Laboratory for Maritime Transport

Economics of Maritime Transport III: Environmental and Safety Analysis

**Operational Planning of Oil Spill management in the tactical level**



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**ABSTRACT**

**Operational Planning of Oil Spill management in the tactical level**

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In this paper, both the environmental consequences and the means for the suppression of a potential oil spill are discussed. Moreover, a genetic algorithm for optimizing the operational procedure in such cases is proposed in the following paragraphs.

**INTRODUCTION**

Nowadays, the trend of maximizing ships’ tanks’ capacity by simultaneously reducing their speed can sometimes lead to unpleasant outcomes. In the case of tankers, the reduced speed means more time outside of port in an unpredictable and sometimes dangerous environment. At the same time, the increase in oil tanks’ capacity leads to an overall greater risk assumed in case of ship loss or capsizing.

Oil spills at sea have been happening over the course of previous years at an overall declining rate either due to ship collisions or due to grounding. Some of them had grave environmental and financial consequences like in the case of Amoco Cadiz (1978) [1] where 220880 m3 of oil were approximately spilled outside of the coast of Britanny, France. It is estimated that the cost of the lost payload was around $25 million and a total of $85.2 million was ordered to Amoco Corp by a federal judge as a compensation to the community 10 years after the accident [2].



Fig.1 The sinking of Amoco Cadiz (1978) [1]

As one can see from history, preventative measures are taken after the accidents themselves. This also happened in the case of MARPOL where a total of six annexes, namely:

Annex I Prevention of pollution by oil &oily water (1983)

Annex II Control of pollution by noxious liquid substances in bulk (1987)

Annex III Prevention of pollution by harmful substances carried by sea in packaged form (1992)

Annex IV Pollution by sewage from ships (2003)

Annex V Pollution by garbage from ships (1988)

Annex VI Prevention of air pollution from ships (2005)

, have been established to prevent environmental pollution induced by ships. The measures described in MARPOL are in the form of ship design instructions addressed to the naval architect or the shipyard stuff and aim in the minimization of oil discharge into the ocean and marine pollution in general.

**How does an oil spill develop in time?**

D. Tsoump

**OIL SPILL MANAGEMENT SYSTEMS & PROCEDURES**

Systems for oil spill suppression have been developed over the course of years such as skimmers, booms, oil dispersants, in situ burning, skimmer vessels, and bioremediation.

Skimmers [5]

Mechanical devices that are designed to collect oil from the sea surface. They are able to do it without changing its physical and chemical properties. Usually, they are being used alongside with booms. Their main advantage is that they can be used without inducing any further environmental problem. There are different types of skimmers, each one more suitable for certain conditions:

1. Drum skimmers: are made from oleophilic drums (attract oil) so that the oil sticks to their surface and then, as the drum rotates, it is eventually removed and collected.
2. Weir skimmers: a weir directs the oil inside a storage hopper
3. Self-launching skimmers: a grooved disc is launched in open water and is gathered along with the oil.
4. Suction skimmers: as their name implies they operate as a vacuum cleaner, they suck the oil up from water surface and store it in a tank.

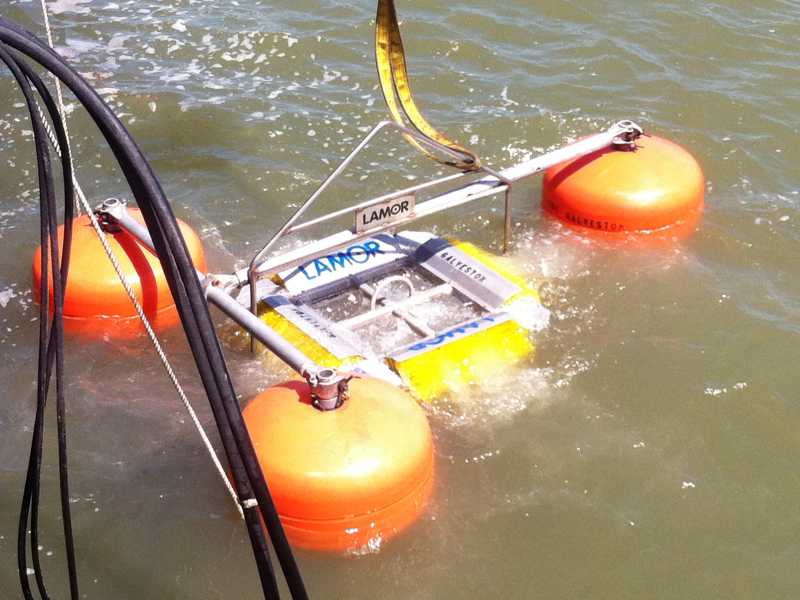


Fig.2 Skimmer (weir) in use

Booms [6]

They are the only available to stop the spread of the oil. Simultaneously they protect the coasts (or resources) by controlling the movement of the oil and help to make the oil spill thicker, so it will be easier to collect by the use of skimmers. Each boom is carried to the area of interest by two or three tugboats, each carrying one end or the middle in the case of three tugs of the boom itself.

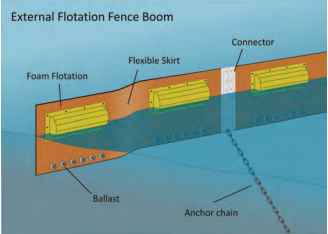
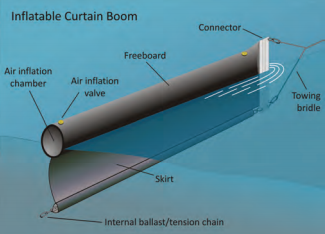
A boom is comprised of the following parts:

* flotation device: keeps boom at the surface level and traps floating oil
* freeboard: sits above the water preventing the oil from washing over the top
* skirt: prevents currents from pulling the oil under the boom
* ballast: keep the boom hanging vertically
* tension line: cables, chains or lines of the boom

The main types of booms are:

* Fence booms: it has tall freeboard so it’s more suitable if the oil moving across the surface of the sea
* Curtain booms: it has a short freeboard but longer skirt, so it’s used if there are stronger underwater currents.
* Shore-sealing booms: Water filled chambers prevent the oil from coming in contact with the shore.

Other types are inflatable, containment, sorbent, fire and snare boom.



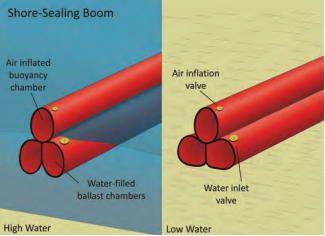
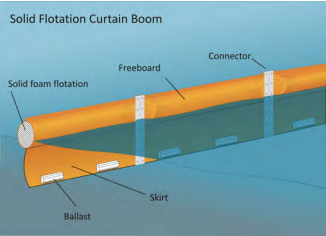


Fig.3 Different type of booms and their design



Fig.4 Boom in use

A boom can be deployed by several ways using two tugboats. The most common schemes are the U, V and J configurations. Skimmers can be then deployed by a third tugboat that follows the boom from behind or by the two tugboats carrying the boom itself.



Fig.5 U configuration example



Fig.6 V configuration example

Oil dispersants

Chemical mixtures which include surfactants that reduce the surface tension between water and oil. This helps the splitting of the oil into very small droplets that are easier to breakdown by the microorganisms and least dangerous for animals. But the usage of the dispersants has two main drawbacks. It has a short time limit for which is effective (first hours) and as chemical substances, are distinguished for toxicity. There are different formulations for oil dispersants and the effectiveness of each one depends on the oil type. There are two major types of dispersants:

* Conventional type: they are hydrocarbon based solvents that are mostly used for shoreline clean up
* Concentrate type: mixture of oxygenates, emulsifiers and moisturizers solvents.



Fig.7 Oil dispersants deployment by air

In situ burning

It’s in essence the controlled burning of oil at the point of its outflow. It has to happen during the first hours of the operation so that the oil film thickness is adequate to maintain the flame and the huge drawback is the trade-off with air pollution. This is the reason that this method is not used very often and isn’t allowed in certain areas.



Fig.8 In situ burning of oil

Skimmer vessels

Specially designed vessels that have the ability to collect oil from the sea surface. They have their own tanks, where they can store the oil and their own regulations that must follow.



Fig.9 Skimmer vessel at sea

Bioremediation

The objective of this method is to speed up the natural process of oil degradation from microorganisms. To accomplish this, the usage of oil dispersants and nutrients is essential, because the oil degradation by the microorganisms is faster for a specific proportion of C, N and P. When we have an oil spill, the oil present leads to a sudden increase of C%, so nutrients are used to increase the N% and P% accordingly.

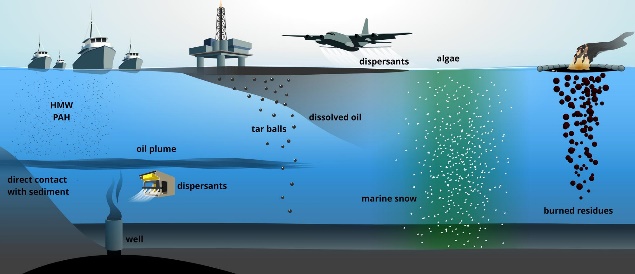


Fig.10 Bioremediation process

Although the existence of such systems and procedures is indeed valuable, the decision maker needs to take into account their limitations in usage as well as other financial criteria before deciding on the final distribution of equipment needed in the scenario in question.

**HOW TO CHOOSE THE APPROPRIATE EQUIPMENT**

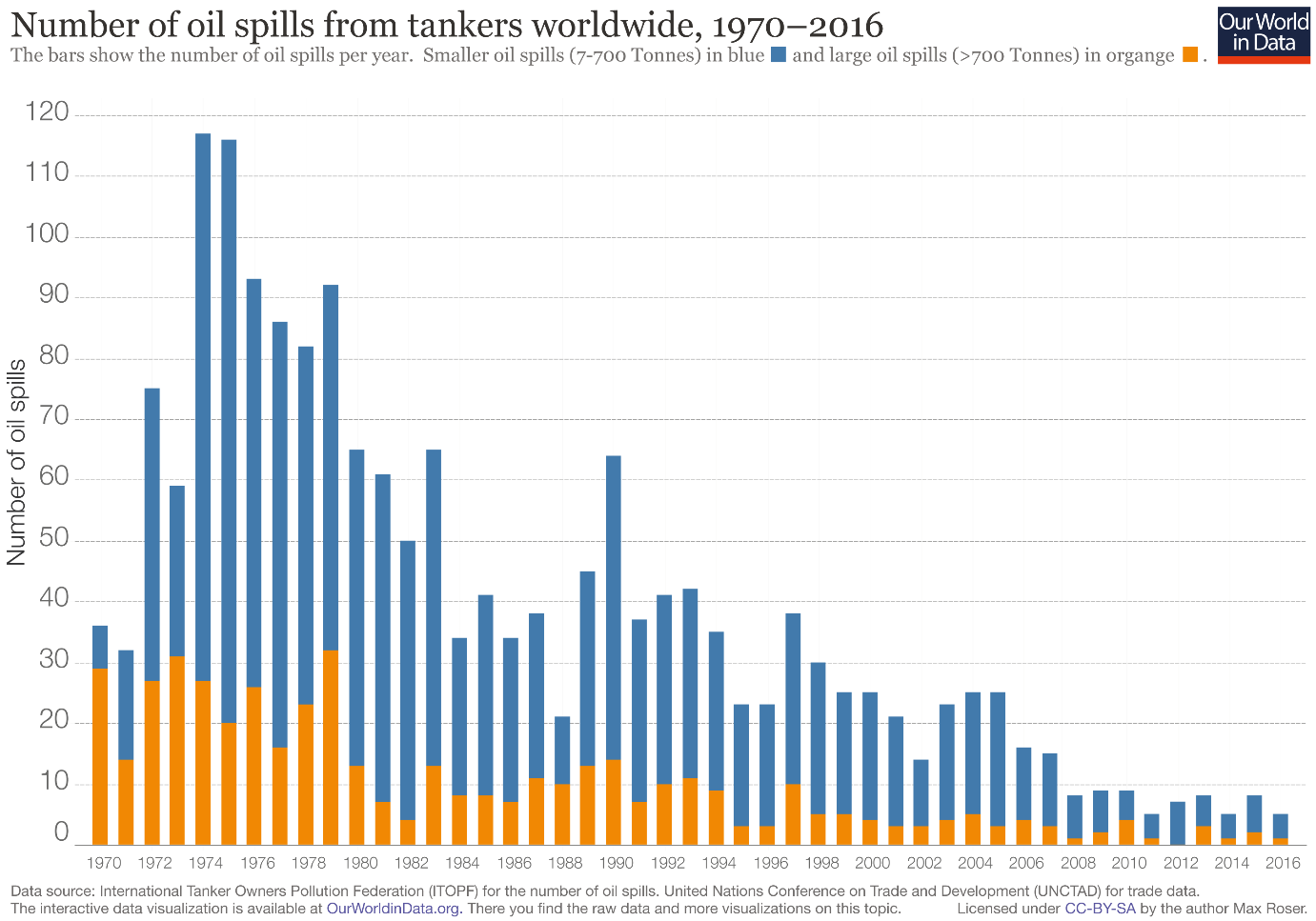
In order for the decision maker to choose the appropriate equipment for treating the oil spill, factors such as the size of the spill, its distance from shore, the weather, the budget of the operation and the landscape need to be taken into consideration.

In the case of skimmers, the different types are distinguished mainly by: the state of the environment (wind, waves) they can work in, the existence of oil keeping and concentrating equipment (i.e. booms) and the preference of the region’s governing body. To illustrate this, a vortex skimmer needs absolutely calm and clean sea conditions to work efficiently whereas a belt or filter skimmer can work up to 1.5 m and 2 m significant wave height accordingly. Moreover, weir skimmers tend to work better in boom-enclosed areas and inclined plane skimmers are favored mainly in the USA.

The choice of booms is mainly dependent on the environmental conditions, the existence of debris other than oil, the size of the spill, the other methods used for treating it and the acceptable drop of the level of safety in the area. For example, fire booms could be deployed in the case of in-situ burning in order for them to last the high temperatures through internal water-cooling. Inflatable and self-inflating booms are preferred when the available storage space for securing the equipment is relatively low and foam-filled containment booms are ideal in case fast deployment is prioritized. Nevertheless, deployed booms may induce the collision of another vessel and thus non-enter zones must be configured properly.

As for the other methods for oil spill treatment, each has its operational boundaries. Chemical dispersants are used with care only when necessary, that means when the weather conditions do not allow for mechanical oil recovery. However, they prove to be toxic for sea species and thus they are viewed only as the last measure. In-situ burning needs a sufficient oil film thickness of 2-3 mm to be effective and as a result the existence of booms is necessary. Moreover, the sea and wind state might reduce the burning efficiency or even extinguish the fire altogether.

**STATISTICAL DATA**



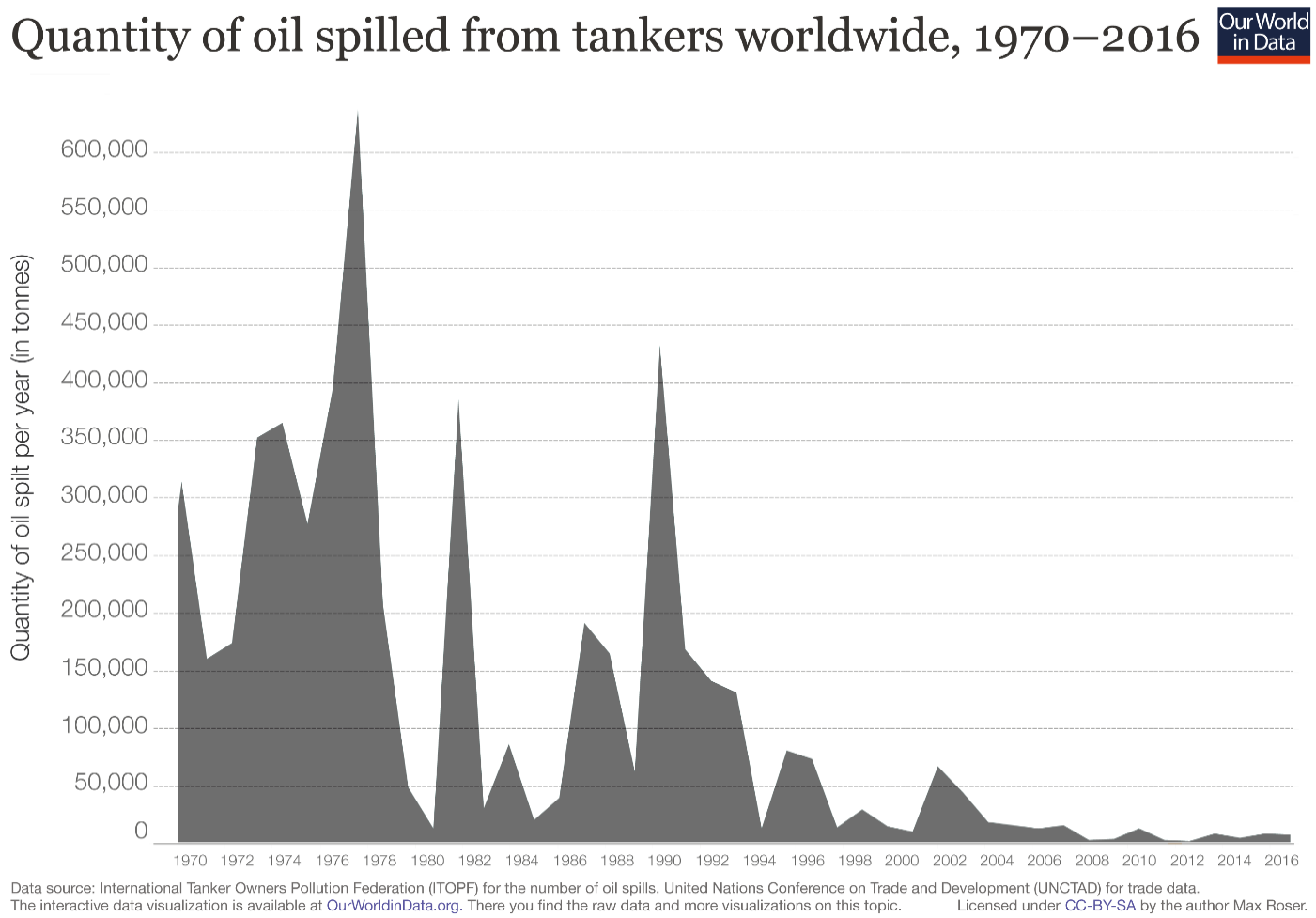


Fig.11 Sea Oil Spills in the years 1970-2016 [3]

D.Tsoump

**PROBLEM FORMULATION**

Let’s suppose we know the remaining oil curve as well as the area and thickness of the oil film for the first three days after the oil spill has started. The position of the center of the spill as well as the nearest coast point is also known from Internet sources. The remaining oil curve in our case is derived from the Adios program after providing the appropriate inputs concerning the size of the spill, the type of oil and weather data.

Next, we need to establish a goal curve to work on to, that means to set the desired individual goal quantities of oil at sea at static intervals. As the goal is steady by definition we need to take into account easy as well as difficult goals in order to grasp the whole picture.

The purpose of the optimization algorithm is to result in a final distribution of equipment (small skimmers, large skimmers, booms) that gets us as close to the goal itself as possible. For this task, the algorithm tests different random distributions of equipment with each other, evaluating them using the product of two metrics. The first metric used is absolute value of the mean of standard deviations between the initial goal curved and the achieved remaining curve. The second metric chosen is the length of booms needed in the worst case scenario to encircle the spill.

The amount of small and large skimmers available acts on the remaining curve. First, the goal curve is subtracted from the remaining curve in order to get the desired losses at each interval. Then small and large skimmers are used in a ratio of 30% and 70% respectively. However, this ratio might change later, as we account for a potential shortage in store for each type of skimmer when the other type is used in its place. We also account for a potential reuse of skimmers taking into consideration the time needed for them to get to the closest coast, get empty and then return to the spill area. Finally, as the volume inflow of large skimmers is twice that of the small skimmers and under the assumption of them using the same storage tanks, we need to account that small skimmers will be able to work continuously for two intervals instead of one.

For simplicity and in order to determine the length of booms needed for each scenario, an assumption of a circular area of oil is made at all time-intervals. Knowing the volume of oil at sea after the skimmer contribution, the area and thickness of the oil film can be retrieved using the following table (Ventikos).

The area of the oil film can be later used to determine the radius of the oil film area and eventually its perimeter at the time moment **.** Next, let’s assume that we have two tugs with a speed of starting from the nearest coast point each carrying one end of an imaginary total boom having length equal to the sum of lengths of all booms that need to be used. The tugboats need to cover the distance up to the nearest circular area point and then half a circle’s perimeter each (). The total distance and the respective time needed are thus:

By iterating through each time point , eventually we will stumble upon the case , meaning that the boom length could encompass the spill by the time . The desired length of booms is as a result equal to . While this approximation is rather pessimistic, at least we are on the safe side. The booms in reality are used individually where needed as shown on the map in a following section.

**GENETIC ALGORITHM**

The genetic algorithm is used to find closer to optimal solutions by mimicking the way species evolve in order to adapt to their physical environment as good as possible. The general idea, for our problem, is that in each step we have a “generation”- a collection- of n possible equipment distributions. Each member of the generation is ranked according to a metric fusing two other metrics, namely the boom length needed and the mean of standard deviations between the remaining and the goal curve measured at static time intervals. In each generation, we have n-3 individuals produced randomly, 2 individuals stemming from the cross-over of the two best and two other individuals from the previous generation and the best individual from the previous generation. That, however, is not the case for the first generation where all individuals are random. After the new members are created there is a process of altering, by a small amount, their characteristics through a process called Mutation governed by a certain probability (not all members are mutated). A good mutation algorithm for our case would be to simply increase or decrease the amount of each equipment unit by a small amount. This process ensures that a level of “gene” diversity is maintained. Following this procedure the next generation is created with equal amount of members as the previous one.

**CASE STUDY – THE PRESTIGE OIL SPILL**

In 2002, the Bahamas-flagged tanker Prestige, which was owned by a Liberian-based company (Mare Shipping Inc) and operated by a Greek company (Universe Maritime Ltd), was on route from Ventspils, Latvia to Gibraltar carrying 77000 metric tonnes of oil. On 13th November the vessel suffered hull damage in heavy seas off northern Spain, and send an SOS to the Spanish government, which denied the access to a port. All the crew, except the master and two more people, was evacuated and tug boats have been dragging the vessel for six days since neither from Spanish, French and Portuguese governments allowed the ship to dock, and eventually, on 19th November the ship split in two and sank 250 kilometers from the Spanish coast releasing a mass of 60000 metric tonnes of heavy fuel oil.



Fig.12 The sinking of Prestige

The vessel was built in 1976 in Japan, a period with an increasing demand for new-buildings. Due to the tight schedule of shipyards, ships from that time were marginally meeting the security requirements. This was proven by the fact that this particular ship didn’t have a double bottom, which in later years became essential for each ship. Also, the American Bureau of Shipping, who was responsible for the supervision of the 26 years old vessel, had found problems that ought to be fixed given a certain deadline. All the above warned for the upcoming disaster, as the vessel wasn't safe enough for sailing.

Spain and nine other European countries took part in a major offshore cleanup operation, but the severe weather and the inability of the using vessels made the operation extremely difficult. Despite all the obstacles they had to face, they managed to collect 50000 tonnes of oil-water mixture. For the protection of the coastal, 20 km of boom have been used, but it didn’t stop the contamination since 1900 km of shoreline were affected as shown in the below Figure 13. The cleanup was made manually by the workforce of over 5000 people, so the process was slow. In May 2004 the Spanish authorities organized an operation (estimated cost €100 million) for collecting the remaining oil in the wreck. The plan was to use bespoke shuttle tanks and was finalized in September 2004.

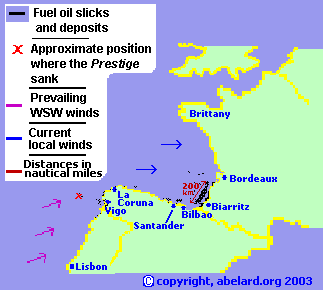


Fig.13 Map and weather conditions for the sinking area

The Prestige oil spill is one of the biggest in history. Although there was no loss of life, the economic and the environmental consequences were catastrophic. The resulting pollution of the Spanish and French coast was the worst ecological disaster until today, 1900 km of shoreline and 1177 beaches were affected, 22000 birds were found dead and scientists claimed that the marine life could suffer for at least ten years. Court documents had put the total financial cost of the spillage at 4 bn euros (cost of cleanup at 2.5 bn). Fishing was banned in this area and tourism decreased, making a huge impact for the economy of the local community. To prevent future disasters the following measures were taken:

* The withdrawal of single-hull tankers
* Revision of the phasing out timetable
* Condition Assessment Scheme – CAS (more strict survey regulations)
* The founding of EMSA – European Maritime Safety Agency
* Changes in contingency plans ( determination of port of refugee)
* Demanding for more strict regulations from classification societies
* Reinforcement of Port State Control

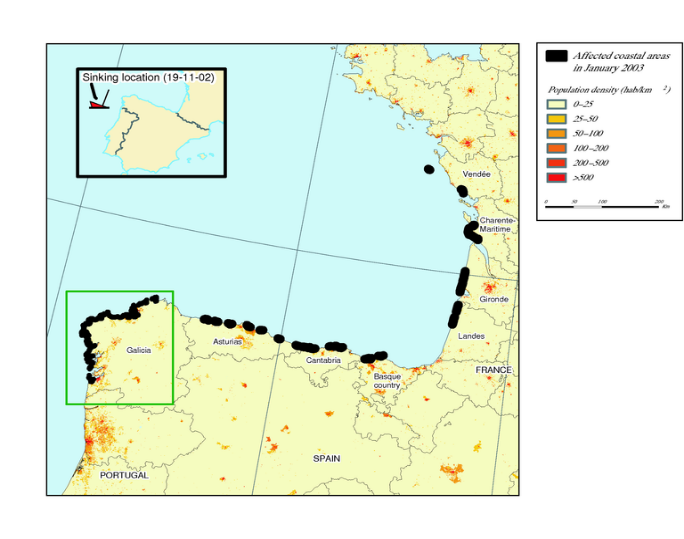


Fig.14 Affected coast line from Prestige Disaster

**CASE STUDY DATA**

A/ Equipment

The equipment whose amount will need to be determined by the algorithm comprises of booms and weir skimmers of two different calibers. The weir type is used as it is the most common, would work well alongside the booms and could withstand as better as possible the weather conditions described above.

The booms used are of the permanent type in order to last the severe wind of the area and for increased durability. They are made by the Manufacturer Abasco and their specifications are given in the following table.

|  |  |
| --- | --- |
| **Boom technical specs** | |
| **Overall height, in (cm)** | 24 (61.0) |
| **Float freeboard, in (cm)** | 10 (25.4) |
| **Skirt draft, in (cm)** | 14 (35.6) |
| **Total tensile strength, lb (kg)** | 36,000 (16,329) |

Table 1. Sigma 24 specs

The large skimmers used for our application are the GSW30OBP made by the Australian Company Globalspill and have the following specifications:

|  |  |
| --- | --- |
| **Large skimmers Technical Specs** | |
| Volume inflow () | 30 |
| Weir diameter (mm) | 550 |
| Floatation | 600 mm diam, foam filled pontoons |
| Oil outlet (mm) | 75 mm male camlock |
| Oil removal | Integral channel impeller pump |
| Construction | Stainless steel |

Table 2. GSW30OBP specs

As for the small skimmers, the GSW15OBP from the same manufacturer are used. Their specs are as follows:

|  |  |
| --- | --- |
| **Large skimmers Technical Specs** | |
| Volume inflow () | 15 |
| Weir diameter (mm) | 450 |
| Floatation | 600 mm diam, foam filled pontoons |
| Oil outlet (mm) | 50 mm male camlock |
| Oil removal | Integral channel impeller pump |
| Construction | Stainless steel |

Table 3. GSW15OBP specs

For both type of skimmers a hypothesis of a 100 tank per unit is made.

B/ Oil and Weather Conditions

As shown on the map above (Fig.13) the wind direction was WSW and its approximate magnitude was equal to

C/ Remaining curve

D/ Goal Curve

E/ Genetic Algorithm structure

**RESULTS**

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**CONCLUSION**

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