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Estimating the Number of Tanker Collisions in the Gulf of Finland in 2015

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ABSTRACT: The paper presents a model for estimating the number of ship-ship collisions for future traffic scenarios. The modeling is based on an approach where the number of collisions in an area is estimated as a product of the number collision candidates, i.e. the number of collisions of two ships, if no evasive maneuvers were made, and a causation probability describing the probability of making no evasive maneuvers. However, the number of collisions is presented as a combination of binomially distributed random variables. The model is applied for the assessment of tanker collision frequency in the Gulf of Finland in 2015. 2015 traffic is modeled as three alternative scenarios each having a certain probability of occurrence. The number of collisions can be presented either for each scenario, or as an estimate including the uncertainty in future marine traffic development by taking into account all scenarios and their occurrence probabilities.

1 INTRODUCTION

The Gulf of Finland is a highly trafficked area in the Baltic Sea. Moreover, its traffic is expected to grow in the future (e.g. Hassler 2010; Kuronen et al. 2009; Ministry of Transport and Communications Finland 2009). Growing traffic increases the risk of ship groundings and collisions, which are the two most common types of maritime traffic accidents in the Gulf of Finland (Kujala et al. 2009). Especially the increasing oil tanker traffic and the possibility of a major oil accident raise concern in the coastal states.

One of the most common approaches to estimating the number of ship collisions was introduced by Fujii et al. (1971) and Macduff (1974). In this approach the number of collisions N is calculated as a product of the number of geometrical collision candidates N_G and a causation probability P_C:

$$N = N_G \times P_C \tag{1}$$

N_G describes the number of collisions of two ships, if they do not perform evasive maneuvers. It is based on traffic properties of the area, such as the routes of the ships, ship particulars (length, width) and velocities. A few models for assessing N_G are existing, such as Pedersen's model (1995) and the MDTC model (Montewka et al. 2010b), or it can be estimated with time-domain micro simulation (Goerlandt et al. 2011). P_C describes the probability of collision candidate ships making no evasive maneuvers. It is determined by various factors affecting human and/or technical failure. The causation probability has been estimated based on the difference between accident frequencies according to accident statistics and the estimated number of collision candidates (Fujii 1971; Macduff 1974), or by applying risk analysis tools such as fault tree analysis (Pedersen 1995, Rosqvist et al. 2002). Bayesian belief networks have been suggested to be utilized in in Step 3 of the Formal Safety Assessment, definition of risk control measures (IMO 2006), and more recently they have been applied in causation probability estimation (e.g. Friis-Hansen and Simonsen 2002, Det Norske Veritas 2003, Rambøll 2006, Hänninen & Ylitalo 2010).

Recently, in several studies the collision probabilities in the Gulf of Finland have been examined with the approach of Equation 1. Montewka et al. (2010a) estimated the number of geometrical collision candidates for a crossing between Helsinki and Tallinn using). The authors of this paper (Hänninen & Kujala 2009) estimated the number of collisions for the same crossing area. Later, the authors (Hänninen & Ylitalo 2010) estimated the collision frequency for the whole Gulf of Finland.

The studies mentioned above had not assessed the future risks in the Gulf of Finland. Further, all of the mentioned studies had estimated the number of collision candidates or collisions as point estimates. In this study, a probability distribution for the number of tanker collisions in the Gulf of Finland is presented. The number of tanker collisions is estimated for 2015 traffic by utilizing AIS data and three alternative maritime transportation growth scenarios. The study also considers the effects of uncertainty in the occurrence of the 2015 scenarios.

2 STUDIED AREA

The main waterways in the Gulf of Finland were included in the analysis. The waterways were defined based on a traffic image from AIS data. However, areas within the vicinity of ports were excluded. Additionally, tanker collisions within four smaller areas of the gulf were studied separately. The studied waterways and the “hot spot” areas are presented in Figure 1. The considered “hot spot” areas were: C1: the crossing of Helsinki-Tallinn traffic and the main route of the Gulf of Finland; C2: the merging of Sköldvik and the main route traffic,; C3: the merging of traffic of Primorsk and St. Petersburg and the waterway to St. Petersburg; and C4: the westernmost part of the Gulf. C1 was chosen due to high traffic within the area. C2 was considered as a possible collision area for two tankers on oil load. C3 included a rather narrow waterway to St. Petersburg and a merging of two waterways near shoals. C4 was an example of a larger area with many crossing and merging waterways.

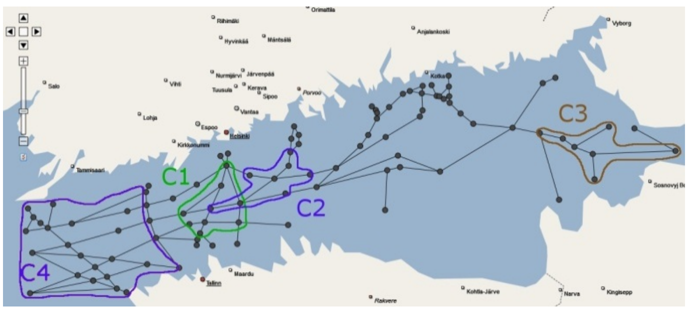

Figure 1. The waterways and "hot spot" areas whose number of tanker collisions were estimated.

3 METHODS

3.1 *2015 traffic estimation*

The estimates for the numbers of ships in the studied waterways in 2015 were based on 2008 traffic and traffic multipliers extracted from growth scenarios for the ports in the Gulf of Finland. AIS data from the area was utilized in determining the traffic in 2008. It should be noted that the winter of 2008 was exceptionally mild, and no ice breaking assistance was needed in the Gulf of Finland. Thus, the results are describing open water season only.

For the 2015 traffic, three alternative scenarios were considered: “slow growth”, “average growth” and “strong growth” (Kuronen et al. 2009). The expected value of the total tonnes for the maritime transportation in the Gulf of Finland in “slow growth” was 322 million tonnes. For the “average growth” scenario, the number was 432 M tonnes, and for the “strong growth”, 507 M tonnes. The growth factors for each port in three scenarios were defined as follows. First, the total amount of oil and other cargoes were defined to each scenario (see Kuronen et al. 2009). Second, the amount of oil and other cargoes were distributed to the ports according to the shares of the cargo amounts in the ports in 2007. Third, these port distributions were modified on the basis of the expertise of the research group, taking into consideration e.g. Ust-Luga port building project, other expected changes in the traffic patterns and the basic assumptions concerning the development of the traffic in each scenario. The growth factors are presented in Table 1.

One should note that the growth scenarios were based on the transport in 2007, whereas the AIS traffic multiplied with the traffic multipliers was from 2008. According to AIS data, the number of ship movements at the entrance to the gulf had decreased by 6.0 % from 2007 to 2008. However, the decrease was not constant in the whole Gulf of Finland: for example, the change was smaller on the main route on the eastern side of Gogland, and the number of passenger vessels even grew on that particular waterway. Overall, the magnitude of the change was only approximately 5 %, and considering other sources of uncertainty related to future traffic prediction, it was decided to define the multipliers based on the growth scenarios from 2007 traffic.

The traffic in 2008 was multiplied with waterway-specific multipliers to obtain estimates for the traffic in the waterways in 2015. Based on the port-specific growth factors, a cargo volume multiplier and an oil volume multiplier were calculated for each segment of each waterway included in the study. For waterways leading to ports, the multipliers were equal to the port’s growth factor. For other waterways, multipliers were deduced as a combination of the multipliers of merging waterways in relation to the traffic volumes. The traffic distributions across each waterway were assumed to remain unchanged. In addition, the ship size distribution was assumed not to change. No changes were made to the numbers of passenger ships, high speed crafts, and other ships, as no similar estimates on the change of their volume were available. Percentages of traffic continuing to separate waterways at waypoints were also adjusted to the changed traffic volumes on the waterways.

It should be noted that no oil was transported from Ust-Luga in 2007, so the number and size of tankers navigating there were obtained by assuming the size distribution of tankers being similar to that of the tankers navigating to St. Petersburg in 2008. The estimated number of tankers was added entirely to the eastern waterway to Ust-Luga since all tankers had used it in 2008.

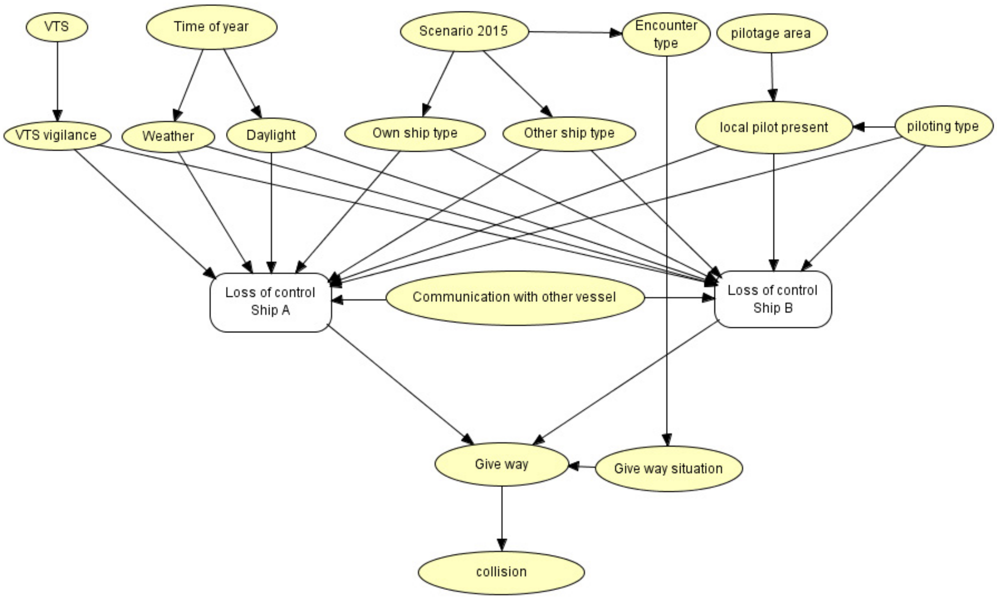

Figure 2. The structure of a Bayesian network model for the causation probability estimation.

Table 1. Cargo and oil volume growth factors from 2007 to 2015 for the scenarios “Slow” (C_{sl} and O_{sl} for cargo and oil, respectively), “Average” (C_{av} and O_{av})and “Strong” (C_{st} and O_{st}).

Port	C_{sl}	O_{sl}	C_{av}	O_{av}	C_{st}	O_{st}
Helsinki	1.01	1.03	1.31	1.05	1.34	1.35
Sköldvik	1.16	1.01	1.10	1.10	0.00	1.18
Kotka	1.01	1.00	1.32	0.97	1.35	1.37
Hamina	1.02	1.00	1.38	1.26	1.40	1.45
Hanko	1.47	1.00	1.47	1.00	1.53	1.00
Vysotsk	1.16	1.06	1.26	1.12	1.40	1.24
Primorsk	-	1.35	-	1.62	-	1.62
St. Petersburg	1.12	1.00	1.37	1.37	1.43	1.43
Ust-Luga	6.41	-	8.54	-	11.29	-
Sillamäe	1.00	0.00	1.06	1.06	1.61	1.61
Tallinn	1.33	0.01	1.84	0.63	2.39	1.19

3.2 *Collision probability modeling*

The number of collisions was calculated separately for the encounters of two oil tankers, and the encounters of an oil tanker and another type of ship. The expected value for the number of tanker collision candidates for the 2015 traffic scenarios were calculated with IWRAP software. IWRAP is recommended for the evaluation of collision probabilities by International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA 2009). The calculations were performed to all three traffic scenarios and to all considered areas in a similar manner as the authors had done for the 2008 traffic in the whole Gulf in (Hänninen & Ylitalo 2010), which gives a more detailed description of the method.

The causation probability was modeled and estimated with a Bayesian belief network. Bayesian networks are directed acyclic graphs which consist of nodes representing discrete random variables and arcs representing the dependencies between the variables (e.g. Jensen & Nielsen 2007). Each variable consists of a finite set of mutually exclusive states. For each variable A with parent nodes $B_1,\ldots, B_n$, there exists a conditional probability table $P(A \mid B_1, \ldots, B_n)$. If variable A has no parents, it is linked to unconditional probability $P(A)$. The model applied in this study was partly based on a collision model network in the Formal Safety Assessment of large passenger ships (Det Norske Veritas 2003) and a grounding model in the FSA of ECDIS chart system (Det Norske Veritas 2006). Additionally, expert knowledge and data from the Gulf of Finland ship traffic and environmental conditions were used in constructing the model. More detailed description of the model variables and the probability parameters can be found in (Hänninen & Kujala, in prep.), where the authors have described a more detailed causation probability model with many similarities to the model applied in this study. A variable “Scenario 2015” with states “slow”, “average” and “strong” describing the degrees of belief of the traffic scenarios’ occurrence was added to the model. In the causation probability model, the traffic scenario was directly influencing only the ship type and encounter type distributions.

The model was constructed as an object-oriented Bayesian network (OOBN). OOBN enables the use of sub classing in Bayesian network models (Jensen & Nielsen 2007). If a Bayesian network model contains a repetitive substructure, a separate sub model or a class could be constructed from this network substructure. In an OOBN, several instances of this class can then be inserted into the main model as instance nodes. This enables data abstraction, i.e., hiding the more detailed variables and their dependencies inside a class whose input and output are only visible in the main model. In this study, a class was constructed from the set of variables and arcs describing a ship losing control, and two instances of this "Loss of control" sub model were then created within the main model, describing the loss of control for each of the two meeting ships. “Own ship type“ distribution was given as an input to the variable “Own ship type” in the instance of “Loss of control” sub model for the “ship A”, and as an input to “Other ship type” for the “ship B”. The main model is presented in Figure 2, and Figure 3 describes the network structure of the “Loss of control” sub model.

After calculating the expected values for the number of collision candidates and the causation probability as is described above, the number of collisions N within a year was modeled with a binomial distribution. Binomial distribution is a discrete probability distribution for the number of successes in certain number of independent yes/no experiments, when success in one experiment occurs with a certain probability. For the number of collisions distribution, the number of experiments was the number of collision candidates, and the probability of one success was the causation probability. Thus the probability of having exactly n collisions was

$$\Pr(N=n)=\frac{N_G!}{n!(N_G-n)!}P_C^n(1-P_C)^{N_G-n} \quad (2)$$

, where N_G is the number of geometrical collision candidates and P_C is the causation probability. Finally, the distributions of the number of “tanker-tanker” collisions and the number of “tanker-not tanker” collisions were combined in order to acquire the number of collisions where at least one tanker was involved.

4 RESULTS

The expected values of the number of collisions involving at least one tanker in the whole Gulf of Finland and in the “hot spots” for the three 2015 traffic scenarios are presented in Table 2. With the “average” scenario, the expected yearly number of tanker collisions in the Gulf of Finland was estimated to be 0.17, which equals one tanker collision within approximately six years. If the “hot spots” are considered, the largest expected collision probability was in the area C3, including the merging waterways of Primorsk and St. Petersburg. For the “average” scenario, 0.044 tanker collisions were estimated to occur there within a year, which equals a collision in every 23 years.

Table 2. The expected values of the number of collisions / year involving at least one tanker for the 2015 traffic scenarios “Slow”, “Average” and “Strong”.

Area	Slow	Average	Strong
GoF	0.127	0.173	0.183
C1	0.010	0.012	0.139
C2	0.016	0.021	0.023
C3	0.033	0.044	0.044
C4	0.011	0.014	0.016

Table 3. The mean time (years) between collisions involving at least one tanker for scenario combinations with various weightings (“Slow-Average-Strong”).

Area	0.33-0.33-0.33	0.35-0.5-0.15	0.15-0.5-0.35
GoF	6.2	6.3	5.9
C1	83.9	86.2	80.2
C2	50.2	51.6	48.0
C3	24.8	24.9	23.6
C4	74.7	76.8	71.7

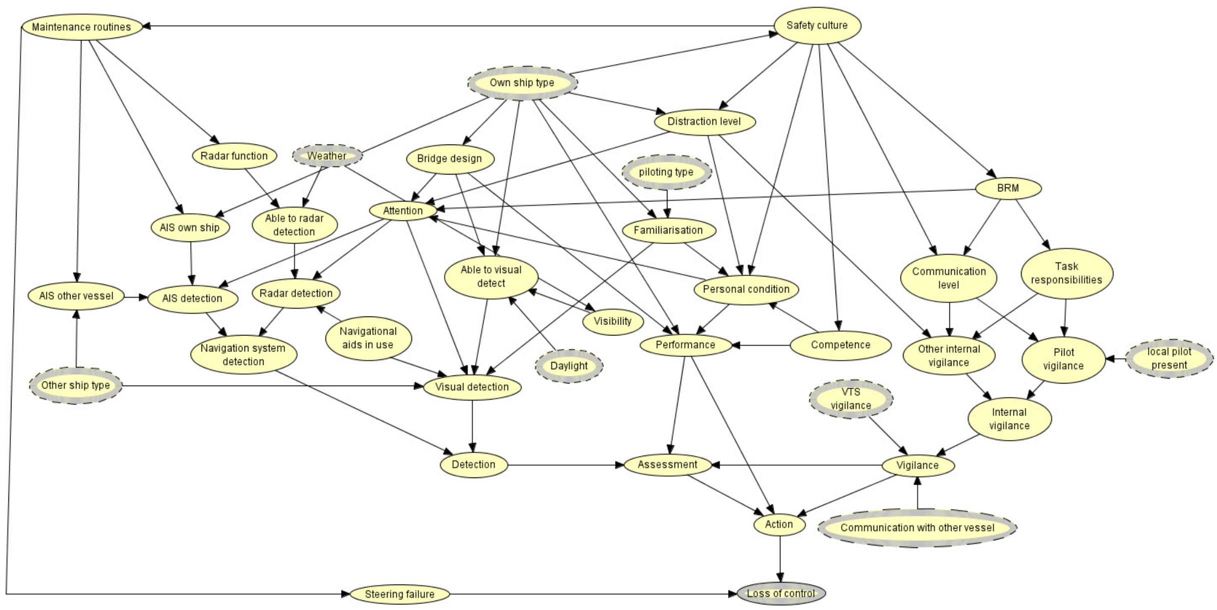

Figure 3. “Loss of control” sub model.

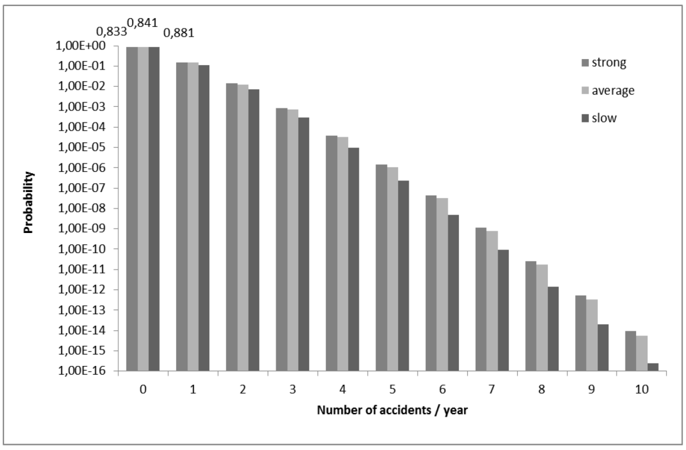

Figure 4. Probability distribution of the number of tanker collisions in the whole Gulf of Finland in 2015 for the three traffic scenarios "slow", "average" and "strong". The probability values of having zero collisions is presented above the corresponding bars.

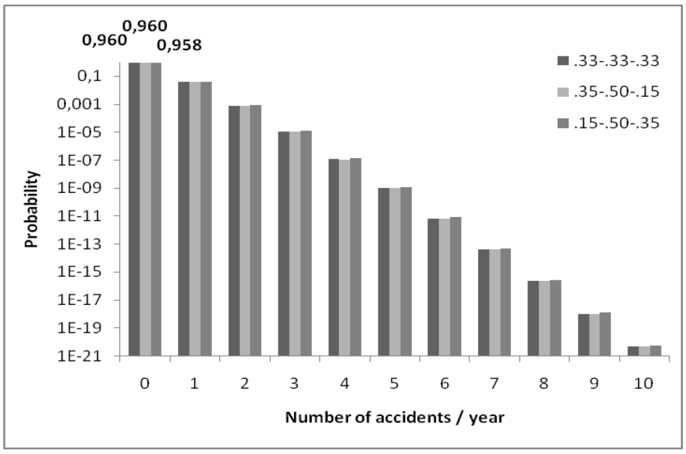

Figure 5. Probability distribution of the number of tanker collisions in the area C3 in 2015 for the scenario combinations with various weightings of the scenarios.

Figure 4 presents the probability distribution of the number of tanker collisions within a year in the whole Gulf given for all traffic scenarios. The probability of having zero tanker collisions within a year was between 0.83 and 0.89, depending on the scenario. The number of tanker collisions can also be examined while taking the uncertainty of the occurrence of the traffic scenario into account. This was done by assigning a weight to each of the scenarios. The weight was describing the degree of belief in the occurrence of the traffic scenario in question, assuming that the “true” scenario is amongst the three alternatives, i.e., the weights sum up to 1.0. Table 3 presents the mean time between tanker collisions in the areas with various weightings of the scenarios: all scenarios equally likely to occur, and two other alternatives, where “average growth” was assigned 0.5 weighting, and 0.15/0.35 weights were assigned to the other scenarios. These weightings were identical to the ones experts had assigned to the scenarios in (Kuronen et al. 2008). Figure 5 presents the probability distributions of the number of tanker collisions for the specific weightings. As can be seen from Table 3 and Figure 5, the differences in weighting had a minor effect on the outcome.

5 CONCLUSIONS

In this study, a probability distribution of the number of collisions in the future given uncertainty in maritime traffic development was presented. The model was applied to the Gulf of Finland maritime traffic growth scenarios. The number of “tanker-tanker” collisions and “tanker-not tanker” collisions were modeled separately using binomial distributions and then combined. According to the results, a collision involving at least one tanker would occur once in approximately every six years. This might seem a rather high number, especially since tanker collisions in the Gulf of Finland within open water season have been quite rare (Hänninen & Ylitalo 2010). Nevertheless, it should be noted that the "average growth" scenario, for example, is estimating a 60 % increase in transportation tonnes compared to the traffic in 2007 (Kuronen et al 2009). Further, the increase is mainly due to increase in oil transport. Therefore, there should also be an increase in the probability of tanker collisions.

The "hot spot" area with the largest estimated number of tanker collisions would be the merging area of St. Petersburg and Vysotsk traffic. This seems realistic, since according to the accident statistics of the Gulf of Finland (Hänninen & Ylitalo 2010), all non-ice related collisions had occurred in the eastern part of the Gulf.

The expected transportation tonnes in "strong growth" scenario was approximately 57 % larger than in "slow growth". Consequently, the expected value for number of collisions in the "strong" scenario is 44 % larger than in the "slow growth" scenario. In contrast, when comparing the results of 15-50-35 and 35-50-15 degree of belief weightings of the traffic scenarios, the difference is not as clear. If a weight of 0.15 was assigned to the "slow growth" scenario and 0.35 to the "strong", the expected value for number of collisions is only 5 % larger than if the weights were assigned the other way round. This can be explained by the relatively large weight given to the "average" scenario (50 %) in both cases.

The modeling of the 2015 traffic included many simplifications: the only difference between the present maritime traffic and the one in 2015 was assumed to be the numbers of oil tankers and other cargo vessels navigating in the waterways. The increase of the number of passenger ships, other ships, high speed crafts, and chemical and gas tankers navigating in the Gulf of Finland was not considered. Moreover, the change in tanker and cargo vessel numbers was estimated based on the assumption of no change in ship size. Also, the locations of the waterways were assumed to remain unchanged from the 2008 situation, and the impacts of winter on collision probability were excluded from the analysis. The changes in variables affecting the causation probability, such as the rules, regulations, safety culture and the competence of the mariners, or in technical equipment and the ships themselves, were not considered in this study and should be taken into account when building a more sophisticated model for assessing the collision risks in the future.

In Kuronen et al. (2009), each of the three traffic scenarios had been presented as probability distributions. In order to include the uncertainty in the scenarios themselves, instead of using only the expected values, the traffic multipliers could also be expressed in a distribution form. Further, considering the large number of variables with complicated interrelations behind accident causation, the quality of AIS data utilized in the traffic image composition, and selection of the models to be applied for the collision candidate and causation probability estimation, one should also address the uncertainty in the number of collision candidates and causation probability as well.

The approach presented in the paper could be utilized in a wider risk analysis and decision-making context. This work has already been started, as in Lehikoinen et al. (in prep.) the presented model was utilized as a part of a probabilistic decision analysis model of oil transportation risks, whose purpose is to aid the decision makers in choosing the best risk control options when considering the environmental consequences of oil accidents.

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