# DESIGN OF COMPLETELY AUTOMATIC ODMCS

**D Dave,** Tolani Maritime Institute, Induri, India
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**SUMMARY**

This paper presents a novel approach for designing a completely automatic Oil Discharge Monitoring and Control System (ODMCS) for the discharge of oily mixtures/effluents from cargo area and slop tank of oil tankers. The Global Positioning System (GPS) and modified World Vector Shorelines (WVS) data are used for the development of a system, which completely automates the working of ODMCS to comply with Marine Pollution (MARPOL) regulations. The system level hardware and software design for the same is discussed. An animated simulator for the completely automatic ODMCS is developed. The developed system may also be used as ODMCS emulator when main ODMCS fails. The results obtained by applying the test inputs to such a system have been presented and verified against the requirements of MARPOL regulations.

**NOMENCLATURE**

| | |
|---|---|
| GPS | Global Positioning System |
| IMO | International Maritime Organisation |
| MARPOL | International Convention for Marine Pollution adopted by IMO |
| ODMCS | Oil Discharge Monitoring and Control System |
| ODV | Overboard Discharge Valve |
| STV | Slop Tank Valve |
| WVS | World Vector Shorelines |
| $\mu_p$ | Oil content (PPM) |
| Q | Flow rate ($m^3$/Hr) |
| $\rho_o$ | Oil density (Kg/$m^3$) |
| V | Volume of Oil ($m^3$) |
| S | Ship speed (Kts) |
| T | Time per simulation step (Hrs) |
| $Q_i$ | The instantaneous rate of oil discharge (Litres/Nautical Mile) |
| $m_o$ | Total oil discharge (Kg) |
| n | Number of simulation steps |
| $V_{so}$ | Oily water discharge in slop tank ($m^3$) |
| K | Number of simulation steps after the ODV is closed and STV is opened |
| $V_s$ | Slop tank capacity ($m^3$) |

## 1. INTRODUCTION

The block schematic of a typical ODMCS is as shown in Figure 1 [1]. The control unit of ODMC system is situated in cargo control room and performs control, record and alarm operations. The controller has four inputs namely, oil in water content, ship speed, discharge rate and ship position (longitudes, latitudes). The controller section of the ODMCS controls the ODV and STV according to MARPOL regulations [2]. The ODMC system continuously generates a record of effluent discharge operation on the vessel in the form of a printed output.

### 1.1 NEED FOR AUTOMATION

ODMCS is an important system for controlling overboard discharge of oily mixtures/effluents from oil tankers [3]. The norms for discharge of oily effluents are specified by international convention of marine pollution, MARPOL 73/78, annexure I, regulations 1,29,31 and 34 [2]. If these regulations are violated by human error, machine error, machine fault, negligence etc., it could be considered a serious criminal offence and may lead from huge monetary penalty to imprisonment, depending on the law of the land and extent of violation [4]. This also leads to serious repercussions for the authorities, the ship management, and the ship owner company. It is in this context that the operations and maintenance of ODMCS has to be understood with utmost care by the concerned personnel [5]. This also warrants complete automation and a reliable warning mechanism to be associated with ODMCS so that any unintentional hazards may be effectively avoided [6], [7].

At present, the ODMC systems onboard the vessels are only partially automatic. These systems need manual operation when the vessel enters or leaves a special area and also, when the ship is less than fifty nautical miles from the nearest land [2]. The paper presents a novel approach, using GPS [8]-[10] and modified WVS datasets [11], for detecting these conditions automatically, and initiating necessary alarms associated with automatic valve control actions. A working prototype model of a completely automatic, location-aware, ODMCS is developed, using ship location information from GPS and WVS database, so as to comply with the requirements of MARPOL regulations.

The ODMCS simulator, which is part of the software system, may also prove to be useful analysis and decision support tool onboard the ship, particularly when the installed ODMCS is out of operation for any reasons. It may also be used as computer based training (CBT) tool to provide training to the students of Marine Engineering, Nautical Technology and related areas, in the operations and the management of the ODMCS. The system also enables the user to select the most suitable discharge pump so as to discharge the oily mixtures/effluent in the shortest time without violating MARPOL regulations.

### 1.2 ORGANISATION OF THE PAPER

The second section, entitled Hardware System Design, presents the system level description of hardware used to implement such an automatic control system. The third section, entitled Software Design, discusses data structures used, algorithms, and flowcharts. The forth section presents the results, obtained from the ODMCS prototype model developed, in response to some typical inputs. The limitations of this system and the assumptions made have been discussed. The fifth section presents the conclusions and future enhancements.

## 2. HARDWARE SYSTEM DESIGN

The organisation of ODMCS simulator/emulator hardware is as shown in Figure. 2. The hardware of ODMCS system with simulation facility consists of following components.

(i) A Front Panel containing three pairs of input sockets for receiving inputs from field. Optionally, these inputs may also be manually provided directly from panel for simulation purpose. These inputs are in the form of 4-20 mA current loop. The inputs are for ship speed in Kts, flow rate in cubic meters per hour, and oil content in overboard discharge water in parts per million (PPM). Three DPDT switches are provided to select between field inputs or manual inputs (simulation mode) from front panel. The front panel also displays the current values of speed (Kts), discharge rate ($m^3$/hr), oil content in discharge water (PPM), oil density (kg/$m^3$), total oil discharged (kg), instantaneous discharge rate (litres/nm), current longitudes & latitudes, and Total Cargo oil on Last Voyage (tonnes). The front panel also contains LED indicators for Power ON, Overboard discharge valve status, and Slop tank valve status. The other LED indicators on the front panel are provided to indicate MARPOL compliance status like, ship not en-route, ship near shore, ship in special area, instantaneous rate limit exceeded, and total oil discharge limit exceeded.

(ii) A data acquisition card (Dynalog™ PCI-1050 DAS Card) [12] is used to read signals from front panel/field into the computer and for sending outputs to front panel and actuating the ODV and STV.

(iii) A DIN-rail mountable screw termination board (Dynalog™ PCID-50) [13] acts as an interface between the front panel and the DAS card.

(iv) A PC with Windows™ operating system.

(v) A GPS device with RS-232 interface (Garmin™ GPS-72) [10].

Figure. 3 shows the snap shot of the developed hardware.

## 3. SOFTWARE DESIGN

The ship speed, flow rate, oil content in water, oil density, ship position (longitude and latitude), slop tank capacity, and total oil on last voyage are the input parameters for the ODMCS developed. Based on these parameters, the system computes the status of control valves for overboard discharge (ODV) and slop tank (STV). The software also produces a hard copy of the ODMCS status with configurable sampling intervals.

### 3.1 DATA STURCTURES AND CLASS LIBRARY

Following are the main classes developed to implement the ODMCS simulator.

a. CParameters class: This class encapsulates all parametric data, as mentioned above, and its associated functionality.
b. ODMC Status: This C style structure stores all the status information related to the operation of system, its internal state and output conditions.
c. CShape class: This class encapsulates all the data pertaining to geometrical shapes used in the line diagram and its functionality. The line diagram is displayed in the main window showing the animated simulation of system operation.
d. CShorelines class: This class encapsulates all the data and functionality corresponding to world vector shorelines.
e. CGPSSerialIO class: This class encapsulates all the data and functionality related to reception, interpretation and error handling related to GPS data.
f. CDataIO class: This class encapsulates all the functions for receiving data from field or control panel and displaying data and status information on control panel.

Figure. 4 shows the architecture of the software system developed.

### 3.2 ALGORITHMS AND FLOWCHARTS

Figure. 5(a) and Figure. 5(b) show the flowchart which describes the oil discharge monitoring and control process. Out of various algorithms used in the modelling and development of the ODMC system simulator, the main algorithms are presented below:

#### 3.2.1 Overboard discharge valve operation

The instantaneous rate of oil discharge, $Q_i$ , in litres per nautical mile, is defined by equation (1).

$$Q_i = \frac{\mu_p Q}{s \times 10^3} \qquad (1)$$

Total oil discharge at any particular time is given by equation (2).

 

$$m_0 = \frac{\mu_p Q \rho_0 \tau n}{10^6} \quad (2)$$

These values are used to find if there is any violation of MARPOL regulations.

3.2.2. Slop tank valve operation

The slop tank valve is opened as soon as the ODV is closed, provided the slop tank is filled less than 80% of its capacity. The oily water discharge in slop tank per simulation step is given by equation (3).

$$V_i = Q \tau k \quad (3)$$

Accordingly, the STV is closed if $V_i \geq 0.8\ V_s$.

3.2.3 Algorithm to detect if ship is in Special area

Following procedure is used to detect the presence of ship in any of the special areas as defined in MARPOL regulations.

1. Get ship position (Longitude, Latitude).
2. Start with any one of the special areas.
3. Get array of points forming a enclosing polygon (for selected special area). Each point in array represents a pair of longitude and latitude.
4. Is ship within selected special area (polygon)? If yes, go to step 7.
5. All special areas checked? If yes, go to step 8.
6. Select next special area. Go to step 3.
7. Set the ship is in restricted area alarm. Return from Procedure.
8. Clear the flag representing alarm that the ship is in restricted area. Return.

3.2.4 Algorithm to detect if the ship is less than 50 nautical miles from the nearest land:

The CShorelines class has been developed for this purpose specifically. The shorelines data is stored in the form of arrays of points organised into 1° x 1° cells [11]. There are in all 360 (longitudes) x 180 (latitudes) = 64800 cells covering whole world. The distance between any two points on the earth's surface, along the great circle, is found using the Haversine's formula [14] as follows;

$$d = R\ c \quad (4)$$

Where,
R is earth's mean radius (≈ 6371 kilometres)
$\Delta lat = lat2 - lat1$, where lat1 and lat2 are the latitudes of the two points
$\Delta lon = lon2 - lon1$, where lon1 and lon2 are the longitudes of the two points

$$a = \sin^2(\Delta lat/2) + \cos(lat1) \times \cos(lat2) \times \sin^2(\Delta lon/2)$$
$$c = 2\ \mathrm{atan2}(\sqrt{a}, \sqrt{(1-a)})$$

*Algorithm:*

a. Current_Ship_Position = (Longitude_From_GPS, Latitude_From_GPS).
b. Cell_Longitude = Longitude of the lower left corner of the current cell.
c. Cell_Latitude = Latitude of lower left corner of current cell.
d. Longitude = (Cell_Longitude - 1). If Longitude is -181, Longitude = 179.
e. If Latitude < 89 OR Latitude > -90 Than Cell_Latitude = Latitude-1.
f. Get the cell, whose lower left corner has longitude and latitude one less than that of the current cell.
g. Get the array of points for the cell obtained in step (f) and check if any of the points in the array has a distance of 50 Nm or less from the current position of ship, using equation (4). If yes, set the flag for this alarm and terminate.
h. Otherwise, repeat step (c) and (d) for all the cells up to one longitude and one latitude greater than the current cell (total 9 cells including current cell).
i. If all the cells are checked, clear the flag for corresponding alarm and terminate.

## 4. RESULTS AND DISCUSSION

Following test cases have been selected for testing the proper working of ODMCS while complying with MARPOL regulations.

Test Case 1: Voyage from shore to shore
Test Case 2: Voyage from shore to way-point
Test Case 3: Voyage from way-point to way-point
Test Case 4: Voyage from way-point to shore
Test Case 5: Instantaneous discharge limit violation (way-point to way-point)
Test Case 6: Total oil discharge limit violation (way-point to way-point)
Test Case 7: Ship not en-route (becomes stationary midway during voyage)
Test Case 8: Ship entering in restricted area (and terminating voyage there)
Test Case 9: Ship passing through restricted area (not terminating voyage)
Test Case 10: Ship in restricted area (starting voyage)

The summary of simulation results for the above test cases is presented in Table 1, wherein the alarms are enumerated as follows;

1. Instantaneous Discharge Rate > 30 L/Nm.
2. Total Overboard Discharge (Oil) > (1/30000) of Total Cargo on Last Voyage.
3. Ship Not En-route.
4. Ship in Restricted Area.
5. Ship less than 50 Nm from the *Nearest Land.*

While generating the results, except test cases 5 and 7, it is assumed that the instantaneous ship speed remains close to the average speed supplied to the simulator. Also, it is assumed that the deviation of the ship from the designated route remains within permissible limits. The simulation results agree with the results obtained using manual calculations. These results clearly demonstrate the accuracy and effectiveness of the simulator as a tool for decision support in case of failure of ODMC system installed on the ship. The additional features also help in taking other technical decisions like calculating, at a certain value of PPM, the optimal value of discharge rate without violating MARPOL regulations. The software provides for both animated graphic output showing line diagram (process view) as well as animated display of the movement of the ship on the world map (world map view) as shown in Figure 6 and 7 respectively. The user may switch between any of the two views at any time.

## 5. CONCLUSIONS AND FUTURE ENHANCEMENTS

The various test results are found to be complying with the MARPOL 73/78 regulations. The system offers a very low cost, user friendly and reliable alternative for providing computer-based training on working and operation of ODMCS, which may be used on-board as well as in training schools. The ODMCS simulator may also be used to test whether the installed ODMCS on-board the ship is functioning properly or not. If the proposed system is present on the shipboard, it may be configure to receive inputs in parallel with installed ODMCS. The outputs of the proposed system and the installed OCMCS may be compared periodically, for verifying the proper functioning of the installed ODMCS. The proposed system may also act as a reliable decision support tool, in case of failure of installed ODMCS. The system may be proposed as a replacement for installed ODMCS after the sea-trials of the same are completed.

Some other location-based management and control features like, waste management, automatic detection of sulphur emission control area (SECA) etc. may be easily incorporated in the system at later stages.

## 6. ACKNOWLEDGEMENS

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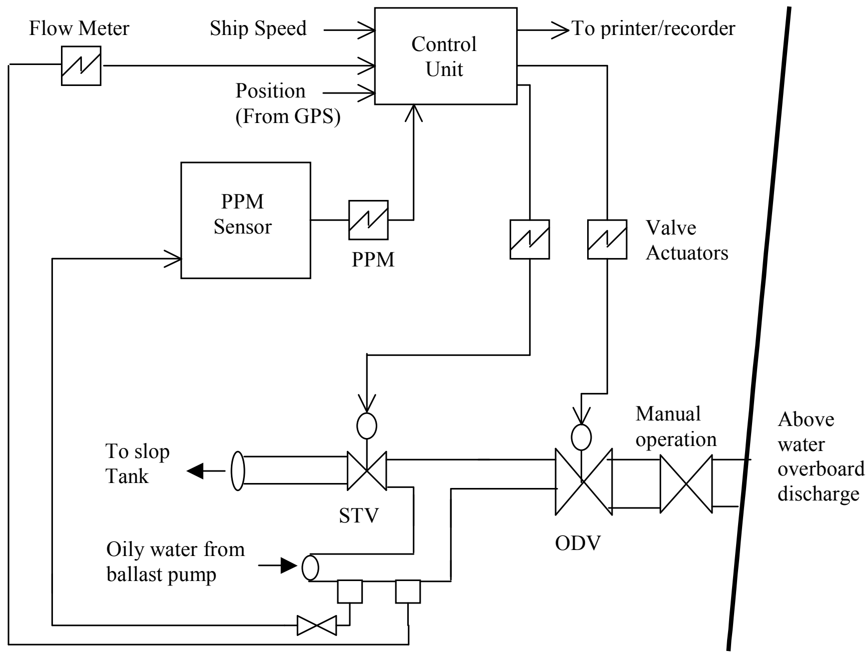


Figure 1: Block Schematic of ODMCS

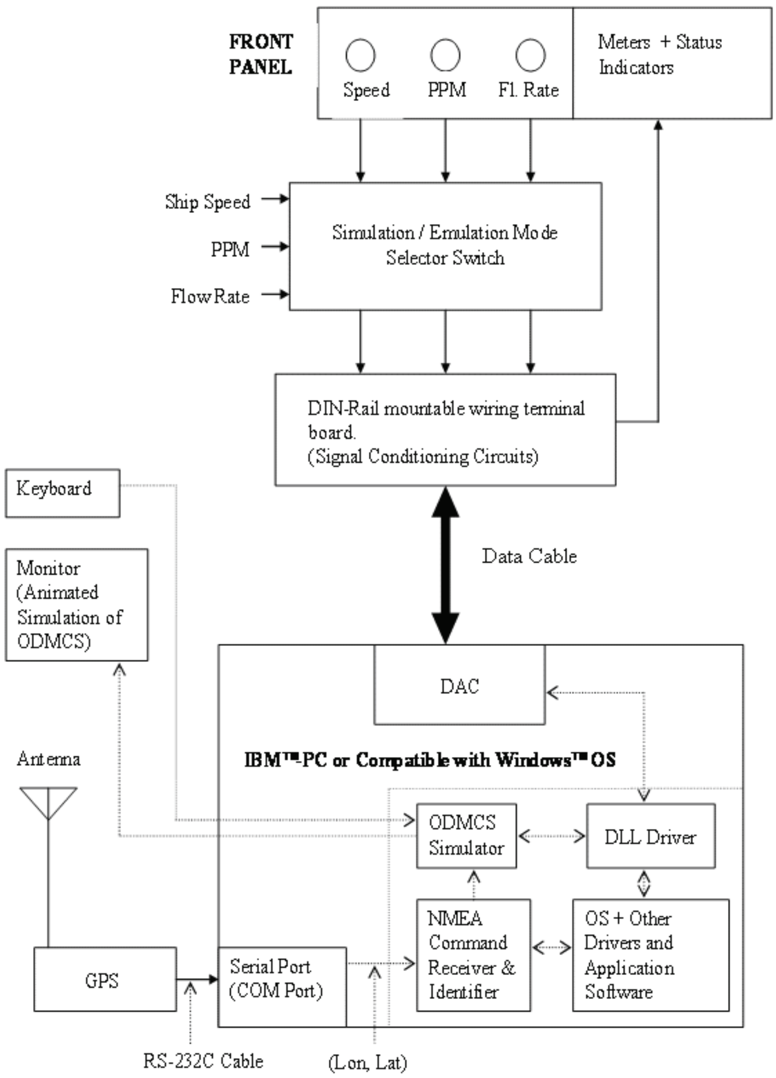


Figure 2: Organisation of ODMCS Simulator Hardware and Software. The solid lines represent the hardware connections (wires and cables) where as the dashed lines represent the software data flow within the system.


Figure 3: Snapshot of the front panel developed for ODMCS Simulator

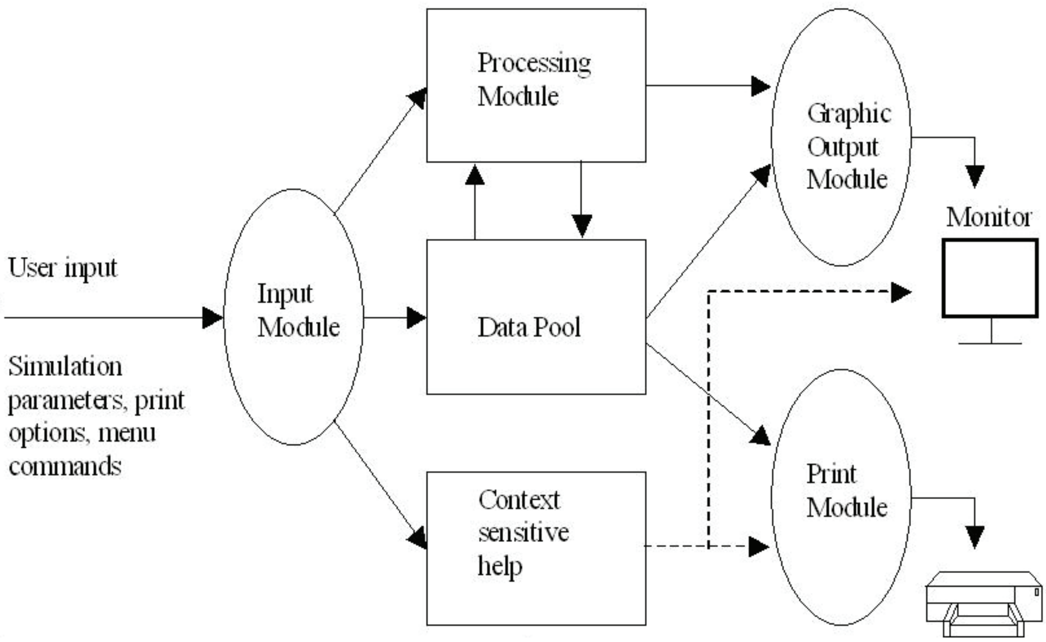


Figure 4: ODMCS Simulator Architecture

 

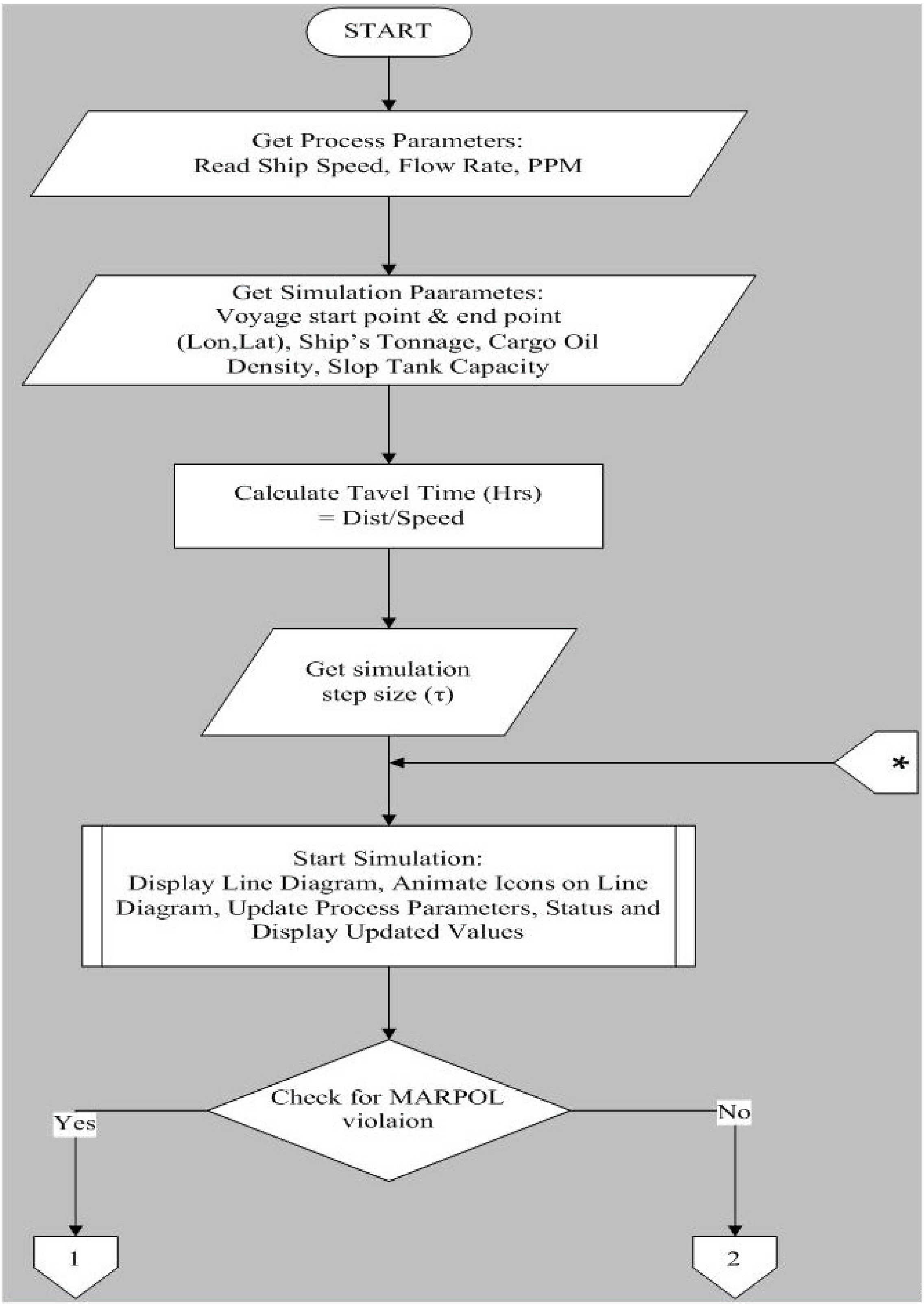

Figure 5(a): The flow chart describing the general system level flow of simulation logic

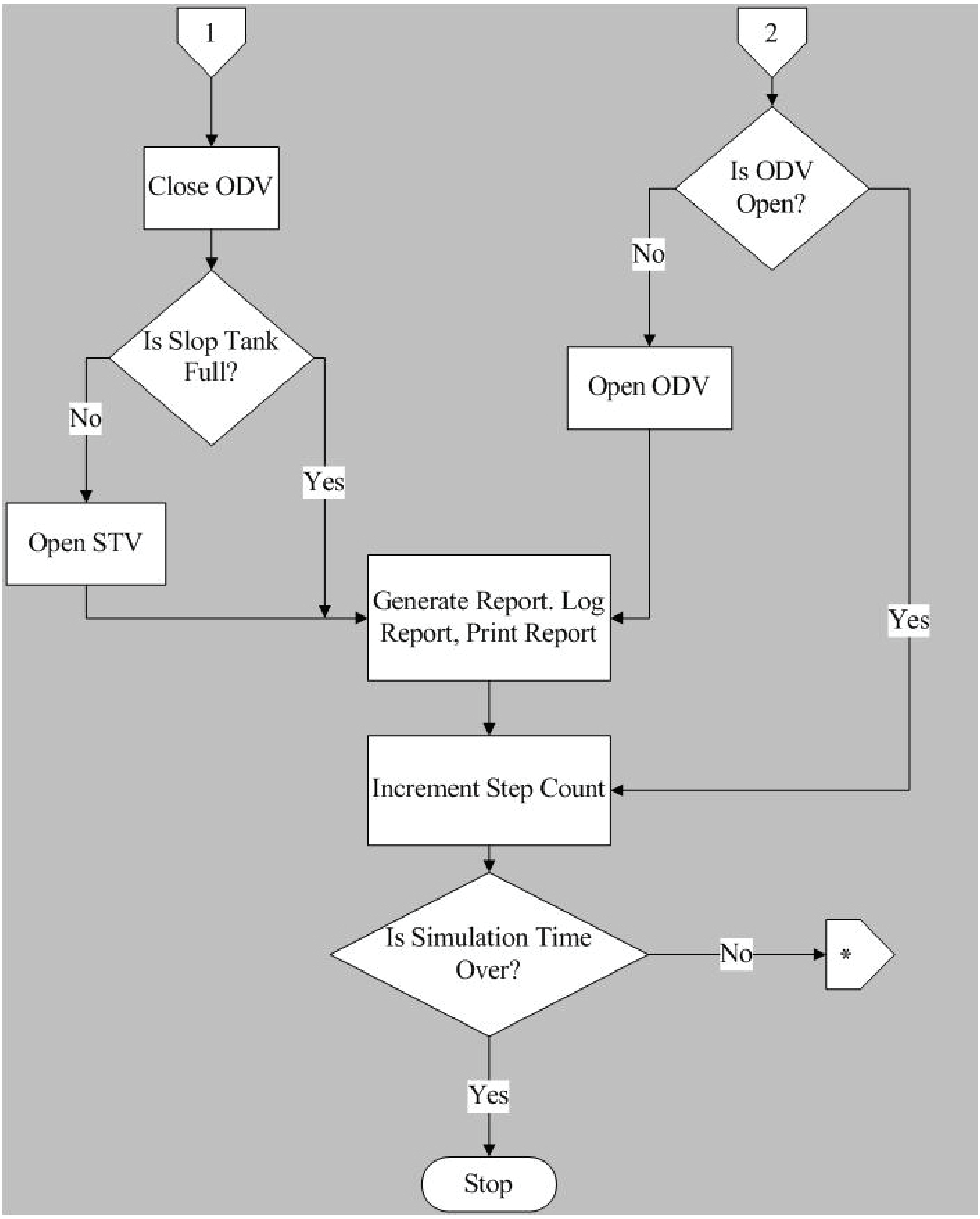

Figure 5(b): The flow chart describing the general system level flow of simulation logic

Table 1: Summary of test results

| Test Case No | Start and End Coordinates of the ships route (Longitude/Latitude) | Alarms generated (if any) in order of their occurrence | Action taken by ODMCS | Test Passed/ Failed |
|---|---|---|---|---|
| 1 | Start: -16°39' 1"/ 19°13' 1"<br>Dest: -44°45'32"/ -1° 7'36" | 5, Slop Tank Full (STF) | For alarm 5 -ODV Closed, STV Opened<br>For STF – ODV Closed, STV closed | PASSED |
| 2 | Start: 80°34'39"/ 5°46'35"<br>Dest: 93°38'59"/ 5°53' 6" | 5 (at start location) | ODV Closed, STV Opened | PASSED |
| 3 | Start: -8°57'25"/ 36° 4'22"<br>Dest: -35°47'38"/ 42°20'36" | Nil | ODV Opened, STV Closed | PASSED |
| 4 | Start: 67°24'51"/ 20°53' 8"<br>Dest: 72°39' 2"/ 19°11'52" | 5 near destination) | ODV Closed, STV Opened | PASSED |
| 5 | Start: 77°32'31"/ 5°14' 6"<br>Dest: 94°24'54"/ 5°56'19" | 5, 1, STF, 5 | For alarms 5,1 before STF occurred – ODV Closed, STV Opened<br>On STF alarm – ODV Closed, STV Closed. Outputs remained unchanged for alarm 5 after STF alarm | PASSED |
| 6 | Start: 76°39' 0"/ 6°25'57"<br>Dest: 109°49'51"/-10°25'56" | 2, STF, 5, 5 | Alarm 2 – ODV Closed, STV Opened<br>STF – ODV Closed, STV Closed<br>For both the Alarm 5 after STF, outputs remained unchanged at ODV Closed, STV Closed | PASSED |

Table 1: Summary of test results (Continued…)

| Test Case No | Start and End Coordinates of the ships route (Longitude/Latitude) | Alarms generated (if any) in order of their occurrence | Action taken by ODMCS | Test Passed/ Failed |
|---|---|---|---|---|
| 7 | Start: 81°33'34"/ 5°27' 8"<br>Dest: 85°44'49"/ 5°27' 8" | 5, 3, STF | For alarms 5,3 – ODV Closed, STV Opened<br>On STF alarm – ODV Closed, STV Closed. | PASSED |
| 8 | Start: -9°52' 4"/ 43° 8'39"<br>Dest: -6°35'46"/ 52° 3'17" | 5, 4, (4)(5), (4)(5), STF, 4, (4)(5) | For all alarms before STF alarm – ODV Closed, STV Opened<br>On STF alarm – ODV Closed, STV Closed.<br>For all alarms after STF alarm, the output remained unchanged | PASSED |
| 9 | Start: -11°59'34"/ 56°45'29"<br>Dest: 0°45'31"/ 63° 9'41" | 4, (4)(5), (4)(5) STF, 4 | For all alarms before STF alarm – ODV Closed, STV Opened<br>On STF alarm – ODV Closed, STV Closed.<br>For alarm 4 after STF alarm, the output remained unchanged | PASSED |
| 10 | Start: 56°29'17"/ 26° 6'31"<br>Dest: 64°18'24"/ 19°27' 9" | (4)(5), 4, (4)(5), 5 | For all alarms - ODV Closed, STV Opened | PASSED |

 

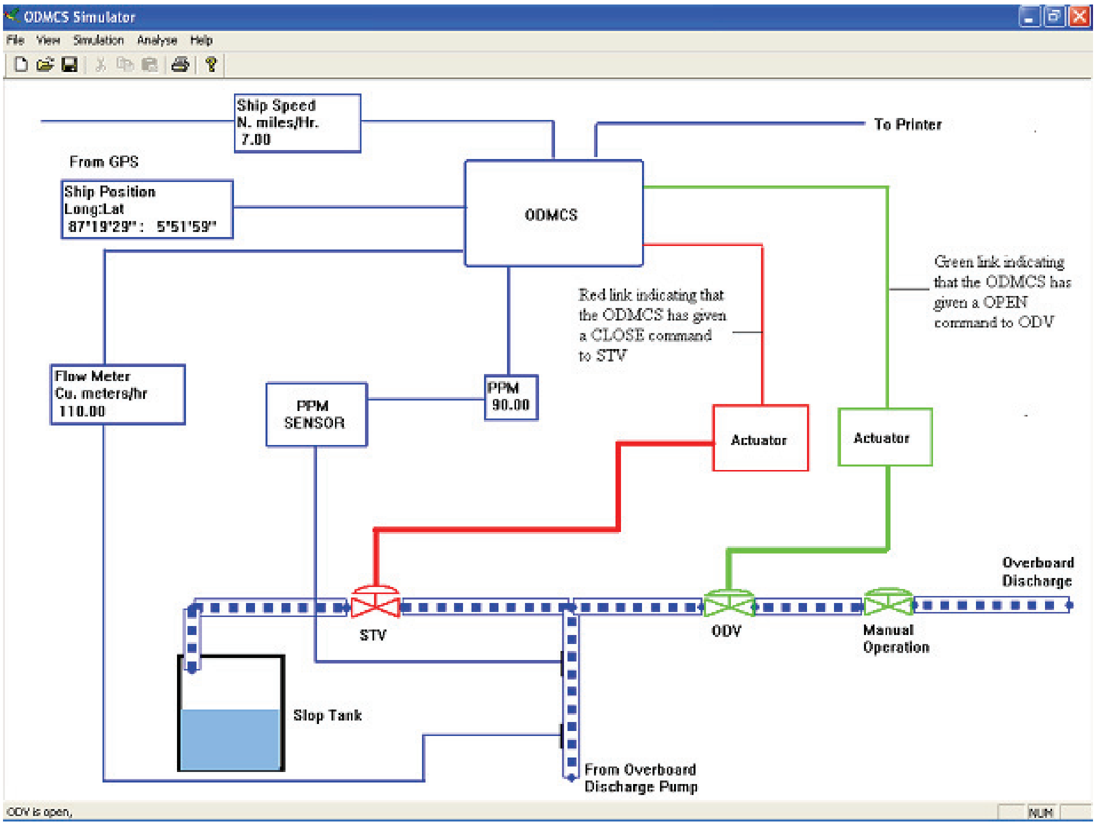


Figure 6: The Process View showing line diagram and animated simulation of overboard discharge and slop tank filling process taken during the simulation run for test case 2 of the results given in table 2

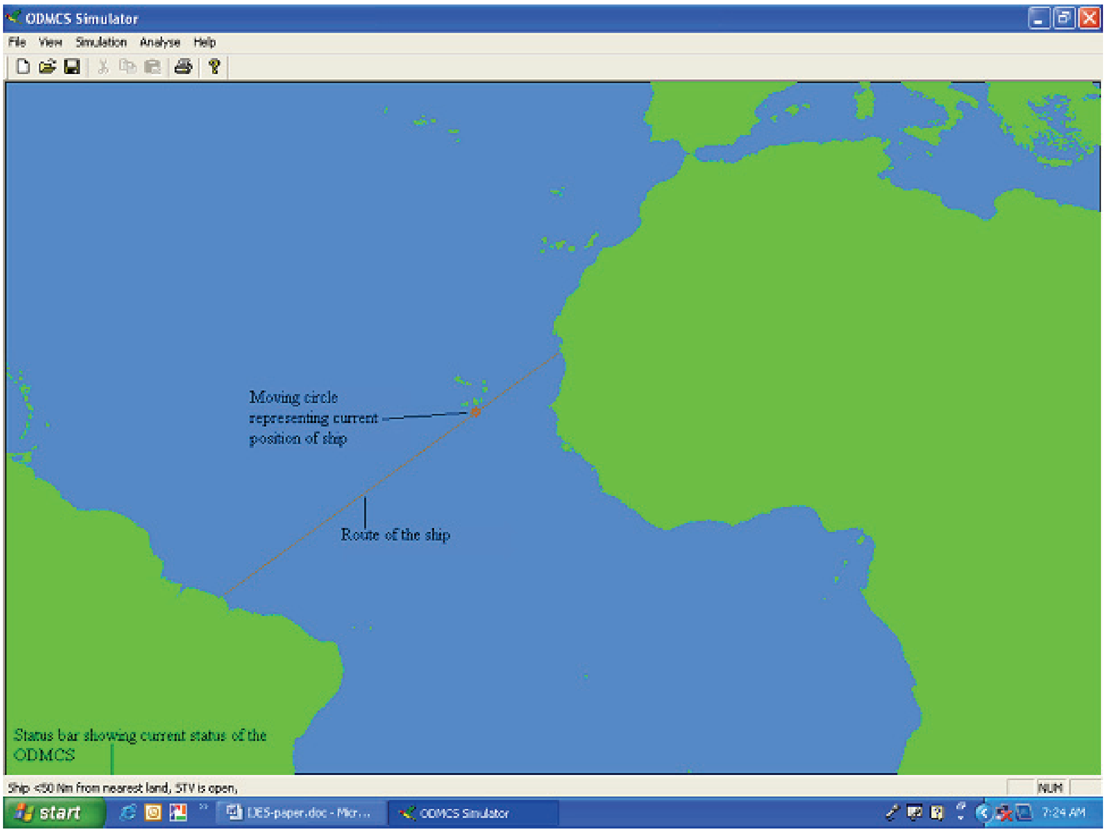


Figure 7: The World Map View, showing movement of ship on world map during the simulation run for test case 1 of the results given in table 2