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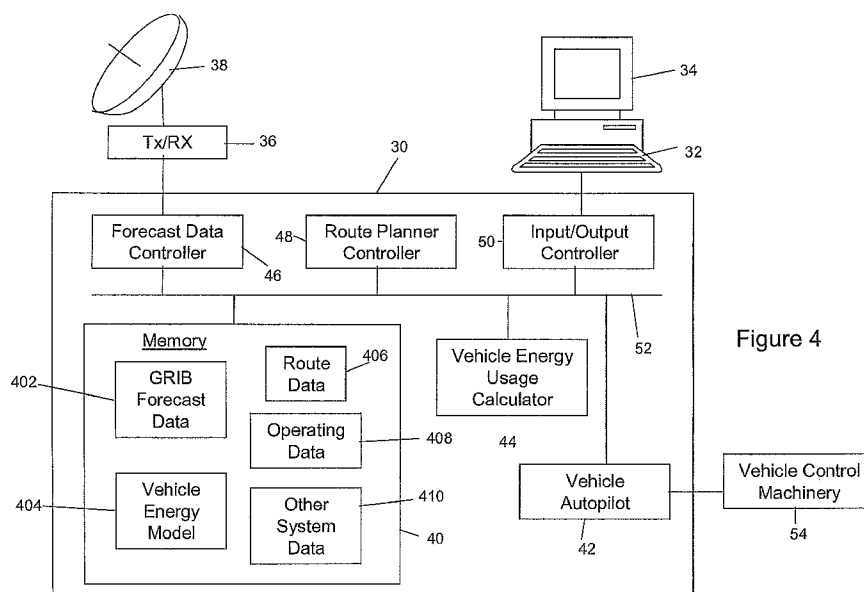(54) **Title:** ROUTE SELECTING METHOD AND APPARATUS

Figure 4

(57) **Abstract:** The invention relates to a route selecting method and apparatus for a vehicle which makes use of information relating to environmental conditions across a geographical region which the vehicle must traverse, so as to select a route from a starting position within the geographical region to a destination position within the geographical region. More particularly, by having regard to the characteristics of the vehicle with respect to external environmental parameters, embodiments of the invention are able to plot a route across the geographic region which, when taking into account actual and forecast environmental conditions across the region, minimises fuel usage, and thereby maximises energy efficiency.

Route Selecting Method and Apparatus

<u>Technical Field</u>

5   The present invention relates to a method and apparatus for selecting a route for a
vehicle, and in particular to such a method and apparatus which selects a route for a
vehicle taking into account environmental conditions along the plotted route, the route
being chosen so as to improve fuel efficiency.

10   <u>Background to the Present Invention and Prior Art</u>

It is known that relatively accurate weather data and other environmental conditions,
together with forecast conditions is readily available, generated by various national
meteorological offices around the world. Typically, such meteorological offices will use
15   computer weather models, to generate computerised forecast data across a region.

In order to allow the easy exchange of weather forecast data, the World Meteorological
Organisation has developed a data exchange format, designated FM 92, and referred to
as GRIB (GRIdded Binary). GRIB is an efficient format for transmitting large volumes of
20   gridded data, using modern communications protocols. In particular, a GRIB data file
will typically provide, for a particular region, weather forecast data at locations across
the region, providing, for each location, a number of parameters. Example parameters
which can be included for each location include parameters such as pressure,
temperature, height, wind speed, wind direction, current speed and current direction,
25   cloud cover (expressed as a percentage), ice concentration and thickness, as well as
various parameters relating to sea conditions. In particular, in this latter category, GRIB
data can include the significant height of combined wind waves and swell, the direction
of wind waves, the significant height of wind waves, as well as their mean period, the
direction and significant height of swell waves, as well as their mean period, as well as
30   information relating to primary and secondary wave directions and periods. Further
information on the GRIB data format can be obtained from the World Meteorological
Organisation website, and in particular, at the following URL:
<u>www.wmo.ch/web/www/wdm/guides/guide-binary-2.html</u>

35   GRIB data is available from several sources, and is amenable to being transmitted using
any modern communications protocol. Thus, therefore, it can be transmitted using
commercial satellite links for example to ships, aircraft, or other vehicles which are in
remote locations, and it can also be transmitted using internet technologies, such as
Internet Protocol. For example, GRIB data generated by the Untied States National

Oceanic and Atmospheric Administration (NOAA) is available from the URL www.grib.us, for any region of the world.

GRIB data is coded, and subject to data packing techniques, and hence is not
5   immediately human readable, for example as a text file. However, GRIB data is readily machine readable, and can be interpreted by GRIB viewing software, so as to produce a weather plot at a present time, and forecast weather plots up to seven days in the future. Typically, GRIB data is available at a resolution of half a degree, that is, a set of parameters relating to the environmental conditions at a location are available for each
10   location across an area at half degree intervals of both latitude and longitude. When interpreted by appropriate viewer software, GRIB data can be used to present to a user a weather map. An example illustration of a GRIB file is shown in Figure 1. Here, it can be seen that a weather plot of the North Eastern Atlantic region extending across the Greenland-Iceland-UK gap is shown. The GRIB weather data 10 can be seen as
15   illustrating isobars across the region, with an indication, at each location, of wind direction, and wind speed. In this respect, Figure 1 is a black and white print out of what would otherwise be a colour plot, with wind speed indicated by the colour and length of the arrow at each location, and direction indicated by the direction in which the arrow is pointing. Due to the number of data points shown in the region of Figure 1,
20   each wind plot is not shown particularly clearly; Figure 8, for example, illustrates the wind markings more clearly.

From Figure 1 it becomes clear that across a region, given that weather data is available with half a degree resolution, a relatively well resolved picture of environmental
25   conditions across the region is obtained. Moreover, although not shown in the view illustrated in Figure 1, for each location for which data points are available, many environmental condition parameters are obtained from the GRIB file, such as, for example, sea conditions, in addition to wind direction and speed. Moreover, also as mentioned, each GRIB file will typically contain a forecast of environmental conditions at
30   each location across the region at, for example, three or six hour intervals, for the next five to seven days. The GRIB data format therefore conveniently presents machine readable weather and environmental condition parameter data over a significant period of time.

35   As is well known, in order for a vehicle to travel from a starting position A to a destination position B then typically fuel will be required to power the vessel to perform such a journey. For example, consider a vehicle such as a ship 20, shown in Figure 2. Here, in order to undertake a journey from position A to position B, then fuel will be

necessary to power the prolpulsion plant 27 of the ship, in order to propel the ship through the water. At the same time, it will be necessary to power internal systems of the ship, for example, to provide heating and lighting for the crew, via a power plant 26, to power various machinery 28, such as cranes, ballast pumps etc. necessary to

5   maintain the operation of the ship, and, in some cases, depending on the ship's cargo, to maintain refrigeration of the ship's cargo, via a refrigeration plant 29. Each of these elements 26 to 29 requires energy, which energy is usually obtained by using additional fuel.

10   For a vehicle such as a ship, however, the amount of fuel which is used in traversing a region from point A to point B is also dependent upon the external characteristics of the vehicle, such as the hull characteristics, and the superstructure characteristics, in combination with environmental conditions across the region which is being traversed. For example, in the case of a ship, the hull characteristics determine how efficiently the

15   hull travels through the water, in different sea conditions. For example, given a particular hull with known characteristics, it may take more fuel for a ship to travel the same distance from A to B in a relatively heavy sea with large wave heights, and where the wave direction is against the direction of travel of the ship, than in a calm sea with relatively small wave heights, or where the wave direction is coincident with that of the

20   ship. Moreover, ocean currents will also have an affect on the speed of travel, and hence the amount of fuel that is used by a ship crossing a region of ocean from point to point. If, for example, the direction of flow of local ocean current is against the direction of travel of the ship, then it will be more difficult for the ship to move in the intended direction of travel, and more fuel will be used. Conversely, where the flow of current is

25   with the direction of travel of the ship, then the ship will be assisted by the current and less fuel will be used.

Similarly, the superstructure characteristics of the ship will also impact on fuel usage, and in particular in dependence on wind speed and direction. In particular, the

30   superstructure 24 will present a drag characteristic to any wind which impinges thereon, and hence depending on the relative direction of the wind and travel of the ship either more or less fuel may be used. That is, for example, with a head wind, then more fuel may be used, whereas with a tail wind, then less fuel may be used.

35   Generally therefore, in order for a vehicle such as a ship to travel from a starting point A to a destination point B across a region, the amount of fuel which is used by the vehicle in performing the journey will be dependent upon many factors, such as internal energy usage for running the internal machinery of the vehicle, as well as propulsion energy to

propel the vehicle. With regard to this latter usage, as described, the amount of energy required to propel a vehicle such as a ship from point to point along a route is dependent not only on the vehicle parameters, but also on environmental conditions along the route, such as wind speed and direction, ocean current speed and direction, and wave

5   height and direction. In view of the ever increasing cost of fuel, and in particular oil based fuels, it would be desirable to minimise fuel consumption required for a vehicle to travel from a start position A to a destination position B.

Summary of the Invention

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In view of the above, the present invention presents a route selecting method and apparatus for a vehicle which makes use of information relating to environmental conditions across a geographical region which the vehicle must traverse, so as to select a route from a starting position within the geographical region to a destination position

15   within the geographical region. More particularly, by having regard to the characteristics of the vehicle with respect to external environmental parameters, embodiments of the present invention are able to plot a route across the geographic region which, when taking into account actual and forecast environmental conditions across the region, minimises fuel usage, and thereby maximises energy efficiency. In some embodiments

20   of the invention, in addition to taking into account environmental conditions, the internal energy usage of the vehicle, for example running internal machinery during the voyage, can also be taken into account in the energy usage calculations, to provide an integrated energy management system for a vehicle, such as a ship. In other embodiments, the object met is to travel from a start location to a destination location, and to reach the

25   destination at certain time. This is important to reduce harbour cost and/or reach harbour within some deadline. In the first case of too early arrival, the ship will incur extra cost for an extra day in the harbour, and in the latter case the ship will incur extra cost in the form of late fees. In another embodiment, the object met is to maximize comfort by reducing the ship motion. This is important for example in cruse ships were

30   the object is to maximize the time passengers spend at the bar, the casino, or other revenue generating activities offered at the ship. In yet another embodiments, the object met is to maximize safety, to name just few such situations we can consider a mega bunkers on a route from Murmansk, Russia through the Arctic Ocean, the object in this case could be multi-variate: stay sufficiently far from shore to avoid environmental

35   hazard due to grounding, stay sufficiently far from ice-bergs to avoid environmental hazard due to collision with ice-berg, select a route avoiding certain wave conditions which may put too much strain on such super structure. This may for example occur in deep ocean areas after long sorm duration. The distance between wave tops in these

areas is longer and the wave height is higher than in more shallow waters. It is known that conditions can arise in these areas, were the strain on the ship structure (of fully loaded mega bunker) is such that the ship breaks in half. To name another such situation, but more common, a freight carrier is transporting goods which are difficult to

5   secure properly or the nature of the goods containers is such that they can only withstand relatively small g-force. Goods which are difficult to secure properly are often of high density weight such as steel bars. During high rolling conditions such freight aften breaks the rig which it was secured with and gets thrown to one side of the ship causing the ship to capsize. Similarly, when transporting marinated food in wooden or

10   plastic barrels one of two mishaps are common cause of a shipwreck. First, due to the round nature of the barrels they can break the rig they are secured with, during high rolling situations (side waves), causing a domino effect on the remaining barrels. Once the barrels are loose they will be thrown around in the cargo hold causing a shift in the centeredness of the ship often leading to a shipwreck. The second common mishap is

15   when the g-force (head waves) becomes too large then the barrels will break causing the same effect as in the first case.

Moreover, whilst in embodiments of the invention described herein we focus on vehicles such as ships, or other sea going vessels, the invention is not limited to such, and can be used to plot routes for any vehicles, such as land transport vehicles, or aircraft, for which

20   environmental conditions play a part in their fuel usage.

In view of the above, from one aspect the present invention provides a route selection method for selecting a route for a vehicle, comprising the steps: receiving information relating to environmental conditions across a geographic area; storing an energy usage

25   model which relates fuel efficiency of the vehicle and the environmental conditions; and selecting a route across the geographic region from a start location to a destination location in dependence on the energy usage model and the received environmental conditions information; wherein the selecting step selects the route so as to maximise fuel efficiency.

30
Further features and aspects of the invention will be apparent from the appended claims.

Brief Description of the Drawings

35   Further features and advantages of the present invention will become apparent from the following description of embodiments thereof, presented by way of example only, and by reference to the accompanying drawings, wherein like reference numerals refer to like parts, and wherein:

Figure 1 is a diagram illustrating a plot of GRIB weather data across a region;

Figure 2 is a diagram of a vehicle of the prior art, illustrating elements which give rise to energy usage in the vehicle;

5   Figure 3 is a diagram of a vehicle according to a first embodiment of the present invention;

Figure 4 is a block diagram of a route planner apparatus according to a first embodiment of the present invention;

Figure 5 is a plot of weather information across a region illustrating various routes

10   between a start position A and a destination position B;

Figure 6 is a diagram illustrating how routes may be calculated in an embodiment of the present invention;

Figure 7 is a diagram of a decision tree illustrating how a route may be plotted in an embodiment of the present invention;

15   Figure 8 is a diagram illustrating weather data across a region used to described embodiments of the present invention;

Figure 9 is a diagram illustrating how way points may be plotted in an embodiment of the present invention;

Figure 10 is a diagram illustrating how way points may be selected in an embodiment of

20   the present invention;

Figure 11 is a diagram illustrating an example route for use in describing embodiments of the present invention;

Figure 12 is a diagram illustrating how way points may be selected in an embodiment of the present invention;

25   Figure 13 is a diagram illustrating how way points may be selected in an embodiment of the present invention;

Figure 14 is a diagram illustrating how way points may be selected in an embodiment of the present invention;

Figure 15 is a diagram illustrating how a route comprising multiple way points may be

30   selected in an embodiment of the present invention;

Figure 16 is a decision tree illustrating how a route is selected in an embodiment of the present invention;

Figure 17 is a flow diagram illustrating the basic steps involved in an embodiment of the present invention;

35   Figure 18 is a flow diagram illustrating how a route is selected using a decision tree in embodiments of the present invention;

Figure 19 is a flow diagram determining energy usage for a next hop way point which may be used in an embodiment of the present invention;

Figure 20 is a flow diagram illustrating a first technique for deriving energy usage between way points for use in an embodiment of the present invention; and

Figure 21 is a flow diagram illustrating a second technique for deriving energy usage between way points using an embodiment of the present invention.

5

Description of the Preferred Embodiments

Preferred embodiments of the invention will now be described. Throughout the description of the preferred embodiments, variants to various elements contained within
10   the preferred embodiments will also be described, which can be substituted or added to provide further embodiments of the invention.

Embodiments of the invention provide a route selecting method and apparatus for a vehicle, and in particular for a sea going vehicle, such as a ship, boat, submarine, or the
15   like. However, the invention is not limited to application in sea going vehicles such as ships, and may find application in other vehicles, such as land based vehicles, or aircraft.

Within embodiments of the invention information relating to environmental conditions across a region across which the vehicle is to travel is used in combination with a
20   predetermined model of the vehicle relating the energy usage of the vehicle to the environmental conditions to determine a route from a start position A to a destination position B across the region, which maximises fuel efficiency. In particular, as noted previously, fuel usage by a vehicle, and in particular a vehicle such as a ship, can be highly dependent upon the local environmental conditions, such as wind speed and
25   direction, wave height and direction, and ocean current speed and direction. However, as also discussed, information relating to environmental conditions across a region is readily available, and in particular using the WMO GRIB format. Other formats may also be used in other embodiments of the invention, and the invention is not limited to the use of GRIB data, although it is preferred. By obtaining information relating to
30   environmental conditions across a region which is to be traversed, and then applying that information to a vehicle energy model which relates vehicle energy usage to the encountered environmental conditions, embodiments of the invention aim to allow a route to be plotted from a start position A to a destination position B across the region, the route being selected so as to maximise fuel efficiency.

35

Figure 3 illustrates a ship 20 according a to a first embodiment of the present invention. The ship 20, as in the prior art ship shown in Figure 2, comprises a hull 22, and superstructure 24, and has within it various machinery which requires energy, such as a

propulsion plant 27, a power plant 26, machinery 28, and a refrigeration unit 29. As also discussed the hull 22 will have certain characteristics with respect to encountered environmental conditions, as will the superstructure 24. In accordance with the presently described embodiment, however, the ship 20 is further provided with a route

5   plotting and control apparatus 30, which is arranged to plot an appropriate route from a start position A to a destination position B across a region taking into account the predicted environmental conditions along the route, and, if necessary, to control a ship autopilot function, so as to control the ship to follow that route. It should be noted, however, that the control of the ship is an optional feature, and instead of taking direct

10   control, navigation commands could, instead, be issued to the ship's crew.

Further details of the route planner and control unit 30 will be described next with respect to Figure 4.

15   More particularly, with reference to Figure 4, the route planner and control unit 30 is firstly provided with a keyboard 32, and a display monitor 34, to allow the input of control commands and data therein, and to display such data, as well as route plotting results, to an operator. In this respect, the route planner and control unit 30 may take the form of a general purpose computer, provided with software which when executed

20   by the computer controls the computer to perform the functions to be herein described. In other embodiments, however, the route planner and control unit 30 may comprise dedicated hardware.

In order to control the keyboard 32, and the display unit 34, the route planner and

25   control unit 30 comprises an input/output controller 50, arranged to drive the keyboard 32 and display unit 34, and to receive commands from the keyboard, and to output a video display image to the display 34. The input/output controller 50 communicates with the other elements of the route planner and control unit 30 via an internal bus 52. Additionally provided within the route planner and control unit 30 is a forecast data

30   controller 46, which is arranged to control a satellite transceiver 36, provided with a satellite antenna 38. In particular, the forecast data controller 46 controls the satellite transceiver and antenna 38 so as to allow a communications link to be established between the route planner and control unit 30 and another station, to allow the forecast data controller 46 to obtain updated weather forecast data for a region of interest,

35   preferably in the form of a GRIB file. For example, the forecast data controller 46 may use the satellite transceiver 36 to download GRIB forecast data from a commercial satellite weather reporting service. Alternatively, in other embodiments the forecast data controller 46 might use internet related technology to establish, via the satellite

transceiver 36, an internet connection, and then download GRIB forecast data via an appropriate web server which provides such data. For example, GRIB forecast data can be downloaded on the internet from the URL www.grib.us, as well as from various NOAA websites. Of course, a satellite link is just one of many medium for transferring data.

5   The present application works also with any data link available such as radio data link. VHS receivers for example can provide a digital data link as well as the well known mobile phone systems all over the world. Whichever communications protocol is used to obtain the GRIB forecast data, the forecast data controller 46 periodically updates the GRIB forecast data for a region of interest, and stores the GRIB forecast data as GRIB

10   forecast data 402, in a memory 40.

Please note that the forecast data controller 46 may obtain the GRIB forecast data for only the region in which the vessel is presently operating, or may instead obtain GRIB forecast data worldwide. In order to keep the forecast data up to date, the forecast data

15   controller 46 is arranged to periodically update the GRIB forecast data, for example by downloading the most recent GRIB forecast data which is available, for example every three or six hours. In this way, the forecast data controller 46 maintains the GRIB forecast data 402 stored in the memory 40 in as up to date a state as possible, so that the most recent forecast is always available for use in selecting a route.

20
Additionally provided within the route planner and control unit 30 is a route planner controller 48, as well as vehicle energy usage calculator 44. The route planner controller 48 controls the overall route planning operation in response to commands received via the keyboard 32 and passed to it via the input/output controller 50. In

25   particular the route planner controller 48 makes use of operating data 408 stored in the memory 40, which contains, for example, information relating to bounds which may be placed on possible way points which can be selected, as well as how the routing operating is to be performed. Additionally, the route planner controller 48 also writes to the operating data 408 data structures which are used in the route planning operation,

30   such as a route decision tree, to be described later. Additionally, once the route planner controller 48 has decided on a route, then it writes the route way points into the memory 40, as route data 406.

The vehicle energy usage calculator 44 is provided to calculate the energy usage of the

35   vessel when travelling from a first point provided to the calculator to another point provided to the calculator. The vehicle energy usage calculator 44 makes use of a vehicle energy usage model 404, which is stored in the memory 40. The vehicle energy usage model 404 relates the fuel usage of the vessel or vehicle to the environmental

conditions which will be encountered between the two points for which a fuel usage estimate is sought. The route planner controller 48 passes data to the vehicle energy usage calculator 44 so as to obtain vehicle energy usage estimates used in the route planning process. Co-pending application PCT/IS2006/000016 describes the vehicle

5   energy usage calculator in detail. For the completeness of this application a section describing the vehicle energy usage calculator is included at the end of the description under the heading the vehicle energy usage calculator.

Additionally provided is a vehicle autopilot 42, which is a conventional autopilot which

10 functions to control the vehicle or vessel so as to follow a particular route. That is, if it is further required that control of the vessel to follow the planned route is required automatically, then the vehicle autopilot 42 accesses the route data 406 stored in the memory 40, and controls the vehicle or vessel to follow the route, via the appropriate vehicle control machinery 54. For example, in a vehicle such as a ship, the vehicle

15 control machinery 54 will principally be the rudder, as well as other control elements, such as bow thrusters and the propulsion plant. The operation of the vehicle autopilot 42, and the vehicle control machinery 54, is generally outside the scope of the present embodiments.

20 Within the presently described embodiment, the route planner and control unit 30 operates so as to plan a route from a starting position A to a destination position B using the environmental information which is available from the GRIB forecast data. In this respect, due to the resolution which is available within the GRIB forecast data, within the present embodiment each location point for which forecast data is available is

25 conveniently used as a possible way point for planning the route. However, even allowing for this constraint on possible way points, as will be seen from Figure 5, when planning a route from a start position A to a destination position B, using the GRIB forecast points as way points still allows for many different routes to be plotted between the start position and the destination position. Figure 5 in particular illustrates a set of

30 GRIB forecast data 56 for the region between the United Kingdom and Iceland, and shows two example routes between Reykjavik and London, being a first example route 58, and a second example route 59. Depending on the environmental conditions encountered along each route, one of these routes may be more efficient from a fuel usage perspective than the other. Many other routes may also be plotted using the

35 GRIB forecast data points as way points between the start position and destination position.

Figure 17 illustrates the underlying method of operation of the route planning and control unit 30. Firstly, at step 17.2 an operator uses the keyboard 32 to input into the route planning and control unit 30 the vessel's present position, time, the intended destination, and the desired arrival time. This information is stored in the memory 40,

5   as part of the operating data 408, by the input/output controller 50. Please note, in other embodiments, instead of the present position being input into the unit 30, the unit 30 may be provided with a position location system, such as a GPS system, or the like, from which present position data and present time data can be obtained automatically. Having obtained the present position and time data, and having had input into the unit

10   the destination and desired arrival time, at step 17.4 it is then necessary to initialise the route planner, for example by defining how the route should be calculated, for example by applying limits to the way points which may be selected, or, for example, by inputting a first, proposed, route as a first approximation for the route to be calculated. Further details regarding these aspects will be given later, although it should be noted that in

15   some embodiments of the invention it is not necessary to provide such information, in which case the route planner is then free to select any way points between the start position and the destination position. Further details as to the bounds which may be applied and how the route may be calculated will be given later.

20   Having initialised the system, at step 17.6 the route planner controller 48 calculates the route, using the vehicle energy usage calculator 44. More particularly, the route planner controller 48 plans the route, as will be described below, by following each possible way point from the start position to the destination position to build a plurality of possible routes from the start position to the destination position. The energy usage is then

25   calculated along each possible route, and a decision tree is built, with each node in the tree corresponding to a possible way point. By then following the branches of the tree from the route to each end node, which must be the destination point, the total energy usage upon each possible route can be determined, and a route selected which gives the lowest energy usage. Once such a route has been calculated, then it is stored as the

30   route data 406 at step 17.8, and then typically displayed to the operator at step 17.10, on the display screen 34. If necessary, the vessel can be controlled to follow the route, using the vehicle autopilot 42, and the vehicle control machinery 54, at step 17.12.

     Further details as to how the route planner controller 48 operates so as to plan a route

35   from a start position A to a destination position B will now be described.

     As mentioned above, the route planner controller 48 uses the GRIB forecast data 402 which is regularly updated in the memory 40 by the forecast data controller 46, as

described, together with the vehicle energy usage calculator 44, to build possible routes, and then decide on a route to be used, which gives the maximum fuel efficiency. The vehicle energy usage calculator 44 makes use of the vehicle energy model 404, which is a predetermined model which relates the vehicle fuel usage to local environmental

5   conditions. The vehicle energy model 404 may be derived theoretically from knowing the hull characteristics and structural characteristics of the vessel, or may, instead, be derived empirically, either through operation of the vessel over a test period of time, or by tests on scale models of the vessel in test tanks, or the like. Howsoever the vehicle energy usage model is obtained, it is required to take as its input local environmental

10   conditions, and to output an estimated fuel usage for the vessel, given the environmental conditions. Please note that a range of outputs may be obtained, in some embodiments, showing, for example, fuel usage at different speeds.

The operation of the route planner controller 48 is generally shown in Figure 18. More

15   particularly, Figure 18 shows in more detail the steps performed during step 17.6, described previously, wherein the route planner calculates the route using the vehicle energy usage calculator.

For the purposes of the present explanation, consider Figure 6, which illustrates a

20   starting position A and a destination position B, with nine possible way points in between. Assume for the purposes of the present explanation that the region between positions A and B represent the geographical region which must be traversed, and the only possible way points are way points 11 to 33 as shown on Figure 6. For each way point 11 to 33, GRIB forecast data 402 is available in memory 40, and the vehicle

25   energy model 404 has already been stored. The route planner controller 48 must therefore use the vehicle energy usage calculator 44 to plot the most fuel efficient route from A to B across the region, via the possible way points.

With reference to Figure 6, as will be seen, from position A it is possible to travel to any

30   of way points 11, 21 or 31. In the present example, the possible routes are fully interconnected, and no bounds are placed on which next hop way point may be selected, in which case, from way point 11 it is possible to travel to any of the next set of way points 12, 22 or 32. Similarly, from way point 21 it is possible to travel to any of the next set of way points 12, 22 or 32, and the same can be said for way point 31.

35   Likewise, for the third hop, it is possible to travel from any of way points 12, 22 or 32, to any of the set of way points 13, 23 or 33. For the final hop from any of way points 13, 23 or 33, each hop then ends at the destination B.

Figure 18 illustrates in more detail the actions performed at step 17.6 wherein the route planner calculates the route using the vehicle energy usage calculator. Here, at step 18.2, the route planner controller 48 sets a present node i to the starting position, at step 18.2. In the example of Figure 6, the present node i would initially be set to be the

5   starting position A. Next, at step 18.4 the route planner controller 48 determines a list of possible next hop positions $j[n]$ and determines energy usages to reach each of these next hop positions. Thus, with respect to Figure 6, the route planner controller 48 will determine that from position A each of the next hop positions is any of way points 11, 21 or 31. The route planner controller 48 therefore stores, in the operating data 408, a

10   decision tree data structure, which has node A as its root, and then as the next level in the tree adds a node for each of the possible next hop positions, being way points 11, 21 or 31. This can be seen with reference to Figure 7, which shows the complete decision tree. In order to calculate the energy usage of the vessel to reach each of the possible next hop way points, the route planner controller, for each possible next hop way point,

15   calls the vehicle energy usage calculator 44, and passes to it the GRIB forecast data for the present position i, equal initially to the starting position A, and the next hop way point. Thus, for example, in order to calculate the energy usage between position A, and way point 11, the route planner controller 48 accesses the GRIB forecast data 402 in the memory 40, and obtains the GRIB forecast data for location A, and location 11, and

20   passes both sets of data to the vehicle energy usage calculator 44. The vehicle energy usage calculator 44 then accesses the vehicle energy model 404, and applies the sets of data, or a single set of data derived therefrom, as will be discussed later, to the vehicle energy model, in order to obtain an estimate of the energy usage to travel between the two points, in view of the present environmental conditions represented by the GRIB

25   forecast data. Thus, in this case, a value E(A, 11) is obtained, representing the energy usage required for the vessel to travel from position A, to position 11. The route planner controller 48 repeats this operation for each possible next hop way point (node), such that, as shown in Figure 6, an energy usage value is obtained to travel from position A to each possible next hop node 11, 21 or 31. Each branch in the decision tree is then

30   labelled with its appropriate energy usage value which is calculated.

Processing then proceeds as set out in step 18.6, wherein the process is repeated for each possible next hop position, until the destination is reached, in order to build a decision tree of possible routes. In more detail, with reference to Figure 6 and 7, we

35   have already described above how the first level of nodes in the decision tree are produced, representing the first hop from the starting position A to the possible first hop way points 11, 21 or 31. Next, the route planner controller 48 takes each possible next hop way point in turn, referred to below as the first hop way points, and calculates the

energy usages for the vessel to travel to each possible next hop way point from that first hop way point. In this case, the next hop way points are the possible second hop way points, being any of way points 12, 22 or 32. In this respect, assuming the route planner controller 48 is calculating the possible next hops for way point 11, the route

5   planner controller 48 calls the vehicle energy usage calculator 44 in turn for each of way points 12, 22 or 32, passing to it each time the GRIB forecast data for way point 11, and the GRIB forecast data for the respective way point 12, 22 or 32. The vehicle energy usage calculator 44 then returns, for each call that is made upon it, an energy usage calculation. At the same time, the route planner controller 48 adds to the decision tree

10   stored in the operating data 408, adding branches into the decision tree representing the possible next hops. Thus, as can be seen from Figure 7, from way point 11 travel can be made to any of way points 12, 22 and 32, and an energy usage value E() is obtained for each possible hop, as shown, for example, by E (11, 12) on the branch connecting way points 11 and 12 in the decision tree. Please note that the decision tree of Figure 7 does

15   not show an energy usage value for every branch, although in a complete decision tree in the presently described embodiment every branch would have an energy usage value associated therewith.

As described, the route planner controller repeats the above operations to follow each

20   possible route through the route network of Figure 6, building the decision tree of Figure 7. The decision tree of Figure 7 then represents every possible route through the network of way points, and provides, on each branch thereof, an energy usage value to travel between the two nodes connected by that branch. Once the decision tree has been completed, after step 18.6, the route planner controller has then plotted every

25   possible route through the network of way points, and has also determined, for each leg, the vehicle energy usage.

Following this, therefore, it then becomes possible to determine which route should be chosen which gives the lowest energy usage, or the maximum fuel efficiency. In this

30   respect, at step 18.8 in order to determine total energy usage for a route, the energy values are summed along each branch of the decision tree to give, for each possible route from A to B a total energy value. Once a total energy value has been obtained for each possible route, at step 18.10 the branch with the lowest total energy sum is determined. Having determined that branch with the lowest total energy sum (which will

35   be at a node B representing the destination), at step 18.12 the decision tree can be traced back from the determined branch backwards towards the destination, in order to determine the route. Thus, with reference to Figure 7, assume that the branch with the B node labelled X has been determined to have the lowest total energy sum, then tracing

back along that branch we find that the determined route, working backwards, is from destination B to way point 13, to way point 12, to way point 21, and then to starting position A. The route to be followed is then the reverse of this, i.e. A-21-12-13-B. This route is then stored as the route data 406. Thus, at this point a route which gives the

5   maximum fuel efficiency has been found. This can then be displayed to an operator on the screen 34, and/or used by the vehicle autopilot 42 to control the vessel to follow the route.

Further details as to how the next hop positions $j[n]$ and energy usages to the next hop

10   positions are found in steps 18.4 and 18.6 will be given with reference to Figure 19.

More particularly, Figure 19 shows in more detail the steps which are performed during step 18.4 or 18.6 while the decision tree is being built. In particular, Figure 19 shows the steps that are performed for a particular node in the decision tree, in order to

15   determine the possible next hop nodes, and the energy usages to get to those next hop nodes.

More particularly, starting at step 19.2, a present hop position i is initialised, with the present position of i, and the GRIB forecast data for that present position. Thus, for

20   example, when the algorithm is first starting out the present position i may be the starting position A, although where the algorithm is being called in the middle of building the decision tree, the present position i may be an intermediate hop way point, such as, for example, way point 12, 22 or 32 of Figure 6. Having initialised the present hop position which is being calculated, at step 19.4 a list $j[n]$ of possible next hop way points

25   is found, applying any bounds which are to be used. The example described previously with respect to Figures 6 and 7 did not apply any bounds, assuming that the set of way points 11 to 33 were all possible way points in the region. However, as will be described later, it is possible to apply bounds to limit the next possible way points which may be included in the list. This has the affect of reducing the number of possible next hop way

30   points in the list $j[n]$.

Having established the list of possible next hop way points, whether any bounds were applied or not, at step 19.6 a processing loop is commenced to process each possible next hop way point in the list. More particularly, for a possible next hop way point in the

35   list the time of arrival at that possible next hop way point is estimated. This estimated time of arrival is required so that the appropriate GRIB forecast data for that time can be used. In this respect, the route planner controller 48 knows the time of departure, and the desired time of arrival, and will also know, for a possible next hop, an estimate of

how far along the route between the start position and the destination position the next hop represents. It is therefore able to calculate a target estimated time of arrival at the possible next hop position and this time of arrival can be used to look up the local environmental conditions at the next hop way point at the estimated time of arrival from

5   the GRIB forecast data. This is performed at step 19.10.

Next, at step 19.12 the local condition information at the estimated time of arrival at the way point is passed to the vehicle energy usage calculator, together with the local condition information from the GRIB forecast data at the present hop position i. In this

10   respect, the route planner controller 48 will also have an estimated time at which it will anticipate finding itself at the present hop position i, and hence the forecast data for the present hop position i is the forecast data for that estimated time. At step 19.14 the energy usage E(i, $j[n]$) to travel from position i to position $j[n]$ is calculated. In this respect, the vehicle energy usage calculator 44 applies the local condition information

15   which it has received to the vehicle energy model 404, to obtain the energy usage estimation. Then, at step 19.16 an additional node $j[n]$ is formed in the decision tree (see Figure 7) and at step 19.18 a branch is formed in the decision tree between the node representing the present hop position i and the node $j[n]$. This branch is then labelled with the energy usage calculation E(i, $j[n]$). At step 19.20 an evaluation is

20   performed as to whether there are any more next hop nodes in the list which have not been processed, and if there are then processing returns to step 19.6, and the next possible next hop in the list is processed. In contrast, if all of the possible next hop nodes have been processed, then at step 19.22 the function returns. The procedure of Figure 19 therefore takes as its input a present way point position and returns possible

25   next hop positions, as well as the energy usages to travel thereto. The function can therefore be used repeatedly to build the decision tree of Figure 7.

With respect to the operation of step 19.14 in the above, the vehicle energy usage calculator 44 receives local condition information relating to the present hop position I

30   and the next hop position $j[n]$, obtained from the GRIB forecast data 402. It also has access to the vehicle energy usage model 404, which is predetermined in advance. However, it will be appreciated that the GRIB forecast data represents the environmental conditions at discrete way points, and does not necessarily represent the environmental conditions between the way points. However, the vehicle must traverse the region

35   between the way points, and it is the environmental conditions at these points between the way points which will determine the vehicle's fuel usage.

In order to get around this problem, Figure 20 presents a first technique for calculating
the energy usage taking into account the two different sets of local condition
information. More particularly, at step 20.2 the vehicle energy usage calculator 44
receives the local condition information at position i, and position $j[n]$. Then, in order to

5   provide a single set of local condition information to apply to the vehicle energy model
404, at step 20.2 it interpolates the local condition information parameters at position i
with the corresponding parameters at position $j[n]$ to obtain interpolated parameters.
Next, at step 20.6 it determines the distance and sailing time from position i to position
$j[n]$, and finally at step 20.8 applies the interpolated parameters to the ship model for

10   the determined sailing time, to determine the fuel usage to get from position i to position
$j[n]$. Thus, by interpolating between the parameters, in this first technique the vehicle
energy usage calculator determines the region between the two possible way points as
having environmental conditions which are the average of the conditions at the
boundaries of the region determined by the way points. For most areas in most regions

15   such an averaging operation should not pose many problems, and is easy to perform.

However, there are some areas of some regions where performing such an interpolation
operation will give incorrect results. In particular this applies to areas at the boundaries
of ocean currents, for example, where two ocean currents are moving in opposite

20   directions side by side, then it is possible to have relatively well defined boundaries
between the two currents. In this case, given the half degree resolution between
possible way points using the GRIB forecast data, it may be that position i is located
within one current, whereas position $j[n]$ is located at a position where the other current
prevails. In this case, averaging the local conditions using an interpolation operation

25   may give incorrect results. This problem is overcome by the input provided by the local
system. The local system includes equipments which measures the ocean current as well
as the path travelled, therefore, crossing current boundaries is easily detected and a new
estimate from the vehicle energy usage calculator will suggest a new path.

30   To get around this problem, Figure 21 illustrates an alternative solution which may be
used by the vehicle energy usage calculator 44. Here, at step 21.2 the vehicle energy
usage calculator 44 receives the local condition information at position i and position $j[n]$
and determines the distance and sailing time from position i to position $j[n]$ at step 21.
4. Then, at step 21.6 the vehicle energy usage calculator 44 applies the parameters

35   from position i to the vehicle energy model 404 for half of the sailing time to determine
fuel usage to get from position i to approximately half way to position $j[n]$, and then,
separately applies the parameters from position $j[n]$ to the vehicle energy model 404 for
the remaining half of the sailing time to determine the fuel usage to get from the half

way position to *j[n]* to position *j[n]*, at step 21.8. These two fuel usage amounts are then summed at step 21.10, to get the total fuel usage to travel from position *i* to position *j[n]*. Again this provides an approximation, as it assumes that the local conditions at position *i* extend halfway towards position *j[n]*, and vice versa. Such a technique should help overcome the problem noted earlier with the interpolation operation.

In order to take into account the desired time of arrival of the vehicle at its location, in the present embodiment, once a route has been selected the total distance of that route is calculated, and an average speed of travel along the route is calculated in order for the vessel to arrive at the intended time of arrival. The vessel can then be controlled to travel at that calculated speed.

In an alternative embodiment, however, the required speed of travel along any particular route can be taken into account in the energy usage calculations, and it may be desirable to do so, as speed of travel from waypoint to waypoint can impact on the energy usage. In such embodiments, instead of calculating the energy usage values for each branch of the decision tree whilst the tree is being built, the possible route network is analysed first and the decision tree of possible routes built in advance, without the branches being labelled with the energy usage values E(*i, j[n]*). Then, the total distance along each possible route is calculated, and an average speed along the route found in order for the vessel to arrive at the destination position B at the desired time. At the same time, the estimations of time of arrival at each way-point along the route can also be made, based on the calculated speed, and the distance between way points along a route. With such information, the route planner controller 48 then traverses each branch of the decision tree, calling the vehicle energy usage calculator 44 for each branch and passing to it on each call the forecast data for the nodes at each end of the branch being processed, as well as the calculated average speed. Here, the forecast data is the data at the estimated times of arrival at the waypoints represented by the decision tree nodes.

With such information, the vehicle energy usage calculator then calculates the energy usage of the vehicle to travel between the two waypoints represented by the two nodes, at the given speed. The returned value E(*i, j[n]*) is then used as the branch energy value label, for that route. By repeating the procedure for every branch in the decision tree for every route, the decision tree branch labels can be populated with energy usage values which have been calculated using the average required speed for a route. Note that with

such a technique, a decision tree branch will have as many energy usage labels as the number of possible routes of which it forms a part.

To decide on which route to select in this alternative embodiment, for each possible route the branch energy labels for the route are summed along the decision tree, to give

5   a total energy usage for each route. The total energy usages are then sorted, and the route selected which gives the lowest energy usage to allow the vessel to arrive at the destination location at its intended time.

With embodiments of the invention, therefore, as has been described a route from a

10   starting point A to a destination position B can be obtained which, taken into account forecast information relating to local environmental conditions, such as wave height, wave direction, current direction, current speed, wind speed, and wind direction, is able to select a route for a vehicle which provides for the minimum energy usage, thus promoting maximum fuel efficiency.

15

Moreover, whilst in the above we have described the vehicle energy model as relating the local environmental conditions to the energy usage, in other embodiments the vehicle energy model can be extended, so as to take into account not only the energy usage used to propel the vehicle between way points in view of the local environmental

20   conditions, but also the internal energy usage of the vehicle, such as, for example, the power plant 26, machinery 28 and any necessary refrigeration 29. It is preferable to take this energy usage into account during the vehicle energy model calculations, such that the energy usage due to internal needs becomes part of the energy usage calculations included in the decision tree. Then, when a route is being selected using the

25   decision tree, because the internal energy usage is included in the total energy usage, a route should be selected which not only provides for the best energy usage to propel the vessel between way points in view of the local environmental conditions, but also takes into account the internal energy usage over the time that it takes to travel between way points. For example, when taking the internal energy usage into account, there may be

30   conditions when just taking into account the propulsion energy and the local environmental conditions which provide a route which takes slightly longer, but which is more fuel efficient. However, once the internal energy needs are taken into account, it may be that when taking into account the requirement to power the internal energy needs for that extra time, then the selected route becomes, in energy terms, more

35   expensive, and hence a different, shorter, route is chosen instead.

Previously we mentioned that in order to reduce the possible number of way points for inclusion in the lists of possible next hop way points when building the list of possible routes, bounds can be applied in order to limit the way points which can be selected. Further discussion of the various possible bounds which may be used within

5   embodiments of the invention will now be undertaken.

First of all, consider Figure 8, which shows GRIB forecast data plotted for the Caribbean. When travelling from a destination A to a destination B in such a region it may be that a ship's captain typically has a preferred route which he has traditionally followed, and

10   from which he would prefer not to deviate too much. An example of such a possible route is route 82 shown in Figure 8.

Such a route may be inputted into the route planning and control unit 30 via an operator using the keyboard 32, and the route planning and control unit 30 preferably provides a

15   user interface to allow such routes to be entered. Once such a route has been entered, then it can be used to form a first approximation to the route which should be followed, by limiting way points which may be selected by the route planner controller 48 as part of the route to those way points which are somehow related to the entered route. For example, as shown in Figure 9, fixed bounds 92 may be placed on way point selection

20   for each next hop way point, limiting the possible way points which may be selected to those way points which are within a certain distance defined by the bound from the entered route. Thus, as shown in Figure 9, for each way point selection, a fixed distance bound may be applied, and only those way points which are within the fixed distance bound, illustrated by the black lines in Figure 9, are entered within the list *j[n]* of

25   possible next hop way points for entry in the decision tree. Moreover, whilst Figure 9 shows the same fixed bounds being applied for every way point selection, as shown in Figure 10, variable bounds 94 may be applied. In particular, in the example shown in Figure 10 variable distance bounds are applied in dependence on the distance of the possible next hop way point from the starting position A. Therefore, as shown in Figure

30   10, a larger bound is applied to determine the possible next hop way points for a hop which is further from the starting position A, than for a hop which is closer to the starting position A. The corollary of this principle may be used when approaching the destination point B. Here, as the route approaches the destination point B, then a smaller bound is applied, the closer the way point is to destination point B. An example

35   of this is shown in Figure 13. In this case, the bounds are applied with respect to the route which has been entered by the operator.

Instead of using distances from either side of the entered route, as shown in Figures 11 and 12, a bound related to heading angle of the route may be used. More particularly, consider the preferred route 112, shown in Figure 11. This route may have been entered by the operator using the keyboard 32. Data concerning the entered route is

5   stored as operating data 408. As shown in Figure 12, rather than applying distance bounds as to possible way points which are off the entered route, as in Figures 9 and 10, in Figure 12 a "heading" bound is applied, in that only those way points which are within a predetermined range of heading directions may be selected. Thus, as shown in Figure 12, for each way point selection, a list of way points is determined by looking at the

10   preferred track, and compiling a list of way points which are within the predetermined angle range from that track.

Additionally, where the bound is determined by a range of possible heading angles, then as with the distance bound the angle bounds may be fixed along the entire route, or may

15   be adapted along the route. For example, the range of angles of possible headings may be narrower closer to the start point and/or destination point, and wider in the middle of the route. This would give greater freedom to the route planner controller to adapt the route for way points in the middle section of the route, and less freedom to select way points off the route just having left the starting position, and/or when approaching the

20   destination.

Figure 13 illustrates an alternative technique by which possible way points may be bounded. Here, instead of a route being entered by an operator from a starting position A to a destination B, the route planner controller 48 simply plots the straight line route

25   130 between points A and B. Then, distance bounds 132 are applied with respect to the straight line route, in order to limit the list of possible way points for each next hop as shown in Figure 13. The size of the distance bounds may be adapted in dependence on the distance of the way point to which the bound applies from either the starting position, and/or the destination position. In particular, a smaller bound may be applied

30   when the way point is closer to the starting position, and likewise a smaller bound may be applied when the way point is closer to the destination position. In other embodiments a fixed bound may be applied i.e. the same fixed bound is applied to every way point selection.

35   Figure 14 shows yet another possible type of bound which may be applied. Here, for every next way point selection, the straight line heading from the "present" position to the destination position is taken, and a way point is selected which is within a predetermined range of headings either side from the direct heading. Thus, as shown,

the direct heading from position A to position B is shown by line 130, and hence the next hop way points from position A may be selected to be any of those way points within the predetermined heading range 142 either side of the direct heading 130. Likewise, assuming that the way points illustrated by the black rectangles are selected by the route planning algorithm, then from the lower most black rectangle the straight line heading is shown by dotted line 134, and hence the range of angles at which the next hop way point therefrom may be selected is shown by angle range 144. Similar considerations apply for the other possible selected way points, in view of straight line headings 136, and 138.

Within the examples shown in Figure 14, the same angular range is used each time, however, within other embodiments, the angular range may be varied along the route. For example, a narrower angular range may be used for way points closer to either the starting position, or the destination position, than for way points within the middle section of the room. Again, this would give the route planner controller 48 greater freedom to plot the mid-section of the route between as many way points as possible, whilst limiting the possible way points of the route planner when just leaving the starting position A, or approaching the destination position B. Such a feature would also have the effect of preventing the route planner from choosing routes which are substantially off track, and would cause the possible routes to automatically converge towards the destination position B.

As mentioned, the effect of applying bounds to the way point selection, whichever form of bound is applied, is that, for each list of next possible way points, the number of next possible way points is reduced. With respect to how this impacts upon the operation of the route planner controller 48, Figures 15 and 16 give an example of this, for comparison with the previous examples shown in Figures 6 and 7.

More particularly, Figure 15 again shows a region containing possible way points 11 to 33, with a starting position of A, and a destination position of B. However, within Figure 15 it is not possible to travel from some of the way points to every possible next hop way point, as was the case in Figure 6. More particularly, whilst it is possible to travel from starting point A to any of way points 11, 21 or 31, when considering the second hop it is not possible to travel from way point 11 to way point 32, or way point 31, to way point 12. Likewise, when considering the third hop, it is no longer possible to travel from way point 12 to way point 33, or way point 32 to way point 13. For example, in respect of the bounds described earlier, it may be that an angular range based on direct

heading e.g. as described in Figure 14 is applied to way points 11 and 31, and 12 and
32, which means that not all of the possible next hop way points are selected.

In respect of how the reduced number of routes impacts the decision tree, Figure 16
5   illustrates the decision tree for the possible route network of Figure 15. Comparing
Figure 16 with Figure 7, it will be seen that the decision tree contains fewer branches,
commensurate with the fewer number of routes. By applying the various types of
bounds described earlier, therefore, the calculation of the possible routes is made easier,
and the decision tree is simplified. Thus, processing can be performed more efficiently,
10   and more quickly.

Within the above described examples of the sort of bounds which have been applied, we
have generally described a single type of bound being applied at once. In other
embodiments of the invention, however, multiple types of bounds may be applied to
15   each next possible way point selection such that a way point is selected only if it meets
all, or a proportion such as a majority, of the bounds which are applied. Other possible
ways of combining the different types of bounds will be apparent to the person skilled in
the art.

20   Various modifications may be made to the above described embodiments to provide
further embodiments without departing from the underlying inventive concept of the
invention. Any such further embodiments are intended to be encompassed by the
appended claims.

25   The Vehicle Energy Usage Calculator
The following text describes what we have, in the application, termed "the Vehicle
Energy Usage Calculator". The text comes from the clients co-pending PCT application
number PCT/IS 2006/000016. The filing date of the Icelandic priority application was the
11th of august 2005, and the priority number is 7976. It should be appreciated at this
30   time that the following text is included to comply with the EP Art. 83 of disclosure. The
text is not intended to limit the present invention to work only with energy model
simulator described in the aforementioned PCT application. The concept of the present
invention can be applied to any such energy model simulator/ Vehicle Energy Usage
Calculator. However, such systems are cutting edge technology and can not be
35   considered available to the person skilled in the art at the time of writing. Therefore, the
text has been included to provide the person skilled in the art with enablement and for
the application to be "self-contained", according to C4.18 of the EPC examiners
Guidelines, rather than simply referencing the pending application.

The fuel consumption of a vessel is determined by the coactions of the vessel's machine system, and is affected by external conditions such as weather and currents. Considering that fuel costs are one of the greatest expenses of a vessel, not forgetting the negative environmental effects that fuel consumption has, it is important that it is managed and minimized.

In the present context the following terminology applies:

PLC	Programmable Logic Controller
OPC	A collection of standards for communications with PLCs and other equipment
OPC Server	Handles communications with one or more PLCs, encapsulating the underlying protocols
OPC Client	Connects to 1 or more OPC Servers to read or write values to PLCs
NMEA	National Marine Electronics Association communication standard
MetaPower	Torque and power measurement system for rotating shafts
Ack	Acknowledge (to admit to have recognized)
GPS	Global Positioning System
Tag	An item being monitored and/or controlled and logged in the system, can be a temperature reading, a pressure value, value derived from other mesurements etc.
UI	User Interface
GUI	Graphical User Interface
HMI	Human Machine Interface
deadband	a range of allowable change in value
Tooltip	A tooltip is a label that displays some text when a mouse cursor on a monitor is positioned over a specific object.
Pdf	Portable document format
RAID	Redundant Array of Independent Disks. A disk subsystem that is used to increase performance or provide fault tolerance.
NA	Not Applicable
TCP	Transmission Control Protocol. TCP ensures that a message is sent entirely and accurately.
UDP	User Datagram Protocol. A protocol within the TCP/IP protocol suite that is used in place of TCP when a reliable delivery is not required.
LAN	Local Area Network
ODBC	Open DataBase Connectivity. A database programming interface from

Microsoft that provides a common language for Windows applications to access databases on a network.

Fuel   Any energy carrying medium e.g. fossil fuel, hydrogen, i.e.

The implementations of the invention being described in this text can obviously be varied in many ways. Such variations are not to be regarded as a departure from the spirit and

5   scope of the present invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

The following non-exhaustive listing of equations is intended to provide some insight into the methodology of creating the computer simulation model disclosed above. The core

10   equations listed here are of course not exhaustive listing and the listing is not intended to limit the scope of the present invention. Using other equations obvious to one skilled in the art should not be regarded as a departure from the spirit and scope of the present invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims. The set of component

15   equations for describing said ship can be selected from the group of: hull core equations, including equations for calculating: block coefficient; water plane coefficient; mid-ship section coefficient; longitudinal prismatic coefficient; frictional resistance; longitudinal center of buoyancy; appendage resistance; wave resistance; eddy resistance; bow pressure resistance; air resistance; wake velocity; and propeller resistance; propulsion

20   core equations, including equations for calculating: expandable blade area ratio; propeller efficiency; thrust coefficient; and torque coefficient; combustion process; total efficiency; mean pressure; specific fuel consumption; combustion air excess ratio; heat loss through cooling water heat exchanger; heat loss through lubricating oil heat exchanger; and heat transfer to ambient; machinery and structural core equations,

25   including equations for calculating: pressure losses inside heat transfer tubes; pool boiling process; convective boiling process; nucleate boiling process; heat transfer coefficients; flux outside the evaporator tubes; Reynolds number; condensing temperature; Prandtl number; Nusselts number; the above mentioned set of component equations describes the ship according to the requirement study (4) (predetermined

30   requirements).

In the following, the invention will be described in further details with reference to the figures. As discussed earlier, there are two integral parts of the overall methodology as depicted by general scheme (1). Firstly, a method, computer program product, and

35   system for the modeling, and optimization and simulation tool for optimizing the design

of a ship for fuel efficiency see partial scheme (2). Secondly, a method, computer program product, and system for optimizing fuel efficiency during operation see partial scheme (3).

5   The development of simple descriptive models to describe energy systems does not necessarily require systematic modeling methods for the modeler to keep the overview of the code.

However, systematic methods are required when developing complicated models for energy systems with hundreds of variables describing the involved components and

10   systems.

All components, like pumps, motors and engines, as well as pipes, electrical wires and shafts that connect the various main components must be modeled. Each component can have parameters, differential and algebraic variables and control variables. The parameters are input variables while the differential and algebraic variables (the design

15   variables) are calculated or solved by a solver. During the first phase of the design, the operator must enter the characteristic variables and values of components that will be used for building the ship into the computer. The characteristic values of each component are stored in a database and eventually a library of components is stored up at the computer and the components can be reused over and over again for different

20   simulations.

The simulation of the computer simulation model comprises the steps of:
initializing the control parameters (100), controlling the execution of the algorithm,
simulate the computer simulation model by performing the following steps until either an

25   optimal solution is obtained or maximum number of tries have been exceeded:
generate a new test set (101);
temporarily replace old test set with said new test set (102);
count constraints variables (103);
solve said model and calculate objective function(104);

30   optimize objective function (105);
if an optimal solution is not reached execute the additional steps:
calculate constraint violations (106);
calculate optimal value (penalty function) (107);
and start over from step (101);

35   store optimized objective function (108);
check if number of iterations are within limit (109);
terminate with optimized computer simulation model (110);

the resulting optimized and simulated computer simulation model represents an optimal design of the ship according to predetermined requirements and constraints, where the constraints variable comprise limiting factors such as:

maximum/minimum number of main engines, and specification; maximum/minimum

5   number of auxiliary engines, and specification; maximum/minimum number of propellers, type, and specification; maximum/minimum propeller diameter; maximum/minimum overall length of hull, and design; maximum/minimum number of refrigeration units, type, and specification; maximum/minimum volume of displacement; where multiple constraints variables can be selected at same time for each simulation.

10

To illustrate the concept lets consider the following example of a heat exchanger and its component model.

Figure 6 shows a diagram of an evaporator (50). The evaporator component model is

15   made by assigning connection points. The point where the evaporator is connected to the suction line is labeled point (51). Connection point (55) is the liquid inlet from an expansion valve. Connection point (53) is the water inlet and connection point and (52) is the water outlet. The label (54) represents the heat losses to the surroundings calculated in the component core. These five connection points define the heat transfer

20   associated with the heat exchanger. However, associated with each connection point, except for (54) which represents losses, are four variables: type of fluid, mass-flow, pressure, and enthalpy.

The heat exchanger model component (56) shown in figure 6 has therefore, 5

25   connectors and 17 pins that are to be connected to the model components that provide input to the heat exchanger and subsequent model components that connect to the heat exchanger. The pins (51x) represents the point where the evaporator is connected to the suction line and the pins (51 a,b,c,d) represents: the type of fluid (heat carrier), mass-flow, pressure, and enthalpy respectively. Similarly, the pins (55x) represents the point

30   where the evaporator is connected to the fluid line after the expansion valve and the pins (55 a,b,c,d) represents: the type of fluid (heat carrier), mass-flow, pressure, and enthalpy respectively. In the same way the cooling water pins (53x) represents the point were the evaporator is connected to the cooling water inlet line, and the pins (53 a,b,c,d) represents: the type of fluid (heat carrier), mass-flow, pressure, and enthalpy

35   respectively. Similarly, the pins (52x) represents the point where the evaporator is connected to the cooling water outlet line and the pins (52 a,b,c,d) represents: the type of fluid (heat carrier), mass-flow, pressure, and enthalpy respectively. Finally, the pin (54) represents the heat losses to the surroundings. Legatos

When cascading components together, see figure 8, the cascaded component inherits at the inlet the information from the previous component. Inheritance relationship can be illustrated by the following generalized set of equations.

Components, for example for the heat exchanger, can be defined by generalized linear equation describing the type of fluid, momentum, continuity and energy:

$$\left(\begin{bmatrix} Fluid \\ P \\ \dot{m} \\ h \end{bmatrix}_{\forall out}\right) = f\left(\begin{bmatrix} Fluid \\ P \\ \dot{m} \\ h \end{bmatrix}_{\forall in}, Param., \begin{bmatrix} W \\ \dot{Q} \end{bmatrix}, Contr.var., Design.var\right)$$

Were the:

fluid is the type of fluid,

P is the pressure,

h is the enthalpy,

m is the mass flow,

W is the work,

Q is the heat transfer,

Param. are the parameters,

Contr.var. are the control variables, and

$$Fluid_1^{out} = Fluid_1^{in}$$

$$\dot{m}_1^{in} - \dot{m}_1^{out} = 0$$

$$Fluid_2^{out} = Fluid_2^{in}$$

$$\dot{m}_2^{in} - \dot{m}_2^{out} = 0$$

Design.var. are the design variables.

There are eight variables in the four equations above. These eight variables, however, do not completely define a closed system. To close the system, four additional equations are needed that connect the outlet of component II to the inlet of component I. Two more components are needed to connect the system to the outside world, a sink component and a source component. The source and sink components have no variables but include parameters for flow, enthalpy and pressure. The four additional equations

needed to connect the system to the outside world are added to the system by connecting the components to sink and source components.

As previously discussed every component (propeller, pump, heat exchangers, etc) is
5   described with a component equation, in addition to the characteristic equations each component has associated with it a cost factor.

When simulating and optimizing a design the operator designing the ship interacts with the Human Machine Interface (5) (HMI) supplying the computer program with the
10   information from the requirement study (4). This would include component equations and component cost factor. After supplying the information the operator executes the simulation and optimization module (6) which in turn creates and delivers the optimized model of the ship (7).

15   In order to formulate a synthesis problem as an optimization problem, the operator develops a representation of all the alternative designs that are to be considered as candidates for optimal solution. To formulate the possible alternatives, a superstructure optimization methodology is applied. Using this methodology and employing computer simulation technique makes it possible to evaluate a much larger set of possible
20   flowsheets than would normally be covered in conventional process design. The inspiration behind the superstructure is to allow complex connections between all the potential system components and to choose the combination that minimizes or maximizes some objective function.

25   As an example of the present invention, a superstructure of a single stage refrigeration plant is shown in figure 9. Each function in the system includes three possible process units (components) in each location. The process unit sets in the system are interconnected by connectors and splitters. The optimized design of the structure is generated by using decision variables, and problem constraints are used to put
30   limitations on the problem.
The process unit sets shown in figure 9 are, RE for three alternatives of cooling water pumps for evaporator, EV for three different sizes of evaporators, CO for compressors, CD for
condensers and RC for three different sizes of cooling water pumps for the condenser. In
35   the
optimization one or more of the process units is selected to be included in the refined flowsheet description, depending on the optimization constraints and the object value of the problem.

The following example involves the design of a purse-seiner refrigerated seawater system (RSW system).

Two cases are studied, one with constraints on evaporating temperature at, TE = 266 °K

5   and another one with TE = 269 °K. The system is required to cool 350,000 kg of water from 288 °K to 276 °K within 5 hours. The minimum required refrigeration capacity Q_E for this task is around 910 kW.

The maximum velocity inside the heat transfer tubes, v_{tube} is 3.6 m/s and the lowest accepted

10   evaporating temperature T_E is 266 °K (case 1) or 269 °K (case 2).

The optimization problem is shown based on a computer simulation model containing performance criteria - the objective function and constraints that the design variables must satisfy. The optimization problem in its generalized the form:

15

Minimise *f(y)*

Subject to: $g_k(y)$ k=0 1,...,m

L≤y≤ U

20   where f(y) is the objective function to be optimized, $g_k(y)$ are the problem constraints and L and U are vectors containing the lower and upper bounds on y respectively. The decision variables, y, are values to be determined using the optimization algorithm. These may be continuous and/or integer variables depending on the problem at hand. An approach to formulate the cost function for components with binary variables is used.

25   In that case, the cost is a constant for each component and the problem is to choose between several different types of component from a superstructure, using the binary variables $y_{i,j}$ indicating whether it is included in the model or not.

The binary variable takes the value 1 if it is included but 0 otherwise. In this formulation,

30   a
predefined set of components is defined (superstructure) and several different types of components are selected from the superstructure using the binary variables $y_{i,j}$ indicating whether a component is included in the model or not.

35   Using this formulation with binary variables, the methodology is used to optimize the refrigeration system shown in figure 9, illustrating a superstructure for the RSW system (storage tank not included). The objective is to minimize the total annual operating costs while

maintaining the storage tank at the target temperature.

The model of the RSW system is considered as a steady-state mixed integer non-linear (MINLP) model where discrete variables are used to denote which components are

5   included in the design. The non-linear terms come from area calculations for heat exchangers, unit operation performance, thermodynamic properties and energy balances. In this optimization problem, only one connection route is described between two components and used for the possible component's choices.

10 The optimization problem is set forth as follows: binary variables y_{ij} are defined where $y_{ij}=1$ if

    component of type i is included at location j, but $y_{ij}=0$ if a particular component is not included. In figure 9, there are 5 locations (RE, EV, CO, CD, RC), and three choices of equipment in each location. Hence the binary variables are: y_{i1} for the pump on the

15 water side of the evaporator, y_{i2} for the evaporator, y_{i3} for the compressor, y_{i4} for the condenser, y_{i5} for the condenser pump. The objective function f(y) is to minimize the annual cost of power and investment. W_{ij} denotes the power needed for component i at location j, ce is the price of electrical power, t is the annual operating time and C_{ij} is the capital cost of component i in location j, including amortization.

20

This gives the following objective function:

$$\min\left[\left[\sum_{i=1}^{n_j}\sum_{j=1}^{n_l}W_{i,j}y_{i,j}\right]tc_e+\left[\left[\sum_{i=1}^{n_j}\sum_{j=1}^{n_l}C_{i,j}y_{i,j}\right]\right]\right]$$

where n_j is the number of equipment choices in location j, and n_l is the number of

25 locations. The maintenance cost is not included in this model. There are two sets of constraints, structural constraints and thermal constraints. Structural constraints are considered first to ensure the correct positioning of various components. The selection of components is controlled by binary variables where only one of each component type can be selected at a particular location.

$$\sum_{i=1}^{n_j}y_{i,j}=1\,for\,j=1,...,n_l$$

30

The thermal constraints are the second set, giving the following constraints subject to:

$Q_E \geq 910kW$

$T_E = \geq 266$ °K (case 1) and 269 °K (case 2)

$V_{EV,tube} \leq 3,6$ m/s

$V_{CD,tube} \leq 3,6$ m/s

5   The master model is formulated based on the initial superstructure including 391
       continuous and 15 binary variables. For the simulation, 3 differential and 3 control
       variables are also included.

       The input into the optimizer includes:
10   Crossover probability $p'c \in [0,1]$

       Parent population size $\mu' \in \{1,...100\}$

       Offspring population size $\lambda' \in \{1,...100\}$

       Number of generations $G \in \{10,...500\}$

       Mutation rate $p'm \in [0,0.5]$

15   Number of crossover points $z' \in \{1,...,3\}$

       The objective function is the lowest annual running cost for operating the system for
       4,000 hours per year, using a capital cost annualized factor of 0.2.

20   The cost of electricity is based on fuel costs and is assumed to be €0.04/kWh. Prices of
       components and their capacity are given in the table of figure 10.

       Graph of figure 11 shows the results from the optimizer when optimizing for case 1. In
       this graph, curve (a) indicates the best solution within each generation. The first feasible
25   solution is found at generation 5, i.e. a solution where the structural and internal
       constraints are not broken. After that, a search for a better solution continues. After 17
       more generations (on generation 22) a better solution is found (a solution that has lower
       cost). At generation 28 an even better solution is found. This is the best solution found
       in 100 generations. Curve (c) shows the penalty for each solution - notice that the
30   penalty is zero after 8 generations i.e. when the first feasible solution is found. Curve (b)
       shows the mean penalty function which varies between 2 and 0.

       In the second case, see Figure 12, the constraint on evaporating temperature (TE) is 269
       K
35   instead of 266 K as in case 1. Here more generations are required to find a feasible
       solution

because of the increased violation of the constraints on the evaporating temperature. The first feasible solution is generated after 79 generations, see curve (c). In generation 90 a better solution is found (lower cost). In the remaining generations (from 90 to 100) no better solution is generated.

5

The best solution found is reported in table of figure 13. The component selection is shown in the table, and the results from the optimizer show that case 1 has slightly lower annual operating costs than case 2. However, the optimal values are closely comparable.

10

After optimizing the system, the optimal system can be validated by simulation. In this example a simulation is presented for the optimal case, case 1, for illustration purposes. Similar simulation is of course also possible for case 2. In the figure 14, the ordinate to the left shows the temperature in Kelvin and the right ordinate shows the refrigeration

15   capacity in Watt and the mass in kilogram. Curve (a) is the refrigeration capacity (W). Curve (b) is the storage tank temperature (K). Curve (c) shows the filling of the storage tank with fish (kg). Curve (d) is the evaporating temperature (K). The simulation starts at storage tank temperature 288 K and the amount of water to be chilled is 350,000 kg. There are three chilling periods (see figure 14). The first period (pre-chilling time) is

20   from time 0 seconds to 18,000 seconds. The second period is from time 18,000 seconds (5 hours), to 25,000 seconds. At this point, the tank is filled with fish and cooled. The third period is from time 25,000 seconds to 43,200 seconds and at this point, fish are added to the tank and the target temperature is maintained. While adding the fish to the tank, the refrigeration compressor is stopped and started again at 19,800 seconds (5.5

25   hours).

The results from the simulation show (figure 14, curve b) that at the end of the pre-chilling time (after 18,000 seconds or 5.0 hours), the temperature in the tank has reached 275.8 K. At this time, the evaporating temperature (Figure 14, curve d) has

30   reached 268.5 K. At time 0 (Figure 14, curve a), the refrigeration capacity of the system is 1,300 kW caused by the high evaporating temperature and ending just below 910 kW at 18,000 seconds. The amount of water in the beginning is 350,000 kg (Figure 14, curve c) ending at 710,000 kg of water/fish after two catches have been added to the tank.

35

The simulation shows that this case (case 1) can meet the design criteria set-up for the system. The lowest evaporating temperature in the system when running, period 1 (cooling) and period 2 (adding fish to the tank) is 268.5 K where the system is able to

chill the storage water within five hours (18,000 sec). The annual operating cost of this case is €78,559 (see table of figure 13) while the total investment is €223,900.

5   The above examples and illustrations show the methodology and operation of the present invention for a given sub problem. When designing large scale energy systems such as in ships, each sub system to be considered is modeled. Each component of each subsystem has associated with it some equations and/or parameters. Most often there are three different families of equations, a component core equations, component connection equations, and component cost equations.

10

The perspective of the operational optimizing system (3) is seen in figure 3. The system (3) is connected with the vessel's machine systems (9) through programmable logic controllers (PLC), as well as equipment that measure various external conditions (18)

15   and equipment that provides global positioning information. Real-time data is stored in a central database (14). Real-time and historical information about the state of the vessel's systems is provided, both to the control room (12a) and to the bridge (12b). To manage energy consumption, the system (3) is both able to recommend fuel saving procedures to the user, and automatically control (11) the machine systems according to

20   operational optimization algorithms and user settings. Moreover, the system provides a web interface, to enable users to access specific web-systems.

The general scenario for the system installation is seen in figure 5. PLCs (19) are responsible for acquiring measurements and controlling controlled objects where

25   applicable.
A server computer (20) is responsible for managing and evaluating all data (real-time and historical), for automatic control, and for delivery of automatic and manual control messages to PLCs (19) where applicable.
The client computers (12) present data (real-time and historical) to the operator, provide

30   for manual control where applicable, and allow for configuration of the system. Multiple clients can run at the same time, and the server can also run the client software.

The operator interacts with the system through the client computer (12) using for example a pointing device such as a mouse and keyboard as inputs, and monitor for

35   output. Information about the status of a vessel's machine systems is collected from OPC servers using the OPC protocol. Conversely, the system delivers control parameters to controlled objects of these systems through OPC interface. Some information, e.g., GPS and MetaPower, is collected using the NMEA protocol. TCP is used in all communications

over LAN, except when the Maren Server talks to the NMEA devices over LAN, in which case UDP is used.

The system functionality is divided into two primary functions. These are: Client functions, and Server functions.

Client:

The client can support two configurations: One for the control room (engineers) and the other for the bridge (captains). The difference lies in the number of UI-components that shall be available to the user through the Navigation pane, and the size of UI-elements.

As previously stated, the operator interacts with the system through a client computer using a monitor, pointing device such as mouse and keyboard. The user interface shall have the following panes available at all times.

A Logo and Date/time is displayed as well as the current system date and time according to the Universal Time.

A Navigation pane allows the user to navigate between the different User Interface (UI) components.

A Message pane displays time-stamped messages and possible recommended operations. The Message pane provides means to acknowledge messages (changing their status from "Pending" to "Acknowledged"). "Acknowledged" messages and "Invalidated" messages are automatically removed from the Message Pane, but are available from history. If the message contains a recommended operation, the user should be able to approve the operation from the Message pane, changing its status from "Pending" to "Approved". Messages should be listed in chronological order, meaning that the newest valid message is listed first.

A System pane displays an interface to the currently chosen UI-component. A UI-component can have its contents divided into at least one page/screen. If the content is divided between two or more pages/screens, the UI-component provides a list of the names of these, which are displayed in a special section of the System pane. The System pane has a titled window to page contents. One page is chosen and visible at each time. If a UI-component has only one page, that is its default page. UI-component's default page is opened when the UI-component is chosen from the Navigation pane.

Trip Information pane displays general information about the current trip, such as its duration, oil usage and costs. For fishing vessels, the duration of ongoing trawling is displayed (trawling clock) and the duration of last trawling is displayed in between

5   different trawling.

The following UI components are available to be displayed in the system pane.

Tag Settings displays the currently defined system tags and detailed information about

10   the currently chosen tag.

Human Machine Interface (HMI) lists system diagrams and other figures currently defined in the system. It shows the currently chosen system diagram or figure. System diagrams are models of the vessel's systems and show the current state of the vessel.

15   Other figures show for example the deviation from optimal operation.

History Viewer charts a historical overview of measurements and derived values. The History
Viewer should list the currently defined tags in the system, and names of line charts that

20   have been created and saved for quick retrieval of frequently viewed data. The History Viewer should show the currently chosen line chart. Each line chart is derived from values of one system tag or a set of system tags.

Report Viewer lists all report types that are generated in the system. When a report

25   type is chosen from the list, a report of that type is generated according to up-to-date information.
Trip Summary shows information about present and past trips, and allows for editing of certain trip properties. The type of information displayed depends on the application area (e.g. fishing vessels or cargo carriers).

30

Web interface is provided and allows the user to access predefined 3rd party web systems (e.g. web-based email client). It should NOT provide complete Internet access. Zero, one or more such web interfaces should be provided and shown as different items in the Navigation pane.

35   Message History shows a chronological list of messages that have been generated in the system and sent to users (to the Message pane), along with their status ("Pending", "Acknowledge", "Approved", "Invalid").

Suppliers' Diagram Library lists all System/Pipe diagrams that are available from the suppliers of the vessel's machine systems. The user should be able to browse between diagrams and zoom in and out of diagrams.

5   *System Monitor* displays the status of system services.

Cruise control assists the operators in controlling the ship when it is steaming. The cruise control UI-component enables the operators to modify the cruise control configuration and constraints and view its status. Different cruising strategies can also be compared.

10   Help User help should be provided in the form of a user manual in portable document format (pdf), enabling browsing between different topics.

Server:

The server primarily handles the Data Acquisition, Storing and Delivery, Operational

15   Optimization, Message Generation and Delivery, Report generation.

Data Acquisition:

The Data Acquisition [DAQ] (37) is shown in figure 16. It receives measurements (22) from PLC's monitoring different items of the machinery and delivers control signals (23)

20   to the control devices. It, moreover, receives measurements and information (24) from external sources such as GPS and weather monitoring instruments. The DAQ (37) also delivers messages (25) to the client computers, and receives control signals (26) also from the client computers. The operational optimization module also receives measurement signals (27) from the DAQ (37) and delivers control signals (28) to the

25   DAQ (37). The DAQ (37) also generates messages (29) based on the measured values. The DAQ (37) also derives (30) new values or tags from received measurements. Finally, periodically the DAQ (37) loggs (stores) (31) values in the database for historical retrieval, and monitoring and control generation(32). The logging interval is configurable, but the default is 15 sec.

30   The DAQ (37) is an OPC client, and connects to one or more OPC servers. In accordance with the OPC specification, OPC server tag groups, containing OPC items, are created for each server connection with a specific update rate (and possibly deadband). Each OPC item is mapped to a specific tag, e.g. "Omron_HostLink.C500.DM0015" might correspond to "Tension to starboard trawl winch". The OPC server delivers to the DAQ

35   (37) updated values for tags in a tag group, at the interval specified for the tag group (e.g. every 500 ms), only for values that have changed more than specified by the tag group's deadband (e.g. 2%).

Tags:

An NMEA tag is mapped to a specific NMEA string and a field number. Example:

The tag "Speed [knots]" is mapped to the NMEA string identifier VTG, and field number 7.

5   If the DAQ receives the following NMEA string: $GPVTG,89.68,T,,M,0.00,N,0.0,K*5F

The value of the tag "Speed [knots]" is set to 0.0 knots (7th field).

Derived tags are tags calculated from other tags. They can be calculated from measeured tags or other derived tags. The derived tags are calculated and sent whenever some parameter tag is modified. Tags that are calculated from time dependent

10   functions such as the running average shall also be updated periodically.

The DAQ shall connect to the operational optimization service and receive model tags. Model tags contain the value of variables that are defined in the simulation model and are updated after its solution. The input parameters used in the simulation model are the measured parameters, i.e. not the optimal parameters.

15   Timer tags are associated with another tag and some condition(s). Timer tags measure time, and tick while the condition is fulfilled. They can be used to monitor running times, e.g. "Running time of main engine" with the condition "Engine RPM" > 100.

Operational Optimization and Message Delivery:

20   The Operational Optimization System (OO) (33) receives measurements (27) from DAQ of the state of equipment onboard the vessel and uses that information to increase its fuel efficiency. To achieve this, the system uses a computer simulation simulation model (7) of the vessel to find optimal values of the ship's operational parameters. The optimal operational parameters are then either used to control (23) onboard equipment or to

25   generate advice (38) to the ship's operators on how its energy efficiency can be increased.

The general objective of the system is to generate control signals (23) and advice (38) such that if the advice is followed the deviation between simulated values and measured values will be within a predefined tolerance after a fixed time interval, and that the

30   simulated values are near optimal.

It is also possible to specify a condition that a specific measured variable (tag) shall fulfill and have the OO system generate a warning if the condition is broken (max, min conditions). Conditional warnings (40) are defined by the ship's operators via the client computers (Tag Settings). The OO receives the latest measurements from DAQ (27).

35   System configuration and constraints are read from the database (14) but can in some cases be configured by the ships operators once the system is started. Constraints and configurations that can be modified are identified as such in the database and all changes to them shall be logged.

The system configuration (35) determines which variables are to be controlled by the system. The configuration (35) is loaded from the database (14) when the system is started and it can also be modified once the system is running, for example when turning on cruise control which requires the system to take control of the propeller

5   thrust.

The constraints (36) are conditions that the system should try to full-fill when controlling equipment. They are loaded when the system is started and can be modified once it is running. The operators can for example specify time constraints for the cruise control.

10   The main units of the OO system are:

Optimization:

The optimization unit (10) uses various optimization algorithms to find optimal values of operational parameters. The OO system includes optimization algorithms that can be used to efficiently optimize the control of, e.g., refrigeration systems, propulsion systems

15   and fishing gear. The optimization problem can be a linear or nonlinear problem of multiple variables that uses a simulation module (7) to calculate its objective function. It shall also be possible to integrate optimization algorithms in external libraries into the system.

The simulation module (7) that describes the system is an external library created

20   specifically for each installation.

State detection:

The state detection unit (34) monitors measurements of the state of equipment and attempts to identify the operation being performed onboard. The possible states differ

25   between vessels, for fishing vessels, e.g., the possible states could be: "trawling", "pay out", "hauling", "steaming", "preparing", and "pumping".

Regulation:

The regulation unit (35) is used to regulate controlled values that are not optimized

30   because of constraints that apply to them. For example, in the cruise control, the operators can specify that the ship should be steeming at a constant speed which requires that the propeller thrust is regulated in order to maintain that speed.

Message management:

35   The message generation unit (37) receives information from the Optimization (10), State detection (34), and Regulation units (35) and generates the messages (29) sent to other systems. It shall keep track of messages sent and which messages have been

acknowledged or approved. The message generation unit shall also invalidate messages if they no longer apply.

The OO system generates eight types of messages:

Control Signals:

The control signals (23) are sent to equipment that is controlled by the server (20). They are set points that are sent to the DAQ (37), which determines where the control lies at each instance (automatic control may have been overridden by the user in some way), and, if applicable, forwards the OO control signals to the PLCs that control the corresponding equipment.

Advice

Advice messages (38) are sent to the client computer where they are displayed. An advice message (38) contains the following information:

Short text message that describes a specific operation that should be performed.

An estimate of the amount of fuel saved by performing the operation.

If the operation described in the advice can be performed from the system (through a controlled object), a confirmative action is attached to the operation. If the operation is confirmed by the user it is performed by the system.

Warnings:

Warnings (39) are short text messages generated if the system detects that it cannot control the vessel within the specified constraints. If the system is for example configured to control propeller thrust with the aim of minimizing oil usage pr. mile with the constraint that the vessel should arrive at its destination before some specified time, the system should generate a warning if it detects that the destination cannot be reached within the time constraint.

Conditional Alerts:

The conditional alert (40) messages contain the message string associated with the condition.

Numerical Results:

A numerical results (41) message is sent for each variable that is displayed in the HMI. The message contains the following information: Measured value used in the simulation (if available), Optimal value, and Deviation between optimal and measured values (if the measurement is available)

Numerical result messages should be sent when significant changes to the state of equipment occur.

State:

The OO shall detect the operation being performed onboard and send a message that identifies the current state (42).

Time in state (43):

The OO measures the time spent in the current state and sends a message. The time spent in a group of states can also be measured.

Achievable savings:

5   An achievable savings (44) message contains an estimate of possible energy savings in each subsystem (propulsion, refrigeration or fishing gear) and an estimate of the total achievable savings.

All messages include a time stamp, i.e. the time they were sent from the OO service.

10   'Pending' advice messages (38), conditional alerts (40) and warnings are displayed on the client computer, and all such messages are available in the Messages History, regardless of their status. Numerical results (41) and control signals (23) are displayed on the client computer.

The time constraints that apply to the delivery of control messages can differ.

15   Sometimes it is sufficient to generate messages in a fixed time interval, for example every two seconds, and sometimes it may be necessary to respond immediately to user input by generating messages, for example when controlling propeller pitch and main engine rotation. There the thrust is set by the user and the system must respond immediately by sending control signals for pitch and rotation that will achieve the

20   specified thrust. The signals do not have to be optimal if the thrust is being modified frequently, for example when the vessel is accelerating, but if the ship is cruising at constant thrust the control should be optimized.

The OO system is equally adaptable to different types of vessels for example fishing ships and cargo vessels. It should not be necessary to modify and rebuild the OO (33)

25   service for each installation. All configurations such as variable definitions, optimization problem descriptions and type of optimization algorithm to use are defined externally and the system configured automatically when it is started.

Report Generation:

The Report Generator has the role of extracting information from the database (14),

30   processing it and presenting it to the user in the form of a report. The report presented to the end user is based on his/hers request parameters and navigation through the Report Viewer UI-component.

Report options and content will vary between different application areas. There will for example be a difference in the reports presented for fishing vessels and cargo carriers.

35   The Report Generator must contain the following features:

Data Handling

Configurability for using different data storages. Connectivity to a data storage associated with the DAQ (37). Fetching of data from data storage and user request parameters.

5   Report Creation
Capability of displaying reports that the user can view and browse between. Capability of rendering reports for HTML, PDF, Excel. Capability of scheduling and emailing reports for report subscription.

10   Report Reusability
Reports should be reusable between similar application areas, i.e. fishing vessels in similar fishing operation.

Data Quality
15   The data required for creating reports depends on the application area, customer needs and data available from the DAQ and the Trip Summary.

Example:
20   The following example shows one of many different ways the present invention can operate, and is included here for illustration purposes. The example is not intended to limit the scope of the application as claimed in the following set of claims.
A ship sails from Reykjavik, Iceland to New York, USA from New York to Copenhagen, Denmark, in a one voyage. Before departing the operator enters the preferred route into
25   the system. The preferred route is the route which the operator thinks is the most appropriate.

The system reads the points entered by the operator which can be of any granularity. The system stores the route in a database once the route has been entered into the
30   system. Moreover, the system requests a weather forecast and starts simulating the preferred route as well as routes for the same kind of voyage already stored in the database as a historic data of previous voyages. Ones the set of potential routes have been calculated the operator is presented with the results and has the option of selecting the route based on the objectives he wants to meet.
35

These objectives may be different for different situations and circumstances. One objective could be to maximize energy efficiency. For example: a cargo vessel with safe cargo would take the most efficient route while a cruise ship might take the route which

will maximize the time passengers spend at the bars and casinos. There may also be more than one constraints or objectives to meet. For example: a cargo vessel wants to take the most efficient route which will in addition meet the objective of arriving at the destination at 6 AM of the arrival day.

5

During the travel the simulator re-calculates the selected route over and over again with the real data acquired by the ships instrumentation and new weather forecasts. If a better route is found the system suggests to the operator the best variant to achieve the desired objectives. Moreover, the voyage is recorded into a database along with exact

10   weather parameters obtained as well as all other parameters relative to the simulation. These are for example ships load, trim, and ballast, as well as all the parameters of the energy system as discussed earlier.

The system would for example suggest an optimal speed during each sub-leg of the

15   voyage. For example: when the weather is expected to be calm and the ocean current in the direction of travel at some leg X, it may be economical to increase the speed during that leg. In such case the system will suggest so. In other instances, for example during leg X+10 the system expects the wind to be ahead of the starboard side of the ship and the ocean current against the direction of travel, in this case it might be economical to

20   slow down the speed during that leg. In making these predictions the system will optimize the operation of the ship according to the objectives entered by the operator.

The weather forecast can be provided in multiple ways, but preferably over a data link from respected meteorological institutions. In the case of areas were no such data link is

25   provided the operator might need to manually enter data received from a satellite broadcast. In other cases a separate weather forecast computer might be used to specifically simulate and forecast weather within some limited area such as the 24 hour traveling radius. This weather forecast would build on the weather forecast, as discussed earlier, as well the local conditions provided by the instruments available on the ship it

30   self. Thus the forecast for the close proximity has the potential of being more accurate over the near future (for example for the next 4, 6, 12, 24 hour periods and travel distance).

35

<u>Claims</u>

1.   A route selection method for selecting a route for a vehicle, comprising the steps:
receiving information relating to environmental conditions across a geographic area;
5   storing an energy usage model which relates fuel efficiency of the vehicle and the
environmental conditions; and selecting a route across the geographic region from a
start location to a destination location in dependence on the energy usage model and the
received environmental conditions information; wherein the selecting step selects the
route so as to optimize an objective function.
10

2.   A method according to claim 1, wherein said objective function is to optimize fuel
efficiency.

3.   A method according to claim 1, wherein said objective function is to optimize
15   time of arrival.

4. A method according to claim 1, wherein said objective function is to optimize
environmental safety.

20   5.   A method according to claim 1, wherein said objective function is to optimize
cargo safety.

6.   A method according to claim 1, wherein said objective function is to optimize
passengers and crew comfort.
25

7.   A method according to claim 1, wherein said objective function is the combination
of one or more of the objective functions of claims 2 – 6.

8.   A method according to claim 1, and further comprising the step of receiving
30   information relating to a desired arrival time at the destination; wherein the route
selecting step further comprises selecting said route and/or said speed of travel along
said route such that said vehicle arrives at said destination location at or before said
desired arrival time.

35   9.   A method according to any of the preceding claims, wherein the environmental
conditions comprise sea conditions.

10.   A method according to claim 9, wherein the sea conditions comprise any one or more of the group comprising: wave height; wave direction; current speed; current direction.

5   11.   A method according to any of the preceding claims, wherein the environmental conditions comprise weather conditions.

12.   A method according to claim 11, wherein the weather conditions comprise any one or more from the group comprising: wind speed; wind direction.

10

13.   A method according to any of the preceding claims, wherein the received environmental conditions information further includes prediction information relating to predicted future environmental conditions, wherein the route selecting step is further arranged to select said route in dependence on said prediction information.

15

14.   A method according to claim 13, wherein the route selecting step comprises, for a candidate waypoint to be possibly incorporated as part of said route, estimating a time of arrival at that candidate waypoint, determining the predicted environmental conditions at the candidate waypoint at the estimated time of arrival, and using the determined

20   predicted environmental conditions with said energy usage model to determine whether to include said candidate waypoint as part of said route.

15.   A method according to any of the preceding claims, wherein said route selecting step comprises the steps of:

25   determining a plurality of possible routes between said start position and said destination position, each route comprising a plurality of waypoints;

         calculating, using said energy usage model, energy usage between each waypoint along each possible route;

         selecting the route which provides the maximum energy efficiency as said route

30   to be followed.

16.   A method according to claim 15, wherein said route determination step further comprises selecting a waypoint as a waypoint to be incorporated as part of at least one of said possible routes in dependence on a geographic location of said waypoint meeting

35   one or more boundary criteria.

17.   A method according to claim 16, wherein a boundary criterion is that said geographic location of said waypoint is less than or equal to a threshold distance from a corresponding location on a predetermined route.

5   18.   A method according to claim 17, wherein said threshold distance is adapted in dependence on distance along said route from said start position or said destination position.

19.   A method according to claim 18, wherein said threshold distance is larger the
10   further away the waypoint is from said start position and/or said destination position.

20.   A method according to claim 16, wherein a boundary criterion is that said geographic location of said waypoint would result in a vehicle heading within a threshold angle of a heading specified by a predetermined route.
15
21.   A method according to claim 20, wherein said threshold angle is adapted in dependence on distance along said route from said start position or said destination position.

20   22.   A method according to claim 21, wherein said threshold angle is larger the further away the waypoint is from said start position and/or said destination position.

23.   A method according to any of claims 17 to 22, wherein said predetermined route is a substantially preferred route entered by an operator.
25
24.   A method according to any of claims 17 to 22, wherein said predetermined route is route which would be taken by travelling on a direct heading from said start position to said destination position.

30   25.   A method according to any of claims 17 to 22, wherein said predetermined route is a route which would be taken by travelling on a direct heading from a present position along a route to said destination position.

26.   A method according to any of claims 17 to 22, wherein said predetermined route
35   is a route which would be taken by travelling on a great circle.

27.   A method according to any of claims 17 to 22, wherein said predetermined route is a route which would be the shortest distance from destination to arrival.

28.   A method according to any of the preceding claims, wherein said energy model further takes into account internal energy usage of the vehicle in addition to energy used for propulsion whilst travelling from said start position to said destination position, the selecting step selecting a route which maximises overall energy efficiency.

29.   A method according to any of the preceding claims, and further comprising the step of displaying said selected route to an operator on a display.

30.   A method according to any of the preceding claims, wherein said environmental conditions information is arranged such that a set of parameters is provided for discrete locations across the geographical region, wherein said discrete locations are used as possible waypoints for said route.

31.   A method according to any of the preceding claims, wherein the environmental conditions information is in the WMO GRIB format.

32.   A method of operating a vehicle to travel from a start position to a destination position, comprising the steps of:
        selecting a route to be followed by said vehicle in accordance with the method of any of the preceding claims; and
        controlling said vehicle to follow said route.

33.   A method according to any of the preceding claims, wherein said vehicle is a sea-going vessel.

34.   A computer program or suite of computer programs, arranged such that when executed by a computer system they cause the computer system to operate in accordance with the method of any of the preceding claims.

35.   A computer readable storage medium storing the computer program or at least one of the suite of computer programs according to claim 34.

36.   A route selection apparatus for selecting a route for a vehicle, comprising:
        a communications receiver for receiving information relating to environmental conditions across a geographic area;
        a memory which stores an energy usage model which relates fuel efficiency of the vehicle and the environmental conditions; and

a route selection controller configured to select a route across the geographic region from a start location to a destination location in dependence on the energy usage model and the received environmental conditions information;

wherein the route selection controller selects the route so as to optimize an objective function.

37.   An apparatus according to claim 36, wherein said objective function is to optimize fuel efficiency.

38.   An apparatus according to claim 36, wherein said objective function is to optimize time of arrival.

39.   An apparatus according to claim 36, wherein said objective function is to optimize environmental safety.

40.   An apparatus according to claim 37, wherein said objective function is to optimize cargo safety.

41.   An apparatus according to claim 37, wherein said objective function is to optimize passengers and crew comfort.

42.   An apparatus according to claim 37, wherein said objective function is the combination of one or more of the objective functions of claims 37 to 41.

43.   An apparatus according to claim 36, and further comprising an input device to allow an operator to input information relating to a desired arrival time at the destination; wherein the route selection controller is further configured to select said route and/or said speed of travel along said route such that said vehicle arrives at said destination location at or before said desired arrival time.

44.   An apparatus according to any of claims 36 or 43, wherein the environmental conditions comprise sea conditions.

45.   An apparatus according to claim 44, wherein the sea conditions comprise any one or more of the group comprising: wave height; wave direction; current speed; current direction.

46.   An apparatus according to any of claims 36 to43, wherein the environmental conditions comprise weather conditions.

47.   An apparatus according to claim 46, wherein the weather conditions comprise any one or more from the group comprising: wind speed; wind direction.

48.   An apparatus according to any of claims 36 to 47, wherein the received environmental conditions information further includes prediction information relating to predicted future environmental conditions, wherein the route selection controller is further configured to select said route in dependence on said prediction information.

49.   An apparatus according to claim 48, wherein the route selection controller is further configured to perform the following steps:-

for a candidate waypoint to be possibly incorporated as part of said route, estimate a time of arrival at that candidate waypoint;

determine the predicted environmental conditions at the candidate waypoint at the estimated time of arrival; and

use the determined predicted environmental conditions with said energy usage model to determine whether to include said candidate waypoint as part of said route.

50.   An apparatus according to any of claims 36 to 49, wherein said route selection controller is further configured to determine a plurality of possible routes between said start position and said destination position, each route comprising a plurality of waypoints; said apparatus further comprising a vehicle energy usage calculator configured to calculate, using said energy usage model, energy usage between each waypoint along each possible route; wherein said route selection controller then selects the route which provides the maximum energy efficiency as said route to be followed.

51.   An apparatus according to claim 50, wherein said route selection controller is further configured to select a waypoint as a waypoint to be incorporated as part of at least one of said possible routes in dependence on a geographic location of said waypoint meeting one or more boundary criteria.

52.   An apparatus according to claim 51, wherein a boundary criterion is that said geographic location of said waypoint is less than or equal to a threshold distance from a corresponding location on a predetermined route.

53.   An apparatus according to claim 52, wherein said threshold distance is adapted in dependence on distance along said route from said start position or said destination position.

54.   An apparatus according to claim 53, wherein said threshold distance is larger the further away the waypoint is from said start position and/or said destination position.

5   55.   An apparatus according to claim 51, wherein a boundary criterion is that said geographic location of said waypoint would result in a vehicle heading within a threshold angle of a heading specified by a predetermined route.

56.   An apparatus according to claim 55, wherein said threshold angle is adapted in
10   dependence on distance along said route from said start position or said destination position.

57.   An apparatus according to claim 56, wherein said threshold angle is larger the further away the waypoint is from said start position and/or said destination position.
15
59.   An apparatus according to any of claims 52 to 57, wherein said predetermined route is a preferred route entered by an operator.

59.   An apparatus according to any of claims 52 to 57, wherein said predetermined
20   route is route which would be taken by travelling on a direct heading from said start position to said destination position.

60.   An apparatus according to any of claims 52 to 57, wherein said predetermined route is a route which would be taken by travelling on a great circle.
25
61.   An apparatus according to any of claims 52 to 57, wherein said predetermined route is a route which would be the shortest distance from destination to arrival.

62.   An apparatus according to any of claims 52 to 57, wherein said predetermined
30   route is a route which would be taken by travelling on a direct heading from a present position along a route to said destination position.

63.   An apparatus according to any of claims 36 to 62, wherein said energy model further takes into account internal energy usage of the vehicle in addition to energy used
35   for propulsion whilst travelling from said start position to said destination position, the route selection controller being further configured to select a route which maximises overall energy efficiency.

64.   An apparatus according to any of claims 36 to 63, and further comprising a display for displaying said selected route to an operator.

65.   An apparatus according to any of claims 36 to 64, wherein said environmental conditions information is arranged such that a set of parameters is provided for discrete locations across the geographical region, wherein said discrete locations are used as possible waypoints for said route.

66.   An apparatus according to any of claims 36 to 65, wherein the environmental conditions information is in the WMO GRIB format.

67.   An apparatus for operating a vehicle so as to cause said vehicle to travel from a start position to a destination position, comprising:
       a route selection apparatus in accordance with any of claims 36 to 66; and
       a vehicle control arrangement for controlling said vehicle to follow said route.

68.   An apparatus according to any of claims 36 to 67, wherein said vehicle is a sea-going vessel.
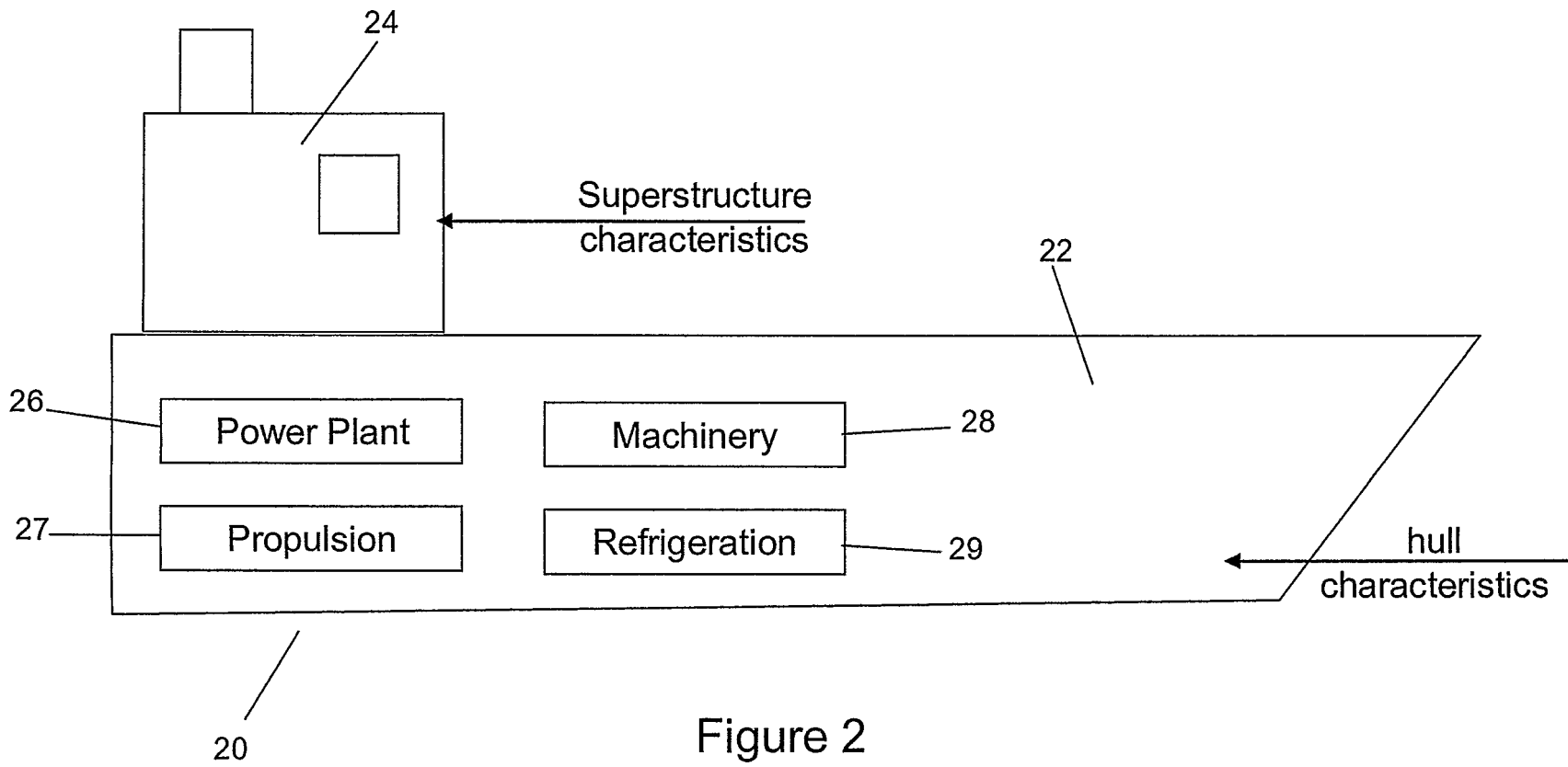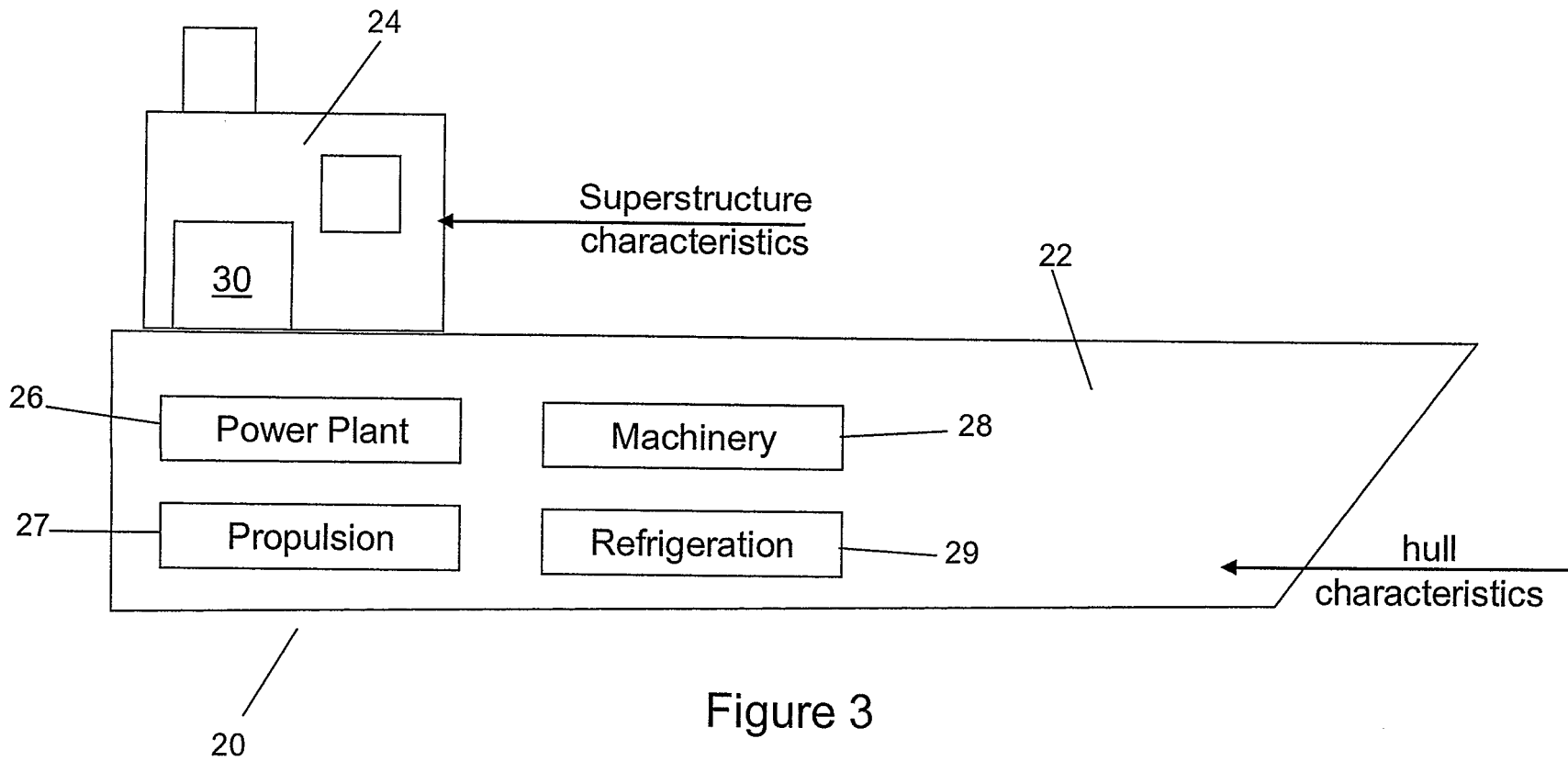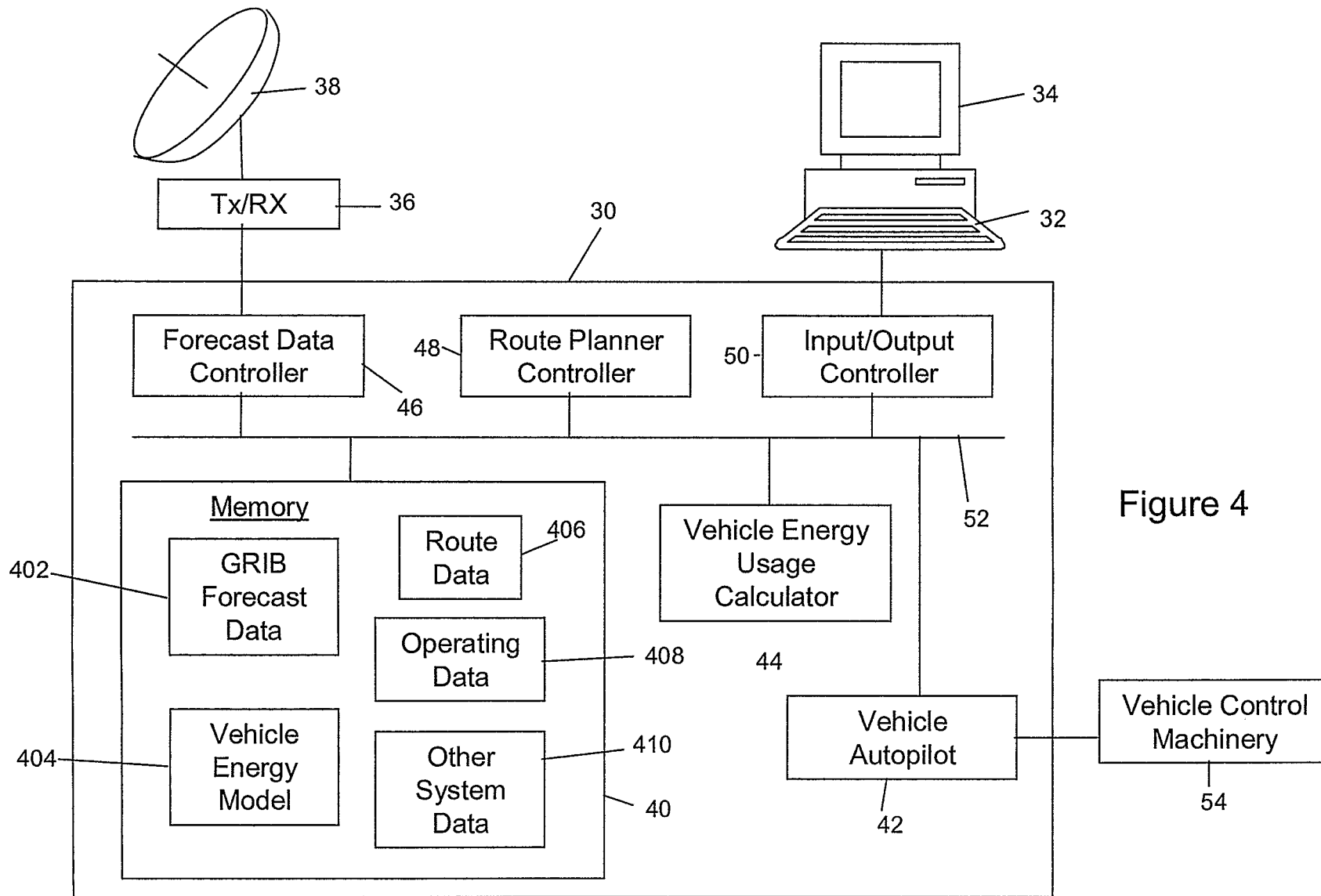
Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

13/21

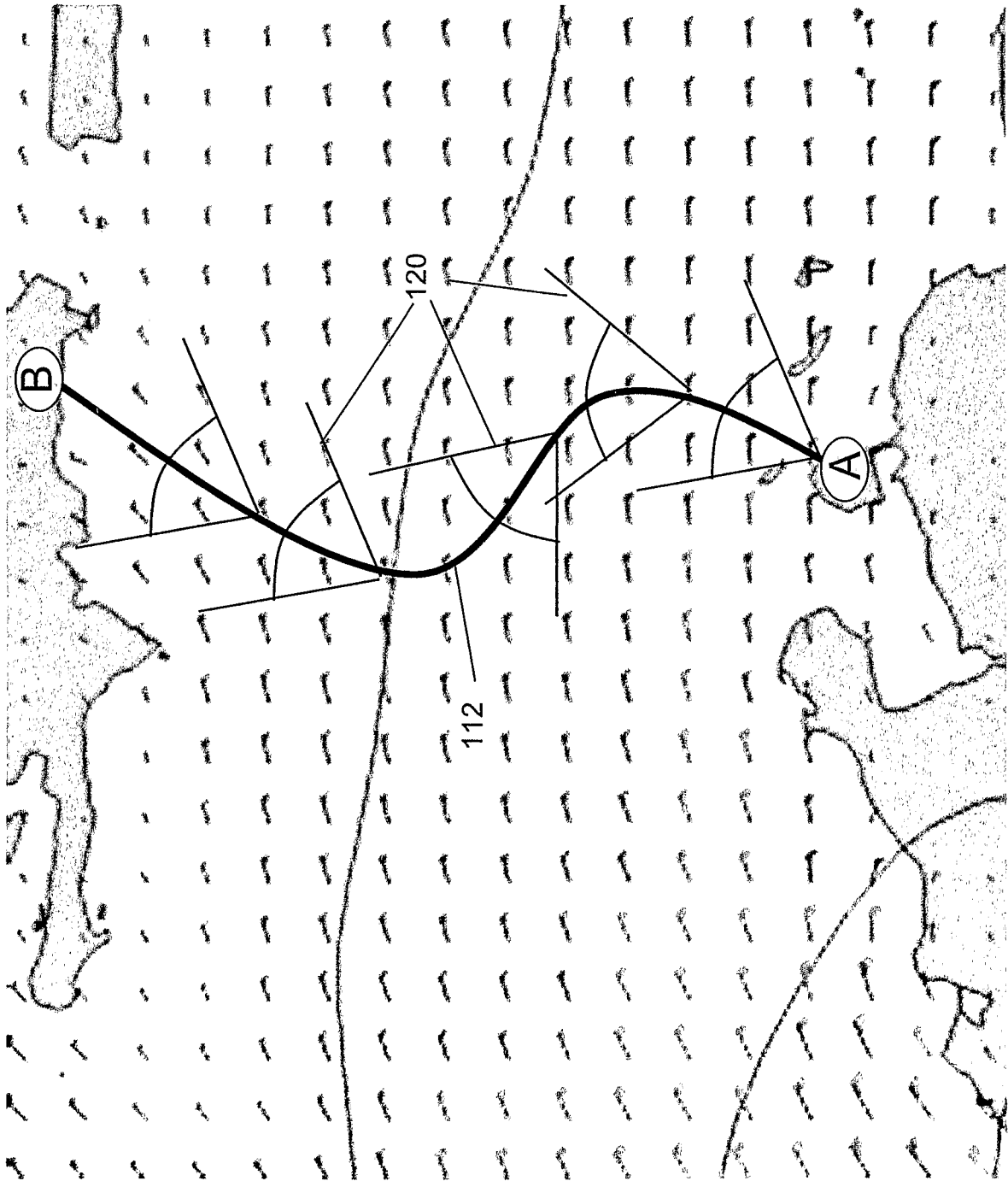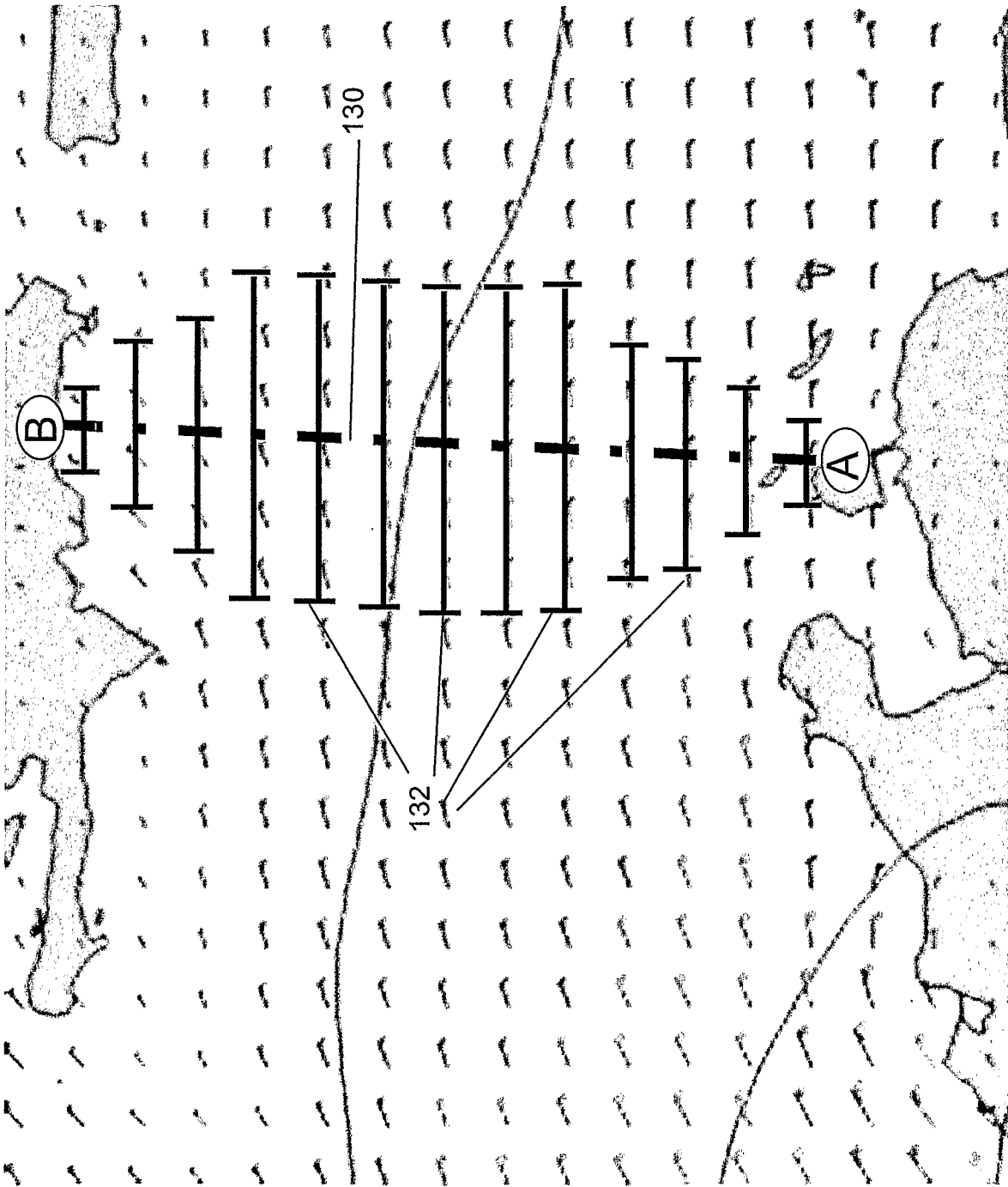Figure 13

Figure 14

Figure 15

Figure 16

S.17.2

```
┌─────────────┐
│   Receive   │
│   Present   │         S.17.4
│ Position,   │      ┌──────────┐       S.17.6
│ Time,       │      │ Initialise│    ┌──────────────┐
│ Destination,│ ───> │   Route  │ ──>│ Route Planner│
│ Desired     │      │  Planner │    │  Calculates  │
│ Arrival     │      └──────────┘    │ Route Using  │
│   Time      │                      │Vehicle Energy│
└─────────────┘                      │    Usage     │
                                     │  Calculator  │
                                     └──────────────┘
```

S.17.8

S.17.10

```
┌──────────┐       ┌──────────┐
│  Store   │       │ Display  │
│Calculated│ ────> │ Route on │
│  Route   │       │  Screen  │
└──────────┘       └──────────┘
                        │
                        │
                        v
                 ┌──────────────┐
                 │Control Vehicle│
                 │ to Follow Route│
                 └──────────────┘
```

Figure 17

S.17.12

Set Present node *i* to starting position

S.18.2

Calculate next hop positions *j[n]* and Energy Usages to next hop positions

S.18.4

Iteratively repeat for each next hop position until destination to build decision tree

S.18.6

S.18.12

Traceback along branch to determine route

S.17.6

S.18.10

Determine branch with lowest total energy sum

Sum energy values along each branch of decision tree

S.18.8

Figure 18

Apply bounds to
determine list *j[n]*
of possible next
hop waypoints

S.19.4

Initialise present
hop position *i*

S.19.2

Return

S.19.22

For each
possible next
hop *j[n]*

S.19.6

Next *j[n]?*

S.19.20

Form branch *(i,
j[n])*, and label
with E(*i, j[n]*)

S.19.18

Form node *j[n]*
in decision tree

S.19.16

Estimate time
at position *j[n]*

S.19.8

Look up local conditions
at position *j[n]* at est.
time from GRIB data

S.19.10

Pass local condition
information to vehicle
energy usage calculator

S.19.12

Calculate Energy Usage
E(*i, j[n]*) to travel from
position *i* to position *j[n]*

S.19.14

S.18.4

Figure 19

Figure 20

S.21.6

| Receive local condition information at position *i* and position *j[n]* | → | Determine distance and sailing time from position *i* to position *j[n]* | → | Apply parameters from position *i* to ship model for half of sailing time to determine fuel usage to get from *i* to halfway to position *j[n]* |

S.21.2

S.21.4

Apply parameters from position *j[n]* to ship model for half of sailing time to determine fuel usage to get from halfway to position *j[n]* to position *j[n]*

Sum fuel usage to get total fuel usage

S.21.10

S.21.8

S.19.4

Figure 21

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01C21/00 G01C23/00 G01C21/20 G05D1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01C G05D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 59 024314 A (NIPPON HAKYO KIKI KAIHATSU; MITSUBISHI HEAVY IND LTD) 8 February 1984 (1984-02-08) abstract -/--	1,2,7, 9-13,15, 28,29, 32-37, 42, 44-48, 50,63, 64,67,68

☒ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 May 2008	05/06/2008

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Hunt, Joke

C(Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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