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The Method of Optimal Allocation of Oil Spill Response in the Region of Baltic Sea

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ABSTRACT: This paper describes the results of a study that aimed at developing an effective anchor watch supporting system to prevent dragging anchor accidents of small domestic merchant ships. The authors performed an experimental study using a training ship in order to investigate the characteristics of the hull movement of a ship lying at single anchor, the cable tension caused by the above movement and etc. Based on the results of the study, the authors propose a standard procedure for safe anchor watch and a new anchor watch supporting system using a PC, a DGPS and an anemometer.

1 PROBLEMATIC OF OIL SPILLS AT SEA

1.1 *Traffic at Baltic Sea*

The Baltic Sea is one of the most heavily trafficked seas in the world. Ships traffic account for 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 (HELCOM, Overview Of The Shipping Traffic In The Baltic Sea, April 2009).

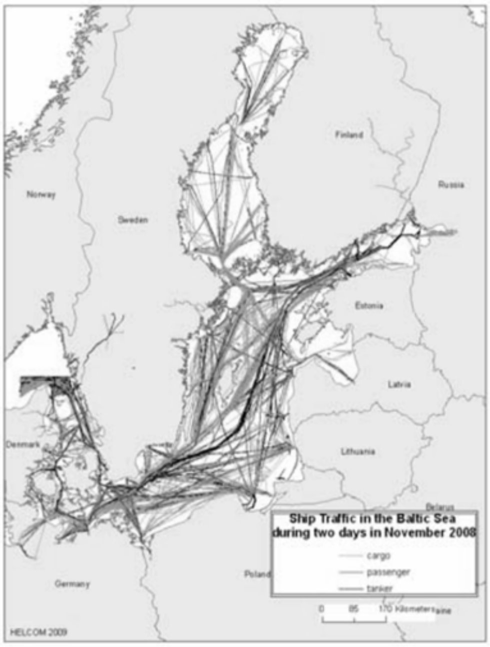

Figure 1. Cargo, tanker and passenger ship traffic on the Baltic Sea during two days in November 2008 (*HELCOM, Overview Of The Shipping Traffic In The Baltic Sea, April 2009).*

1.2 *Overview of oil spills at the Baltic Sea*

The transportation of oil and other potentially hazardous cargoes is growing steeply and steadily. More than 4,400 tankers loaded with oil left or entered the Baltic Sea in 2007 and in both 2007 and 2008 approximately 170 million tonnes of oil were shipped on the Baltic Sea. Both the number and size of the ships (especially oil tankers) have been growing during last years and now ships carrying up to 150 thousand tons of oil can be seen in the Baltic. By 2015, a 40% increase is expected in the amounts of oil being shipped on the Baltic and the number of large tankers is expected to grow, with more tankers carrying 100,000-150,000 tonnes of oil (*HELCOM, Overview Of The Shipping Traffic In The Baltic Sea, April 2009*).

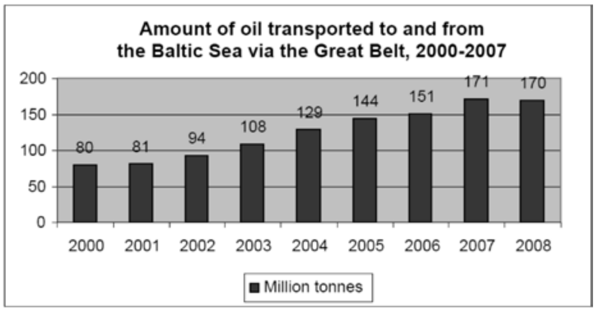

Figure 2. Amount of oil transported to and from the Baltic Sea via the Great Belt during 2000-2008 (*SHIPPOS 2000-2007 and Danish reporting system, 2008)*

2 METHOD OF OPTIMAL ALLOCATION OF OIL SPILL RESPONSE RESOURCES

2.1 *Response resources allocation at Baltic Sea*

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.3) shows location of those equipment.

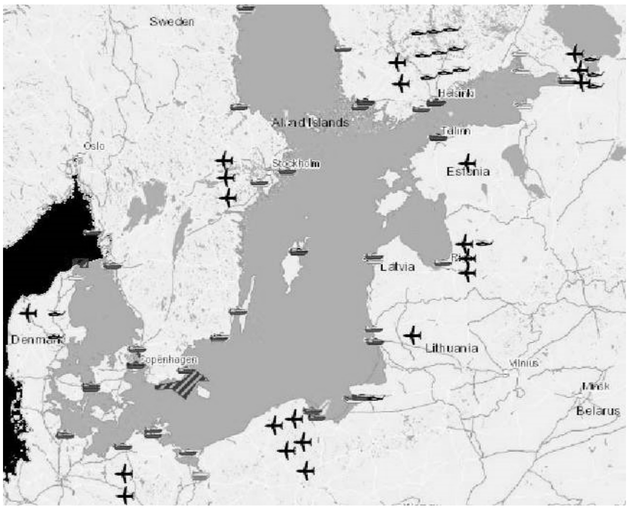

Figure 3. Response resources at Baltic Sea *(HELCOM database)*

2.2 *Model of optimal allocation*

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.

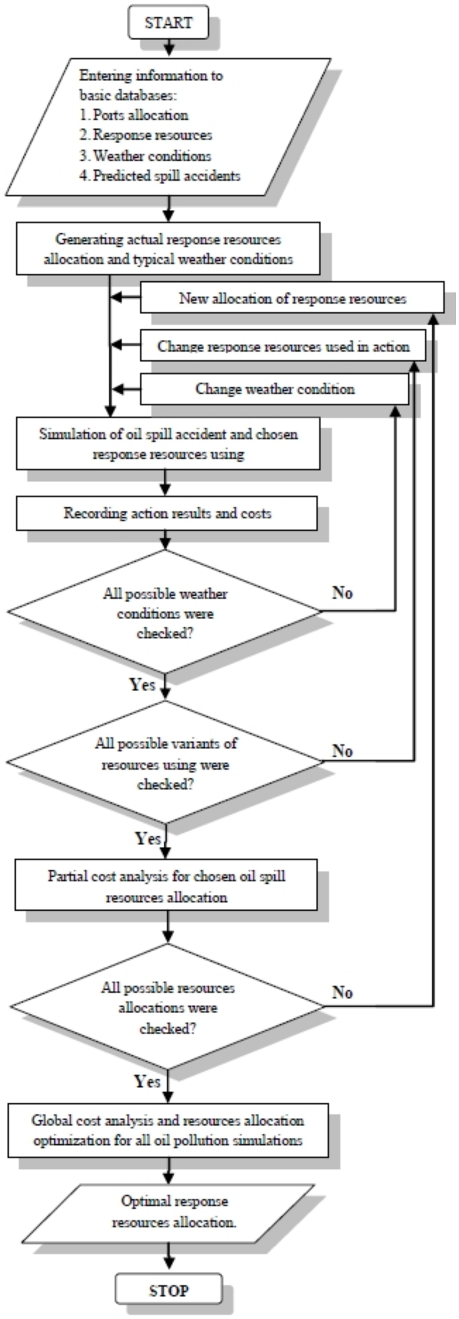

Figure 4. Model of optimal allocation.

3 COST OPTIMIZATION OF ALLOCATION OF ANTI POLLUTION RESOURCES

3.1 *Optimization model*

It is assumed that the fixed costs of opening facility site and the operating costs of the equipment are known. Costs include the costs of acquiring the equipment to be located at the site (these costs depend on the location of the site and vary with the geographical location), cost of maintaining the equipment, the transportation and cleanup costs. The following goal function is applied:

$K_A + K_s \rightarrow min$

where:

K_A-cost of cleanup operation,

K_S-cost of environmental pollution,

with restrictions:

O_1- allocation of resources are only in specific locations (eq. ports),

O_2- the number of available rescue units and the cost of their maintenance in standby for action does not exceed the state budget,

O3- disposal of recovered oil and oily waste should only be considered after all possibilities of processing it for use as a fuel or raw materials have been exhausted.

4 MODEL APPLICATION - CASE STUDY

4.1 *Simulation model*

PISCES II is an incident response simulator designed for preparing and conducting command centre exercises and area drills. The application is developed to support exercises focusing on oil spill response. The PISCES II provides the exercise participants with interactive information environment based on the mathematical modelling of an oil spill interacting with surroundings and combat facilities. The system also includes information-collecting facilities for the assessment of the participants' performance.

The PISCES II spill model simulates processes in an oil spill on the water surface: transport by currents and wind, spreading, evaporation, dispersion, emulsification, viscosity variation, burning, and interaction with booms, skimmers, and the coastline (stranding or beaching). The following factors are taken into consideration in the math model:

- Environmental parameters: coastline, field of currents, weather, wave height and water density;
- Physical properties of spilled oil: specific gravity, surface tension, viscosity, distillation curve and emulsification characteristics;
- Properties of spill sources;
- Human response actions: booming, on-water recovery, application of chemical dispersants.

4.2 *Simulation input data*

The simulation scenarios have been build on with application of two potential oil spill points at Baltic Sea: the first in Gdańsk Bay and the other in the vicinity of Bornholm. Those points have been chosen from stochastic oil spill risk model presented in *Gucma L., Przywarty M.: "The Model of Oil Spills Due to Ships Collisions in Southern Baltic Area"*. The *"National Plan of Fighting Threats and Environmental Pollutions at Sea"* have been also considered.

Oil spill accident can occur in arbitrary moment. Scenarios were simulated for risk of oil spill impact evaluation. Meteorological conditions represent average Baltic Sea conditions. On the base of wind and current data probable situations were formed. The data show hypothetical pollution zones for no ice conditions.

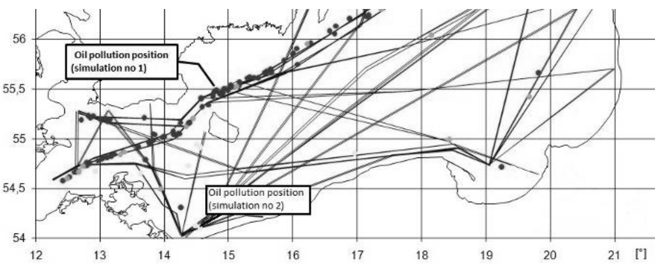

Figure 5. Risk points at the Baltic Sea *(Gucma, Przywarty TRANS'NAV 2007).*

4.3 *Simulation no 1*

First stage of simulations was held in the vicinity of Bornholm and average spring weather conditions were used. In the accident point 6 000 ton of light oil reached the leak. Accurate data concerning spilt oil and weather conditions are described in the table 1.

Table 1. Simulation 1- weather conditions

Accident coordinates	φ=55°29,435’N λ=014°48,462’E
Current direction	90°
Current speed	0,25 kts
Wind direction	270°
Wind speed	8 kts
Air temperature	20 °C
Water temperature	8 °C
Sea state	1 m
Water density	1,006
Pressure	1012 hPa
Cloudiness	5
Amount of oil	6000 t
Ratio	6000 t/h
Type of oil	IFO 180

Figure below shows oil slick movement after oil spill at Baltic Sea (Bornholm).

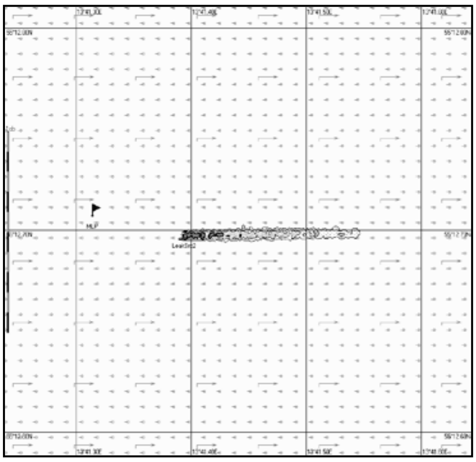

Figure 6. Oil slick after 16 min.

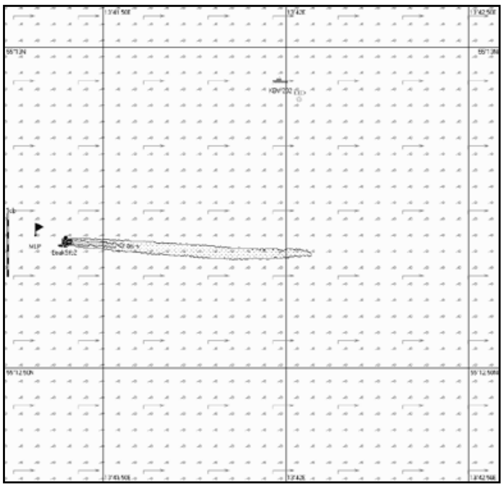

Figure 7. Response vessel under way.

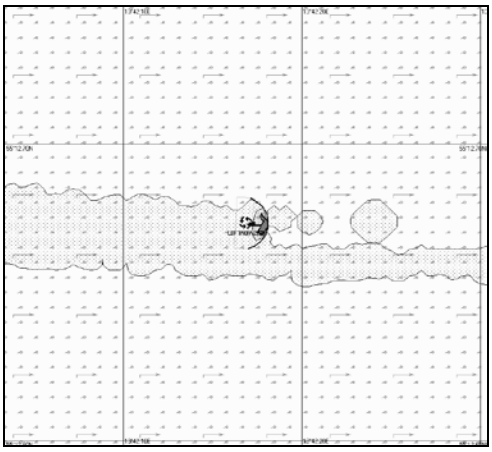

Figure 8. Movement of boom formation.

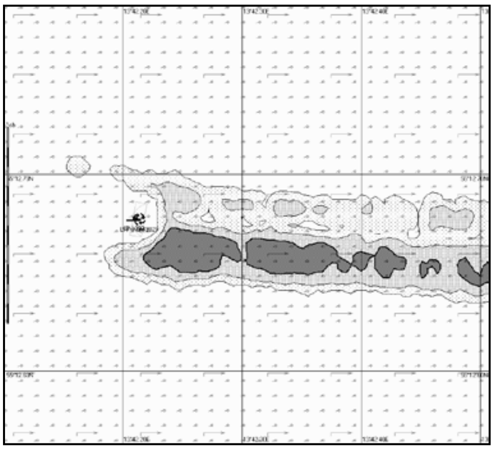

Figure 9. Oil slick after 3 h 20 min.

4.4 *Simulation no 2*

This scenario was held in Pomorska Bay and average summer weather conditions (June) were simulated. In the set point 5000 tons of oil reached the leak. Oil and weather conditions are described in the table 2.

Table 2: Simulation no 2- weather conditions.

Accident coordinates	φ=54°18,6’N λ=014°15,6’E
Environmental conditions	
Current direction	90°
Current speed	0,25 kts
Wind direction	100°
Wind speed	3 kts
Air temperature	20 °C
Water temperature	15 °C
Sea state	0 m
Water density	1,006
Pressure	1012 hPa
Cloudiness	5
Amount of oil	20 000 t
Ratio	5000 t/h
Type of oil	IFO 180

Boom Formation:

- Boom: RO-BOOM 1500

- Left vessel: m/s Zefir
- Right vessel: m/s Czesław
- Skimmer: Seaskimmer 50
- Middle vessel: m/s Kapitan Poinc

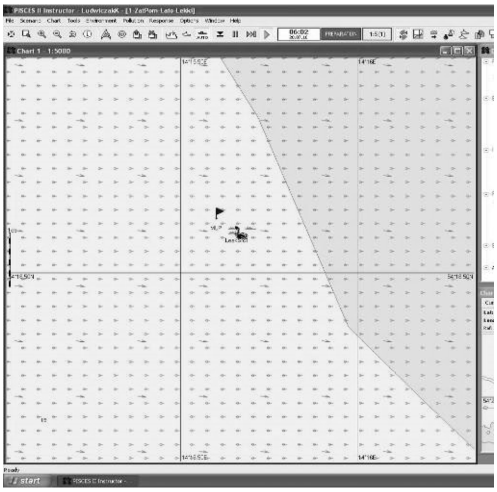

Figure 10. Simulation start.

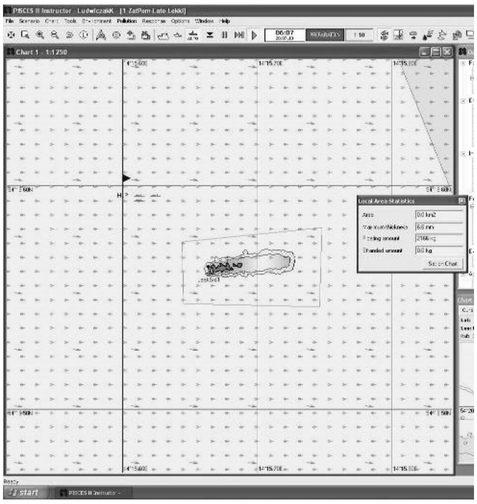

Figure 11. Oil slick thickness is 6.6 mm.

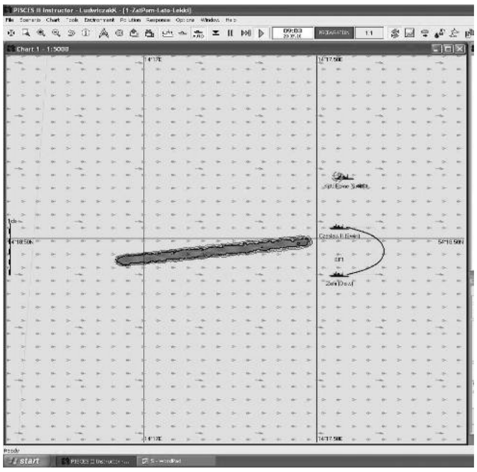

Figure 12. Creating boom formation

Table 3: Response operation costs.

Report	time	date	
begin	06:00	20.07.2010	
end	15:43	20.07.2010	
Costs by organizations			
No organization			
	Capitan Poinc		$7 112,60
	Expandi 4300 (800m)		$874,50
	m/s Czeslaw II		$2 176,53
	m/z Zefir		$796,77
	Ro-Boom 1500 (600m)		$1 739,28
	Seaskimmer 50		$871,50
Total			$13 571,18
			40713,55 PLN

5 CONCLUSION

A major use of this model could be for control of response resources (contingency planning) and find new locations for vessels and equipment to minimize costs of cleanup. It could be used for simulations and training. Further research needs to test the validity of such model.

Optimization of location response resources depending on reduction of costs is also 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. First results of accident and antipollution action based on the real data are described in this paper.

ACKNOWLEDGEMENT

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