Abstract—Safe seafaring is closely related to the weather observation. The improvement of the system that covers the integration on board of weather information available on the ship’s bridge, should keep in mind the ship’s type and track but also the human factor or the task to be carried out by the officer on watch. This paper tries to provide a set of criteria to be used for designing an ergonomic concept of a weather receiving information station within a Ship Control Centre, to optimise the ship track.

Index Terms—Decision support systems, marine vehicle control, meteorology.

I. INTRODUCTION

Weather is the most important information required by seafarers and meteorological observation from ships has been one of the pillars supporting the modern science of meteorology. It provides a greater quantity of observational detailed data in areas that may only be accessed by ships.

In the sea side, the automation on board merchant ships suffered during some decades, a kind of blocking that has changed only some years ago towards a progressive assimilation of the in the market offered technical advances.

That main conversion pillars has been as on shore, the growing computer capacities and the telecommunications, affording the ship’s technical, functional and operational [1], [2] integration.

Within the control centres on board, referred as not only the ship’s navigation bridge but also the functions carried out in it by their users and the utilised technology, from the mid nineties, it has been possible to percept the integrated bridges growing that are fitting integrated navigation systems.

From the point when the IMO (International Maritime Organisation) establishes the standards related to the bridges, their builders have been converging up to similar concepts and definitions. In this sense when talking about IBS (Integrated Bridge System) we understand an integrated bridge containing an INS (Integrated Navigation System). The INS has been defined because the progressive add of the ship’s functions automation, their planning, saving in records and memory, monitoring and automatic track execution tasks.

The requisites applicable to the equipment have been defined by the normative of the classification societies, by means of additional requirements related to the control centre physical distribution, the minima visual field range determination, always focused to facilitate an efficient extern look out by the officer in charge [3].

Therefore the bridge is going to host, among others, electronic charts, automatic identification systems, voyage data recorders, high speed data transmission systems and meteorological data reception for the track planning.

The entire package of operations’ functional integration, together with the operative safety elements management [4] on designed screens, should respect the principles of user utility and interaction with the control centre. It would supersede the paper material and the uncountable number of equipment around the bridge, bringing real navigation aiding systems permitting the decision process towards a safer ship operation.

This paper is organised as follows: sections II, III and IV are dealing with different perspectives as rules, meteorological observation and data integration, providing the pillars for proposing the methodology for the criteria in section V, that should be considered in a track planning station on board (section VI). Section VII provides an example demonstrating the benefits coming from the use of that station and finally section VIII gives the key conclusions.

In the example, the proposed ship could carry around 2,000 containers, needing approximately 24,000 kW output for providing a 20 knots theoretical (machine) speed. This means that every day the ship sails, represents around 58 tonnes of fuel. The existing fleet of such a size of ship is nowadays around 500 units worldwide.

The conclusions defend the general utility of the proposed methodology, in terms of safety of navigation, human working conditions, and also the related fuel consumption.

II. MAIN RULING RELATED WITH ONBOARD OBSERVATIONS

Legislation that is directly related to acquiring meteorological and oceanographic data on board shipping vessels is echoed in the international forums such as the IMO and the SOLAS [5] 60 & ‘92 agreements. These legal bodies provide guidelines and obligations for the Master or Captain of the ship who should have the necessary tools available in order to fulfil them.

SOLAS Chapter V –Safety of Navigation- identifies certain navigation safety services that should be provided by Contracting Governments and sets forth provisions of an operational nature applicable in general to all ships on all voyages. This is in contrast to the Convention as a whole, which only applies to certain classes of ship engaged on
international voyages.

The subjects covered include the maintenance of meteorological services for ships; the ice patrol service; routing of ships; and the maintenance of search and rescue services or design standards when talking about ship control centres, among others.

III. METEOROLOGICAL OBSERVATIONS MADE ONBOARD

The more engaged ships on these matters are the ones classified as Vessel Observing System. They carry a copy of the Guide to Meteorological Instruments and Methods of Observation (WMO-Nº8) Part II, Chap 4. Marine Observations. This lists the instruments that should be carried on board together with any recommendations and advices referring to observation methods. Any instruments installed on board need constant attention.

As already mentioned, the SOLAS convention in its Rule V/5 mentions the obligation of the Captain of each ship to send out a warning message if they should meet objects or conditions that would represent immediate danger to shipping. Warning messages refer, among others, to gales, storms and tropical cyclones or when the own ship is experiencing a wind speed of 50 knots or higher in respect of which no storm warning has been received. This is specified in the new Ch V rule 31 on Danger messages and Ch V rule 32 on its content.

In relation to international scientific and economic programs, observations of all types are needed from ships at sea and the WMO are pressing for these to be provided through the VOS program.

An appropriate example would be the log report of waves phenomena [6]. A wave phenomenon would be defined as a very high wave. It is not normal to come across such waves that would be extremely dangerous to shipping. The reports could contribute to the mapping of particularly recurrent, and therefore dangerous, areas.

Surface currents are the objects of additional observations. Ships and drift-buoys may acquire such data and they lay the basis for evaluating surface current circulation.

Another aspect to be kept in mind is the crew formation on weather observation. The most recent regulation regarding the minimum education level for the maritime professions is the European Council directive 98/35/EC of 25th of May of 1998, modifying the EC directive 94/58/EC of 22nd of November of 1994. There it is confirmed the absolute requisites to be covered by any captain, officer and seaman for the proper job developing.

IV. INTEGRATION OF METEOROLOGICAL DATA INTO THE SHIP’S SYSTEMS

The Integrated Ship Control (ISC) centre is one of the technologies capable of yielding a highly positive impact on the current situation in terms of enhanced dependability, safety, efficiency and even competitiveness at sea. A properly designed integrated system, will enable vastly improved support of the ship’s crew and specially the officer-of-the-watch with relation to navigation, communication, monitoring of on-board systems, emergency response, cargo monitoring, maintenance and shipboard administration.

The established hierarchy among rules always consider on top the IMO, followed by ISO and closed by IEC.

Performance standards for integrated bridge systems were adopted by IMO in 1996 by the Resolution MSC.64(67) and in the ISO 8468:1990 [8] apart from specific IEC rules [9].

The revised SOLAS Chapter V, adopted in December 2000 and entered in force in July 2002 states in Regulation 19 carriage requirements for ship-borne navigational systems and equipment in its paragraph 6 on Integrated Bridge Systems, specifies that they shall be so arranged that failure of one sub-system is brought to immediate attention of the officer in charge of the navigational watch by audible and visual alarms, and does not cause failure to any other sub-system.

Also the Maritime Safety Committee, in its 73rd session (from 27th of November to 6th of December 2000), published the MSC 982 circular Guidelines on Ergonomic Criteria for Bridge Equipment and Layout, which were developed for easing the designers, when carrying out an ergonomic bridge design with the aim of improving the efficiency and reliability of the navigation.

Those guidelines were prepared for helping the provisions made in the revised SOLAS convention rule V/15, Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures, to be discussed initially in the MSC 77. As in MSC 77 was not contemplated a working group on human factor, in the MSC 76 was decided to postpone it to MSC 78 (December 2003), to be applied to all new or under construction ships.

Some other amendments have been approved as the resolution MSC 86(70), annex 3 on Performance standards for Integrated Navigational Systems and the MSC 982, this last from December 2003, trying to settle guidelines for ergonomic design of the ship control centre. In the mentioned circular 982 appendix 2 are contemplated the proposed equipment for the working stations together with MSC/Circ. 603 and 1993 annex and rule ISO 14612.

The information presentation is covered by IMO resolution A.694(17) and ruled by the IEC through the standards IEC 60945 rev.4, IEC 60936, IEC 60872 and IEC 61174.

Automation of on board observations has advanced greatly due to the use of personal computers and satellite communications. Computer programmes are specific and they facilitate, among others:

1. Calculation of true wind, sea level pressure and dew point
2. Verification of data comparing observations with extreme weather, among others.
3. Storage of observations in a code and preparation
for transmission.
4. Format the observations and storage or transmission to a shore station via satellite.

The meteorological stations on a completely automated ship might lack appropriate positioning of the sensors particularly related to wind and dew point measurements. However the optimal position of the sensors would mean a remote connection to the bridge that could be solved through a client/server radio link. Equipment for automatic measurement of visibility, current weather, clouds and wave height cannot be placed in a confined space.

V. USED METHODOLOGY FOR CRITERIA SELECTION

It was intended to board every wide module as feed by a series of homogeneous directives and criteria, starting from the more generic rules and limitations to the more specific ones, related with the working station containing the proposed meteorological and oceanographic presentation system.

Those proposed modules are described below:
1) Actual and future related regulations and normative: Providing some criteria and limitations, to be followed at risk of invalidating the proposed design, because those are compulsory.
2) Study of the technical possibilities: It would propose some technical criteria that will afford to deduct the existing possibilities. Also it would afford to see future technical improvements to be applied in the system.
3) Analysis of the operational needs: It would provide some operational criteria, depending on the normal tasks carried out by the crew. In a more specific stage it will provide different operational scenarios depending on the ship’s type and traffic.
4) Ergonomic criteria study: Based on the optimal interaction between the user and the machine, it is possible to obtain some ergonomic criteria to be elevated as proposals and to be respected if considered as compulsory.

VI. THE ERGONOMIC INTEGRATION OF THE INFORMATION WITHIN THE ISC

Few years ago, we have seen a wide revolution on board, in technological terms. In fact we can find advances in computers fitting processors doubling its working speed, every 12 months or the example of the TFT screens, what it can confirm that in a near future would be possible to adopt on board ships those new concepts as:
1) Better resolution of Radar equipment, making an easier and safer navigation in heavy traffic and poor visibility areas, rivers or port entries.
2) Expert systems as an aid to navigation and a tool for decision making, by the navigator.
3) Manoeuvring consoles operated through a joystick, controlling not only rudder but also engines.
4) The graphics processing permitting the overlapping of different information layers as could be the Radar or Automated Radar Plotting Aid (ARPA) images, electronic charts targets, buoys and marks.
5) The overlapping of a meteorological information layer affording a safer and quicker track calculation over an Electronic Chart Display System (ECDIS).

The solutions proposed by the market relay on the systems integration, with which it is possible to increase the Ship Control Centres technical reliability, and in parallel with a human intervention reduction on it. By means of an automatic rationalisation and information transmission from every specific sensor and the function concentration in the working place, it is possible to reduce the possibility of human error incidence through a reduction of the working load. Also the safety of navigation is improved because the redundancy implied in a superior number of processors and screens, affording a fast change from one not working correctly to another. However and independently from the equipment quality, reliability and the own system, the human presence is not superseded in the navigation bridge.

The tendency adopted some years ago is the progressive approximation of the SCC to the trans-oceanic planes flying cabins as the Boeing 747, A340 or related, where a more compact cockpit organisation exists for getting all the information needed for the navigation, with no need for moving from the seat, as it also occurs in high technology ships as fast vessels or fast rescue boats.

The information presentation on screens, is better provided through a unique monitor, for easing the integration, concentration and information tracing, reducing although the lack of integration of any component [11]. Also the future seems to be addressed to integrate the engine controls within the software by means of keyboard and mouse or tactile screens. However the rudder might maintain its physical format, similar to a joystick.

Thus the main trends dealing with integration, from a technical point of view in a navigation bridge, are:
1) Reduction in the number of consoles.
2) Reduction in the wiring and installation cost.
3) Reduction in design time.
4) Reduction of electrical connections.

This situation is leading to a commercially more viable design because a reduction of the discussions among the owner, the manufacturer and the yard. And also because of the pass from the bridge operation through an officer and a helmsman, to a one officer only on watch, adding the engine supervision when the engine room is unattended.

The criteria to be used nowadays for better solve this situation in the bridge, are based on an ergonomic design in order to be operated by only one officer during long periods of time. It should provide a clear and fast access to all the needed information, and an automatic release of alarms for safety purposes in case of a ship system failure or a human lack of attention.

The ergonomic criteria should be the point of start in the
planning work station design, because its application means to work in a friendly environment for the crew, what means to be working in a comfortable way. Then, in a first view has been considered as a not very important factor, but later and looking to the persons, being of deep consequences because the additional working loads on the officer. Because the long periods passed during the watch, a possible loss of attention, and the stress that it would produce during compromised situations.

So, this approach leads us to consider the working environment and a proper level of operator versus machine interface. Legislation, work load and attention level, as well as human capacity with all its limitations are all questions that must be addressed, together with the impact of the device on bridge team and work organization [12].

VII. VALIDATION AND VERIFICATION

Such a kind of system should be checked on board a ship developing a real track. As a first exam, the legal criteria should be in compliance with the latest international legislation endorsed by the IMO, ISO and IEC, and taking the best solutions proved in other areas.

Further considerations conduct us to the point that the objective of the ship’s master is to safely carry the ship and the cargo to the port of destination. This requirement brings to the need of precise information mainly regarding the weather but also with the ship’s stability and her reactions and loose of speed in front of heavy weather episodes.

Within the work taken as basis for this paper, it was made an exhaustive study comparing the different distances needed for a specific ship by means of a recursive algorithm divided in different steps from the port of origin [13].

In 1974, the Shipbuilding Institute of Hamburg University [14], published a related software and the Delft University of Technology, also developed a method for predicting the speed loose depending on the ship’s power, propeller torque and parasite movements due to waves.

The dynamic programming was developed at first by Bellman in 1957, further updated in 1962 and used by different authors as Motte [15] in 1988, where all the steps are conducted with the objective of the final optimality, considering each step [16] as one different isochrone. The movement between two points is obtained by the integration of the ship and environmental data, affected by the limitations suffered in the vessel movements and getting the optimal track by means of the system.

In fact the track calculation procedure affords us with various possibilities as the following ones:

1) The calculation of the variations, using the ship’s speed for obtaining the total time [17].
2) The method known as the heuristic, very similar to the Isochrones, but graphically not fully solved [18].
3) The Isochrones method in itself, initially proposed by James in 1957, as a manual method for solving the optimal track problems.


In the last years there are companies dedicated to produce accurate weather reports in specific areas, transmitting those reports together with recommendations to the master of the ships. Those systems known as weather routing systems, have been possible due to the technology advancements and are a valuable support.

It is possible to obtain different information packages [20] rated to prices from 700 $ (near 600 €) per voyage to ten times more expensive software packages aboard, affording interaction between the ship and the service provider.

A cheaper option, at least considering the ship’s time life, would be getting a proper weather station onboard that only is going to pay a certain cost when receiving weather information by means of satellite communication channels.

The reason for spending money to get only weather information is that, in fact, the weather, as has been mentioned before, could be a powerful factor affecting the ship’s safety not only because the risk of structural damages or the loose of stability but also because the crew could be much more tired sooner, and statistically, this means more accidents.

A. Planning the voyage

The planning procedure needs the following tools:

1) Information and documents related to the factors affecting the ship’s speed as the curves stating the speed for each wave period, highness and angle on the hull.
2) Ship’s hull block coefficient and surfaces exposed to the wind and seas.
3) Ship’s structure particulars and kind of cargo. Total surfaces exposed to the wind and waves.
4) Eventually, maximum sheering stresses and bending moments curves.

The models studying the ship’s performances are based mostly on the log book notes and further drawing the relationship between speed and wave highness and angle of incidence. From those experiences it has been possible to predict the certain ships’ type speeds based on coefficients proposed as the ones by Aertssen & Townsin [21].

A good example of wide spectra of information covering, are the algorithms proposed by Babbedge [22], that consider also the ship’s engine output and displacement. The basic expression giving the ship speed is:

\[ V_{ship} = V_{calm} – \text{(wave factor)} – \text{(wind factor)} \] (1)

Some private optimisation track services have used algorithms taking as a starting point this expression.

In our example we have considered shipping from Europe to America, the theoretical model ship’s speed affected by the sea currents, waves and wind, using the proposed formula of Krasiuk [23] This formula has proved valid for ships between
20 and 20,000 tonnes and speeds between 8 and 20 knots, and properly modified for larger vessels as the DART ATLANTIC, a container carrier from OOCL, with 37369 tones and 218 metres of length, is:

$$V = V_0 - (0.745 \cdot \theta_h \cdot h) \cdot (1.0 - 1.35 \cdot 10^{-6} \cdot D \cdot V_0)$$  \hspace{1cm} (2)

Where $D$ is ship’s displacement, $V$ the final ship’s speed, $V_0$ the ship’s speed in calm waters, $h$ the significant wave highness and $\theta_h$ the wave angle of incidence in radians taking the breast as point zero of the relative bearing.

It was possible, after knowing the wave direction and highness together with the ship’s particulars, to calculate the real speed in her own course point, being useful data for a final report on the trip guide and providing a data base answering the ship’s speed loose depending on the wave and wind conditions.

The planning procedure in the developed system, after look at the weather situation, calculates the track. This track should avoid as much as possible the worst wave and wind conditions for getting the less ship’s motion and best power efficiency. The proposed track is determined, as first approach, as a weighted average of tracks from great circle and better weather gradient. Then the decision for altering the course depends on the capacity for avoiding heavy weather situations, based on the weather data provision in advance.

### TABLE I

**Detail of the Great Circle Waypoints and Distances between Them**

<table>
<thead>
<tr>
<th>Longitude</th>
<th>Latitude</th>
<th>Distance</th>
<th>Navigation time at 17 knots</th>
</tr>
</thead>
<tbody>
<tr>
<td>008° 50'W</td>
<td>42° 14'N</td>
<td>515'23&quot;</td>
<td>1d 06h 18 m</td>
</tr>
<tr>
<td>020° 00'W</td>
<td>45° 09,6'N</td>
<td>427'56&quot;</td>
<td>1d 01h 09 m</td>
</tr>
<tr>
<td>030° 00'W</td>
<td>46° 41,6'N</td>
<td>410'85&quot;</td>
<td>24h 09 minutes</td>
</tr>
<tr>
<td>040° 00'W</td>
<td>47° 18,5'N</td>
<td>407'96&quot;</td>
<td>24h 00 minutes</td>
</tr>
<tr>
<td>050° 00'W</td>
<td>47° 02,9'N</td>
<td>418'78&quot;</td>
<td>24h 38 minutes</td>
</tr>
<tr>
<td>060° 00'W</td>
<td>45° 53,6'N</td>
<td>524'68&quot;</td>
<td>1d 06h 52 m</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2,678'</td>
<td>6d 21h 49 m</td>
<td></td>
</tr>
</tbody>
</table>

This information was processed and displayed to the officer on watch in the proposed weather station, affording him to take a decision.

The track following a great circle, has been calculated at an average effective speed of 17 knots, because we have considered the effect of the real weather (rougher seas), and the Gulf Stream, directly received to the bow.

### TABLE II

**Detail of the Calculated Track and Distances between the Selected Waypoints**

<table>
<thead>
<tr>
<th>Longitude</th>
<th>Latitude</th>
<th>Distance</th>
<th>Ship’s speed</th>
<th>Navigation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>008° 50'W</td>
<td>42° 14'N</td>
<td>454'56&quot;</td>
<td>18,94 kn</td>
<td>24 hours</td>
</tr>
<tr>
<td>018° 21,7'W</td>
<td>45° 26,1'N</td>
<td>76,88&quot;</td>
<td>18,14 kn</td>
<td>04h 07,5 m</td>
</tr>
</tbody>
</table>

030° 00,0’W  46° 00,0’N  416,80’   18,14 kn  22h 58,6 m  
040° 00,0’W  46° 00,0’N  421,00’   17 kn   24h 46 m  
050° 00,0’W  42° 33,9’N  480,90’   19,44 kn  25h 07,5 m  
057° 25,8’W  42° 00,0’N  331,30’   17,35 kn  19h 05,7 m  
060° 00,3’W  40° 07,0’N  159,8’    13,31kn  12 hours  
064° 31,8’W  40° 19,3’N  207’      17,35 kn  12 hours  
069° 30,0’W  40° 35,0’N  295,24’   18,30 kn  15h 42,3 m  
TOTAL  2,843,5  6d 15h 42 m

Fig. 1. Chart with the first track. Source of chart NOAA US Government.

Fig. 2. Image simulating the different tracks. Continuous line, great circle.

### VIII. CONCLUSIONS

The solution proposed for the availability of meteorological information, is mostly keeping in mind the recent incorporation of a weather overlay on the ECDIS screens that has been an advance for the final weather fax data in the integrated information available on the bridge of high level competition sailing ships. It is the combined forecasting based from the shore services charts and modified when needed by the ship observations. If the information acquired by a ship can be incorporated to its own consoles and is added to the synoptic situation, even this data could be transmitted to all ships close by through VHF over AIS data protocol packet transmission. Thus a “real-time” vision of the weather situation “here-and-now” would be real aid to navigation.

The data presentation on the screen should be made by
means of standardised colours, symbols and icons; easily understood by the user and supported by the international organisations and governments. In fact the displaying criteria in a screen should be coincident with all the other working stations; for example, data physical position, colours and size; should be the same in all screens in the bridge.

The text data and the variables should be compliant with S.52 and S.57 standards, to afford the overlapping of data. In fact the geo-referentiation of that information in a chart is what gives value to the system, because the officer can quickly understand the synoptic context in which the ship is immersed.

Another functionality from the integration point of view, is the data exchange between some different working stations, and other different working stations in the bridge. This is another reason justifying the need for standardised protocols and languages, among the different working stations. As a general criterion, the used language should be at least the NMEA 0183, due to be the most used on board the ships’ bridge.

Comparing the two tables, the ship, apart of not be sailing at higher latitudes with the risk of ice conditions and worst weather, has arrived around 6 hours before. But with a better planning in advance of the track (longer reliable forecast and larger computer work), even better results might be achieved. The consequent fuel consumption reduction, suffering less stresses on the ship’s hull, and less fatigue of the crew, should be kept in mind.

The economic trends are pointing to much larger ships with a capacity of around 12,000 containers and then a larger exposed surface to bad weather conditions and with relatively similar results in terms of consumption and sailing time.

The display on board the bridge affords a tactically good justified track that, at least once per day, would be sent to the owners’ office as all the masters do as proof of their position.

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[7] In Spain it is endorsed in the Spanish Official Digest (BOE) from 20-5-2003. From 1998 he is lecturer at the Faculty of Nautical Studies of Barcelona. He joined the university after being sailed in Danish chemical tankers. He is secretary of department and member of the Spanish Institute of Navigation Catalan Meteorological Association and regional government examiner for pleasure yacht licenses.

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