OPTIMAL PLANNING OF POLLUTION EMERGENCY RESPONSE WITH APPLICATION OF NAVIGATIONAL RISK MANAGEMENT

ABSTRACT

According to the HELCOM AIS, there are about 2,000 ships in the Baltic marine area at any given moment. The main environmental effects of shipping and other activities at sea include air pollution, illegal deliberate and accidental discharges of oil, hazardous substances and other wastes, and the unintentional introduction of invasive alien organisms via ships’ ballast water or hulls. Original oil pollution model and optimal allocation of response resources was proposed in the paper.

Keywords: sea pollution model, response resources.

INTRODUCTION

The Baltic Sea is one of the most heavily trafficked seas in the world, accounting for up to 15% of the world’s cargo transportation. Both the number and the size of ships have grown in recent years, especially in respect to oil tankers, and this trend is expected to continue.

The main environmental effects of shipping and other activities at sea include air pollution, illegal deliberate and accidental discharges of oil, hazardous substances and other wastes, and the unintentional introduction of invasive alien organisms via ships’ ballast water or hulls.

According to the HELCOM AIS, there are about 2,000 ships in the Baltic marine area at any given moment, and each month around 3,500–5,000 ships ply the waters of the Baltic.

The main goal of the research work was the designing and development of oil pollution model and microscopic model of ship traffic, and finally, verification of the correctness of the oil-spill resources allocated along the Baltic coast. Model applies the statistical data obtained by navigational safety assessment model which consist
of the frequency, volume, type, location, weather conditions, and sea-state of an oil spill event. Statistical analysis is made with use of historical data to determine the expected volume, type and weather and sea conditions for Baltic Sea region. The algorithm of optimal allocation model of response resources was proposed.

THE ALGORITHM OF OPTIMAL ALLOCATION OF RESPONSE RESOURCES

The main important targets of research were:
1. To identify the high risk areas for ships colliding and grounding in the Baltic Sea.
2. To determine the possible effects of the probable accidents considering average seasonal weather conditions dominating in the Baltic Sea.
3. To propose the possible allocation oil spill resources allowing secure determined segments of coast in the shortest possible time, taking into account the probability of the occurrence of oil spills.

To identify possible collision positions the simplified statistical model was used. The model used real statistical data and achieved results are very close to reality. The most unknown parameter necessary for collision probability assessment on large sea areas is number of ships encounter situations.

![Fig. 1. Results of use statistical model of collision](image-url)
When an oil spill occurs it is necessary to respond with sufficient cleanup equipment within the shortest possible time in order to protect marine environment and minimize cleanup and damage costs. At Baltic Sea region every country is equipped with their own response resources. Picture below (fig. 2) shows location of those equipment.

![Fig. 2. Response resources allocation in southern Baltic [Helcom]](image)

For better resources allocation the optimization recursive type algorithm was proposed (fig. 3). The main dynamic data used in optimization process are:

— actual resources allocation;
— possible changes of allocation;
— weather conditions data;
— the most probable oil spill accident (calculated in statistical model use).

Model apply the statistical data consist of the frequency, volume, type, location, weather conditions, and sea-state of an oil spill event. Statistical analysis is performed on historical data to determine the expected volume, type and weather and sea conditions for Baltic Sea region. The analysis is performed to determine certain input parameters such as the number and type of equipment required to respond to a given spill and the expected travel times for transporting the equipment from a facility site to spill site. The travel time for response equipment depends on the distance between facility site and the spill site, the type of equipment, and on the weather and sea conditions. After obtain the required data they are used to simulate an oil spill on PISCES II simulator.
Fig. 3. Model of optimal allocation of response resources [own study]
SIMULATIONS DESCRIPTION AND RESULTS

Optimization of location response resources depending on reduction of costs is very important. Full complement of planned simulations, based on predicted ships’ accidents, should give an answer: whether an allocation of responses or their expansion are necessary. Protection of the Baltic Sea environment without bearing the unnecessary costs is a main purpose of research.

As an example of optimization resources in polish coast the series of the simulation was conducted. To run these simulations spill/accident positions were chosen near ports of Świnoujście, Kolobrzeg and Gdynia. Also those ports were chosen as a possible locations of ‘Kapitan Poinc’ rescue vessel. In all simulations weather conditions were the same (table 1).

| #  | Name            | Value       | Spill type: | Leak |
|----|-----------------|-------------|-------------|------|
| 1  | Water temperature | 15°C        | Type of oil | ADGO |
| 2  | Air temperature  | 20°C        | Amount      | 100 tones |
| 3  | Sea state       | 2.5 m       |             |      |
| 4  | Water density   | 1030 kg/m³  |             |      |
| 5  | Cloudiness      | 5           |             |      |

Every simulation began at the base that when the oil spill accident happened the rescue ship had been moored in the basic harbor so the first period of the action
Simulating consists in arriving the ship to the catastrophe position and removing oil spill began then. Results of examples of removing action are showed in the next figures.

Simulation No. 1
Spill site: 54°18,189 N 014°08,339 E
‘Kapitan Poinc’ location: Gdynia

Fig. 5. Simulation 1 — oil spill and rescue ship positions [own study]

| #   | Time  | Amount spilled, t | Amount floating, t | Amount evaporated, t | Amount dispersed, t | Amount recovered, t | Amount floating mixture, t | Max thickness, mm | Slick area, m² | Viscosity, cSt |
|-----|-------|-------------------|--------------------|----------------------|---------------------|---------------------|--------------------------|-----------------|---------------|---------------|
| 1   | "0:00" | 0                 | 0                  | 0                    | 0                   | 0                   | 0                        | 0               | 0             |               |
| 2   | "1:00" | 99.2              | 95.5               | 0.2                  | 3.6                 | 0                   | 0                        | 0               | 5.8           | 98            |
| 3   | "2:00" | 100               | 92.4               | 0.7                  | 6.9                 | 0                   | 0                        | 234             | 3.6           | 0.1           | 402          |
| 4   | "3:00" | 100               | 90.3               | 1.4                  | 8.3                 | 0                   | 0                        | 285             | 3.4           | 0.1           | 767          |
| 5   | "4:05" | 100               | 88.2               | 2.3                  | 9.5                 | 0.1                 | 301                      | 0               | 2.1           | 0.1           | 1032         |
| 6   | "5:05" | 100               | 84.3               | 3.5                  | 11.1                | 0.1                 | 292                      | 4.9             | 1.7           | 0.2           | 1241         |
| 7   | "6:05" | 100               | 79.3               | 4.8                  | 13                  | 0.2                 | 277                      | 10.1            | 1.6           | 0.2           | 1467         |
| 8   | "7:05" | 100               | 74.4               | 6.2                  | 15.2                | 0.3                 | 259                      | 14.8            | 1.4           | 0.3           | 1731         |
| 9   | "8:05" | 100               | 68.9               | 7.6                  | 17.4                | 0.6                 | 240                      | 21              | 1.5           | 0.3           | 2030         |
| 10  | "9:05" | 100               | 63.6               | 9.1                  | 19.7                | 0.7                 | 221                      | 27.2            | 1             | 0.3           | 2353         |
| 11  | "10:05"| 100               | 58.3               | 10.1                 | 21.8                | 0.9                 | 202                      | 34.2            | 1             | 0.3           | 2681         |
| 12  | "11:05"| 100               | 53.6               | 11.2                 | 23.8                | 1.1                 | 185                      | 39.9            | 0.7           | 0.3           | 3008         |
| #  | Time    | Amount spilled, t | Amount floating, t | Amount evaporated, t | Amount dispersed, t | Amount sunk, t | Amount recovered, t | Amount floating mixture, t | Amount recovered mixture, t | Max thickness, mm | Slick area, m² | Viscosity, cSt |
|---|---------|-------------------|-------------------|---------------------|---------------------|----------------|------------------|------------------------|---------------------------|------------------|--------------|--------------|
| 13 | "12:05" | 100               | 48.7              | 12.1                | 25.6                | 0              | 13.6             | 168                    | 47.1                      | 0.8              | 0.3          | 3330         |
| 14 | "13:05" | 100               | 43.2              | 12.9                | 27.3                | 0              | 16.5             | 149                    | 57.2                      | 0.8              | 0.3          | 3637         |
| 15 | "14:05" | 100               | 38.2              | 13.6                | 28.9                | 0              | 19.2             | 131                    | 66.5                      | 0.7              | 0.3          | 3928         |
| 16 | "15:05" | 100               | 33.5              | 14.2                | 30.4                | 0.1            | 21.8             | 115                    | 75.4                      | 0.8              | 0.2          | 4202         |
| 17 | "16:05" | 100               | 29.3              | 14.7                | 31.8                | 0.1            | 24.1             | 100                    | 83.2                      | 0.6              | 0.2          | 4454         |
| 18 | "17:05" | 100               | 24.9              | 15.2                | 33.1                | 0.2            | 26.7             | 85.3                    | 92                        | 0.5              | 0.2          | 4681         |
| 19 | "18:05" | 100               | 21                | 15.6                | 34.2                | 0.2            | 29               | 71.8                    | 100                       | 0.5              | 0.2          | 4878         |
| 20 | "19:05" | 100               | 17.8              | 15.9                | 35.2                | 0.3            | 30.8             | 60.9                    | 106                       | 0.5              | 0.2          | 5045         |
| 21 | "20:05" | 100               | 14.5              | 16.2                | 36                  | 0.4            | 32.9             | 49.5                    | 113                       | 0.5              | 0.1          | 5187         |
| 22 | "21:05" | 100               | 11.9              | 16.4                | 36.7                | 0.5            | 34.5             | 40.4                    | 119                       | 0.4              | 0.1          | 5305         |
| 23 | "22:05" | 100               | 9.5               | 16.6                | 37.4                | 0.6            | 35.9             | 32.4                    | 124                       | 0.4              | 0.1          | 5400         |
| 24 | "23:05" | 100               | 7                 | 16.7                | 37.9                | 0.7            | 37.7             | 23.6                    | 129                       | 0.4              | 0.1          | 5472         |
| 25 | "24:05" | 100               | 4.8               | 16.8                | 38.3                | 0.8            | 39.2             | 16.2                    | 135                       | 0.4              | 0.1          | 5526         |
| 26 | "25:05" | 100               | 3.7               | 16.9                | 38.6                | 1              | 39.8             | 12.6                    | 136                       | 0.4              | 0.1          | 5562         |
| 27 | "26:05" | 100               | 2.7               | 17                  | 38.9                | 1.1            | 40.4             | 9                      | 139                       | 0.4              | 0            | 5586         |
| 28 | "27:05" | 100               | 1.5               | 17                  | 39                  | 1.2            | 41.2             | 5                      | 141                       | 0.4              | 0            | 5598         |
| 29 | "28:05" | 100               | 1.1               | 17                  | 39.1                | 1.4            | 41.4             | 3.6                     | 142                       | 0.3              | 0            | 5602         |
| 30 | "29:05" | 100               | 0.5               | 17.1                | 39.2                | 1.5            | 41.7             | 1.8                     | 143                       | 0.3              | 0            | 5609         |

**Simulation No. 2**

Spill site: 54°18,189 N 014°08,339 E

‘Kapitan Poinc’ location: Kołobrzeg

![Fig. 6. Simulation 2 — oil spill and rescue ship positions [own study]](image-url)
Simulation No. 3
Spill site: 54°18,189 N
014°08,339 E
‘Kapitan Poinc’ location: Świnoujście

Fig. 7. Simulation 3 — oil spill and rescue ship positions [own study]

For other oil spill accidents the same way of simulation were carried out. Runs of example simulation are showed in fig. 8–10.

Fig. 8. Oil spill removing action — beginning phase [own study]
SUMMARY

Spill positions, possible ‘Kapitan Poinc’ locations and distances between those points are shown in fig. 11. Results of simulations, their efficiency and the necessary time to the oil spill removing are shown in table 3.
Table 3. Results of simulations [own study]

| Simulation No. | Oil spill position | ‘Kapitan Poinc’ location | Distance between spill position and ‘Kapitan Poinc’ location | Time of simulation [h] |
|----------------|-------------------|--------------------------|-------------------------------------------------------------|-----------------------|
| 1              | 54°18,189 N 014°08,339 E | Gdynia                   | 244,0                                                       | 30                    |
| 2              | Kołobrzeg         | 57,0                     | 15                                                          |                       |
| 3              | Świnoujście       | 26,8                     | 16                                                          |                       |
| 4              | 54°35,845 N 015°14,939 E | Gdynia                   | 195,0                                                       | 26                    |
| 5              | Kołobrzeg         | 31,0                     | 13                                                          |                       |
| 6              | Świnoujście       | 60,5                     | 15                                                          |                       |
| 7              | 55°16,459 N 018°36,727 E | Gdynia                   | 76,0                                                        | 18                    |
| 8              | Kołobrzeg         | 144,0                    | 23                                                          |                       |
| 9              | Świnoujście       | 196,0                    | 28                                                          |                       |

Average the time of the action running is shortest for Kołobrzeg location (17 hours). The next preferable port is Świnoujście (19,67 hour) and the last is Gdynia (24,67 hour). Of course these simple simulation can show analyzing method use but it should be taken into consideration both different weather condition (winter, summer etc.) and more possible accidents scenarios. Every decision about resources allocation should be taken under financial and efficiency criteria.
REFERENCES

[1] Gucma L., Przywarty M., The Model of Oil Spills Due to Ships Collisions in Southern Baltic Area, Conference proceedings TRANS’NAV 2007 ‘Advances in Marine Navigation and safety of sea transportation’, monograph, edited by Adam Weintrit, The Nautical Institute, Gdynia 2007.

[2] PISCES II User Manual, Transas Ltd, 2008.

[3] Specification for PISCES II, Transas Ltd, 2007.

[4] The national plan to combat hazards and pollution of the marine environment, Maritime Search and Rescue, Gdynia 2005.

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