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Comparison of ship performance optimization systems and the bon voyage onboard routing system

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Abstract

A significant increase in demand for navigation support systems called Onboard Routing Systems (ORS) can be observed in the World's merchant fleet. ORS is a navigation-support system that enables route programming to warn of dangers and navigation constraints and determine the required route-safety level directly onboard the vessel. In this article, an attempt to analyze and compare two ORS systems has been made: the Ship Performance Optimization System (SPOS), by the Meteo Consult Group; and the Bon Voyage system by Applied Weather Technologies (AWT). Individual items, methods, and criteria of both systems for optimization and weather forecasting models utilized have been compared. Particular attention has been paid to the usefulness of the systems regarding the problem of identification and avoidance of hazards such as tropical cyclones and wave resonance. Ergonomics of both systems has also been compared.

Introduction

Vessel safety and the economic results of a voyage depend on many factors. One such factor is undoubtedly the way in which the ocean voyage of a ship is planned and executed – that is, the optimization of the ocean route according to a given criterion (e.g. the minimal time en route, minimal voyage cost, fixed voyage time) keeping a required safety level. In this article, a comparative analysis of two onboard tools (ORS – onboard routing systems) serving that purpose have been made. They are the Ship Performance Optimization System (SPOS) by the Meteo Consult Group and the Bon Voyage System by Applied Weather Technologies (AWT) (Meteo Consult BV, 2009; Applied Weather Technologies, 2014).

Description of weather data

In both systems, weather data are received onboard as a compressed weather file containing all weather information, prognosis, and analysis. Their decoding and reading are only possible with the use of the dedicated, weather-optimization, software tools.

Users of the SPOS system have a choice of ocean and coastal regions for which the weather data will be received. There are 7 ocean regions (North Atlantic, South Atlantic, Indian Ocean, North Pacific, South Pacific, Arctic Region, and Antarctic Region) and 6 coastal regions (European, North American, South American, African, Asian, and Australasian). Another division and choice of sub-regions in each of the coastal regions are available. Weather data can be ordered for a maximum of 4 ocean or coastal regions in a standard or extended format for 3, 5, or 9 days and in low or high resolution. Weather data for coastal regions is available for only 5 days. Weather files are not ship-specific; they can be decoded and read on any SPOS system application (Wiśniewski, Wielgosz & Korwin-Piotrowski, 2012; Applied Weather Technologies, 2014).

In the Bon Voyage system, the user can freely determine the geographical borders of the region for which the weather data will be received by defining its geographical latitudes and longitudes. Weather data, together with the types of required weather elements, can be ordered for a period of 1 to 16 days. Irrespectively of the user's preferences, information on the pressure, fronts, tropical systems, and icebergs are always included (Applied Weather Technologies, 2014). Weather files are ship-specific; it is only possible to read them on a system dedicated for the use on a specific ship (Applied Weather Technologies, 2014).

A comparison of the SPOS and Bon Voyage systems regarding the aspect of accessible weather data is presented in Table 1. Mark "e" at the mark "X" in a column for SPOS system means that a given weather element is available in an extended format.

A received weather file has to be uploaded in the route optimization software. In the SPOS system, it is done by copying the file into a defined catalogue on a hard drive and then updating the weather in the software. The system will upload the latest-by-date weather file available in the default catalogue. In the Bon Voyage system, it is only necessary to double-click the received weather file to upload the file into the system and update the data.

The size of the weather file depends on the amount and type of weather data contained in it. A weather file for a sample route has been comprised in both systems to compare the size of such a file. The sample route was from Vancouver to Pusan along the great circle line through the Bering Sea. Weather

Table 1. Comparison of SPOS and Bon Voyage systems: accessible weather data [authors' findings based on (Meteo Consult BV, 2009; Applied Weather Technologies, 2014)]

Weather element	SPOS	Bon Voyage
Atmospheric pressure	X	X
Troipcal systems	X	X
Fronts	X	X
Wind, direction and velocity	X	X
Significant waves h1/3, direction, height, period	X	X
Swell, direction, height, period	X	X
Seas	X	X
Rogue waves		X
Pressure for 500 hPa level	Xe	X
Weather type	Xe	X
Precipitation	Xe	X
Clouds		X
Air temperature	Xe	X
Sea surface temperature	Xe	X
Visibility	Xe	X
Air humidity		X
Surface current, direction and velocity	X	X
Ice bergs and ice pack	Xe	X
Vessel's icing		X

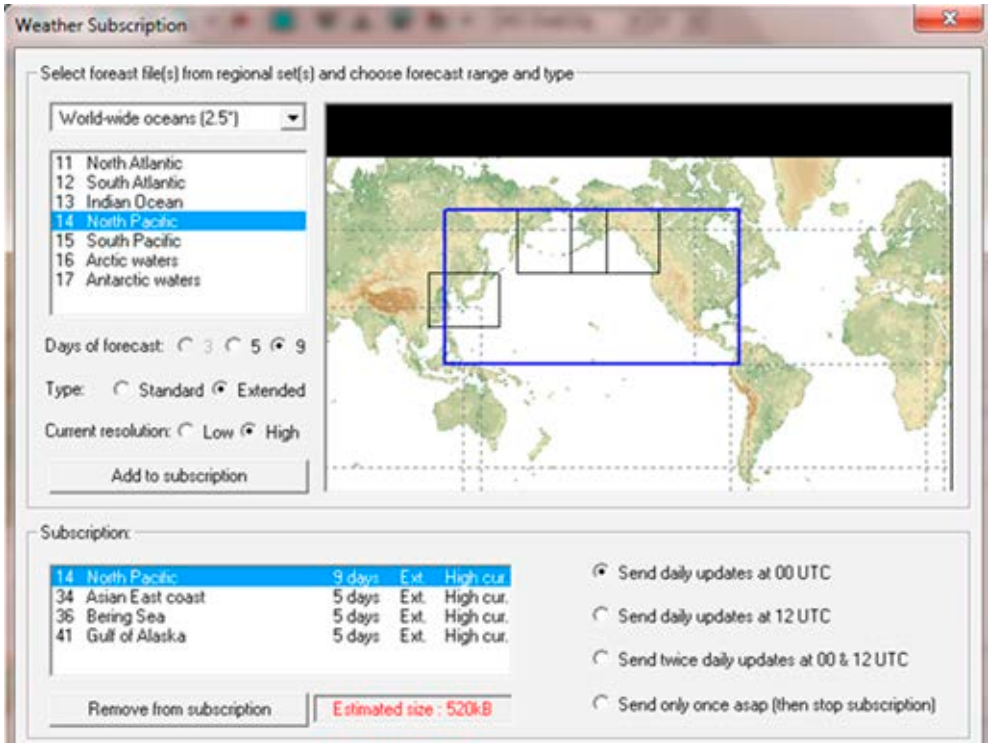

Figure 1. An example of a weather file ordered in the SPOS system for a voyage from Seattle to Pusan (Meteo Consult BV, 2009)

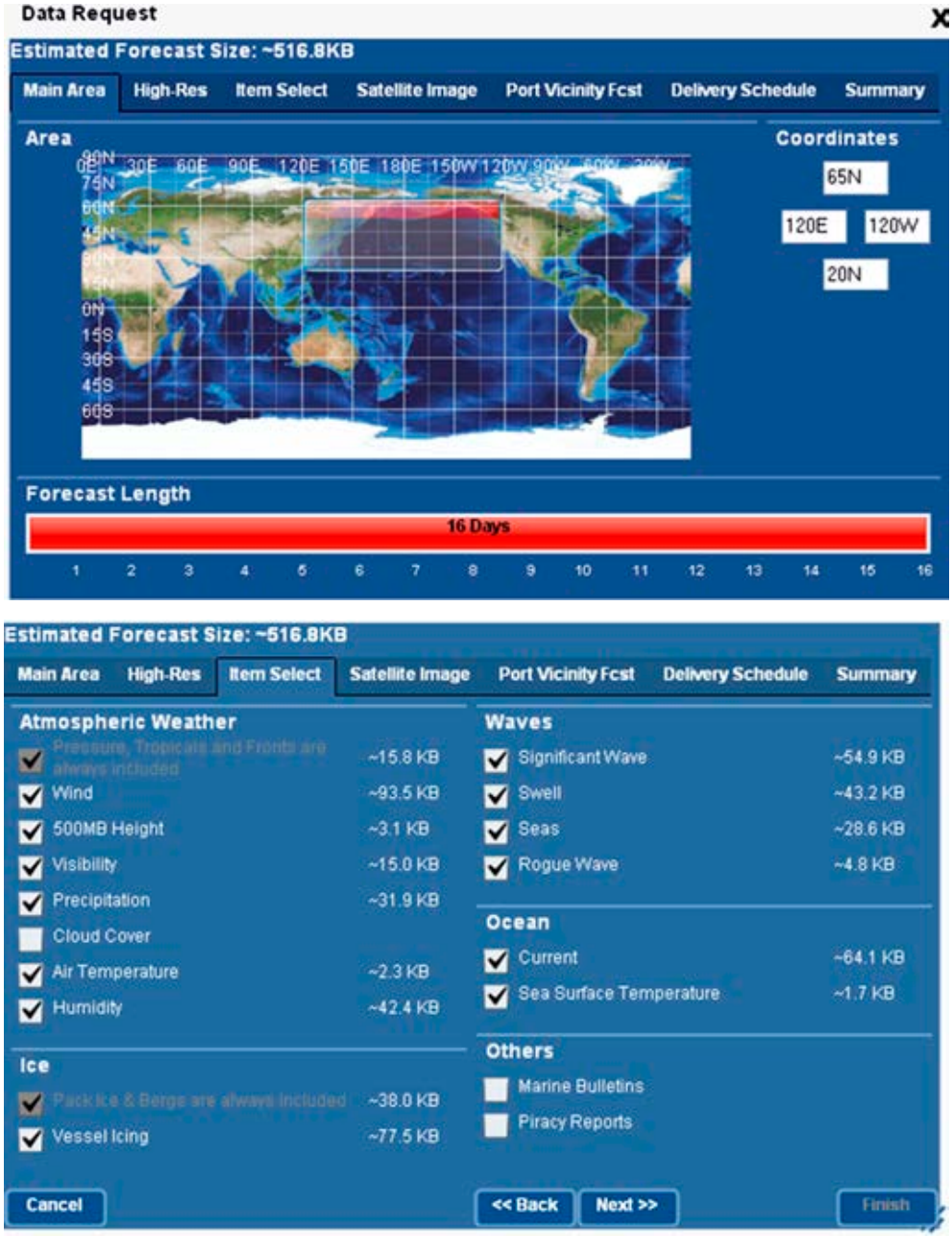

Figure 2. An example of a weather file ordered in the Bon Voyage system for a voyage from Seattle to Pusan (Applied Weather Technologies, 2014)

data and elements in both systems were configured to be as similar as possible. The results are presented in Figures 1 and 2. The sizes of the files are very similar. In the SPOS system, the size of the weather file is 520 kb, and in the Bon Voyage, the file is 517 kb.

Weather simulation in the SPOS system is available for 9 days; past that time, the system uses the climatic data (*Routing Charts*). In the Bon Voyage system, weather simulation is available for 16 days; past that time, weather simulation is not possible. Climatic data are not available in the system.

The difference between the systems is very significant, in particular when the voyage lasts 2 – 3 weeks. With 16 days of weather forecasts in the Bon Voyage system, forecasts for the period from day 10 until day 16 can be regarded as a long-term outlook, which seems to be better than adoption of the middle-term climatic data as is done in the SPOS system.

In both system, their own specific weather-forecasting systems are used, based on various weather models, world, local, and own.

Sources of weather data and weather models of the SPOS system are described in Wiśniewski, Wielgosz, & Korwin-Piotrowski (2012). Reception of the weather data in the SPOS system is possible once or twice daily, at 0000UTC and 1200UTC.

In the Bon Voyage system, weather data are from the following sources (Applied Weather Technologies, 2014):

- Surface barometric pressure and wind, pressure for 500 mbar – NOAA and GFS model;
- Significant waves h1/3, seas and swell – WAVEWATCH III model;
- Weather forecasts and outlooks, tropical cyclone warnings – National Hurricane's Centre, JMA, JTWC and local sources;
- Satellite images – Meteosat, MTSAT&GOES;
- Surface currents – Hycom model for first 4 days of the forecast, then own AWT model;
- Iceberg and icepack info – JMA, National Ice Centre, local sources;
- Sea surface temperature – NCEP/MMAB model, with the use of Real Time Global Sea Surface Temperature High Resolution (RTGSSTHR);
- Air temperature, clouds, air humidity – GFS model;
- Weather type – own AWT model, with the use of GFS data as entry data of their own AWT model;
- Visibility, vessel's icing – NCEP/MMAB model with the use of GFS model data as entry data;
- Rogue waves – own AWT model.

In the Bon Voyage system, weather files are available 4 times daily, at the following times (Applied Weather Technologies, 2014): 0300UTC, 0900UTC, 1500UTC, and 2100UTC. The period of time needed to obtain the weather forecast in relation to the international meteorological times (0000, 0600, 1200, 1800UTC) is 3 hours. Warnings and forecasts regarding tropical systems (cyclones, storms, and depressions) are also available 4 times daily at the following times (Applied Weather Technologies, 2014): 0400UTC, 1000UTC, 1600UTC and 2200UTC.

Both systems fully comply with the requirements of shipping.

Illustration of a weather situation

In both systems, the basic map-view projection is the Mercator projection. Orthographic projection is also available in both systems, and the Bon Voyage system additionally offers a gnomonic projection. ECA zones are presented and taken into consideration in calculations in the Bon Voyage system only; the SPOS system has no such option.

Ergonomics in both systems are comparable; the user menu is intuitive and working with the system does not cause any problems.

The legibility of weather charts in both systems is different; charts in the Bon Voyage system are less legible than those in the SPOS system (e.g., unnecessary port names, too intensive range of colors, unnecessary graphics not related to weather, unclear symbols of weather fronts). Figures 3 and 4 present the same weather situation for the day 26.08.2015 in both systems.

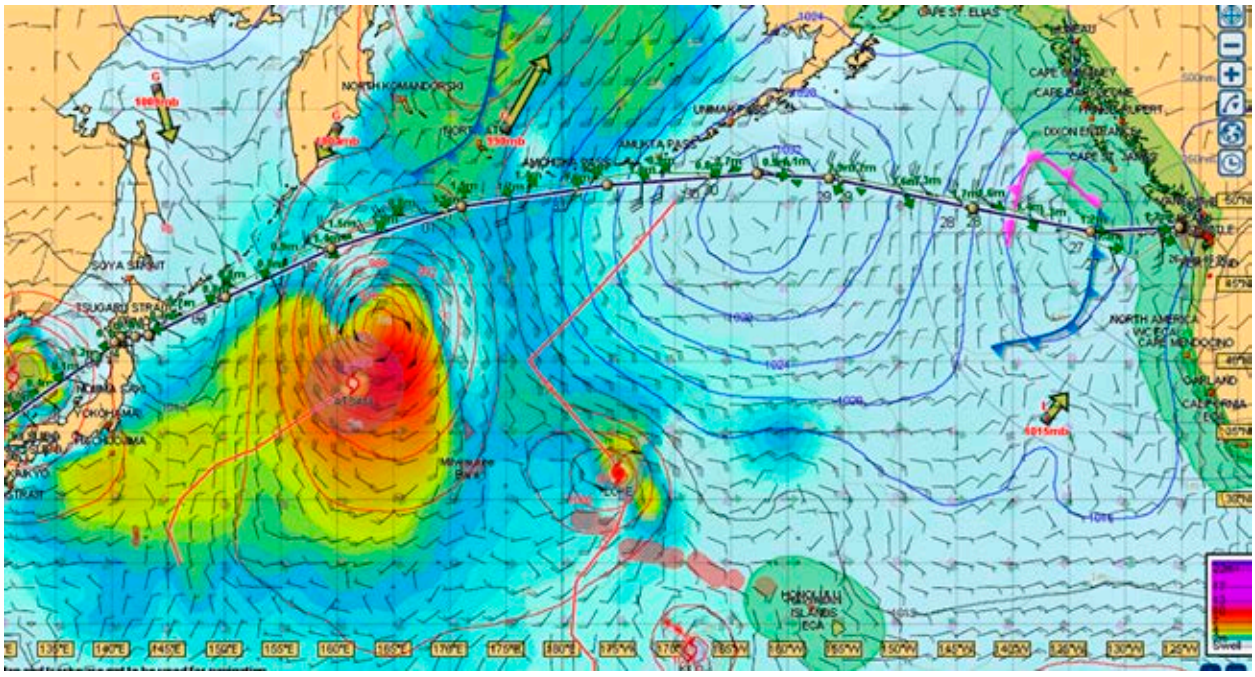

Figure 3. Route Seattle – Pusan optimized in Bon Voyage system, optimization least cost/fuel with fixed arrival time. Weather situation for 26.08.2015 [source: authors' test using the Bon Voyage system]

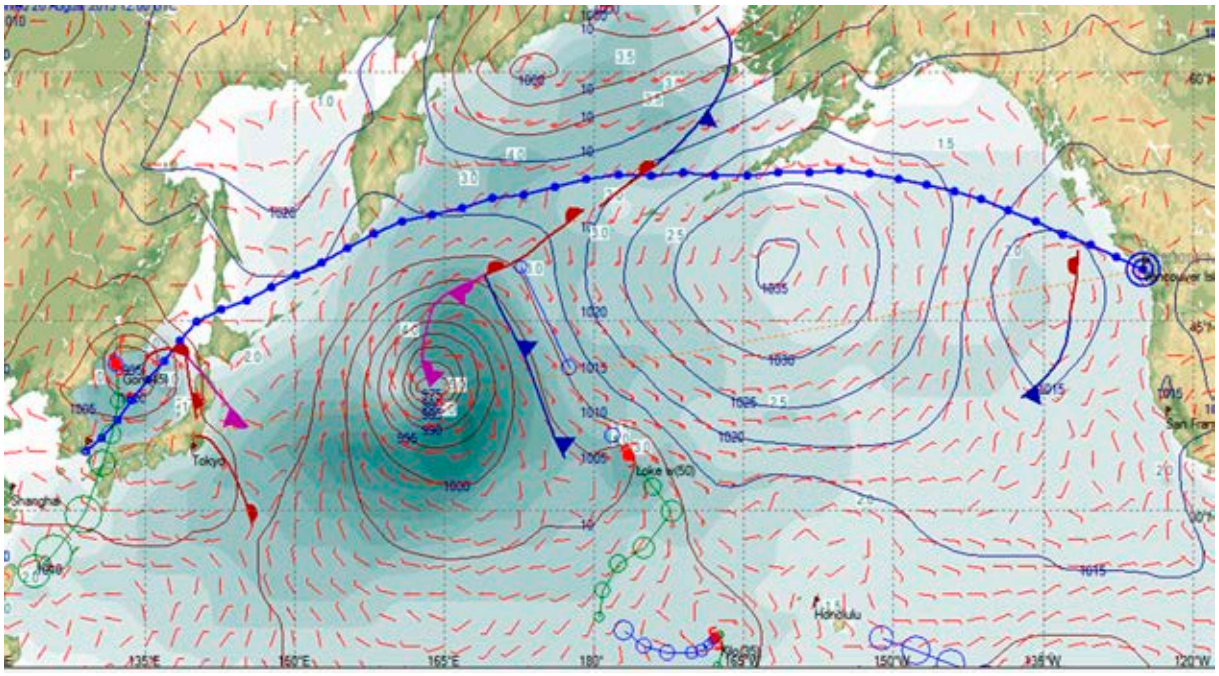

Figure 4. Route Seattle to Pusan optimized in the SPOS system, optimization Optimum High & Wide. Weather situation for 26.08.2015 [source: authors' test using the SPOS system]

There is no option for wide searching of isochrone courses in the Bon Voyage system. Due to this, it was not possible to find the route between the islands of the Kuril Archipelago. In that instance, it is necessary to introduce intermediate waypoints at passes between Kuril Islands.

There is no ECA-zones illustration in the SPOS system. In the Bon Voyage system, ECA zones are taken into consideration by the way of fuel-cost (including two fuel types) calculations in the overall voyage optimization. As a result, the initial waypoints of the great circle in both systems are not the same.

Route optimization – navigational function

In both systems, ocean-routes optimization is performed with the use of the isochrones method. The Bon Voyage system offers 3 modes/criterions of optimization:

1) Minimum time en-route – *least time* – the route will be optimized so as to obtain the minimum time of the voyage.
2) Minimum fuel consumption – *least fuel* – the route will be optimized so as to obtain the minimum fuel consumption during the voyage.
3) Minimum fuel consumption with fixed arrival time – *least fuel with fixed ETA* – the route will be optimized for minimum fuel consumption en-route with a fixed time of arrival at the port of destination.

The least-fuel optimization is, as a matter of fact, a minimal-time-en-route optimization with a given, fixed, calm-sea speed that does not exceed the critical RPM of a ship's main propulsion system. It is not a minimum-fuel-consumption methodology in as described in Wiśniewski (1991).

In the SPOS system, only a minimal time-en-route optimization is available. The calm sea speed must be defined by the user. There are three options for the isochrone-course calculations interval available: 5° (Low), 3° (Medium), and 1° (High). An additional option of „wide searching", in which the interval between searching courses is doubled, is available (Wiśniewski, Wielgosz & Korwin-Piotrowski, 2012). Such diversity in route-searching options enables the user to create a collection of routes to rank them for safety and choose the route that offers the best possible trade-off between the safety of the voyage and the economical and operational results. In the Bon Voyage system, a collection of routes can only be created manually by arduous programming of each route separately.

Beside the method of route programming, the second factor affecting the efficiency of the route optimization process is the speed-down curves – i.e., the ship's speed characteristics on waves and wind. Makers of both systems present a different approach to this subject.

The Bon Voyage system provides the user with a set of default speed-down curves for a variety of different types of ships: bulkers (cape size, handy

size, handymax, panamax, ULOC, VLOC), car carrier, container vessel (feeder, feedermax, small feeder, new panamax, panamax, post panamax, ULCC), fishing vessel, general cargo vessel, OBO carrier, passenger vessel, reefer, roro vessel, chemical carrier, gas boats (LNG, LPG), tankers (aframax, panamax, suezmax, handy size, VLCC, ULCC), sailing yacht, and motor yacht. The library of speed-down curves is spacious and extensive. They consist of a seas speed-down curve and a swell speed-down curve presented in graphical (diagram) and tabular form. They include percentage values of speed that can be achieved by a ship under the given weather conditions (swell and seas, in Beaufort scale and meters, respectively) in relation to ship speed in calm seas as a function of angle of attack by seas and swell. The angle of attack by seas and swell is described as follows:

- Head – head seas/swell;
- FQtr – forward quarter, angle of attack by seas/swell from forward quarter (0°–90°);
- Beam – angle of attack by seas/swell from abeam;
- RQtr – rear quarter, angle of attack by seas/swell from a stern quarter (90°–180°);
- Stern – angle of attack by seas/swell from the stern (180°).

Gradation of the wind force is according to the Beaufort scale, from 0 to 12. Gradation of swell is from 0 to 18 m, in full-meter increments. The default speed-down curves for a postpanamax container vessel are presented in Figure 5.

Boxes in the tables can be edited to enable fine adjustment of the curves to a specific ship. It is, however, not possible to save the edited curves and tabular values.

In the SPOS system, only one default speed-down characteristic is available (Figure 6). It is not possible to edit it but additional speed-down curves, delivered from the owner's office, can be downloaded into the system. They can be edited and saved as necessary by the user onboard.

Speed-down curves and characteristics presented in Figures 5 and 6 are similar. They have been used in a true voyage, which is described further in this paper. Speed-down curves of the Bon Voyage system show a certain shortcoming. Usually, true speed-down curves show a certain gain in speed of the vessel in relation to the speed on the calm seas for seas of 0 to 4 m high for quarter and stern angles of attack (120° to 180°). Such a gain in speed, depending on the type of vessel, can be significant; it amounted to 3% for con-ro ships operated by the Polish Ocean Lines on the North Atlantic in the 1970s and 1980s (Wiśniewski, 1991). Default speed-down curves of the Bon Voyage system do not show such a feature.

The way in which constraints and limitations of the voyage-optimization process are programmed into the system is crucial for the process itself. In both systems, a deterministic approach is used.

Figure 7 presents the weather-constraints programming panel of the Bon Voyage system. Only a possibility to define limit values of seas and swell

Figure 5. Speed-down curves in the Bon Voyage system (Applied Weather Technologies, 2014)

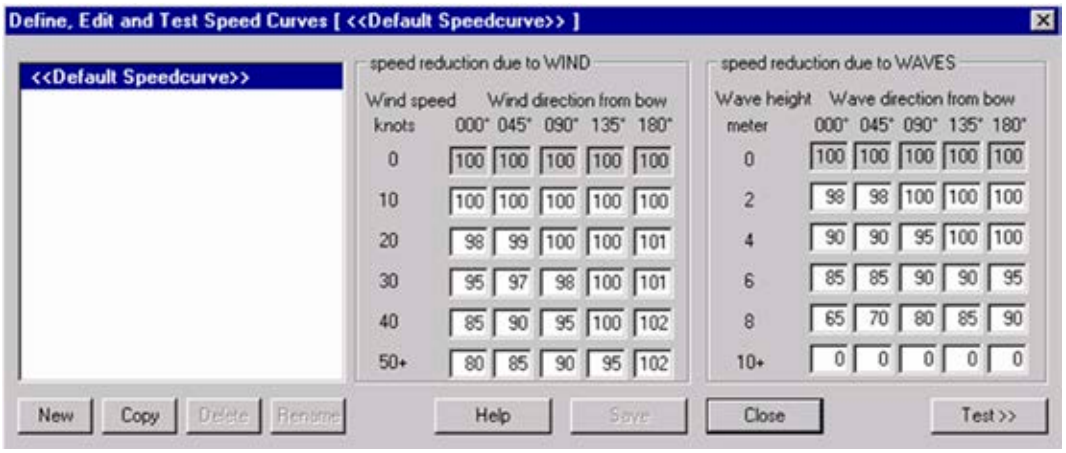

Figure 6. Default speed down curves in the SPOS system (Meteo Consult BV, 2009)

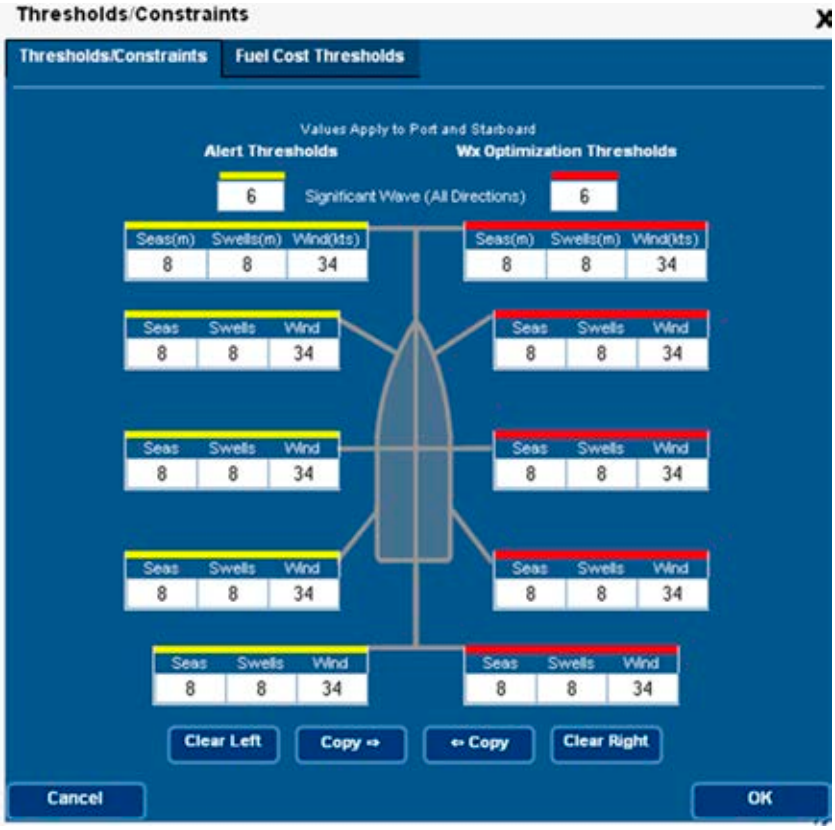

Figure 7. Weather-restriction programming panel in the Bon Voyage system [source: authors' test using the Bon Voyage system]

and wind velocity as a function of angle of attack are available with warning (alert) or avoidance (optimization) options.

In the SPOS system, this issue is solved in a more active way and offers the user more options. The weather-constraints programming panel of the SPOS system is presented in Figure 8. Apart from standard limit values of wind velocity and sea height in the function of angle of attack, the user has other options that significantly increase his or her influence on the voyage-optimization process.

Most importantly, in the SPOS system, the user can define the minimum distance to a tropical system; however, it is not possible to define the rules of avoidance of these systems. Other options include avoidance of bad visibility areas, a vessel's icing risk areas, areas of icepack and icebergs, and vertex – a geographical parallel. The user can also define the critical range of sea and swell heights. All limit values can be declared as to-be-avoided (Avoid – the optimal route will not run through these defined and declared areas) or as a warning only (Warn

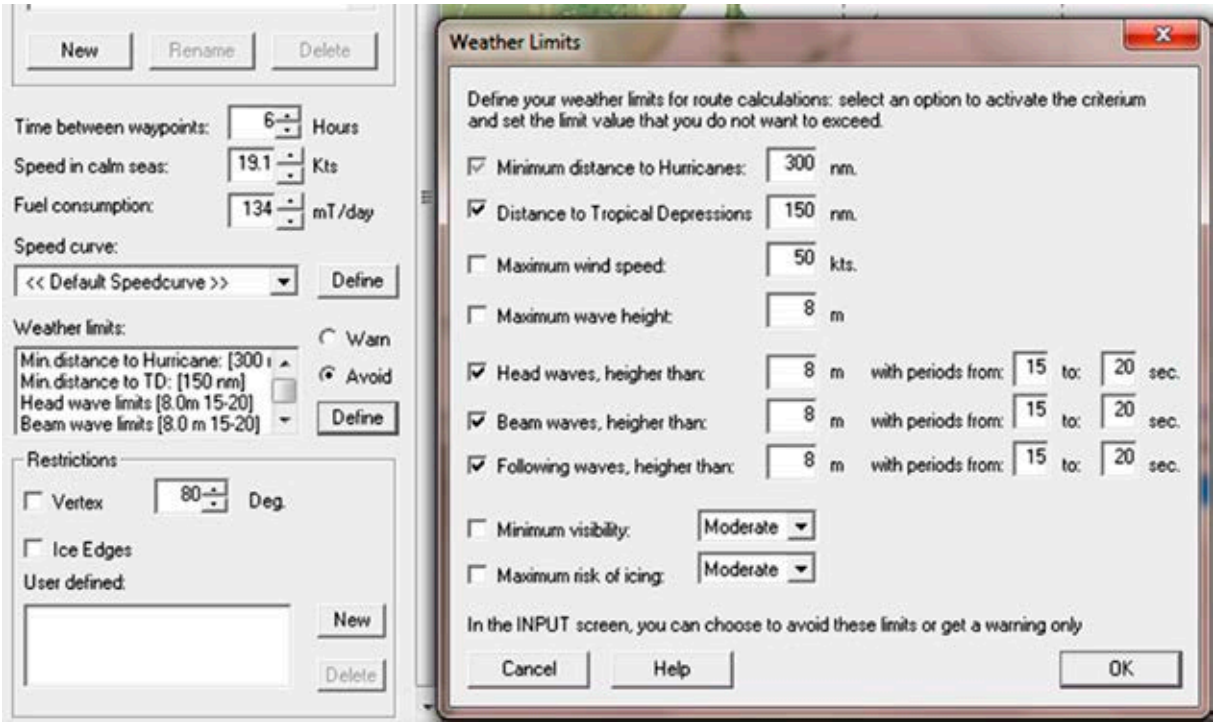

Figure 8. Weather-restrictions programming panel in SPOS system [source: authors' test using the SPOS system]

– the optimal route will lead through these defined and declared areas and the system will display the respective warning for the user).

Illustration of wave resonance

Wave resonance and its influence on a ship's safety during its voyage must be a part of each voyage-optimization process. A very serious shortcoming of the SPOS system is a complete lack of consideration for such information. The system enables only a presentation of a weather situation in the ship's position and cursor's position (Figures 9 and 10). More weather information is available in the cursor's position than in the ship's position, which is also a concern.

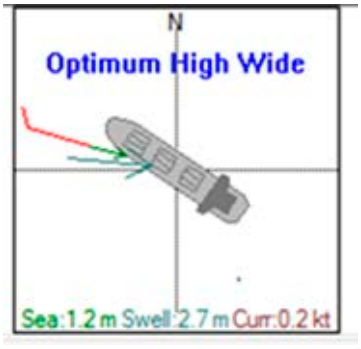

Figure 9. Illustration of weather situation of a ship's position using the SPOS system (Wiśniewski, 1991)

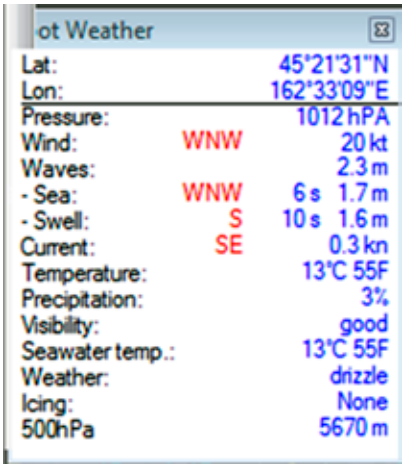

Figure 10. Illustration of a weather situation using cursor positions using the SPOS system (Wiśniewski, 1991)

In the Bon Voyage system, this issue is solved satisfactorily. Wave-resonance-data programming and weather-situation presentation in a ship's position is possible in the panel Snapshot (Figure 11). The following data can be programmed:

- Ship's initial stability (GM – initial metacentric height).
- Ship's roll period, calculated after the insertion of the GM according to the IMO formula. However, it can also be amended according to the available ship's documentation or observations onboard.
- Draught means of means calculated on the basis of the declared forward and after draughts.

- Limit values for 4 types of wave resonance: *Parametric Roll, Synchronous Roll, High Wave,* and *Broaching*.

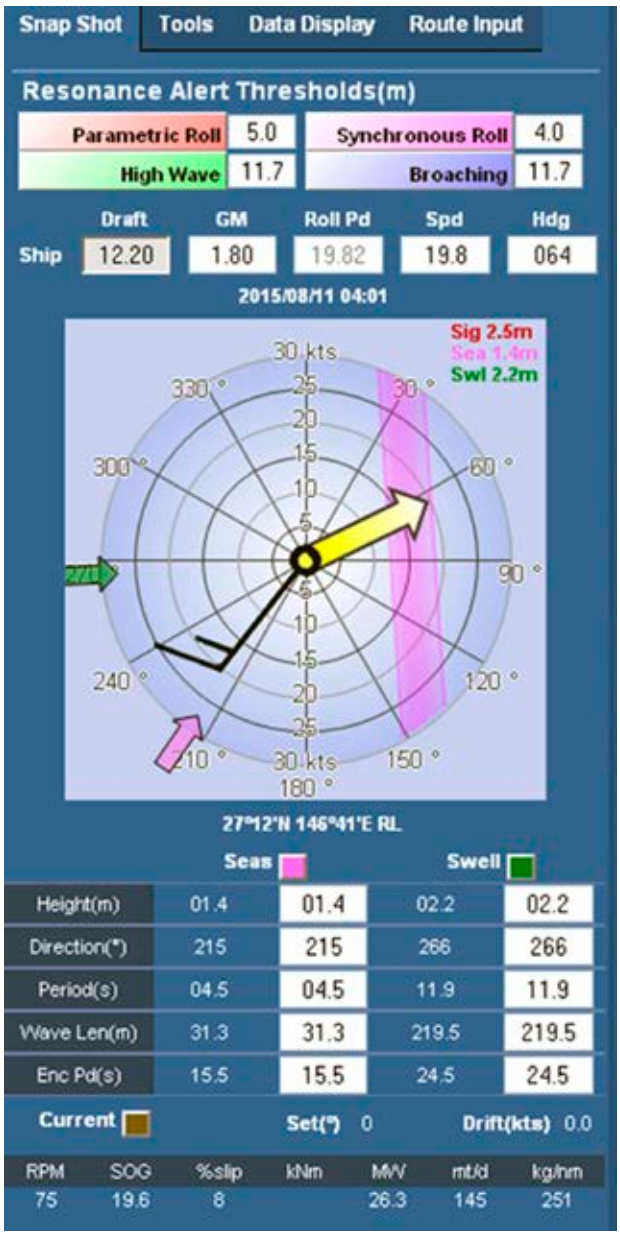

Figure 11. Illustration of wave resonance in the Bon Voyage system (Applied Weather Technologies, 2014)

In case the wave resonance is predicted along the optimized route, the respective alarms will be shown on respective computation points. Detailed information on the risks is available in the Snapshot panel. The system does not optimize the route in such a way as to avoid the areas of wave resonance; such an amendment must be carried out by the user.

The default limit values of the wave resonance that the Bon Voyage system utilizes for its computations are given below. They can, however, be changed, according to the user's preferences.

- *Parametric Roll* – limit values are related to significant wave $h_{1/3}$ by which a phenomenon of a *Parametric Roll* is possible.

LOA – length overall	significant wave limit value
0–124.99 m	3.0 m
125–149.99 m	3.5 m
150–229.99 m	4.0 m
230+	4.5 m

Example: a ship of LOA = 220 m, the correct value is 4.0 m.

- *Synchronous Roll* – limit values are related to significant wave $h_{1/3}$ by which a phenomenon of a *Synchronous Roll* is possible.

LOA – length overall	significant wave limit value
0 – 124.99 m	3.0 m
125 – 149.99 m	3.5 m
150+	4.0 m

Example: a ship of LOA = 140 m the correct value is 3.5 m.

- *High Waves & Broaching* – limit values are related to significant wave $h_{1/3}$ by which a phenomenon of a *High Waves & Broaching* is possible and calculated according the following formulas:
  Significant wave limit value = 0.04 LOA [m] for ships of LOA below 275 m;
  Significant wave limit value = 0.035 LOA [m] for ships of LOA above 275 m.

Fuel consumption on a selected route

An important item for ocean-route optimization of least fuel with fixed arrival time type is the knowledge of a fuel-consumption curie for various speeds of the ship through the water or various RPMs of the ship's main propulsion system.

In the SPOS system, which utilizes the minimum-time-en-route optimization only, fuel consumption is calculated according to the daily consumption rate programmed into the system by the user. Required average speed en-route, according to the required ETA, can only be calculated manually by the user.

In the Bon Voyage system, the user has two types of fuel optimization: least fuel and least fuel with fixed ETA. Fuel consumption is utilized by a declared daily consumption at NCR (Nominal Continuous Rate) and a standard, default, fuel-consumption curie, the same for all available in the system types of vessels (speed-down curves). The system does not offer the possibility to view the fuel curve nor to edit it.

System reports

In both systems, evaluation of the optimized route is done with the use of system reports. Their detailed list and comparison is presented in Table 2.

Table 2. Comparison of elements of a programmed route in system reports from SPOS and Bon Voyage [authors' findings based on references (Meteo Consult BV, 2009; Applied Weather Technologies, 2014)]

Compared item	SPOS (Route Info)	Bon Voyage (Voyage Details)
Waypoint, position, ETA AT waypoint	X	X
Course over ground	X	X
Type of navigation (great circle/rhumb line)		X
Distance between waypoints	X	X
Distance to go		X
Speed over ground	X	X
Calm sea speed	X	X
Type of weather data (forecast/climatic data)	X	
Wind (direction, velocity)	X	X
Significant waves $h_{1/3}$ (direction, height, period)		X
Swell (direction, height, period)	X	X
Seas	X	X
Surface current (direction, velocity)	X	X
Weather and current factor		X
Vessel icing		X
Ice pack and icebergs	X	X
M/E RPM		X
M/E indicated power		X
Daily fuel consumption		X
Average M/E RPM		X
Torque		X
M/E Power		X
Slip		X
Thrust		X
Thrust power		X

In the Bon Voyage system, the user can export the data from the table *Voyage Details* into MS Excel for further processing; there is no such option in the SPOS system.

In the SPOS system, an additional table of weather situations on a created route is available (*Comparison Wx*). It includes the following:

- Route name;
- Type of optimization;
- ETA;
- Average and maximum wind velocity en-route;
- Number of hours with wind velocity exceeding 34 kts;
- Average and maximum wave height;
- Number of hours en-route with wave height exceeding 4 m and 8 m; and
- Influence of the surface current on the speed over ground.

Conclusions

Both ocean-voyage planning and programming systems compared in this article, the SPOS system from the Meteo Consult Group and the Bon Voyage system from AWT, meet the requirements of shipping in terms of weather-navigation safety as stipulated in the respective chapters and rules of the SOLAS and STCW conventions. They can be used as a decision-making-support tool in the process of planning and programming of a ship's ocean route.

The approach to the optimization process in both systems is different and emphasis on route-programming process is placed differently in each system. Route-planning-and-programming tools in both systems seem to be designed for two different systems of ship operations. For the SPOS system, emphasis is placed on the navigational aspects of the voyage, weather navigation safety considerations, and achievement of the most-accurate navigational results when determining the minimal-time route. It has also been designed to solve the problem of time optimization of the voyage, and seems to be best suited to the needs of irregular, tramp shipping, in particular for ships under charter. Comparatively, the Bon Voyage system has priorities placed on the economical and operational issues of shipping and hence will find more applications in regular, liner trade.

Both systems are route-optimization tools using the isochrone method; however, there are significant differences in both systems in terms of weather information, file size, procedure of creating the route population, and their ranking in the aspect of navigation safety, limitations, and restrictions definition and route evaluation in system reports, etc.

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