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Summary

Recent major spills on European coasts have highlighted the primary policy relevance for the EU of oil spills. This paper assesses the risks related to carrying oil to the EU along the route from the Russian Black Sea coast to Sicily, Italy (one of the most congested and strategically relevant European import routes). We develop a methodology based on Fault Tree Analysis, and we apply it to the most likely causes of an oil spill. We couple the resulting probabilities with data on expected spill size, types of oil carried and cleanup costs, to estimate expected costs for cleanup and loss of cargo. The route analysed appears to be a risky one; there is a “high” to “very high” risk of a spill along this route. The Turkish Straits turn out to be the major danger point; however, there is no obvious hierarchy amongst the other sites along the route.

Keywords: Oil spills, Cleanup costs, Risk analysis

JEL Classification: Q32, Q51, Q52, Q53

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1. Introduction

Assessing the externalities related to the extraction and transport of oil has proven in the last decades an issue of primary policy relevance. Recent major spills such as the *Erika* on the French Atlantic coast and the *Prestige* on the north-western Spanish coast have meant that public and governmental attention is firmly focused on the issue of how to minimise the impact of such disasters. Given the predicted global increase in energy demand, securing Europe's future energy needs will become of increasing geopolitical and strategic importance.

In order to arrive at a comprehensive evaluation of the external costs associated to importing oil into Europe, one needs to take into account the likely future oil demand-supply scenarios, the relative relevance of import routes and pipelines, the local specificities in terms of critical passages, the differences in terms of burdens and environmental and socio-economic impacts along the different routes and pipelines, and the development of oil spills prevention and remediation technologies and regulations. Last but not least, the intrinsic stochastic nature of the phenomenon should be carefully analysed. The role of the perception by the European citizens of the risk involved in carrying oil to Europe and the role of the associated *risk aversion* are particularly important in this context. In order to incorporate all these features into a consistent evaluation framework, one needs to develop a methodology suitable to deal with *probabilistic externalities*.

In this perspective, we address the issue of creating a methodology for analyzing the risks related to oil tanker accidents. A sample route from Novorossiysk on the Black Sea coast in Russia to Augusta in Sicily, Italy, is used as a benchmark to test the developments of this methodology. The basic scenario considers a Suezmax type tanker carrying approximately 145'000 tonnes of oil cargo. Tankers of this class are the most likely to be used along this route. The Bosphorus cannot be navigated by tankers larger than 150'000 tonnes; moreover, small tankers are unlikely to be used along this route due to recent European regulations which have banned tankers cruising under the flag of countries notorious for having lax regulatory criteria for registering ships – medium-sized and large tankers are unlikely to be operated under these flags.

The selected route has a number of special features which make it of singular importance and interest, not least the fact that it passes through the Bosphorus Straits, a highly congested and navigationally difficult sea passage passing through the heart of Istanbul in Turkey.

Four locations along the route were chosen due to a combination of the high likelihood of an accident happening in that particular site and the high environmental and socio-economic consequences that such an accident would entail. The parts of the route not considered, through the Black Sea and from the Aegean to Sicily, not only have a lower chance of a spill occurring due to a

relative lack of obstacles, but also should a spill occur the consequences would be, again relative to the other sites, less severe due to the absence of a nearby coastline and the fact that the oil would be naturally dispersed more quickly in the open sea. As a consequence their expected risk values are orders of magnitude lower than those of the selected sites.

This paper is organised as follows. The next section describes the route under scrutiny. Section 3 introduces and discusses the methodology used. Section 4 presents the main results and Section 5 concludes.

2. The Route

2.1. Novorossiysk

Novorossiysk is the largest port in Southern Russia and its oil terminal at Sheskhrańis is responsible for over 50% of Russian crude oil exports by sea. There is a second terminal at Novorossiysk, the Caspian Pipeline Consortium's (CPC) new oil terminal at Yuzhniy Ozerejevka. Oil is predominantly pumped to the terminal from the Tengiz oilfield in Western Kazakhstan and oil fields in Azerbaijan. The CPC terminal is situated 5 km offshore in waters more than 50-metre deep and is located west of the Sheskhrańis oil terminal.

2.2. Turkish Straits

By Turkish Straits is meant the passage from the Black Sea, through the Istanbul Strait (Bosphorus), the Sea of Marmara, and the Canakkale Strait (Dardanelles) into the Aegean Sea. It is the only sea route out of the Black Sea and as such the only sea route through which Russian and Caspian exports can reach the Mediterranean.

The Bosphorus passes through the heart of Istanbul, Turkey's largest city with a population of approximately 12 million. It is 31 km long and on average 0.8 nautical miles wide, though at its narrowest point it is only 660 metres wide. Depth varies from 35 to 12 metres and vessels passing through are required to make 12 course alterations, including one turn of 45° at the narrowest point and another turn of 80°.

The Dardanelles is another waterway similar to the Bosphorus. It is 70 km long though it is not as narrow as the Bosphorus: its narrowest point is 1.5 km wide. The accident risk is therefore much lower as, firstly, it does not pass through the centre of a large city (reduced consequences) and secondly, the topology allows for a safer passage (reduced incident probability). As such, when referring to the Turkish Straits, a number of factors refer mainly to the Bosphorus, however, where appropriate, data for the Dardanelles have been included.

Though a number of pipeline projects bypassing the Straits have been constructed or are being planned¹, their high transport costs per barrel mean that oil transport by tanker through the Bosphorus is still by far the preferred transport route for exporters. At present roughly 1.7 million barrels of oil per day (bpd) is moved through the Bosphorus. Predicted increases in Russian and Caspian exports mean that by 2010 another 2-3 million bpd could be added. The International Energy Agency (IEA) estimates that the Straits have a maximum capacity of 1.8 million bpd.

The Straits are classed as international waters and as such Turkey has an obligation under the Montreux Convention of 1936 to permit free transport for merchant traffic. At that time there were only approximately 17 vessel transits per day, weighing on average 13 tonnes and mostly carrying grain. Today there are over 130 vessel transits a day of which roughly 15% are oil tankers, often as big as 150'000 tonnes – the maximum size for the Turkish Straits. In addition to this 1.5 million people commute from one side of the Bosphorus to the other each day, which makes it one of the busiest waterways in the world.

Despite Russian opposition, Turkey unilaterally implemented certain traffic regulations in the Straits following an accident in 1994, with the aim of enhancing the navigational and environmental safety and security in the Straits which at that time already had a dense level of traffic. In 1998 Turkey introduced further regulations governing vessel flow through the Straits including a five-fold increase in passage tariffs to help pay for ship safety measures. Both the regulations in 1994 and 1998 were supported by the United Nations International Maritime Organisation (IMO). Turkey has also recently completed installation of a new vessel tracking System (VTS) which should help further reduce the risk of accidents.

2.3. Aegean Sea

The Aegean Sea is located between the coasts of Greece and Turkey and the islands of Crete and Rhodes. It covers an area of 210 square kilometres and contains over two thousand islands of varying sizes, most of which belong to Greece. The Aegean is also filled with submerged rocks and island populations that depend on fishing and tourism for their livelihood. It has been named as a key area of the Mediterranean in need of protection by the World Wildlife Fund.

This area of the Mediterranean has a massive amount of tanker traffic, as it is here that tankers travelling from the Black Sea and the Suez canal converge, increasing the likelihood of a collision.

¹ On 9th November 2005, a project for a new bypass pipeline between Samsun (on the Black Sea) and Ceyhan (on the Mediterranean) was announced. Once realised, this pipeline will substantially relieve (by removing 1million bpd from the Turkish Straits traffic) but not completely solve the problem, if the projections of sustained demand growth for Russian and Caspian oil prove correct.

2.4. Augusta

The port of Augusta in Sicily is the third largest in Italy after Trieste and Genoa in terms of oil imports. It can handle tankers of up to 385000 dwt and serves the ISAB refinery, Italy's second largest. The port is situated in the Marina di Melilli between Siracusa and Augusta. The area is one often frequented by tourists most of the year, and there is a nature reserve on the coast just south of the port. In 2003, 31 million tonnes of oil were imported through Augusta.

3. Methodology

The risk analysis proceeds via the following framework pathway.

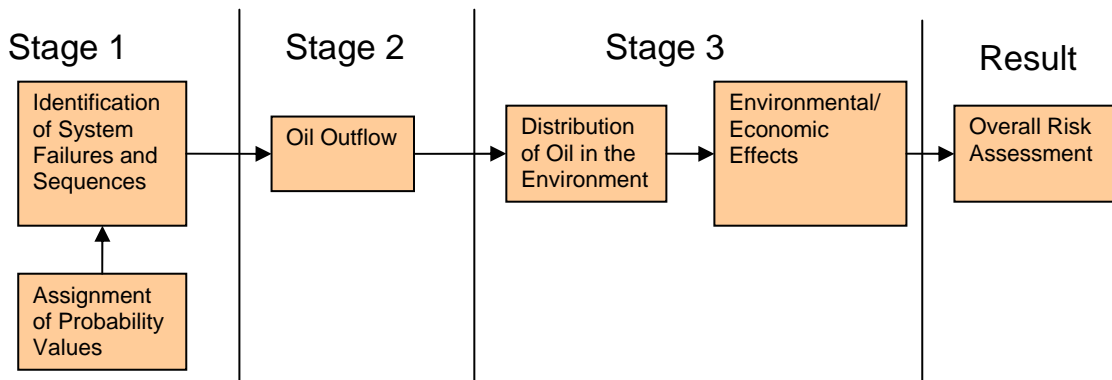


Figure 1. Outline of risk analysis methodology

3.1. Stage 1. Causes and probabilities of oil spills

The first task is to identify the possible causes of an oil spill. Ship-related oil pollution is attributed mostly to operational discharges which have consistently overshadowed accidental discharges. Apparently the majority of these discharges happen either close to the mainland or within port areas and terminal stations resulting usually in small spills which are dealt with by the local authorities and are seldom reported. Less frequently, the cause of an oil spill from a tanker is an accidental event. The most likely causes of accidental oil spills are grounding and ship to ship collision. Fire and explosion used to be significant causes of accident. Their importance is now negligible, due to recent changes in unloading regulations that prevent the formation of explosive gas mixtures in the hull. Structural failures, foundering and loading-unloading errors can also cause sizeable spills; in these cases the human element, which can play a role also in case of grounding and collision is particularly important.

The rest of this paper focuses on *groundings* and *collisions* as these are the two most likely sources of accidental oil spills.

The probabilities of a grounding or collision incident occurring and causing oil to be spilled are calculated via Fault Tree Analysis (FTA). The probabilities were calculated using data from Brown² using human error performance values under various situations and previous oil spill statistics.

The Fault Trees in the Appendix show the possible accident trajectory of opportunity which could lead to an oil spill, and standard probabilities were attributed to the initiator events. These are combined using Boolean algebra techniques. If, for an event to occur, two or more causal events need to happen (or not happen as the case may be), then the probabilities of these two events are multiplied together. This new value gives the probability of each events occurring, commonly known in Boolean algebra as the intersect of events. This is represented by an AND gate in the Fault Tree. For example, in the Fault tree for grounding in the Appendix, for drift grounding to occur, four events must happen simultaneously:

1. There is a loss of steering or propulsion.
2. There is an anchor failure.
3. There is a failure in the ability of assistance to prevent the grounding.
4. There is an unsafe wind or current which propels the vessel into a place where it grounds.

Only if all of these factors occur at the same time will grounding occur.

If, on the other hand, for an event to occur only one of any number of casual events is required for an event to occur, these probabilities are added together. In Boolean algebra this is the union of events³ and is represented by an OR gate.

For there to be a failure of assistance to prevent grounding, any one of these events is sufficient.

1. Assistance is not requested.
2. Assistance does not arrive.
3. Assistance unable to prevent grounding.

For the sake of simplicity, where there is a pathway that is far more important (difference is more than two orders of magnitude) than the others where only one is necessary (OR gate), only that pathway is considered. These probabilities are per tanker passage.

These probabilities are then multiplied by the site-specific weightings which are listed in Table 1. The weightings take into account the physical variations between the sites. For example, the chance of assistance not arriving in the Bosphorus is a lot lower than it is for the Aegean. This is because the Bosphorus is very highly monitored and there is plenty of assistance available along it. The Aegean

² [25]

³ To be precise, the union is the sum of the probabilities minus the probability that the events occur simultaneously (intersect). As the probabilities used in this analysis were quite small, the intersect was negligible and therefore not considered.

on the other hand is very large, less well monitored and assistance is more scattered. The Aegean therefore has a higher weighting factor for this event than the Bosphorus.

The pathways in the fault trees in the Appendix which are coloured light blue from the initiating event through to the grounding/collision occurring are generic faults which are independent of the location, i.e. they could happen anywhere along the route. Elements shaded in grey have a site-specific weighting and as such shall be different for each location. The probability values on the fault tree will be multiplied by the factors in the following Table to give the relative site probability of this accident trajectory of opportunity.

Factor		Novorossiysk	Turkish Straits	Aegean Sea	Augusta
w_{1s}	Assistance unable to help	2	4	1	1
w_{2s}	Non Arrival of Assistance	2	1	4	1
w_{3s}	Desired track unsafe	4	5	2	4
w_{4s}	Grounding obstacle	4	5	1	4
w_{5s}	Other vessel	3	5	2	3
w_{6s}	Vision impairment	3	4	1	1
w_{7s}	Erroneous/untimely action	1	3	1	1
w_{8s}	Bad weather/currents	2	4	1	1
w_{9s}	Manoeuvre not possible	3	4	1	3
h_s	Passage Time (hours)	8	20	100	8

Table 1. Site specific factor weighting

Where:

1 = No increased risk

4 = High increased risk

2 = Slight increased risk

5 = Acute increased risk

3 = Medium increased risk

Combining FTA with site-specific weightings according to Equations (1) to (4) below, leads to the probabilities of an accident occurring as at the four selected locations follows. The computed probabilities are reported in Table 2.

$$P(\text{Collision}) =$$

$$w_{5s} * P(\text{vessel in erroneous position}) * w_{9s} *$$

$$P(\text{Manoeuvre not possible}) + w_{7s} * P(\text{Remedial action not taken}) + P(\text{Error not detected}) \quad (1)$$

$$P(\text{Grounding}) = P(\text{Drift Grounding}) + P(\text{Powered Grounding}) \quad (2)$$

Where:

$$P(\text{Drift Grounding}) =$$

$$h_s * P(\text{Lost Steering/Propulsion}) * P(\text{Anchor Failure}) * [P(\text{assistance not requested}) + w_{2s} * P(\text{Assistance does not arrive}) + w_{1s} * (\text{Assistance unable to help})] * w_{8s} * P(\text{Unsafe wind/Currents}) \quad (3);$$

$$P(\text{Powered Grounding}) =$$

$$P(\text{Course Leaves Desired Track}) + w_{3s} * P(\text{Desired Track Unsafe}) \quad (4)$$

Location	Grounding		Collision	
	Computation	Result	Computation	Result
Novorossiysk	$[8 * 8.4E-4 * 0.25 * (0.1 + 2 * 0.1 + 2 * 0.1) * 2 * 0.01] + [1 * 1.95E-4 + 4.11E-5 + 4 * 2,371E-4 * 3 * 0.01]$	$1.68E-4 + 2.65E-4 = 4.33E-4$	$3 * 2,371E-4 * 3 * 0.01 + 1.95E-4 + 4.11E-5$	$2.57E-4$
Turkish Straits	$[20 * 8.4E-4 * 0.25 * (0.1 + 4 * 0.1 + 1 * 0.1) * 4 * 0.01] + [3 * 1.95E-4 * 0.9999 + 4.11E-5 + 5 * 2,371E-4 * 4 * 0.01]$	$1.01E-3 + 6.73E-4 = 1.68E-3$	$5 * 2,371E-4 * 4 * 0.01 + 1.95E-4 + 4.11E-5$	$2.84E-4$
Aegean Sea	$[100 * 8.4E-4 * 0.25 * (0.1 + 1 * 0.1 + 4 * 0.1) * 1 * 0.01] + [1 * 1.95E-4 * 0.9999 + 4.11E-5 + 1 * 2,371E-4 * 1 * 0.01]$	$1.26E-4 + 2.38E-4 = 3.64E-4$	$1 * 2,371E-4 * 1 * 0.01 + 1.95E-4 + 4.11E-5$	$2.38E-4$
Augusta	$[8 * 8.4E-4 * 0.25 * (0.1 + 1 * 0.1 + 1 * 0.1) * 1 * 0.01] + [1 * 1.95E-4 * 0.9999 + 4.11E-5 + 4 * 2,371E-4 * 3 * 0.01]$	$5.04E-6 + 2.65E-4 = 2.70E-4$	$3 * 2,371E-4 * 3 * 0.01 + 1.95E-4 + 4.11E-5$	$5.04E-6$

Table 2. Probability computations for Grounding and Collision.

Two calculations were made for each site, the probability of a spill occurring and being of an Average size and the probability of a “Worst Case Scenario”.

A Worst Case Scenario is defined as 90% of cargo is lost (spill size =130’000 tonne) and cargo is 100% crude oil.

The probable spill size and the likelihood that an incident came under the Worst Case Scenario category were taken from statistics of previous tanker accidents. The probability that, once an oil spill has occurred, it results in a Worst Case Scenario, is computed as follows: (from Table 4):

$$P(>100'000 \text{ tonnes spilt}) = \text{Expected value} * 0.02_{\text{grounding}} \text{ OR } 0.01_{\text{collision}} \quad (5)$$

The fact that not every grounding or collision which occurs causes a spill is then also taken into account (Table 3).

3.2. Stage 2. Oil outflow assessment.

Once the probabilities of each initiator event have been established, they are multiplied by a weighting factor for each site, usually based on the physical characteristics, preventive measures and level of spill preparedness of the location. This allows us to determine:

1. given that grounding or a collision has occurred, the probability that oil is spilt, and then,
2. given that oil is lost, the probabilities of different amounts of oil being spilt.

From 1993, all new tankers above 5'000 dwt were required to have double hulls or equivalent. 39% of all tankers had double hulls in 2001.⁴ A report commissioned in the US after the Exxon Valdez disaster in Alaska showed that double-hull designs reduced the number of spills (over the single-hulls) by 54 percent for the 150'000-dwt tankers. However in collisions, the double-hull vessels had a larger average spill size (given a spill) than the single-hulls, but the single-hulls had a larger maximum spill. For the grounding scenarios, in comparing average spill size given a spill, the single-hull vessel had a larger average spill than the double-hull in the 150'000-dwt size. The double-hull designs had a larger maximum spill than the single-hulls.⁵

Ship Size (dwt)	Cargo Spill Probability					
	Collision		Grounding		Average Collision	Average Grounding
	single hull	double hull	single hull	double hull		
0 – 2,000	0.52	0.364	0.19	0.171	0.45916	0.18259
2,000–5,000	0.56	0.392	0.19	0.171	0.49448	0.18259
5,000–20,000	0.24	0.168	0.35	0.315	0.21192	0.33635
20,000 – 50,000	0.24	0.168	0.35	0.315	0.21192	0.33635
> 50,000	0.31	0.217	0.39	0.351	0.27373	0.37479
Average	0.39	0.273	0.3	0.27	0.34437	0.2883

Table 3. Spill probabilities for oil tanker collisions and groundings (data 1980 - 1995)⁶

Table 3 calculates the probability of a tanker collision or grounding provoking an oil spill. The average probability takes into account the percentage of tankers with double hulls and their reduced susceptibility to loss of cargo.

From the data available, it appears that the average tanker travelling from Novorossiysk to Augusta is a Suezmax class tanker with a size of 145'000 dwt. Given there is an oil spill due to a collision or grounding, the likelihoods of different quantities of oil being released are shown in Table 4.

⁴ [19]

⁵ [19]

⁶ [20]

Type of Accident	Probability of Spill Size (tonnes)				
	0 – 1'000	1'000–10'000	10'000–50'000	50'000–100'000	>100'000
Collision	0.65	0.22	0.07	0.05	0.01
Grounding	0.68	0.24	0.05	0.02	0.02

Table 4. Spill size probability for 145'000 tanker⁷

Values for Average and Worst Case scenario incident probabilities are calculated for each of the selected sites per tanker passage. In the next section, the (cargo loss and cleanup) costs related to these probabilities are combined with them in a consistent way in order to evaluate the risk an expected cost per passage.

	Collision	Collision + Spill	Grounding	Grounding + Spill	Total
Novorossiysk					
Average	2.57E-04	7.03E-05	4.33E-04	1.62E-04	2.49E-04
Worst Case	5.14E-06	1.41E-06	8.66E-06	3.25E-06	3.28E-06
Turkish Straits					
Average	2.84E-04	7.77E-05	1.68E-03	6.30E-04	7.43E-04
Worst Case	5.68E-06	1.55E-06	3.36E-05	1.26E-05	8.31E-06
Aegean Sea					
Average	2.38E-04	6.51E-05	3.64E-04	1.36E-04	2.16E-04
Worst Case	4.76E-06	1.30E-06	7.28E-06	2.73E-06	2.90E-06
Augusta					
Average	2.57E-04	7.03E-05	2.70E-04	1.01E-04	1.85E-04
Worst Case	5.14E-06	1.41E-06	5.40E-06	2.02E-06	2.65E-06

Table 5. Grounding and collision spill probabilities

The average spill size for a tanker collision is found to be 8175 tonnes. The equivalent for a spill caused by grounding is 6790 tonnes⁸. In 2% of grounding spills and 1% of collision spills, the outflow will be of a “Worst Case Scenario” variety.

From Table 5, it follows that, along the whole route, the probability of an Average size spill is **1.39E-3**, while the probability of a Worst Case spill is **1.71E-5**.

⁷ [20]

⁸ Average grounding oil spill size = $500 \cdot 0.68 + 5,000 \cdot 0.24 + 25'000 \cdot 0.05 + 75'000 \cdot 0.02 + 125'000 \cdot 0.02 = 6790$ tonnes. Average collision oil spill size = $500 \cdot 0.65 + 5,000 \cdot 0.22 + 25'000 \cdot 0.07 + 75'000 \cdot 0.05 + 125'000 \cdot 0.01 = 8175$ tonnes

3.3. Stage 3. Distribution of Oil in the Environment, Environmental and Economic Effects

The European average cleanup cost per tonne of crude oil spilt is \$10'800. This value was then adjusted using a modification factor again based on the physical characteristics of the environment and the gravity of the impact an oil spill could have on them. The weightings (Table 7) vary significantly depending on factors such as type and quantity of oil, location type, environmental sensitivity, economic use and the response capabilities on site. These weighting factors and the cleanup costs per tonne are listed in Table 8.

Combining weighting factors, cleanup cost per tonne and the quantity of oil spilt respectively in case of grounding and collision, yields the total cleanup costs for Worst Case Scenario and Average size spills in the different locations listed the third and sixth column of Table 9.

The cost of lost revenue is computed taking an arbitrary value of \$50 per barrel (\$370/tonne). For Average size spills, this equates to \$630'850 in case of collision and to \$518'000 in case of grounding. For the Worst Case Scenario (the spill size is independent from the cause in this case) the loss in revenue rises to 48.1 million. The total cost to the carrier is the sum of the cleanup costs and the loss in revenue.

The costs computed in this section will be then used in Section 4, where expected costs will be computed as the product of the probability of occurrence and its monetised consequences at each location⁹ and then summed over the whole route.

3.3.1. Modification Factors

The cleanup cost are based on the European average cost of \$10'800 per tonne¹⁰ spilt.¹¹ This has been adjusted by the following modification factors which were calculated using previous oil spill statistics. The ratings given are based on data available on the sites under scrutiny.

- **Oil Type.** This is the factor by which different types of oil affect the spill cost. Cleanup costs for lighter crude and refined oils tend to be below the average spill cleanup cost. Heavier crude and fuel oils, as well as emulsions, are considerably more persistent and viscous. These oils are difficult to clean up using dispersants, skimmers and pumps, resulting in

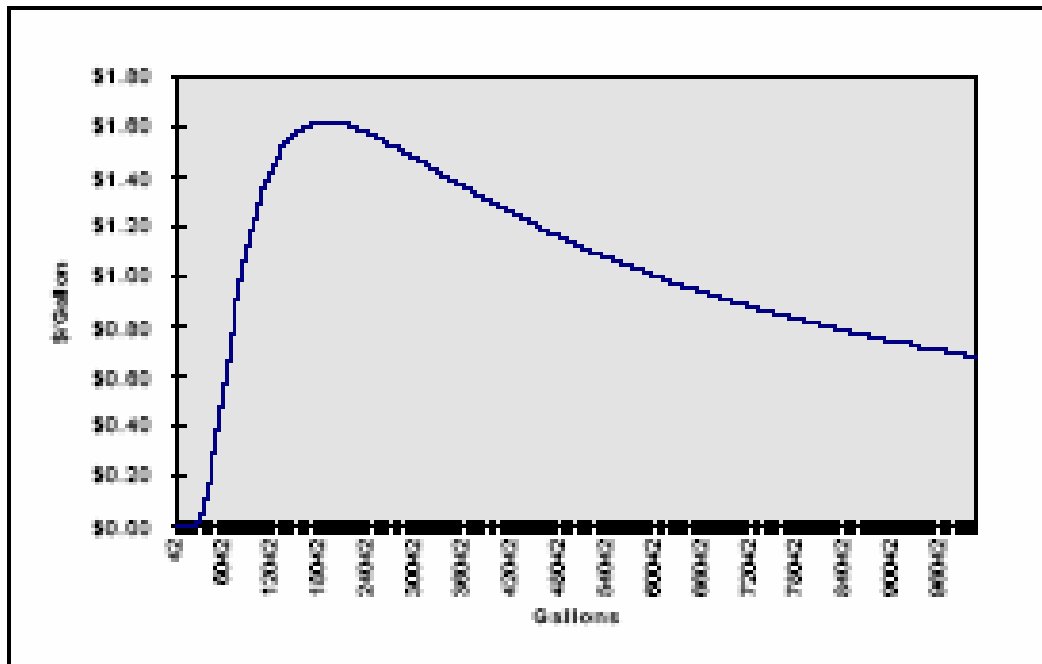
⁹ To anticipate, for revenue loss this is dealt with in section 4.2, while for cleanup costs, this is shown in Table 9.

¹⁰ This assumption is likely to be too high, especially for a spill in the Russian Black Sea; however more precise data was not available at the time of writing.

¹¹ [23]

considerably higher cleanup costs¹². Typically only 10 – 20% of spilled oil is contained and recovered.¹³

- **Spill Size.** As Figure 2 demonstrates, the cost of a spill does not increase linearly with the size of the spill. Obviously a larger spill costs more to clean up than a smaller one, but there is a maximum cost per tonne which occurs at around 7 tonnes, after which the cost of dealing



with the extra oil diminishes.

Figure 2. Spill unit cleanup cost (1 gallon = 0.0032 tonnes)¹⁴

Table 6 show the shares of different oil types by spill size. As the average spill size is greater than 700 tonnes we shall assume that 75% of the cargo is crude oil and the other 25% is refined products.

%	Bunkers	Crude Oil	Refinery Products	Other
< 7 tonnes	22	51	15.7	11.3
7 – 700 tonnes	8	44	34.7	13.3
> 700 tonnes	3.6	67.8	25	3.6

Table 6. Oil spill sizes by oil type¹⁵

- **Location Type.** This factor accounts for whether the spill is found near a shoreline or in a port.

¹² [21]

¹³ [16]

¹⁴ [24]

¹⁵ [22]

- **Area Sensitivity.** Here the presence of national parks, areas of specific ecological interest are accounted for as a potential to experience long term damage (months to years).
- **Preparedness.** This factor takes into consideration the availability of cleanup equipment and personnel etc. and their efficiency (effective oil cleanup).
- **Response Time.** The time taken for a cleanup operation to commence.
- **Human Use.** The presence of habitations or economic activity (fishing/tourism) on the site and their potential to experience long term damage.
- **Weather.** Previous spills¹⁶ have shown that weather can be counted as neutral as it either helps to naturally disperse the oil or hinders cleanup.

Table 7 shows the modification factors by which the spill cost/tonne should be adjusted for Average and Worst Case Scenarios for each location. In Table 8 the weightings are multiplied with the European cost per tonne (\$10'807.83)¹⁷ of the Average and Worst Case Scenario to give the cleanup cost per tonne of such a spill.

¹⁶ The Braer spill in the Shetland Islands was one of the largest spills ever. Bad weather prevented a major retrieval operation from being put into effect through ultimately this same bad weather dispersed the spill to such an extent that major environmental damage was avoided.

¹⁷ \$ = US Dollar = € 0.8211 (21/09/2005)

	Weighting							
	Oil Type	Spill Size	Location Type	Area Sensitivity	Response Time	Preparedness	Human Use	Total
Novorossiysk								
Average	0.5675	0.27	1.28	1.2	0.8	1.15	1	0.2165253
Worst Case	0.65	0.01	1.28	1.2	0.8	1.15	1	0.0091852
Turkish Straits								
Average	0.5675	0.27	1.46	3.8	0.8	1.15	3	2.3462547
Worst Case	0.65	0.01	1.46	3.8	0.8	1.15	3	0.0995311
Aegean Sea								
Average	0.5675	0.27	0.46	3.2	0.97	1	1.7	0.3719273
Worst Case	0.65	0.01	0.46	3.2	0.97	1	1.7	0.0157776
Augusta								
Average	0.5675	0.27	1.28	1.2	1.15	1	1	0.2706566
Worst Case	0.65	0.01	1.28	1.2	1.15	1	1	0.0114816

Table 7. Weightings for Average and Worst Case spill scenarios

	Weighting	Cost/tonne
Novorossiysk		
Average	0.216	2338.47337
Worst Case	0.009	99.201024
Turkish Straits		
Average	2.346	25339.55128
Worst Case	0.099	1074.936096
Aegean Sea		
Average	0.372	4016.815194
Worst Case	0.015	170.3984256
Augusta		
Average	0.271	2923.091712
Worst Case	0.011	124.00128

Table 8. cleanup costs for Average and Worst Case spill scenarios.

4. Results

4.1 Inherent risk

The expected damage, or “risk” can be defined as the expected unwanted consequences. Here the unwanted consequences for the carrier are the probable costs that would have to be paid for cleanup and loss of revenue. In this analysis the risk will be taken as product of the calculated spill probabilities multiplied by the relevant damage costs.

$$M_1 = \sum_{i=1}^n P_i D_i \quad (6)$$

where P = Probability of a spill, D = damage cost and i = the site being assessed. The risk for the whole route (M) is the sum of these component risks.

Values for Average and Worst Case scenario incident probabilities are here calculated for each of the selected sites per tanker passage, along with the consequent costs. The risk is then evaluated as an expected cost per passage.

4.2. Loss in Revenue

When thinking about the total cost of a spill, the cost of the oil lost must also be taken into account. Due to the highly fluctuating oil prices, an arbitrary value of \$50 per barrel (\$370/tonne) was used to calculate loss in revenue.

$$\text{Average loss in revenue}_{\text{Collision}} = 8175 * 370 = \$3'024'750 \quad (7)$$

$$\text{Average loss in revenue}_{\text{Grounding}} = 6790 * 370 = \$2'512'300 \quad (8)$$

$$\text{Worst case scenario loss in Revenue} = 130'000 * 370 = \$48'100'000 \quad (9)$$

4.3. Total Cost

Total Average and Worst Case Scenario costs can be calculated for each location.

For example, if there was a Worst Case Scenario spill in the Bosphorus then the total cost would be the sum of the cleanup cost and the loss in revenue:

$$\text{Total Cost} = 48'100'000 + 140'000'000 = \$188'100'000 \quad (10)$$

4.4. Risk

The risk calculated here is the risk for the carrier, which is different than the risk for society. Carriers are only likely to be liable for cleanup and lost revenue costs. The risk is the product of the probability of occurrence and their monetised consequences. The tables below show the monetised risk per transit for grounding and collision per location in US dollars.

The cleanup risk would be the amount a tanker should expect to pay in remediation of the damages due to an oil spill caused by grounding or collision at each location.

	Grounding			Collision		
	Probability	Cost (\$)	Expected Cost (\$)	Probability	Cost (\$)	Expected Cost (\$)
Novorossiysk						
Average	1,62E-04	1,59E+07	2,57E+03	7,03E-05	1,91E+07	1,34E+03
Worst case	3,25E-06	1,29E+07	4,19E+01	1,41E-06	1,29E+07	1,81E+01
Turkish Straits						
Average	6,30E-04	1,72E+08	1,08E+05	7,77E-05	2,07E+08	1,61E+04
Worst case	1,26E-05	1,40E+08	1,76E+03	1,55E-06	1,40E+08	2,17E+02
Aegean Sea						
Average	1,36E-04	2,73E+07	3,71E+03	6,51E-05	3,28E+07	2,14E+03
Worst case	2,73E-06	2,22E+07	6,04E+01	1,30E-06	2,22E+07	2,89E+01
Augusta						
Average	1,01E-04	1,98E+07	2,00E+03	7,03E-05	2,39E+07	1,68E+03
Worst case	2,02E-06	1,61E+07	3,26E+01	1,41E-06	1,61E+07	2,27E+01

Table 9. Expected cleanup costs for oil spills caused by groundings and collisions

The total cleanup expected cost is the sum of the grounding and collision cleanup expected costs.

Figure 3 shows the expected cleanup costs of the Average and Worst Case Scenario spills for each site.

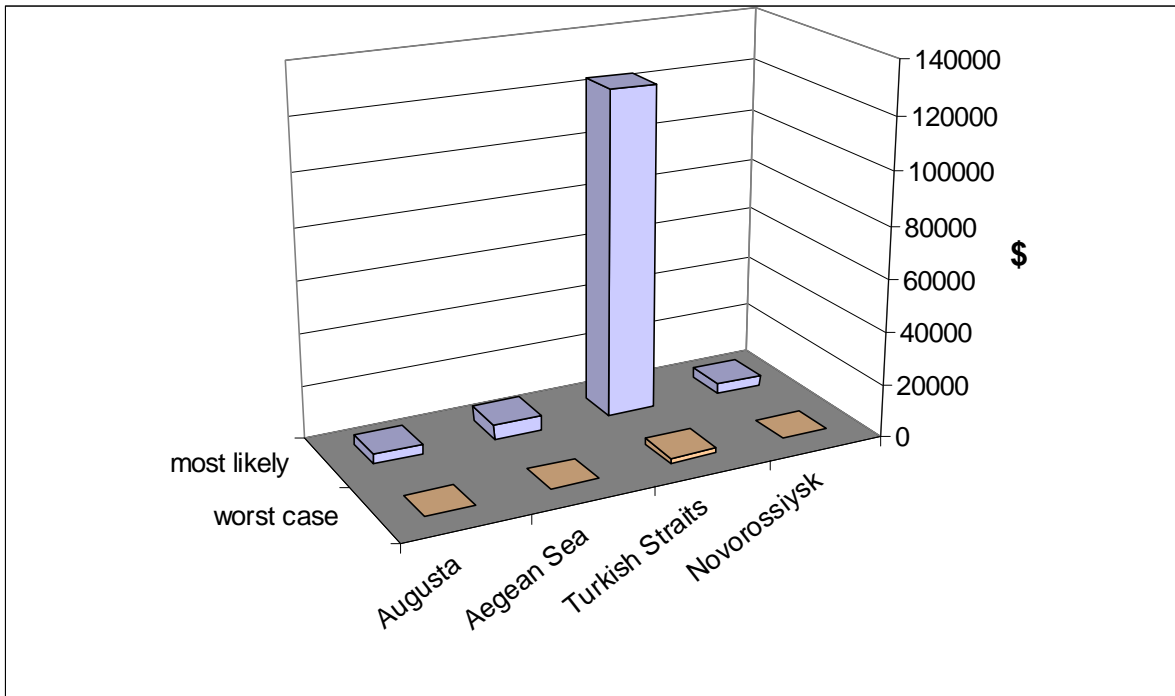


Figure 3. Expected cleanup costs for oil spills caused by groundings and collisions

The expected loss in revenue for an Average size spill is¹⁸ $1.39E-3 * 2'778'015 = \$3861$. The expected loss in revenue for a Worst Case Scenario spill = $1.71E-5 * 48'100'000 = \$822$.

The total expected costs under the two scenarios, for a tanker travelling from Novorossiysk to Augusta due to a collision or grounding is the sum of the expected loss in revenue due to the loss of cargo and the expected cleanup costs for grounding and collision:

$$\begin{aligned} \text{Total Route Expected Cost}_{(\text{Average spill})} = \\ 3916 + 124'491 + 5847 + 3685 + 3861 &= \$141'800 \end{aligned} \quad (11)$$

$$\begin{aligned} \text{Total Route Expected Cost}_{(\text{Worst Case Scenario})} = \\ 6.00E+01 + 1.98E+03 + 8.93E+01 + 5.53E+01 + 822 &= 2'202. \end{aligned} \quad (12)$$

4.5. Discussion

Using the professional judgement risk equivalence values from the table below, we can say that there is a “high” to “very high” risk of a spill occurring along this route ($\sim 1.0E-3 - 1.0E-4$), and a medium

¹⁸ The revenue loss figure of \$2'778'015 is computed as a weighted average of the figures computed in (7) and (8) for average size spills. The weights (approximately 0.481 for grounding and 0.519 for collision) are derived by comparing the relative shares of these events as accident causes.

risk of a Worst Case Scenario accident ($\sim 1.0\text{E-}6$). This is corroborated by the data on previous tanker spills in the Black Sea and Mediterranean areas.

Rating Categories	Probability of Occurrence	Professional Judgment on Risk Equivalence- Chance That Spill Will Occur
Will never occur	None	Zero
Very low or no risk	Rarely if Ever occurs	$1\text{X}10^{-9}$
Low	Unlikely to occur	$1\text{X}10^{-7}$
Medium	May occur	$1\text{X}10^{-6}$
High	Likely to occur	$1\text{X}10^{-4}$
Very High	Most likely to occur	$1\text{X}10^{-3}$

Table 10. Professional judgement risk categories¹⁹

Unsurprisingly given their special nature and location, the Turkish Straits have the highest probability of a spill occurring along with the gravest consequences. In fact, the Turkish Straits account for over 70% of the risk of an oil spill along the route. This, and the fact that a major spill is likely to occur due to a collision, is borne out by previous spill data – two of the largest spills on record, the *Independenta* and the *Nassia* were both caused by collisions in the Bosphorus.

4.5.1. Comparison of spill costs

It is interesting to look at how the spill costs compare to other historical spills. The Exxon Valdez tanker disaster which happened off the coast of Alaska in 1989, spilling 35'000 tonnes of oil, had a cleanup cost of roughly \$2 billion²⁰ (\$2.73 billion in today's money when adjusted for inflation).

A Worst Case Scenario spill in the Bosphorus where 130'000 tonnes of oil are lost would have a calculated cleanup cost of \$0.14 billion.

There is an order of magnitude difference in the two cleanup costs which can only partially be explained, and this despite the higher spill volume in the case of the Bosphorus. One factor not taken into account is the higher base per-unit oil spill cleanup costs in North America (\$19'814.63). This is roughly twice that of Europe (\$10'807.83). A probable discrepancy arises from the incompleteness of the weighting system. The data comes from the US Environmental Protection Agency (EPA) and was meant to be used for mapping out oil spill risks in US waters. As the Bosphorus Strait is unique in that it has very high tanker density, passes through the centre of Istanbul, and is difficult to navigate, it is reasonable to assume that the EPA weighting factors do not take these circumstances into account with sufficient emphasis. Unfortunately, cleanup data for actual accidents in the Bosphorus is not available.

¹⁹ [3]

²⁰ [26]

5. Conclusions

The route analysed appears to be a risky one: in terms of professional judgement risk equivalence values used in a similar context by Hildrew (2001), we can say that there is a “high” to “very high” risk of a spill occurring along this route ($\sim 1.0\text{E-}3$ – $1.0\text{E-}4$), and a medium risk of a Worst Case Scenario accident ($\sim 1.0\text{E-}6$). This is corroborated by the data on previous tanker spills in the Black Sea and Mediterranean areas.

The total cost of transporting a Suezmax tanker load of crude oil from Novorossiysk to Augusta is in the order of \$1'200'000²¹. Therefore, the expected cleanup cost per passage due to tanker collisions and groundings (\$141'800) represents approximately 11,8% of the total cost. This cost can in a sense be regarded as a lower bound for the premium an insurance company should charge to insure each tanker passage along the route against cleanup and loss of revenue due to spills caused by collisions and groundings.

It is quite conclusive from the results that the Turkish Straits are the major danger point along the route, both in terms of occurrence probability and spill impact. However it is interesting to note that there is no obvious hierarchy amongst the other sites. The fact that, for example, Novorossiysk has a comparatively high spill occurrence probability yet a comparatively low impact, should, in principle, provide reliable guidance to decision makers when considering investments into either spill prevention or spill response programs.

The costs for cleanups and revenue losses due to tanker accidents are enormous, running into billions of dollars in Worst Case scenarios. There have been huge improvements in tanker safety in the last decade or so, as oil carriers realise that it is in their own interest as much as the public to avoid such accidents as far as possible. As engineering standards improve, so the rate of accidents should decrease. The analysis initiated with this paper can help making rational decisions about where future investments into oil transit safety and further regulations from national and supra-national authorities should be focused.

The analysis is currently being extended. Our research agenda includes the following issues:

- *Refining the methodology*: extend to other accident causes, anchor spill probabilities on more recent data, create weightings from European spill statistics, use more accurate European data for specific cleanup costs, factor in technology developments for spill prevention and cleanup;
- *Extending the coverage of the evaluation exercise*: diversify by actual spill and tanker size, apply the methodology to other tanker routes, adapt and apply the methodology to pipelines;

²¹ [5]

- *Extending the scope of the evaluation exercise:* include impacts on the environment and socioeconomic activities, include risk aversion, apply benefit transfer methodology for the evaluation of non-monetized impacts.

We expect the impact of these developments to be considerable. By way of illustration, consider that back-of-the-envelope application of benefit transfer methodology indicates a willingness to pay for Istanbul inhabitants up to 400 million dollars, in order to avoid an Average size spill in the Bosphorus.

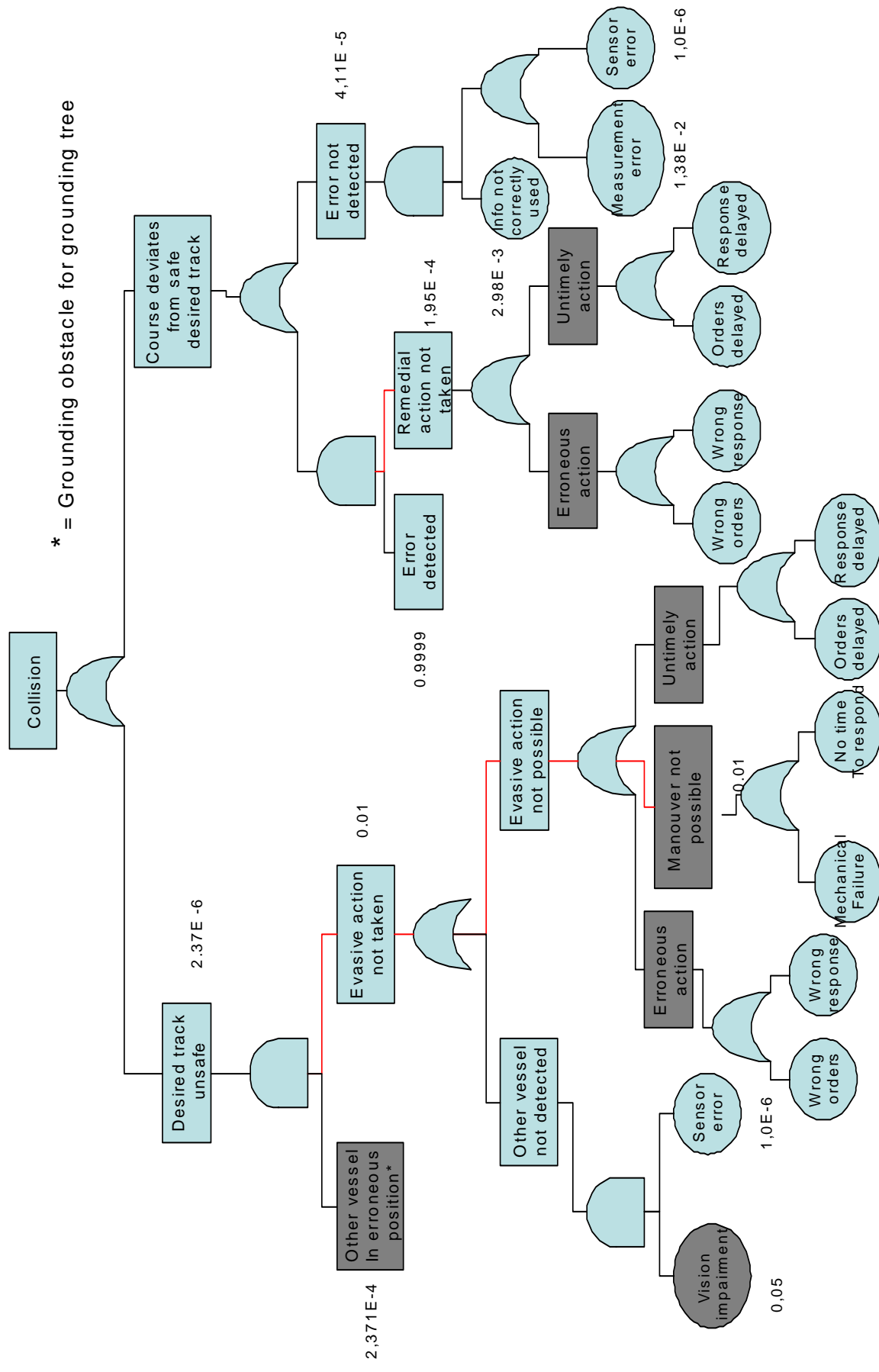
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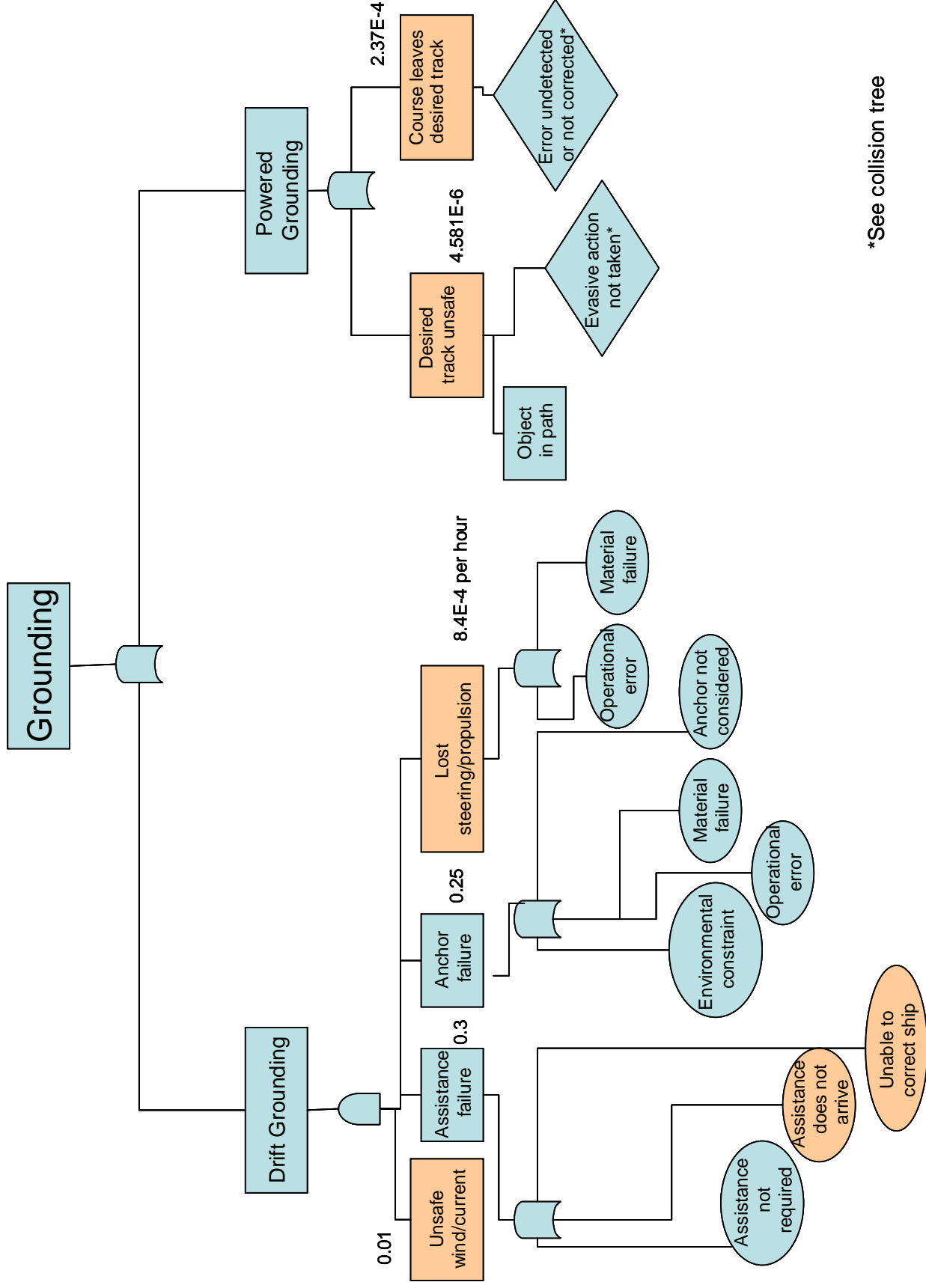
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Appendix : Fault Trees for Collision and grounding





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