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The analysis of the risk of an accident between a passenger ship and a tanker carrying hazardous substances in the Western Baltic

Keywords

navigational safety, risk assessment, chemical tanker, Ro-Pax ferry, ship-ship collision

Abstract

The paper presents an analysis of the accident between a passenger ship moving on the route Swinoujscie Ystad with tanker carrying hazardous substances category X. In order to assess the safety of navigation in the study area the authors have developed a probabilistic domain, which aims to estimate the number of incidents of navigation on the basis of real data from AIS and to find potentially dangerous areas, where there is the highest number of incidents. Then the vessel traffic model was built and the model of navigational safety assessment to evaluate the probability of Ro-Pax Ferry-Chemical tanker collision. Finally the consequences assessment of collision between Ro-Pax and chemical tanker carrying ammonia was performed, taking into consideration ammonia release.

1. Introduction

Due to the large number of narrow straits and shallow waters the Baltic Sea has always been a difficult area for ships to navigate. Despite of huge investments in the protection in form of improved technical equipment and the training of navigators, on the Baltic Sea the lack of downward trend in the number of navigation accidents is observed which is quite alarming. To get a full picture of the shipping safety in the Baltic, basic information on the intensity of shipping is of importance. According to HELCOM's data on some routes the total number of vessels during the year exceeds 60 thousand. For the safety of navigation Traffic Separation Schemes are organizing the movement of vessels, but also reducing the width of the traffic flow, the maneuvering area available for vessels at the main routes intersections is often so reduced that in some areas the passing distances between vessels are decreasing to a value at which we can talk about the occurrence of incidents of navigation . In this study the selected area is covering three major and one minor routes intersections with the route of passenger ferries proceeding from Swinoujscie to Ystad.

Information on the type of the vessel and her cargo that we can get based on AIS data is limited to the "Identifier number" to be used by ships to report their type. The first digit represents the general category like: 6 - Passenger, 7 - Cargo, 8 - Tanker etc. While the second digit gives some information as to the cargo:

1 – Carrying DG, HS, or MP IMO hazard or pollutant category X;
2 – Carrying DG, HS, or MP IMO hazard or pollutant category Y;
3 – Carrying DG, HS, or MP IMO hazard or pollutant category Z;
4 – Carrying DG, HS, or MP IMO hazard or pollutant category OS;

Where DG: Dangerous Goods, HS: Harmful Substances, MP:Marine Pollutants.

The paper analyzes the likelihood and possible consequences of the most dangerous accidents, where a collision occurs between a passenger ferry and a tanker carrying dangerous goods category X (Noxious Liquid Substances which, if discharged into the sea from tank cleaning or deballasting operations, are deemed to present a major hazard to either marine resources or human health and, therefore, justify the prohibition of the discharge into the marine environment) [2].

1.1. The initial assessment of the safety of navigation

The first goal of the study was an analysis of ship traffic based on real AIS data. For the initial assessment of the safety of navigation, an analysis of incidents of navigation was performed. For the selected route between the ports of Swinoujscie and Ystad probabilistic ships domains were constructed and due to the large number of encounter situations between vessels domains were determined based on actual data for one month AIS research period 01.07.2011 - 01.08.2011. A ship domain shall be understand as a certain area around the vessel which the navigator likes to keep clear of other fixed and movable objects. In order to construct the statistical domain around the ship, assumptions are used as described in a previous work [2]. These involve searching for a range constituting a maximum distance over which most of the navigators passes other vessels while encounter on a defined relative bearing. As a navigational incident ("statistical incident") has been defined a meeting of two vessels with the distance less than average statistical ship domain border corresponding to a given encounter situation that occurred.

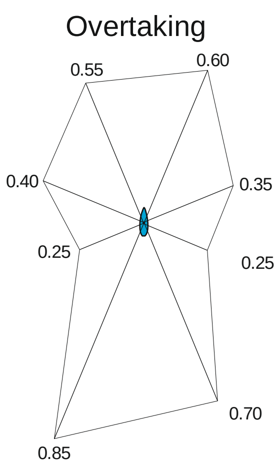

Figure 1. Probabilistic domain for the overtaking encounters

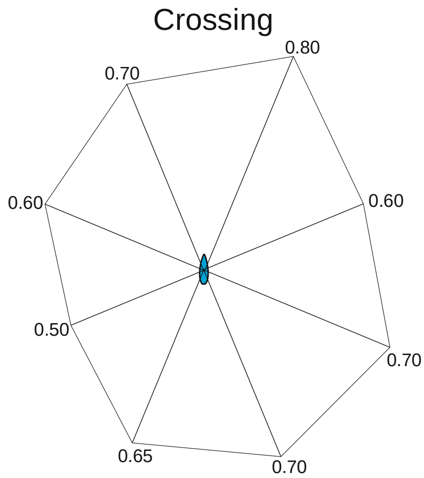

Figure 2. Probabilistic domain for the crossing encounters

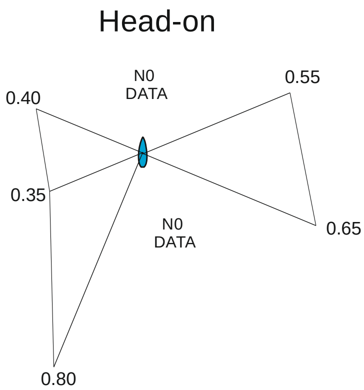

Figure 3. Probabilistic domain for the head-on encounters

Table 1. The statistics of probabilistic domain for all vessels (one month period)

Encounter	Number of encounters	Total length of domains boundaries	Number of incidents
Crossing	544	5.25 NM	59
Overtaking	686	3.95 NM	55
Head-on	364	4.15 NM (5 sectors)	33

In *Figures 1-3* and *Table 1.* the numerical information about the vessel encounters in the study area are presented. On the basis of the shape and the size of the domain the number of incidents of navigation, i.e. meetings between the vessels for which the domain limit was exceeded, is calculated for each encounter situation. The shape of the domain for crossing situations is the closest to circles, due to the fact that the length of the boundaries are comparable to each other. This shows that either vessels while crossing ahead of the other ship (generally action by stand-on vessel), but also while crossing astern (generally action by give way vessel) kept the same passing distance. Most of the crossing encounters took place in sector VII (270°-315°) with a total number of 270 encounters and 20 navigational incidents. Most of the overtaking encounters (78%) took place in sectors forward of the beam I, II and VII, VIII (270° - 90°) with a number of 40 navigational incidents. The shape of the domain for overtaking situation is narrowed on the beams because that is where the CPA are the smallest. For vessel on opposite directions the majority of CPA's occurred abeam, from which over 80 percent on the port side. Astounding is the number of 48 CPA's on the starboard side, in particular because COLLREGS Rule 14 about Head-on situation indicates that: „(a). When two power-driven vessels are meeting on reciprocal or nearly reciprocal courses so as to involve risk of collision each shall alter her course to starboard so that each shall pass on the port side of the other. "

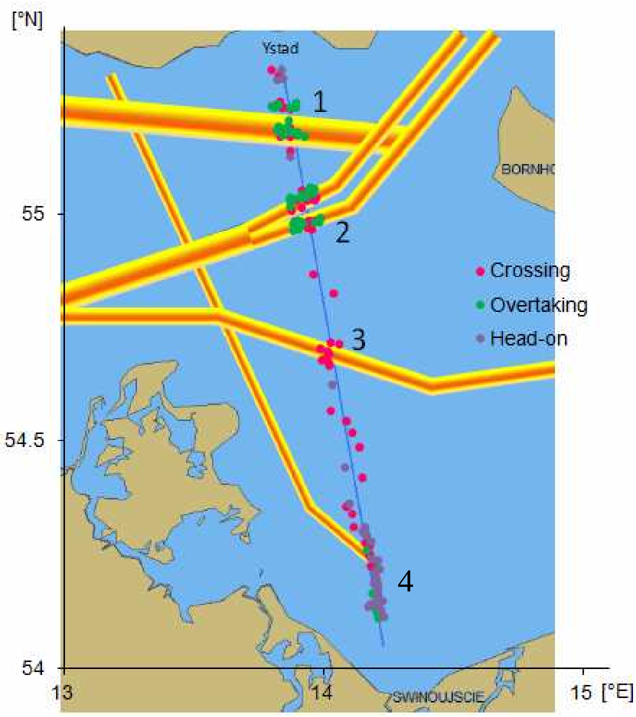

Figure 4. Navigational incidents in the study area

Figure 4.. indicates the locations where the incidents occurred, additionally they are divided by colors due to the type of encounter. Head-on incidents occurred at the beginning and end of the route, near the ports, where vessels traffic flow is narrowed, and therefore the passing distances for vessels proceeding in opposite direction are reduced. Navigational incidents while crossing situation occurred primarily at the intersections of routes, especially where there is heavy traffic (1,2,3). The incidents during overtaking occurred mainly at the intersection of routes and at the approaches to ports.

- 55° 10.170'N - 55° 14.598'N and 13° 48.138'E - 13° 53.712'E
- 54° 57.732'N - 55° 03.306'N and 13° 52.926'E - 13° 58.086'E
- 54° 06.678'N - 54° 21.342'N and 14° 05.394'E - 14° 14.160'E

These coordinates define the places of the concentrated number of incidents that are identified as potentially dangerous for navigation.

2. Model of navigational safety assessment

To evaluate the probability of Ro-Pax Ferry-Chemical tanker collision model of navigational safety assessment developed in Maritime University in Szczecin was used. Structure of the model is presented in *Figure 5* It works in fast time, so it gives statistically adequate number of scenarios.

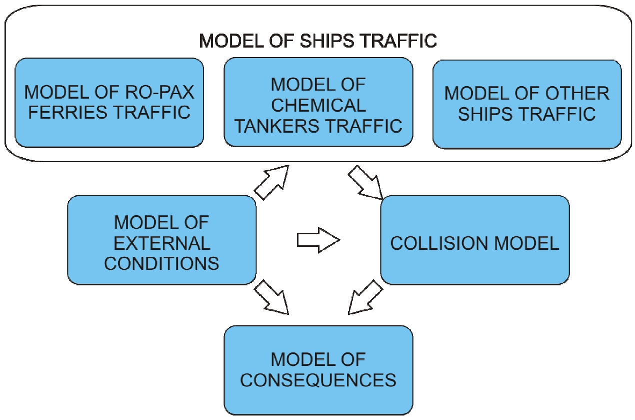

Figure 5. Model of navigational safety assessment

2.1. Model of chemical tankers traffic

The traffic of chemical tankers is modeled by nonhomogeneous Poison process where actual intensity of traffic is evaluated on the basis of real AIS (Automatic Identification System). The collected AIS data is used also for determination of ships routes (*Figure 6*), length and draught distribution.

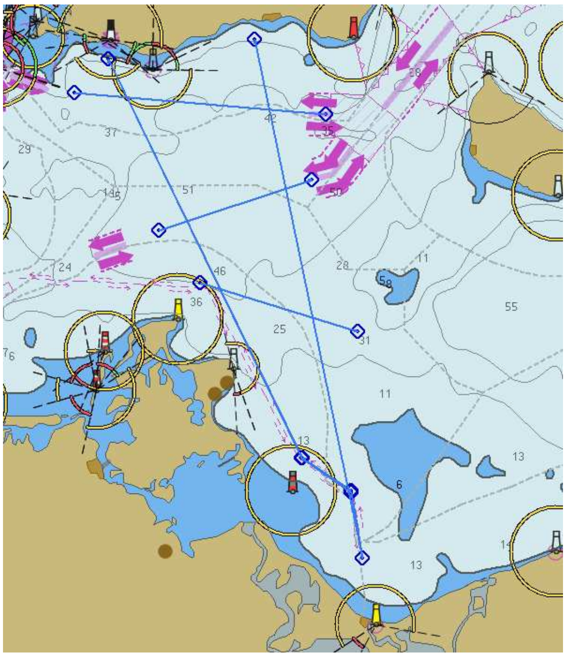

Figure 6. Routes of the Ro-Pax and chemical tankers considered in the model

2.2. Model of Ro-Pax ferries traffic

Traffic of Ro-Pax ferries to and from Świnoujście Harbour was developed on the basis of the real data gathered from timetables and the model of time differences between scheduled and actual time of departure of sea ferries. Model of time differences was developed on the basis of research which was performed in Ferry Terminal in Świnoujście Harbour [6]. During this research times of departure were measured, next the differences between real and scheduled time were calculated. The measurements were carried out for almost all ferries entering to the Świnoujście Harbour. In the next step statistical analysis of the data was performed. The following results were obtained [6]:

- Mean difference between actual and scheduled time of departure: 4min
- Maximum difference between actual and scheduled time of departure: 34min
- Minimum difference between actual and scheduled time of departure: -9min (ferry unberthed before scheduled time)
- Standard deviation: 8.2min
- Skewness: 1.84
- Mode: 3min

Histogram of the differences between actual and scheduled time of departure is presented in *Figure 7.*

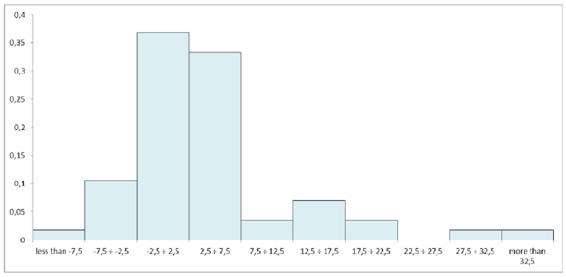

Figure 7. Histogram of the differences between actual and scheduled time of departure of ferries in the Świnoujście Harbour

According to characteristics of a random variable, calculated parameters and on the basis of the histogram theoretical distributions were chosen for further analysis. Analysis of fit goodness was conducted on the basis of Kolmogorov-Smirnov Test and the Anderson-Darling Test. For both tests Generalized Extreme Value Distribution was best fitted theoretical distribution and it was used for further simulation of ferries traffic.

2.3. External conditions model

Model takes into account several parameters which may have influence on the navigational safety such as wind speed and direction, waves, fog, time of day, and hour of sunrise and sunset. Data necessary for distributions of external conditions was obtained from Polish meteorological stations and extrapolated in order achieve open sea conditions. The navigation data was obtained from navigational charts, guides and own seamanship experience.

2.4. Collisions model

To model the collisions statistical model is used. The model neglects several dependencies but because it is based on real statistical data the 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. In complex systems with several traffic routes this number could be evaluated only by traffic streams simulation models.
The variability of mean ships routes is modeled by two-dimensional normal distribution which parameters were estimated by AIS data and expert navigators opinion. After collecting necessary input data the simulation experiment was carried out and the expected number of encounter situation was calculated. The critical distance where navigators perform anti-collision maneuver was assumed on the base of expert opinion separate for head on (heading

difference±160°), crossing and overtaking situations (heading difference ±20°).
Statistical data from southern part of the Baltic Sea accidents were used for evaluation of mean intensity of ship collision accidents in the Southern Baltic. Only the accidents in the open sea area was considered. *Figure 8* presents number of accidents per year in the whole Southern Baltic Sea area.

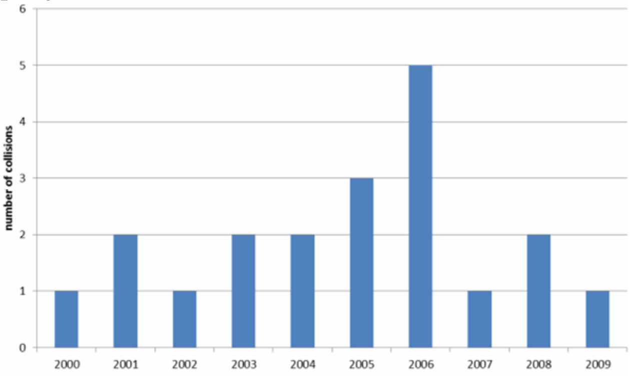

Figure 8. Number of collision accidents per year located at the open sea of the Southern Baltic

Data presented in *Figure 8* and the simulation results of ships encounter situation have been used for estimating the probability of collisions. The calculated probability of collision in single encounter situation is presented in *Figure 9*.

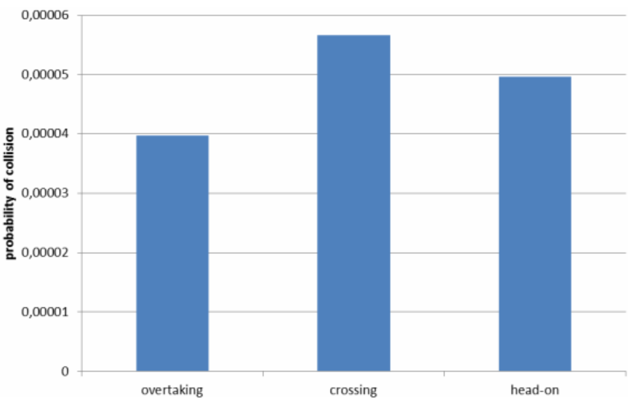

Figure 9. Calculated probabilities of the collision in particular types of encounter situations

3. Results

On the basis of gathered data and developed models simulation experiment was carried out. The model runs in accelerated time, so it is possible to achieve statistically sufficient number of scenarios. In the experiment over 7000 of iterations were taken. One iteration is a simulation of one year of traffic. The achieved results shows that the number of collision between Ro-Pax ferry and chemical tanker in the selected area equals 0,004 collision per year. Particular results are presented in *Table 2* and in the *Figure 10*.

Table 2. Results of the simulation experiment

Number of encounter situations	Number of collisions	Number of iterations	Time between collisions
Overtaking 29705	31	7113	229,5 years
Crossing 574656			
Head-on 38767			

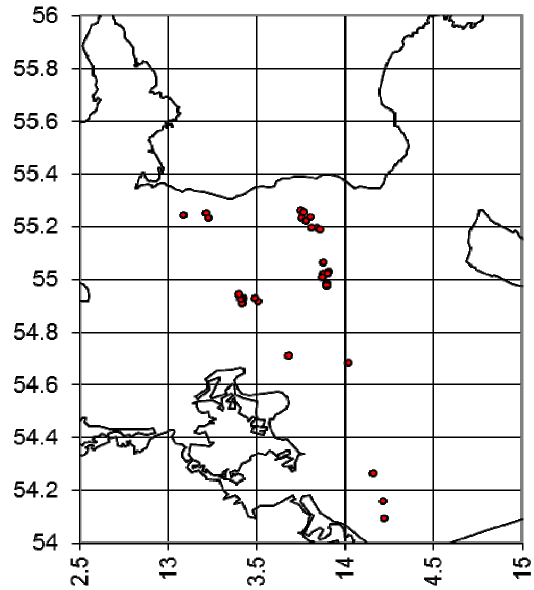

Figure 10. Positions of simulated collisions between Ro-Pax and chemical tankers

4. The consequences assessment of collision between Ro-Pax and chemical tanker carrying ammonia

4.1. Consequences of collision of chemical tanker and Ro-Pax ferry

One of the first and still used general statistical formula for collision of the ships consequences assessment is the one proposed by V. Minorsky [4]. Minorsky created regressive dependences between energy of collision and destroyed material (*Figure 1*) for 26 colliding ships. By means of this method it is possible to qualify, knowing the total energy of colliding ships, the volume of damaged material of both ships according to the following dependence:

$$E = 47{,}09 R_T + 32{,}37 \ \text{[MJ]}$$

where:
- E – the energy absorbed during the collision [MJ],
- R_T – the entire volume of material of damaged ships [m3].

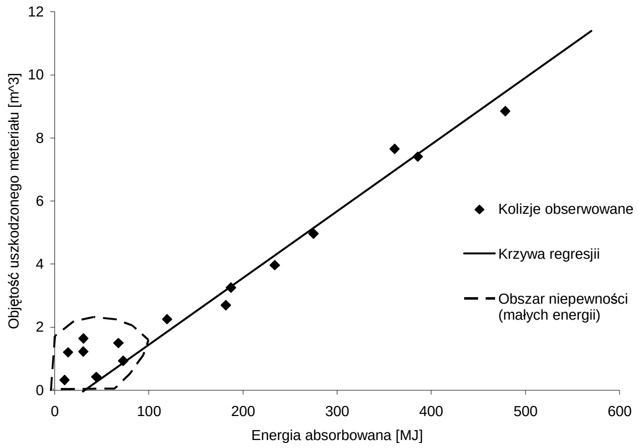

Figure 11. The regression Minorski curve and observed collisions of ships

P. Reardon and J. L. Sprung [7] verified Minorski data, they add more data possessed from 16 collision cases with smaller energy and formulated the following enhanced formula:

$$E = (47{,}1 \pm 8{,}8) R_T + 28{,}4 \text{ [MJ]}.$$

In presented study only one case is analysed and consequences are assessed. In further studies the whole methodology should be built to include statistical variation of ships and other relevant parameters. To calculation the following conditions have been assumed:

- Case descriptions: perpendicular collision between Ro-Pax (m/f "Polonia" size) and chemical tanker carrying ammonia on the approach to Świnoujście port.
- Chemical tanker parameters: *LOA*=129m, *B*=17.8m, *T*=8.6m, *V*=16.5kn, capacity total =8600cbm, 3 tanks each approx. =3000cbm (*Figure. 12*).
- Ro-Pax ferry parameters: m/f Polonia: *LOA*=170m, *B*=28.0m, *T*=6.0m, v_m=20kn, passengers =918 (82 crew).
- Speed and course: chemical tanker C=270º , v=12kn, m/f Polonia C=000º , v=8kn (approx. 4m/s) (slight speed reduction after failed anti-collision manoeuvres).
- Accident description m/f *Polonia* due to errors of both navigators collided with the bow of chemical tanker causing rupture of midship tank.

Energy have been calculated with the simplified formula given by PIANC [5] with the coefficient equals 0.8. The results for further calculations are:

1. *E*=137.1 MJ
2. R_T=2.3 m3
3. Radius of the hull rapture assuming its round shape: *r*=1.7m,
4. Diameter of tank rapture due to its horizontal separation from the ships side *d*=0.2m,
5. Released material ammonia from midship tank of capacity 3000cbm.

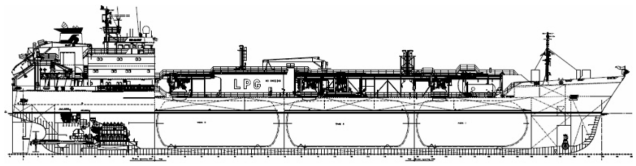

Figure 12. Considered in the study 8600cbm chemical tanker (side view based on www side of Hartmann Reederei)

4.2. Consequences assessment taking into consideration ammonia release

For the consequences assessment the ALOHA® the free software released jointly by U.S. EPA and NOAA have been applied [1]. ALOHA® is capable to evaluate thereat zones for different chemical and release scenarios. The following assumptions have been set up:

- SITE DATA: Location: Świnoujście approach POLAND, φ=53º 57.0'N, λ=14º 16.6'E.
- CHEMICAL DATA: Chemical Name: AMMONIA, Molecular Weight: 17.03 g/mol, AEGL-1 (60min)=30ppm, AEGL-2 (60 min)=160 ppm, AEGL-3 (60 min)=1100 ppm.
- ATMOSPHERIC DATA: Wind: 15kn from E.
- SOURCE STRENGTH: Tank Volume: 3000 cubic meters, Tank is 98% full, Circular Opening Diameter: 0.2 meters, Opening is 8.77 meters from tank bottom.
- Note: The chemical escaped as a mixture of gas and aerosol (two phase flow).

Some results of consequences analysis are presented on *Figure 13* where areas of Acute Exposure Guideline Levels (AEGLs) plotted on the satellite picture of Świnoujscie approach area. The AEGL is defined as the airborne concentration of chemical in ppm and time of exposure which causes:

- AEGL-1 discomfort,
- AEGL-2 serious and long-lasting adverse health effects or an impaired ability to escape,
- AEGL-3 life-threatening health effects or death.

It is clearly visible that in case of unfavourable wind conditions the passengers of Ro-Pax ferry could be exposure or life threatening effects (red area).

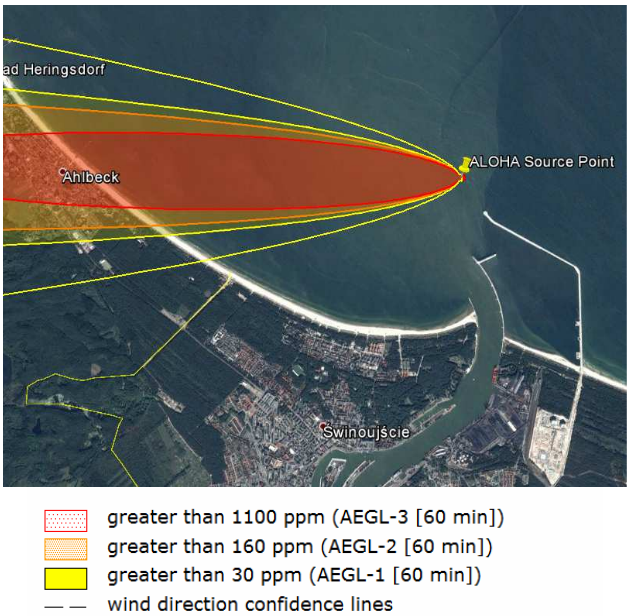

Figure 13. AEGL levels of released ammonia on the approach to Swinoujście (ALOHA data exported to Google Earth).

5. Conclusion

The paper presents an analysis of the accident between a passenger ship and a tanker carrying hazardous substances. Although the probability of an accident is one per 229,5 years, the possible consequences of such a collision are very serious, the adverse winds could threaten not only the lives of people on board both the passenger ship and the tanker but also could be harmful for the people living in the coastal towns lying in the area of contamination. Therefore the possibility of such an accident should be closely examined, the probable location where it can occur shall be determine in advance to prevent its occurrence.

References

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