measuring system.

In (Deakin, 2006), the author proposes a similar approach to the Norwegian stability poster for displaying the stability information of the UK fleet. However, in this case the risk level associated to each situation not only depends on the loading condition, the analysis of the GZ curve and the arrangement of load items, but is also dependant on other ship characteristics such as length, breadth and freeboard and sea state (significant wave height). This work will be revisited in subsequent sections.

Figure 2 a. Different alternatives for fishing vessel crew information systems. Stability poster. Norwegian Maritime Directorate (Wolfson, 2004).

Figure 2 b. Different alternatives for fishing vessel crew information systems. Womack stability matrix. Image courtesy of Mr. John Womack.

2.2. REQUIREMENTS

The system proposed here was developed from the analysis of the aforementioned systems, and from a set of basic requirements. Taking into account that it is intended to be used on board in small and medium sized ships, and that the training of the crews of these types of vessels is very low, the system should be very easy to use and to understand, much in the same way as the stability poster commented before is. At the same time, it should be affordable in acquisition, installation and operation, and changes due to ship modifications should be easy to implement. Secondly, it should be able to reproduce in the most accurate way, the highest number of loading conditions possible, as in the case of the Stability Matrix but in an easier way, especially in the case of ships with many tanks. In order to do so, a computer application is the best alternative, following the Canadian and Icelandic approaches. Finally, the system should be able to deal with all the possible situations involving ship instability, not being limited to major issues, as some of the aforementioned systems are.

These situations should include dynamic stability phenomena as well as static ones, as they are a frequent cause of accidents, usually together with some static stability problem. The most common issues that lead to stability related accidents, and that the system should be able to cope with, are the following, divided into four groups (Womack and Johnson, 2003):

- *Changes in Weight Distribution.* It includes situations that could lead to reductions in the ship stability caused by changes in the initial weight distribution without checking the stability criteria after them. By themselves they do not usually cause accidents, but due to the reduction of the righting ability of the vessel it could happen that, under theoretically secure conditions, a serious heel or even capsizing could happen.

The following classes are included in this group:

Changes in the vessel structure and its equipment, raising the centre of gravity and decreasing the stability level.

Changes in the use of spaces, leading to non-studied and potentially dangerous loading conditions.

- *Operational Situations.* In this group we could include all those situations that could happen during fishing, due to incorrect operation or an unexpected situation, and that by themselves or combined with other situations, could imply a serious risk for the vessel (Womack, 2003).

Overloading, reducing freeboard and stability levels.

Inappropriate loading, raising the centre of gravity, blocking clearing ports or generating cargo shifts.

Heavy hanging loads, leading to large heel angles and raising the centre of gravity.

Fishing gear grounding, causing sudden slowdown decreasing the stern freeboard.

- *Weather Situations.* These situations include navigation during adverse meteorological conditions or in reduced stability situations due to other causes, like inappropriate loading. Some sea or wind conditions, which under regulatory requirements might not be considered as dangerous, could be so in situations with reduced freeboard or high centres of gravity.

Water intake/Flooding, causing free surfaces or flooding due to bad vessel operation.

Breaking waves. Especially dangerous when sailing in beam seas in reduced stability situations.

Wind. Could contribute to heel increase in some ships with very large depth and big superstructures, and be dangerous in low stability situations.

Ice. Ice formation results in the elevation of the centre of gravity, for ships sailing in cold environments.

- *Dynamic instabilities.* These situations happen when the vessel is sailing and they imply stability problems related to the interaction between ship and waves (Belenky and Sevastianov, 2007, Neves and Rodriguez, 2006, Womack and Johnson, 2005). Their appearance is independent from the initial stability although their effects are reduced for larger stability margins. These phenomena, associated with reduced stability, could lead to capsizing or loss of the vessel. The best way to avoid them is to sail out of the speed ranges and courses in which these situations are more likely to occur.

Parametric resonance, involving sudden high amplitude rolling motions, leading to the vessel capsizing if not stable enough.

Loss of stability, sailing in following seas, the stability of the vessel is reduced compared to that in still water. Dangerous in low stability conditions.

Broaching, sailing with following or quartering seas, due to the loss of the vessel's steering capacity. It is especially dangerous with heavy seas and low stability conditions.

2.3. THE SYSTEM

Naval Architecture Software

For the evaluation of the static stability of the ship, it was necessary to use a naval architecture software, capable of obtaining the hydrostatic characteristics of the ship from the integration of its hull forms, for a set of different drafts, heel and trims, and also capable of obtaining the equilibrium and stability values resulting from a given loading condition. To this end, a naval architecture software has been developed by the Integrated Group for Engineering Research. This system met the aforementioned requirements, and also included a subdivision module, where the compartment and tank definition of the ship were made, and a loading condition module, that was able to obtain the loading condition parameters from each tank levels and other load items. From the data obtained from these modules, the stability module computed the different intact and damage stability values of the ship. This system can also compute the equilibrium values of the ship under a given loading condition, both intact or damaged, including trim and heel angles, drafts and the whole set of hydrostatic values.

Although this is a quite easy-to-use tool, it is not designed to be operated by people without an engineering background. Consequently, a whole new application, SKIPPER, was then developed. This application includes the stability and equilibrium calculation algorithms of previous software, but with a simpler structure and a user-friendly interface, installed in a compact PC with a touch screen, that can be easily installed in any new or operating vessel.

2.3.1. System Description

In order to fulfil the requirements of ease and simplicity of use, the parameters that the crew should introduce in the system have to be reduced to the essential ones for defining the loading condition of the vessel. In this case, these parameters are the levels of the different tanks and the value and approximate position of the different load items.

These values are usually known by the skippers, as they always have a quite clear idea of how much cargo they are carrying and where it is inside the holds, how much fuel or water they have in the tanks, or what is the approximate weight of the nets they are carrying and where are those nets situated on deck (but as mentioned before, they are not able to relate these values to the stability of the ship). As will be seen, and in order to simplify the system even more, the user will not have to introduce the exact position of each load item. He will only have to select an area of the ship, which has its own centre of gravity (previously defined by the designer). In the case of tanks, and if the vessel is equipped with remote soundings, the system has been designed to be able to take these values as inputs and compute the tank loading in a fully automated way, reducing even more the information needed from the skipper.

As a first step before being installed onboard, the designer must configure the software for each vessel, through a configuration file. Its hull forms, tank and hold definition (including different types of cargo and their permeability), flooding points, decks, minimum required freeboard, lightweight and other ship particulars as well as a matrix with all possible situations of loads in the ship and their centres of gravity have to be included. This matrix is made up of by the areas where loads can be situated, which have to be defined by the designer after studying the operation of the ship. Each area has an approximate centre of gravity, which will be the one assigned to the load associated to each area. A proper selection of the areas and an accurate definition of the associated centre of gravity are fundamental for a good performance of the system. The experience of the designer is needed to define all these areas and the vertical centre of gravity of the cargo that is normally stowed in them. It has to be taken in account that the vertical centre of gravity associated to these areas is very relevant regarding the stability of the ship, and should always be selected with some margin in order to keep the system always on the safe side. The designer should also introduce the different diagrams of the general arrangement of the vessel that will be displayed in the user interface. All these data won´t be modifiable by the user.

Once all the data is in the system, that is, hull forms, vessel characteristics and diagrams, compartment definition and loading condition definition, the system will automatically calculate the equilibrium and the stability of the ship. This includes fore and after drafts, heel and trim angles and the parameters resulting from the analysis of its stability curve, that is, positive range of righting levers (GZ), GZ maximum values and their corresponding angles, initial metacentric height, residual freeboard and downflooding angles.

As will be seen in the next section, the equilibrium parameters will be presented using a diagram of the ship profile, where the waterline and trim angle are shown and a transversal view where waterline and heel angle can be appreciated.

At the same time, and depending on the ship stability parameters that will be described below, the “level of stability” of the ship is displayed using a coloured bar going from a low risk situation (green) to an extremely dangerous one (black), with intermediate values in yellow, orange and red. This “level of stability” of the ship is obtained following two different approaches. From them, the most restrictive one is selected, after the analysis, as the one characterizing the level of risk of the ship.

The first one is based on analyzing the fulfilment of the stability requirements of the Torremolinos International Protocol for ships of more than 24 meters length (IMO,1993) or Real Decreto 543/207 (MEF, 2007) for smaller vessels, for the ship condition under analysis and including actual draft, heel and trim.

These criteria are shown in Table 1:

Table 1. Fishing vessels stability criteria.

As one of the objectives of the presented software is also to simplify the information contained in the stability book, and also to help the National Authority inspectors to check the stability of the ship, it is necessary to include the evaluation of the current compulsory requirements. It is also obvious, that the crew of a ship that in any moment of operation is not complying with its mandatory requirements in terms of stability should be alerted and informed about this fact. At the same time, these requirements provide good levels of safety in sheltered waters and, as the actual loading condition is used for obtaining the GZ curve, the effects of unsymmetrical loading and hanging loads are also included.

However, the importance of wave height is not considered in the IMO criteria. Although the IMO dynamic stability criterion (area under GZ curve) gives an idea of the capacity of a ship to withstand the effects of waves and so its resistance to capsizing, neither the encountered sea state nor the size of the vessel have any influence on them. In order to properly evaluate the level of risk of a ship in a realistic seaway, it is necessary to also consider the influence of those two parameters.

In order to take in account the seastate and the size of the vessel for evaluating the risk level of the ship, the method proposed by B. Deakin in (Deakin, 2006, and Wolfson, 2006) has been used.

According to this method, the risk level of a vessel sailing in a given seaway could be addressed by obtaining its critical significant wave height (minimum significant wave height to capsize) and comparing it to the level of safety that in terms of significant wave height, implies complying with the minimum IMO requirements.

In the aforementioned reference, the minimum significant wave height to capsize could be estimated by:

$$H_{S_{Crit}} = \frac{Rng_{\mathrm{Res}}\sqrt{\Delta \cdot GZ_{\mathrm{Res}_{Max}}}}{20 \cdot B}$$

Where Rng_{Res} is the positive range of the residual GZ curve, $GZ_{Res.Max}$ is the maximum residual GZ, Δ is ship displacement in the actual loading condition and B is ship breath.

In order to determine the level of safety of a given sailing condition, the previous value is compared to the level of safety that in terms of significant wave height, is provided by the minimum IMO requirements regarding GZ curve, i.e. minimum GZ maximum of 0.2 m and an estimated positive GZ range of 45 degrees; this IMO reference value could be obtained in terms of ship length by $H_{S_{IMO}} = \sqrt{1 + 0.4 \cdot L} - 1$ (Wolfson, 2006). This formula has been obtained for a data set of UK fishing vessels, whose minimum significant wave height was computed using the mentioned minimum IMO requirements. Taking into account the heterogeneity of the Spanish fishing fleet and its differences with the UK one, the suitability of the proposed $H_{S\ IMO}$ formula for the ships under analysis has not been proven. However, this value has been used as an approximate reference value in this work; future research could be aimed at studying the application of this correlation for the Spanish fishing fleet.

As previously indicated, in the proposed system the "level of stability" of the ship is determined by following the two described approximations, and is defined as a number going from 0 (very high risk) to 1.2 (low risk), that are subsequently related to a colour code that will be displayed to the user. The two levels of stability obtained are compared, and the most restrictive one is selected as the one defining the risk level of the analyzed condition.

Regarding the IMO approach, the stability index is computed taking into account the values of the six criteria described in Table 1. Once computed for the actual loading condition, these parameters are normalized with the minimum required value for each one of them. From these normalized parameters, the minimum one is selected as the IMO Stability Index (SI_{IMO}):

$$\text{i}^{th}\ \text{IMO Normalized Value} = \frac{\text{i}^{th}\ \text{Criterion Load Condition Value}}{\text{i}^{th}\ \text{Criterion IMO Min. Req. Value}}$$

$$\text{Stability Index}_{IMO} = \text{Minimum IMO Normalized Value}$$

In order to take into account the effects of sea state and the size of the vessel, a second stability index, the wave height stability index (SI_{Hs}), is computed using the Deakin method (Deakin, 2006). For each condition, the value of the minimum significant wave to capsize ($H_{S\ Crit}$) is calculated, obtaining the necessary values from the actual GZ curve of the ship. This value is divided by the reference IMO significant wave height ($H_{S\ IMO}$) described above:

$$\text{Stability Index}_{Hs} = \frac{H_{S\ Crit}}{H_{S\ IMO}}$$

Once both indexes are computed, the minimum of the two indexes (SI_{Min}) is selected as the Stability Index of the ship. According to this value, the level of risk of the vessel and the colour displayed will be defined the following way:

SI_{Min} ≥ 1.2. In this situation, the ship fulfils all the requirements, both wave and static stability ones, by a safety margin of at least 20 %. It is supposed to be sailing in a low risk condition, and green colour will be associated to it.

1.2 > SI_{Min} ≥ 1. For SI_{Min} = 1, the ship is exactly fulfilling the IMO requirements, whether the static stability criteria, the wave height criterion or both of them. Although the ship is supposed to be at low risk in this situation, even a small modification in the loading condition could make it non-compliant with the minimum requirements. A moderate risk will be associated to this index, together with a yellow colour. This condition will be maintained for a safety margin of 20 % over the minimum requirements, i.e. SI_{Min} = 1.2.

1 > SI_{Min} ≥ 0.5. The ship is sailing in a situation where some of the static stability criteria are not fulfilled or the minimum significant wave to capsize is smaller than the minimum IMO equivalent wave height. As the margin of non – compliance is still not extremely large (up to 50 %), but it is clearly a dangerous situation, the red colour and high risk condition will be associated to these values.

0.5 > SI_{Min}. The ship stability and resistance to capsizing is very low, as at least one of the analyzed criteria is well under its minimum (by more than 50 %). A very high risk condition and black colour are the ones selected for this range of the stability index, in order to indicate a severe risk of capsizing.

In addition to the analysis of these criteria, the compliance with the minimum required freeboard, the immersion of a downflooding point or the weather deck, or simply if the vessel is not upright, are also evaluated from the loading condition equilibrium data.

If the vessel is found out not to be upright in the proposed condition, a very high risk message and black colour will be displayed. The other three situations (i.e. minimum freeboard exceeded, downflooding point submerged or deck immersion) will be associated with a high risk level (red colour) although the Stability Index would lead to moderate or low risk conditions; this is done in order to take into account the increase of risk associated to a possible flooding of the ship (open hatches or doors, etc.). If in these three situations the computed SI_{Min} is under 0.5, then the corresponding risk level and colour will be very high and black.

In the following flow diagram (Figure 3), the process for determining the level of risk of the ship for a given loading condition is summarised.

Figure 3.Definition of risk level. Flow diagram.

The calculated level of risk and the corresponding colour will be displayed in a message on the screen after each calculation, in the way described in the following section. In this message, the minimum wave height to capsize for the condition under analysis ($H_{S\ Crit}$) will be also displayed, in order to alert the crew about the maximum recommended seastate for the given risk level. Finally, this message will also alert in a clear and unambiguous way if in the equilibrium of the analysed condition, the minimum mandatory freeboard is exceeded, the main deck or a non watertight opening (defined by the designer) are flooded or simply if the vessel is not upright.

2.3.2. Graphic User Interface and Operation

Once the system is configured and installed onboard, it is ready for the operation by the skipper. As will be shown in the following sections, the operation and understanding of the software is very easy and no major training is required to add and evaluate different loading conditions; the messages the system displays are clear and straightforward.

As can be seen in Figure 4, the graphic user interface (GUI), is composed of four main areas. In the main upper part of the screen, a profile view of the ship is displayed, including the different decks, tanks and other places where load items can be placed. The current draft is displayed with a blue dotted line and light blue colour under it.

Figure 4 a. Fishing Vessel Stability Guidance System. GUI main screen. General view.

Figure 4 b. Fishing Vessel Stability Guidance System. GUI main screen. Stability indicator detailed view.

On the main lower side of the screen, the different deck views of the ship are displayed. In order to select between the different decks, the user has to press on the area he wants to see in the profile view. The plan view of the selected deck will then appear here. This area of the screen is where the user can select the different spaces to load or unload, and thus create the loading conditions.

As can be seen in Figure 4, the compartments are displayed in different colours. Blue stands for tanks, green stands for cargo holds and brown stands for places where different cargo items can be placed. On the right side of the screen, the load, unload and move load buttons can be found, together with a transversal view of the ship (where draft and heel angle are displayed) and the coloured bar that indicates the stability level of the ship. As was previously said, this bar goes from green to black depending on the stability of the vessel in each loading condition. Finally, on the small lower taskbar, we find some buttons that show the list of the compartments, tanks and load items and the weights in each one, and the EXIT button that closes the application.

In order to create and evaluate the stability of the ship, the user just has to create a loading condition by introducing the loads in the different locations. Each possible load location is represented in the diagrams by a coloured box (blue, green or brown, as seen before) that can be directly selected by pressing on it. Once selected, the Load button should be pressed. A dialog box is then opened, where the user has to introduce the load (see Figure 5).

In the case of tanks, load can be defined using the weight contained in it or using its filling percentage. The process for holds is similar to that for tanks, but allowing the user to select between different types of loads (different fish species, shellfish, seafood, ice, etc.), that have an associated density.

In the case of other load items, the user only has to select the area where he wants to place the item, and then introduce the weight and the number of items. As indicated before, the centre of gravity of this load has been previously defined by the designer, and is associated to the area. In this group all loads different from tanks and cargo in holds are included, like nets, fishing cables, boxes, fishing gear, etc. If the ship has cranes, derricks, lifting blocks or poles, a load item could be included in the hanging point, in order to consider the effects of hanging loads or nets in beam trawlers or purse seiners.

Figure 5 a. Screenshots with different types of load zones selected. Cargo hold. General view.

Figure 5 b. Screenshots with different types of load zones selected. Cargo hold. Detailed view.

After the loading condition has been defined this way, the system automatically calculates the equilibrium and the stability of the ship.

The equilibrium values are shown in the profile view, as the draft moves to its position in the analysed loading condition (this view makes it possible to appreciate both draft and trim in a clear way) and also in the transversal view on the right of the screen, as the ship diagram heels to its equilibrium position and the draft is also moved to it. To increase clarity, heel angle is also displayed numerically next to the diagram of the ship.

In order to display the level of stability of the condition under evaluation in a clear and unambiguous way, different alternatives are used. As previously mentioned, the coloured bar stability indicator will move into the colour that best represents the stability level of the vessel according to the values mentioned in the previous section.

At the same time, in case of poor stability levels (high and very high risk conditions), if the minimum freeboard is exceeded, the main deck or a non watertight opening are flooded or simply the vessel is not upright, the colour of the draft line and the coloured area under it will turn bright red, making clear that the ship is in danger in that situation (See Figure 6).

Figure 6 a. Screenshots with stability calculations results. Low risk. General view.

Figure 6 b. Screenshots with stability calculations results. High risk. General view.

Finally, and after the calculation of every loading case, a pop-up window will appear, showing the vessel situation with a clear message. These windows are of different colours, according to the risk of the condition. A “Low Risk” message with a green window is displayed in safe situations. A “Moderate Risk” message together with a yellow window is displayed in case of a ship within the statutory limits of stability, but near them. A red window together with a “High Risk” message is displayed when a high risk situation arises, and finally a black window together with a “Very High Risk” or a “Risk of Flooding” message is displayed when such a situation arises, or when it can lead to flooding of the vessel. Moreover, the maximum recommended wave height value for that condition is displayed under the condition risk level, for instance:

“Maximum recommended height for this condition: $H_{S_{Crit}}$ m”

These windows have to be closed by the user if he wants to continue using the software, making sure that he has seen them and that he is aware of their content (See Figure 7).

Figure 7 . Vessel situation messages. Detailed view.

2.3.3. Usability Analysis

As seen in the previous sections, the system is quite easy and quick to operate and the displayed messages are clear and describe in a straightforward manner the stability levels of the vessel. However, when dealing with software, what is easy for the designer may not be easy for the user, in our case the skippers of the fishing fleets, especially taking into account that their training in the field of software operation and stability is quite low. So, it was necessary to test that the system could be used and understood by skippers without problems. In order to do this and to verify that the system complies with the basic requirements defined at the beginning of the project, a usability analysis of the software has been conducted.

Definition of usability

Usability is a qualitative attribute of the software applications that indicates the ease of use of a user interface. ISO (International Organization for Standardization) defines the term usability as "The extent to which a product can be used by specified users to achieve a specified goal with effectiveness, efficiency and satisfaction in a specified context of use" (Nielsen, 2003). In order to measure the usability of a system, a usability testing technique has been applied. This technique measures how well the subjects respond in four areas:

-Performance or efficiency: how much time or how many steps are needed to accomplish the basic tasks.

-Accuracy: how many mistakes are made by users.

-Recall or learnability: how much do the users remember after periods of non-use.

-Emotional response: how does the user feel about the task completed? Is the person confident, stressed?

Usability testing involves the creation of a number of realistic scenarios where the users perform a list of tasks while observers compile information. There are several "using testing" techniques such as hallway testing (Nielsen, 1997), remote testing, expert review or automated expert review (Forsythe et al., 1997). In this work, the hallway testing method, also known as hall intercept testing, has been selected, where five or six random people are chosen as users. This number of users is chosen because of the recommendation of Jakob Nielsen, the father of the usability testing techniques, who defends that no more than five users are enough for testing an application (Nielsen, 2003).

Scenarios definition

With the aim of creating the scenario for the usability test of the Skipper application, six main tasks have been identified. These are:

-Loading of a tank, compartment or separate weight zones.

-Unloading of a tank, compartment or separate weight zones.

-Moving load among tanks, compartments or separate weight zones.

-Calculating stability.

-Creating new loading conditions.

-Obtaining information about the loading condition of the ship: filling of the tanks, compartments and separate weight zones.

Three different scenarios that involve all the identified tasks have been created in order to test the application.

Usability metrics

The usability of a system can be measured from two points of view: a subjective one, that provides qualitative conclusions about the application and an objective one, which provides quantitative data.

The subjective point of view measures the satisfaction of the users about the application during the performance of the test and after it. The metrics used in this type of tests include percentage of user´s satisfaction.

The objective or quantitative point of view includes metrics that let us measure the ease of use of the application in terms of task time or success rate and its learnability level. In this type of test, the following metrics have been analyzed:

-Time in task, which measures the time that a user takes to accomplish a task with or without success.

-Mouse clicks counts, which measure the number of clicks used for completing a task.

-Successful completion rates, which measure the percentage of successful tasks of a user.

-Error rates, by measuring the number of mistakes made by a user while accomplishing a task.

These metrics have been applied to measuring the usability of the application and its learnability. The results are measured during two different days (Day 1 and Day 2). The results of the first day are used to analyse the usability of the system. Three days later, the users conduct the same scenarios to measure the learnability of the system. The learnability is measured by studying how the usability results improves after three days without using the application, i.e., measuring how much the users remember about the use of the application.

After the execution of the usability test, the users will fill a survey that will be used to measure the satisfaction level.

Results on usability

The testing procedure starts by giving the users a brief manual of the Skipper application. This manual specifies the basic commands and tasks that a user could execute in the application. Once read, the users should have any doubts they have clarified. The manual and the explanations to these doubts, is the only information the users will get before starting to use the application. Finally, the description of the scenarios is given to the users, and the usability test is carried out.

The results of the test are shown in Figures 8-11. Figure 8 shows the results of this analysis in terms of the number of clicks made in order to complete the task. The blue bar shows the average number of clicks executed by the testing users and the red bar the number of clicks executed by an expert. Figure 9 shows the results of the usability analysis in terms of time for completing the different tasks measured in minutes. Again, the blue bars show the average time required by the users and the red bars represent the time required by an expert. In both cases, the results obtained by the expert are considered as a reference value of how good is the performance of the testing users.

Analysing the time required to complete a task during the first test day, the users need 125%, 197% and 147% more time than the expert user in task 1, task 2 and task 3, respectively. It may seem a poor result, but looking at the average count of clicks, the results are not so bad. The average count of clicks executed by the users is just 50%, 55% and 20% higher than the number of clicks executed by the expert. Relating these two results, we can conclude that the application presents a high level of usability according to the number of clicks and that the difference in time with the expert is due to the fact that the testing user needs to understand the task and the application at the same time. But once the user comprehends what should be done, the task is easy to solve in a small numbers of clicks. This hypothesis can be verified if we analyse the number of errors committed by the users. This result is shown in Figure 10. It is true that the number of errors committed on task 1 is high, but it must be highlighted that it is the first time that the users test the application; they were getting used to it and learning how to perform with it. As can be seen in the results of tasks 2 and 3, the number of errors decreases as the user becomes familiar with the application.

Finally, the success distribution of the usability analysis is shown in Figure 11. From the observation of this data, it can be again concluded that the results improve as the user executes more tasks. At the beginning, the users present more difficulties to complete the task, improving their results in the last task.

From the analysis of the previous results, the ease of use of the application was demonstrated, especially once the tasks were understood and some experience with the interface was gained.

Taking into account that no information regarding the application is given to the users before starting the tests (apart from the aforementioned manual), and after analyzing the average number of clicks, it can also be concluded that the objective of intuitiveness of the application was fulfilled.

Results on learnability

Learnability is the other feature that we could measure after the execution of a usability analysis. In order to measure it, the testing users execute the same tasks of the usability analysis three days after the first test. The results of this second test are shown in the previous figures with the legend of Day 2.

To measure the learnability of the system, we compare the results obtained the first day to the results obtained the second day. The more outstanding result is related with the time in task; in the second day, time is reduced by 41%, 25% and 40% on task 1, task 2 and task 3, respectively. The improvement on the number of clicks is less than in the previous case; it can be pointed out the improvement on task 1, in which the first day results are improved by 20%. As can be seen in Figure , the difference in the number of errors is also highly remarkable. Finally, the success distribution of the second day shows that the performance of the users when they execute the tasks gets better. In this second, day the majority of the tasks are solved with ease. Only a few executions are completed with difficulty, but, as it shown in the graph, there are no failed tasks.

Summing up, this application was developed with the objective of being highly intuitive. This objective was achieved as can be seen by studying the results of the usability analysis. Moreover, the system presents a high level of learnability as demonstrated by analysing the results obtained the second day of the test and comparing them to the results of the first day.

Results on satisfaction

After the execution of each task and carrying out the “use tests”, each user received a survey. This survey includes ten questions about the feelings of the user when he/she is executing the application, so we can evaluate our software from a subjective point of view. These questions let us know the stress or anxiety level of the user, measured from one to five during each process, or if the application turned out to be cumbersome for the testing users. With these results we have calculated a satisfaction level as a percentage. After the second day of the test, the satisfaction level reached 84%, which is a high value and demonstrates that the interface under development is usable also from the subjective point of view.

Figure 8 - Average count of clicks executed by a user to complete each task.

Figure 9 - Average time needed by the users to complete each task.

Figure 10 - Number of errors made by the users to complete each task.

Figure 11 - Success distribution of the usability analysis.

3. CONCLUSIONS

In this work a novel ship stability guidance system, SKIPPER, has been presented. The need for such a system has been demonstrated at the beginning of this work; most of the accidents of small-medium sized fishing vessels are caused by stability-related issues and by the lack of consciousness of ship masters regarding the stability levels of their ships. Providing the masters with easy to use information systems that could help them to objectively assess the risk level of a given sailing condition is, together with improving crew training, the way of reducing fishing vessel accidents.

The SKIPPER application provides information about ship stability to the master, allowing him to evaluate any desired loading condition before ordering it and avoiding possible risky situations. This application has also been designed in order to be able to include some improvements that increase its operability and efficiency, such as remote tank sounding (which would simplify the work of the skipper obtaining tank levels automatically).

Apart from the master, this system also provides useful information to the National Authority Inspectors when a revision is performed onboard. Since data and ship layout, which has been introduced in the system by the designer, cannot be modified, the inspector can check that the general arrangement and the space subdivision remain the same as it was originally designed, avoiding uncontrolled modifications that may generate stability problems.

The requirement of reduced acquisition, installation and operation costs, has been fulfilled by choosing a standard integrated PC with a touch screen, that can be easily integrated in the bridge consoles with minimal effort and by storing all ship data in a configuration file that could be straightforwardly substituted by the designer if any modifications are done to the ship.

The ease and simplicity of use and understanding has been demonstrated through a usability analysis, the results of which have also been presented in this work. Apart from being easy to use, the results of the usability tests have shown that the learnability of the application is also good, as the success rates of the users increase from the first day of use to the second day.

In its current state, the system is able to help prevent the situations related with the static stability of the vessel. From the situations described in the Requirements section, the ones related to weight distribution and operational issues, are completely covered. Moreover, the system follows Deakin's approach for determining the maximum recommended wave height for the operation of the vessel in the analysed loading condition. However, the system does not currently consider the effect of wind and dynamic instabilities. It has been seen that considering dynamic instabilities is a must for a proper operational security evaluation. Thus, the assessment of the risks associated with operation in different wave and wind conditions (including the effects of water on deck) and the consideration of the effects of dynamic instabilities such as broaching or parametric roll resonance, are being undertaken.

Regarding this last point, the Integrated Group for Engineering Research is currently developing a research line focused on obtaining a parametric rolling prevention system and other dynamic instabilities such as the loss of stability (Míguez González et al., 2010).

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5. ACKNOWLEDGEMENT

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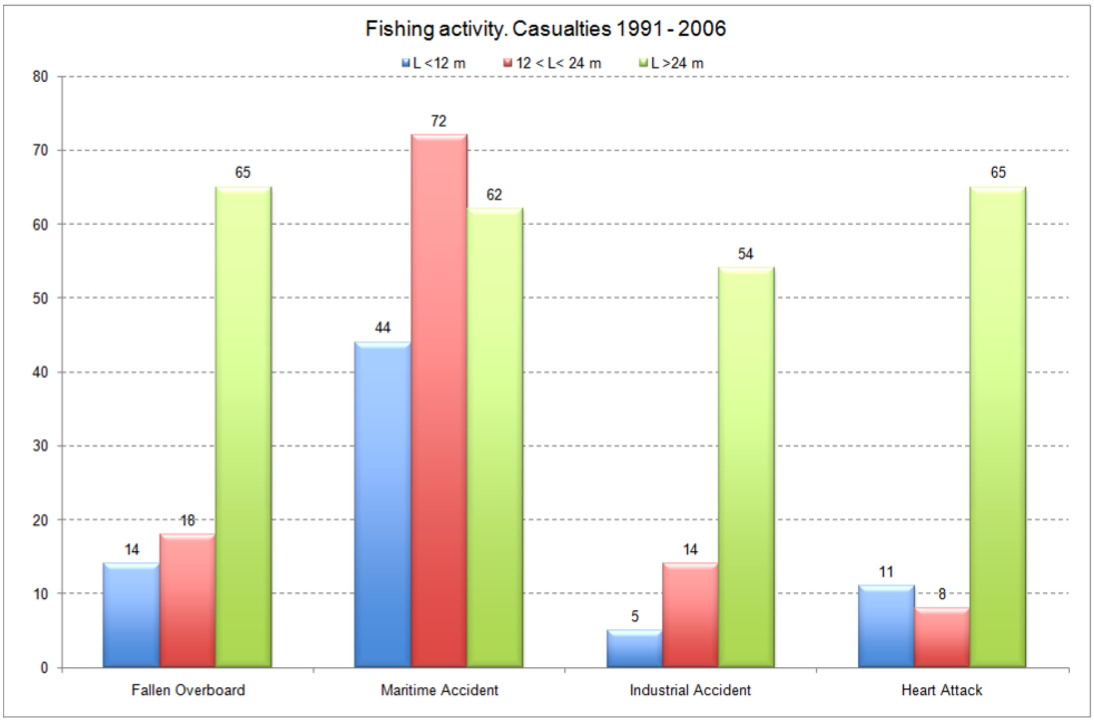


Figure 1 a. Number of Galician fishermen casualties. 1991- 2006 period. Source: Xunta de Galicia. Consellería de Pesca.

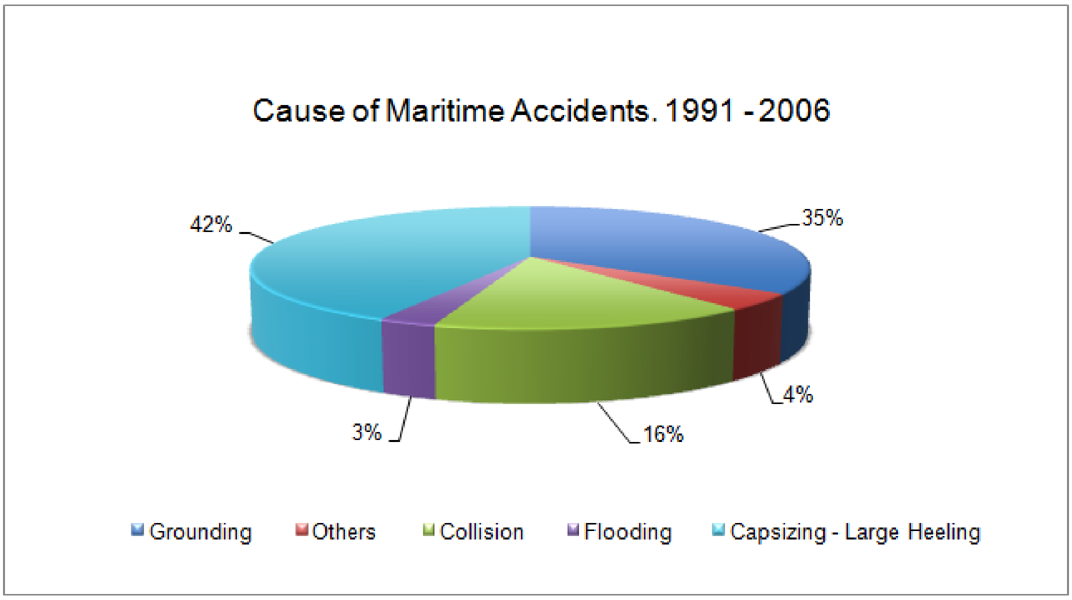
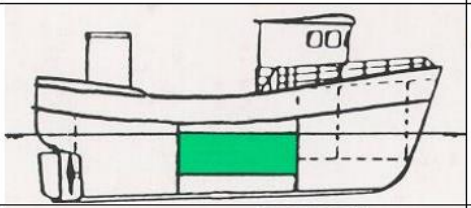
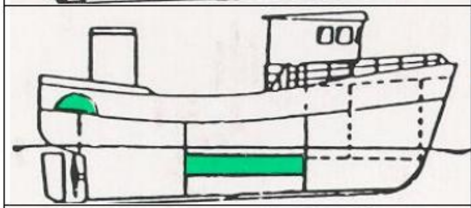
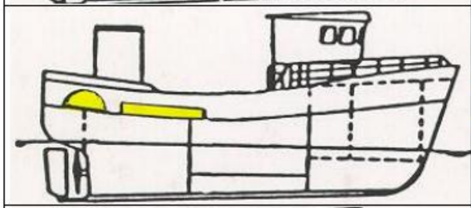
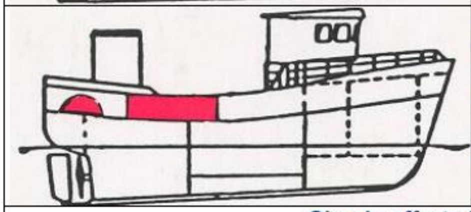


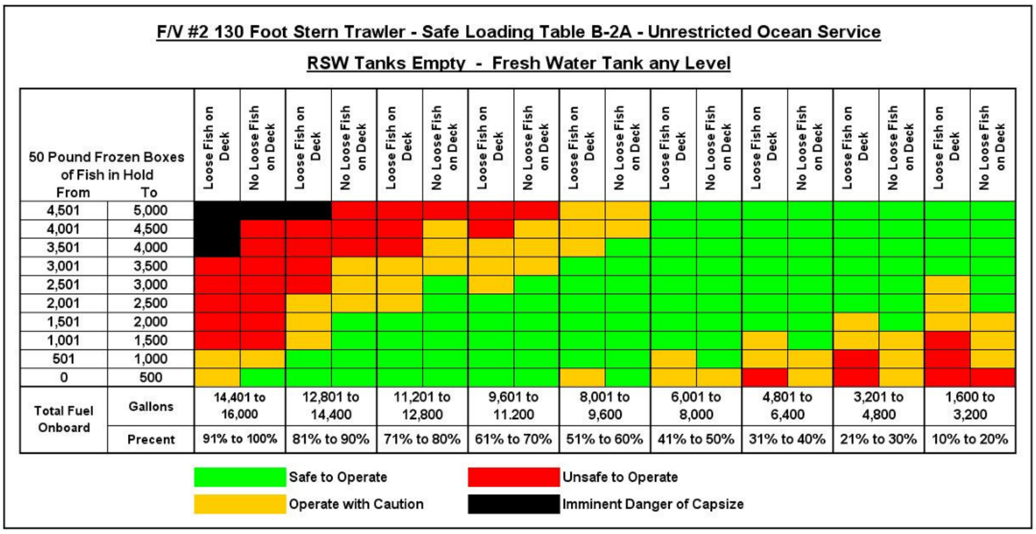
Figure 1 b. Cause of maritime accidents of Galician fishing vessels. 1991- 2006 period. Source: Xunta de Galicia. Consellería de Pesca.

STABILITY NOTICE				
	PLACEMENT OF GEAR AND CATCH	STABILITY		
		Acceptable	On the Limit	Danger of Capsize
	• Catch in cargo hold			
	• Part load in hold • Gear on deck			
	• Some catch on deck • Gear on deck • Empty cargo hold			
	• Considerable catch on deck • Gear on deck • Empty cargo hold			

Simple efforts for maintaining stability:

Close doors of hatches
Ensure scuppers are open to allow water to drain
Secure catch and gear against shifting
Move gear and catch from deck into cargo hold
Freeboard amidships should be at least 20cm
Avoid excessive aft trim
Minimum Freeboard at stern should be 20 cm
Avoid following seas
Large heeling moments when hauling gear are to be avoided.
Change of trim and heel when trying to free snagged gear can impair stability of vessel.
Do not go to areas with danger of icing.
Remove snow and ice from vessel.

Figure 2 a. Different alternatives for fishing vessel crew information systems. Stability poster. Norwegian Maritime Directorate (Wolfson, 2004).



F/V #2 130 Foot Stern Trawler - Safe Loading Table B-2A - Unrestricted Ocean Service

RSW Tanks Empty - Fresh Water Tank any Level

50 Pound Frozen Boxes of Fish in Hold From	To	Loose Fish on Deck	No Loose Fish on Deck	Loose Fish on Deck	No Loose Fish on Deck	Loose Fish on Deck	No Loose Fish on Deck	Loose Fish on Deck	No Loose Fish on Deck	Loose Fish on Deck	No Loose Fish on Deck	Loose Fish on Deck	No Loose Fish on Deck	Loose Fish on Deck	No Loose Fish on Deck	Loose Fish on Deck	No Loose Fish on Deck	Loose Fish on Deck	No Loose Fish on Deck	Loose Fish on Deck	No Loose Fish on Deck
4,501	5,000																				
4,001	4,500																				
3,501	4,000																				
3,001	3,500																				
2,501	3,000																				
2,001	2,500																				
1,501	2,000																				
1,001	1,500																				
501	1,000																				
0	500																				
Total Fuel Onboard	Gallons	14,401 to 16,000		12,801 to 14,400		11,201 to 12,800		9,601 to 11.200		8,001 to 9,600		6,001 to 8,000		4,801 to 6,400		3,201 to 4,800		1,600 to 3,200	
	Precent	91% to 100%		81% to 90%		71% to 80%		61% to 70%		51% to 60%		41% to 50%		31% to 40%		21% to 30%		10% to 20%	

Safe to Operate
Unsafe to Operate
Operate with Caution
Imminent Danger of Capsize

Figure 2 b. Different alternatives for fishing vessel crew information systems. Womack stability matrix. Image courtesy of Mr. John Womack.

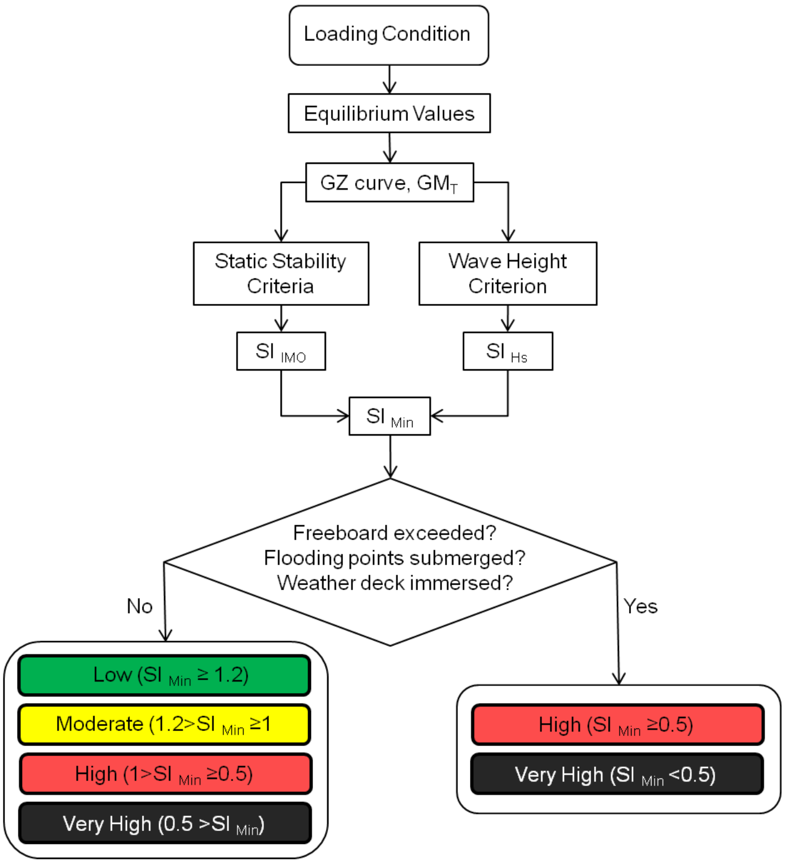


Figure 3.Definition of risk level. Flow diagram.

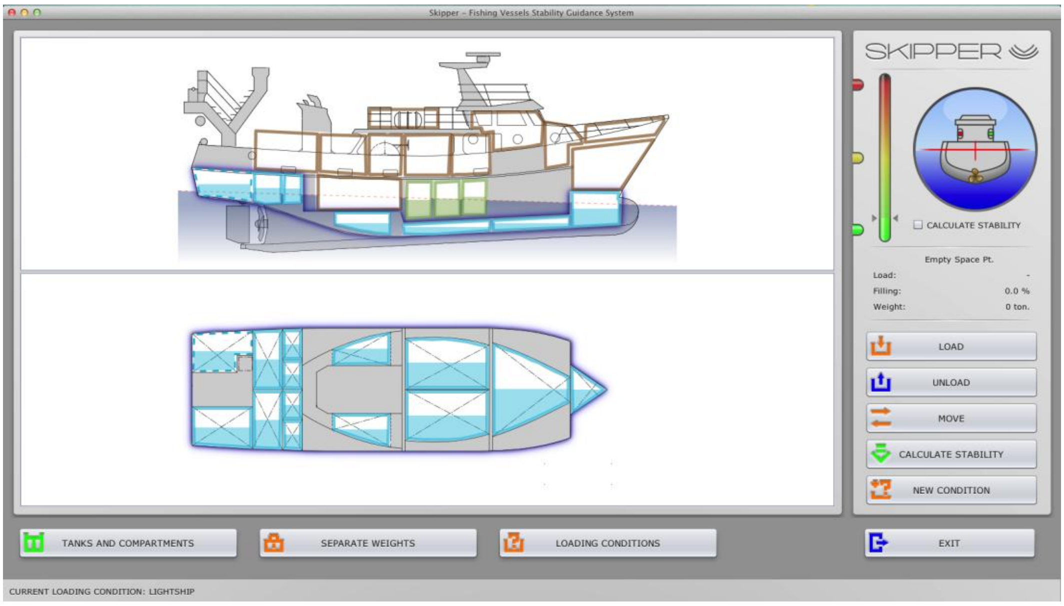


Figure 4 a. Fishing Vessel Stability Guidance System. GUI main screen. General view.

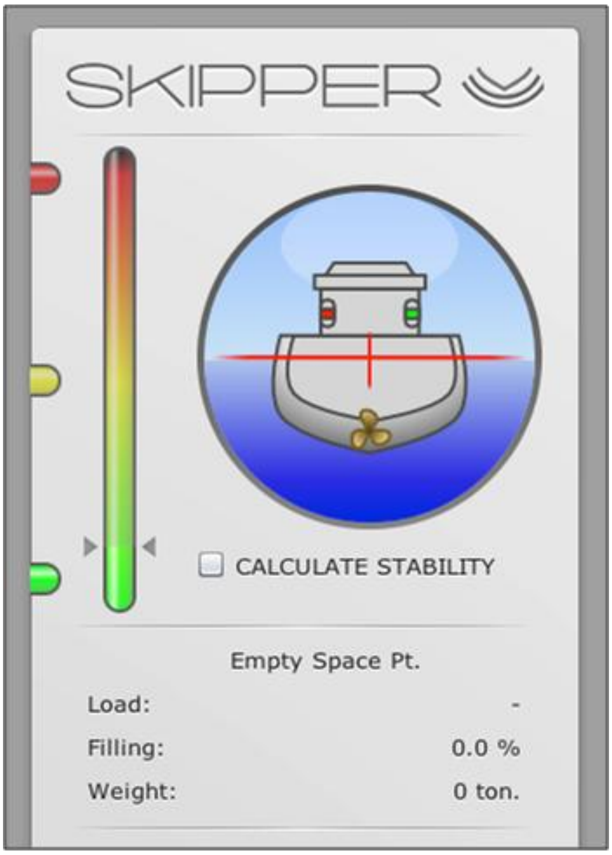


Figure 4 b. Fishing Vessel Stability Guidance System. GUI main screen. Stability indicator detailed view.

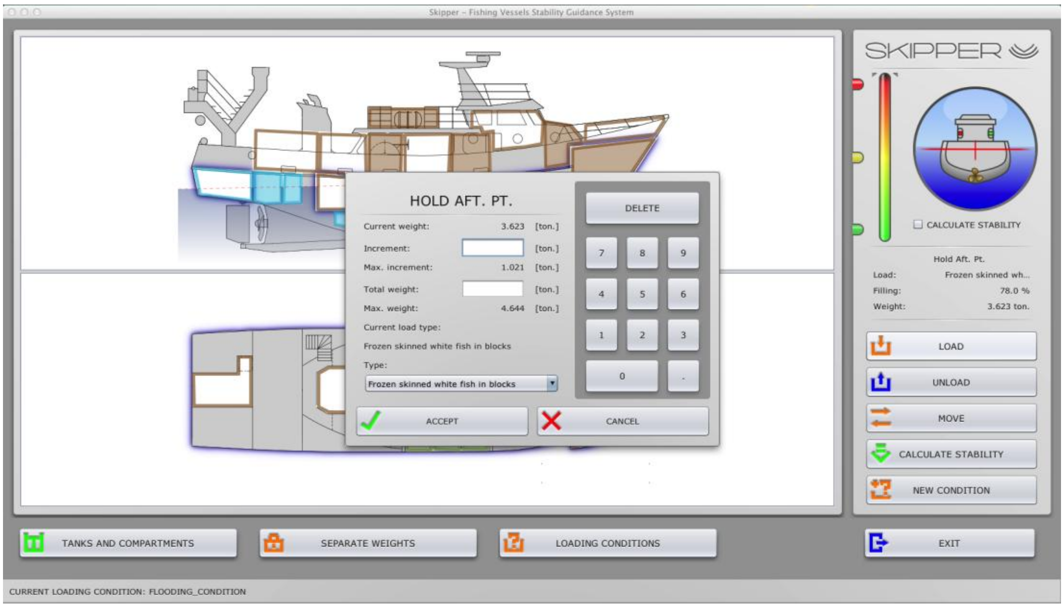


Figure 5 a. Screenshots with different types of load zones selected. Cargo hold. General view.

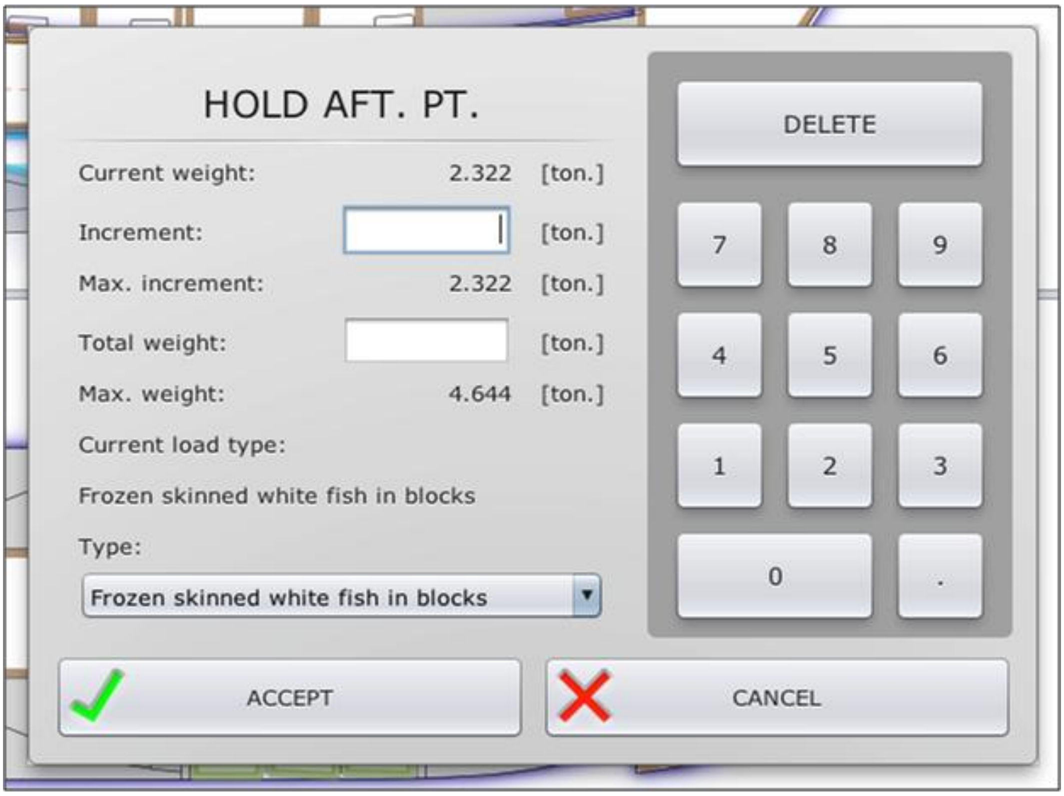


Figure 5 b. Screenshots with different types of load zones selected. Cargo hold. Detailed view.

Figure 6 a. Screenshots with stability calculations results. Low risk. General view.

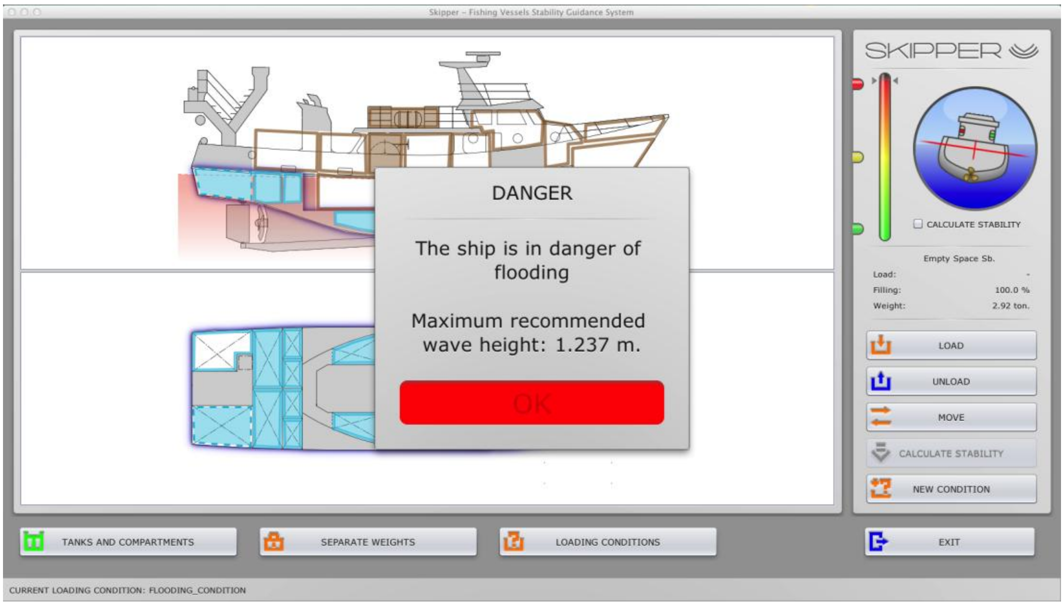


Figure 6 b. Screenshots with stability calculations results. High risk, flooding condition. General view.

Figure 7 . Vessel situation messages. Detailed view.

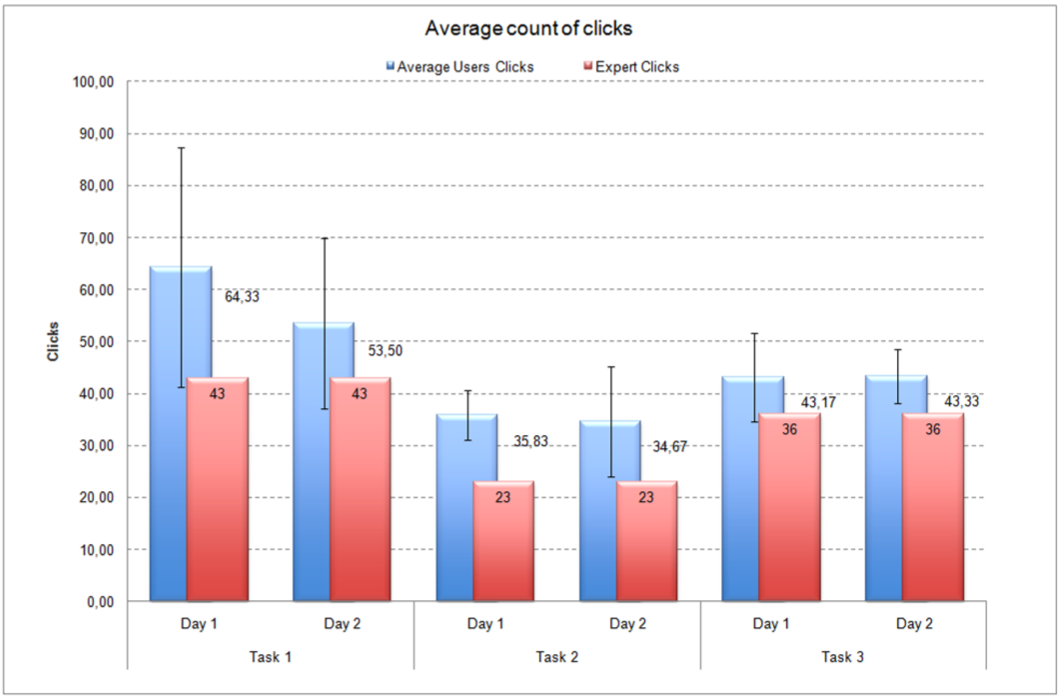


Figure 8 - Average count of clicks executed by a user to complete each task.

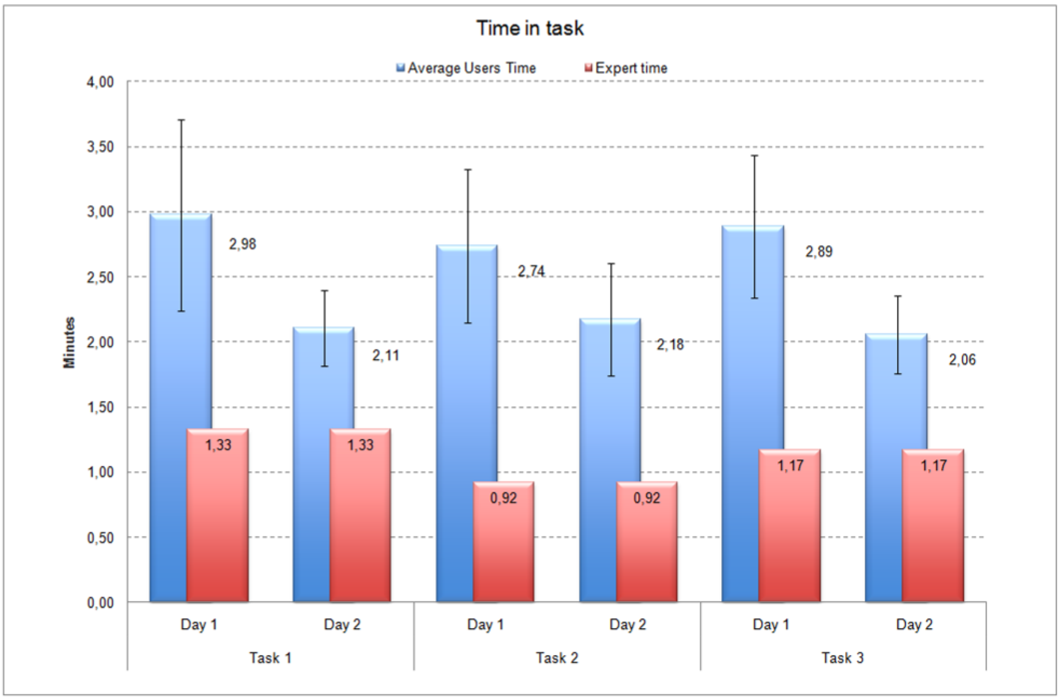


Figure 9 - Average time needed by the users to complete each task.

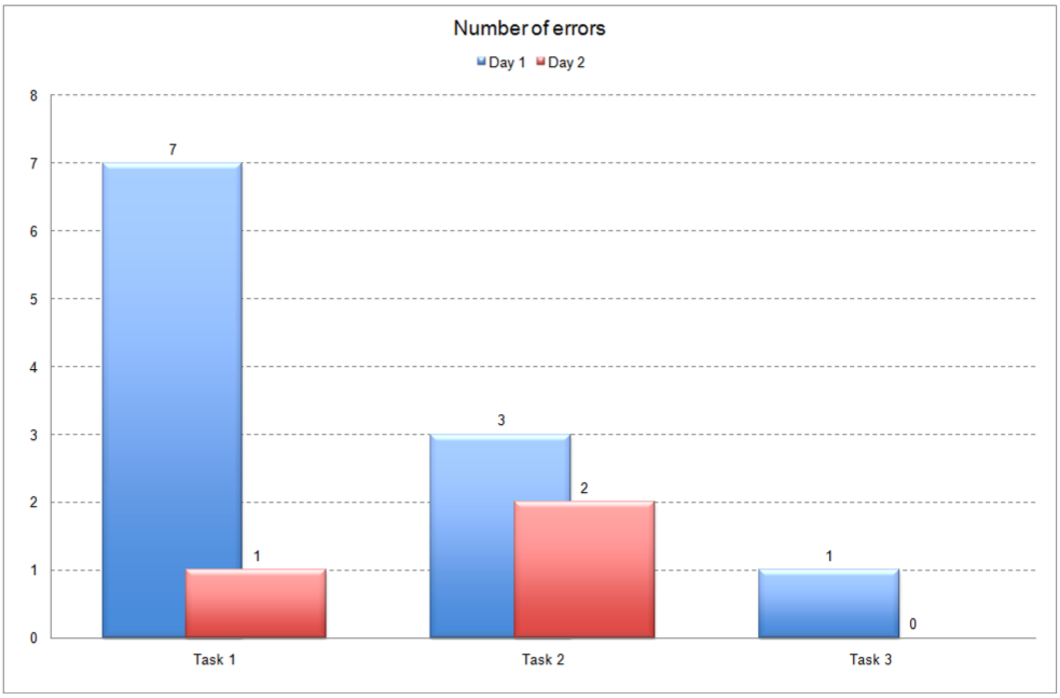


Figure 10 - Number of errors made by the users to complete each task.

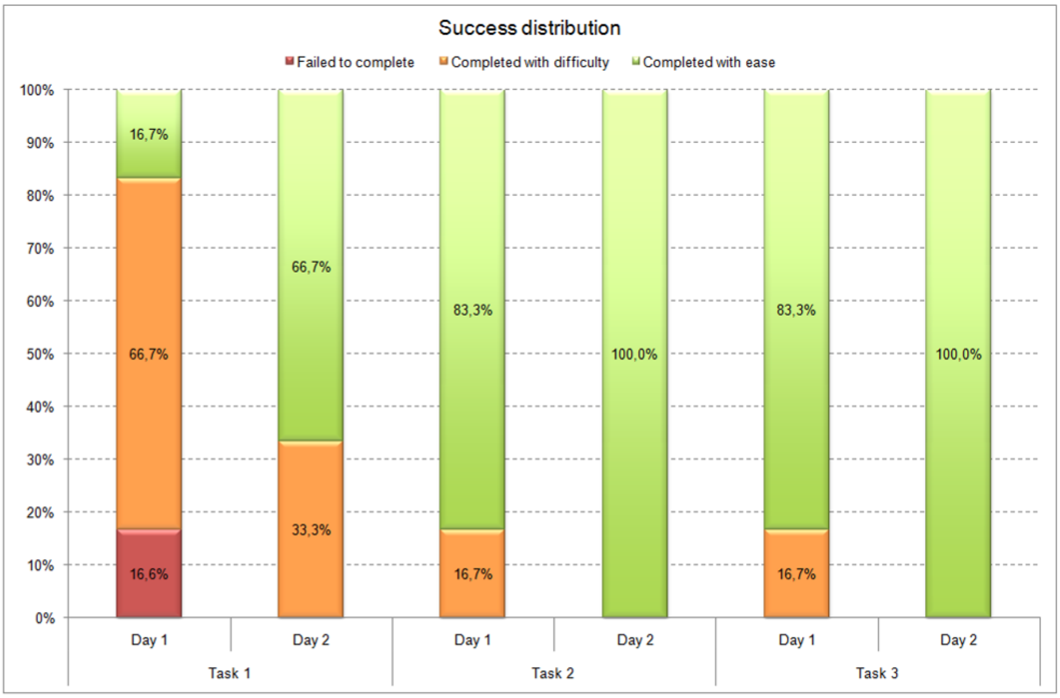


Figure 11 - Success distribution of the usability analysis.

Minimum initial metacentric height (GM_T)	0.350 m
Minimum GZ at a heeling angle of 30 º or more	0.200 m
Minimum heel angle corresponding to maximum GZ	25 degrees
Minimum Area under GZ curve between 0º and 30º	0.055 m.rad
Minimum Area under GZ curve between 0º and 40º or flooding angle	0.090 m.rad
Minimum Area under GZ curve between 30º and 40º or flooding angle	0.030 m.rad

Table 1. Fishing vessels stability criteria.