Development and Prototype Application of an Oil Spill Risk Analysis in a Coastal Zone

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Abstract
This paper introduces the development of a methodology for performance of oil spill risk analysis in coastal zones through a prototype application. The main objective of the research effort is to develop the basis for a tool that can assess risks due to the occurrence of an oil spill event aiming at assisting to the risk response process. The methodology concerns the processes of probability and consequence assessment. The two processes are accomplished qualitatively with a risk prioritization based on Analytic Hierarchy Process. Being a decision-making technique, Analytic Hierarchy Process can only be used after some appropriate modifications, which transform it into a tool for prioritizing risks with respect to their probability and consequence in different oil spill scenarios. This is an approach that attempts to rationalise the risk analysis stages and to indicate the uncertainties imposed to the problem, hence creating a basis for optimization of the risk analysis results.

Keywords
Risk Analysis, Oil Spill, Analytic Hierarchy Process.

1. Introduction

The aim of oil spill risk management is to minimize the probability of occurrence of an oil spill event, and to optimize the risk response process once the event occurs. The present research effort is orientated to the risk response process, and particularly to the assessment of risks that occur after an oil spill event. The main objective is the elaboration of the basic processes of a risk analysis, which are the identification of risks, the assessment of their probability and consequence, and finally the actual risk assessment.

The analysis is performed in an imaginary coastal area that is assumed to concentrate some particular features which allow demonstration of a broad number of oil spill cases. Those features are the existence of wetlands, fisheries, a port with both commercial and passengers' services, an oil refinery and coastal tourism.

2. Risk identification

The risk identification has been based on literature (Kassomenos, 2004) and the author's experiential review, and facilitated by the event-tree technique. Accounting for the assumed characteristics of the application area, a number of mainly short-term risks were initially recorded, which were then presented with an event-tree. The event-tree as well as the identified risks are presented in figure 1.

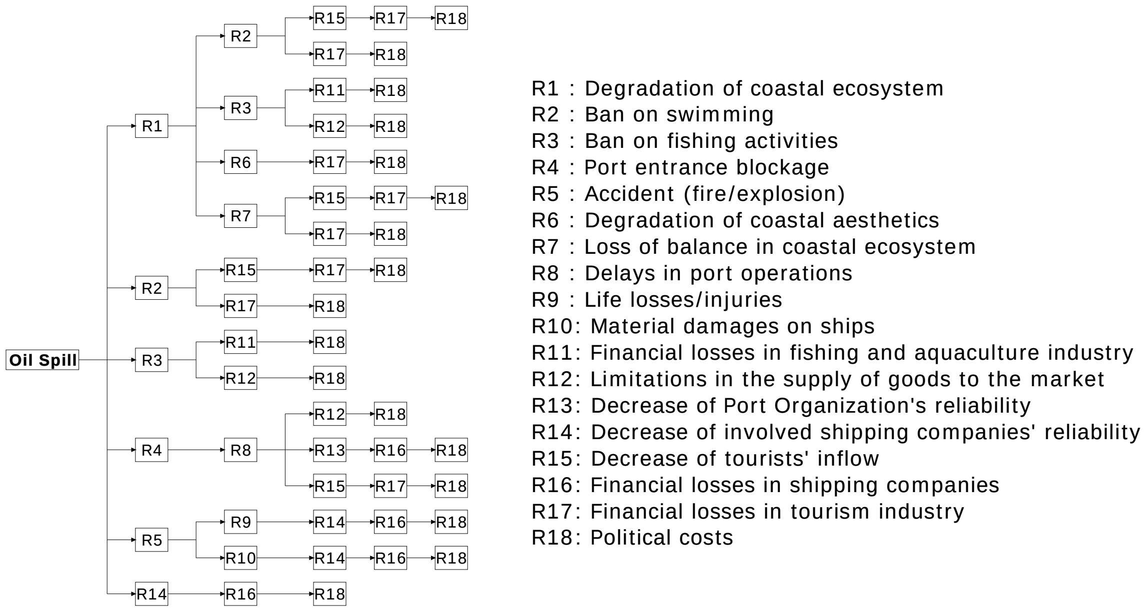

Fig 1: Event-tree and identified risks

The identified risks can be classified in three categories based on their position in the event-tree. They can be direct, indirect or dual. Direct are the risks that constitute direct consequence of the oil spill event. Indirect are the risks that constitute direct consequence of another risk that has occurred, and not of the oil spill event. Dual are the risks that can be consequence of both the initial event and some other risk. In the above event-tree, direct are the risks R1, R4 and R5, dual are the risks R2, R3 and R14, while all the remaining risks are indirect. In the upcoming analysis it is assumed that dual risks belong in either set of direct and indirect risks.

3. Probability assessment

The probability of occurrence of the identified risks is assessed qualitatively. The choice for a qualitative analysis is based on the fact that records referring to follow-up risks of an oil spill are usually not available, and therefore a quantitative analysis is not possible. The product of this process is qualitative probability values for every identified risk. For this reason a probability scale is required. The scale proposed contains five probability classes, characterized with the integer numbers from 1 to 5. Each class corresponds to a probability range. The description of the five classes together with an indicative correspondence to real probabilities is presented below (table 1).

Class	Probability range	Description
1	0-20%	very low
2	20-40%	low
3	40-60%	medium
4	60-80%	high
5	80-100%	very high

Table 1: Probability scale

The probability of each risk varies under different conditions. For direct risks it depends on the characteristics and the nature of the oil spill event. For indirect risks, it depends on the probability of all preceding direct and indirect risks. The main parameters that affect the probability of direct risks are the following: P1) Oil spill size, P2) Weather conditions, P3) Oil spill location. These parameters can take various values. The combination of certain values of the three parameters determines certain oil spill scenarios for which the risk probability can be assessed. The parameter values that are used in this research are presented in table 2. The oil spill size is determined in accordance to the oil spill categories of the International Tanker Owners Pollution Federation. The weather conditions are determined by a combination of wind speed and direction. The wind direction is characterized favorable or unfavorable, depending on if it results in decrease or increase of a certain risk probability respectively.

P1	**P2**	**P3**
S1: < 7t S2: 7-700t S3: > 700t	W1: 0-15km/h, favorable W2: 15-35km/h, favorable W3: 35-55km/h, favorable W4: > 55km/h, favorable W5: 0-15km/h, unfavorable W6: 15-35km/h, unfavorable W7: 35-55km/h, unfavorable W8: > 55km/h, unfavorable	L1: close to wetlands L2: close to tourism installations L3: close to fisheries L4: port entrance L5: commercial quay in the port L6: passengers' quay in the port

Table 2: Parameter values

Based on the above parameter values, 168 different oil spill scenarios can be derived. The probability assessment of the direct risks in each of these scenarios can be facilitated if an intermediate process of risk prioritization with respect to probability is accomplished. In order to minimize the uncertainties imposed by a qualitative prioritization, it is necessary that the process is rationalized in a way that all steps requiring subjective decisions by the analysts are distinguishable. This can be achieved with application of a modified form of Analytic Hierarchy Process. The modifications made concern mainly its transformation from a decision-making technique to a tool for risk prioritization.

Analytic Hierarchy Process offers a rational framework for structuring and solving multi-criteria decision-making problems. The outcome of its application is a prioritization of the alternative choices by means of numerical factors. Its framework can be easily adapted for use in a risk prioritization process when different hazard scenarios are examined. In this case the process has to be repeated as many times as the number of direct risks. The outcome is a prioritization of the scenarios with respect to the magnitude of probability that they impose to the examined risk. Two additional simple steps can lead to the final objective, which is the prioritization of all direct risks with respect to their probability in every single scenario. A presentation of the risk prioritization steps as applied to the example area is given below. Only steps that are not identical to the corresponding steps of Analytic Hierarchy Process are described. These are steps 1, 2, 3 and 7. Steps 4, 5 and 6 are in absolute correspondence with Analytic Hierarchy Process, and therefore their presentation is neglected. The application refers to risk R3.

1. Definition of the problem parameters and their possible values. They have been already introduced. There are three parameters namely P1, P2 and P3 with values S1-S3, W1-W8 and L1-L7 respectively.
2. Comparisons of the problem parameters in pairs with respect to the rate that they affect the probability of the examined risk. The comparisons made are based on a series of assumptions related to the importance of parameters and their values, whose reliability is directly dependent to the analysts' experience on the subject. This step is therefore a source of uncertainty. The comparisons are facilitated by a comparison grading scale that determines the rate of importance of a parameter i when compared with a parameter j. This scale is absolutely correspondent to the fundamental scale of Analytic Hierarchy Process (Saaty, 1990), and is presented in table 2.

Class	Description
1	i and j are of equal importance
2	intermediate class
3	i is slightly more important than j
4	intermediate class
5	i is fairly more important than j
6	intermediate class
7	i is much more important than j
8	intermediate class
9	i is absolutely more important than j

Table 2: Comparison grading scale

The comparisons made are presented in a matrix as shown in table 3. When the importance of parameter j is higher then the inverse values of the comparison scale are used.

i \ j	P1	P2	P3
P1	1	1/3	1/3
P2	3	1	1
P3	3	1	1

Table 3: Comparison matrix of parameters

3. Comparison of the parameter values in pairs with respect to the rate that they affect the probability of the examined risk. This step follows in practice the same procedure as step 2. The comparison matrix of parameter P1 is demonstrated in table 4. The matrices of parameters P2 and P3 are similar, hence their demonstration is neglected.

i \ j	S1	S2	S3
S1	1	1/7	1/9
S2	7	1	1/7
S3	9	7	1

Table 4: Comparison matrix of values of parameter P1

4. Consistency control of the created matrices.
5. Computation of normalized Eigen vectors of the matrices of steps 2 and 3.

6. Computation of weight ratios of the problem parameters and parameter values.
7. Computation of the final prioritization factors of each scenario. This is the final prioritization step. The scenario with the highest factor imposes the highest probability to risk R3, while the one with the lowest factor imposes the lowest probability.

A step further stands the estimation of the probability class in which every direct risk belongs. This can be achieved through a correlation code between prioritization factors and probability classes, so that every factor corresponds to a certain probability class. Since there is already a correlation available among the different scenarios expressed by the prioritization factors, it is sufficient to estimate the probability class in only one scenario. The probability class of the remaining 167 scenarios can be then derived with a straight forward calculation.

A quick examination of the established scenarios reveals that the probability class of some of them can be reasonably estimated. Such a case is scenario C164 (S3-W8-L3). It refers to a large oil spill, occurring under the highest possible wind speed with unfavorable direction, and is located close to fisheries. In this case the probability that risk R3 occurs is very high, and thus a probability class 5 can be considered. C164 can be therefore used as a base-scenario for the calculation of probability in the remaining scenarios as follows:

$$P_{Ci} = \frac{V_{Ci}}{V_{C164}} P_{C164} \qquad (1)$$

In this equation V_{Ci} is the prioritization factor of scenario Ci, V_{C164} the prioritization factor of scenario C164 and P_{C164} the probability of risk R3 in scenario C164. Since the performed analysis is quantitative, the probability P_{C164} is not a certain numerical value. The only information about it is that it belongs to the range 80-100% which is indicative of probability class 5. In the present analysis the maximum probability of the corresponding range is considered for the base scenarios. This way a conservative risk assessment is accomplished, since the most unfavorable risk values will be extracted. Choosing the median or lowest value of the range would result in more favorable risk estimation. This choice constitutes another source of uncertainty in the analysis.

Another point that needs to be stressed is that the probability calculated with equation 1 is not a real probability, but it indicates the probability class that scenario Ci imposes to the examined risk. If for instance P_{Ci} is equal to 29%, then in case of scenario Ci, the probability class of risk R3 is 2.

The risk prioritization process and probability class estimation is repeated six times, since there are in total six direct risks. The results of this procedure are used in the probability class estimation of the indirect risks. This estimation can be realized with the use of the event-tree that has been previously presented and of the principles of Probability Theory. In particular a methodology with two basic steps is proposed. These steps are presented below:

1. Empirical assessment of the probability class in which every indirect risk belongs, when the preceding direct or indirect risk according to the event flow lines has occurred. This is in fact an empirical determination of conditional probabilities. The imposed probability classes to the indirect risks that may occur

after the occurrence of risk R3 are presented in figure 2. This step is highly subjective and therefore imposes a high degree of uncertainty to the analysis.

2. Assuming that the numerical probability value that corresponds to a certain probability class is the highest value of its probability range, and according to the Probability Theory principles, a probability is calculated for every indirect risk. Similarly to the estimations made for direct risks, the calculated probabilities are not real, but their value is indicative of the probability class in which every indirect risk belongs.

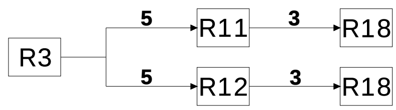

Fig 2: Probability classes of event-flow lines following the occurrence of R3

It should be noted that there are risks occurring in more that one event sequences, such as risk R12. According to the event tree of figure 1, risk R12 can be a cause of the occurrence of risk R3 or of risk R8. The final probability class of this kind of risks is the most unfavorable of the two resulting classes.

4. Consequence assessment

The consequence assessment of the identified risks follows a methodology similar to the one of the probability assessment process. The two problems are not identical, hence some adaptations are necessary. In accordance to the probability assessment, the consequence assessment process is qualitative and makes use of a consequence class scale with the integer numbers from 1 to 5. The description of the consequence classes is absolutely correspondent to this of the probability classes.

The risk consequence is affected by five parameters. The three of them are the same with the probability parameters, P1, P2 and P3. The remaining two parameters are the following: P4) Oil type, P5) Season. The possible values of oil type are: O1) Crude oil and O2) refined oil. The possible season values are: T1) Spring, T2) Summer, T3) Autumn, T4) Winter.

In total 1344 new oil spill scenarios are produced with combination of the parameter values. The risk prioritization with respect to consequence is accomplished through application of the modified form of Analytic Hierarchy Process. The followed steps are identical to the ones presented in chapter 3. The determination of the consequence class in which every identified risk belongs follows too the base-scenario technique that has been used for determining the risk probability classes. Unlike the probability assessment, the determination of consequence classes does not differ between direct and indirect risks. The severity of consequences of any risk is considered correlated to the oil spill scenarios, and there is no correlation between the consequences of direct and indirect risks. Hence all risk consequences are calculated with the same method.

A minor divergence between the base-scenario technique for probability and consequence assessment is that there are no ranges of consequence indicative of the consequence classes to be used as boundary values. The consequence classes could be described with damage ranges expressed in real damage costs. Such quantification is out of the scope of a quantitative analysis. A practical solution to this problem is the use of numerical ranges correspondingly to the probability ranges for indication of each consequence class. Thus class 1 can be described with the range 0-20, class 2 with the range 21-40 and so on.

5. Risk assessment

Following a qualitative probability and consequence analysis, the risk assessment has to be qualitative as well. A risk scale similar to the scales of probability and consequence is necessary in this process too. The proposed scale contains three classes, 1, 2 and 3 correspondent to low, medium and high risk respectively. The nature of results extracted by the two previous processes enables the use of a probability-consequence table, which seems to be the most appropriate technique for the assessment of risks. The table used is presented in figure 3.

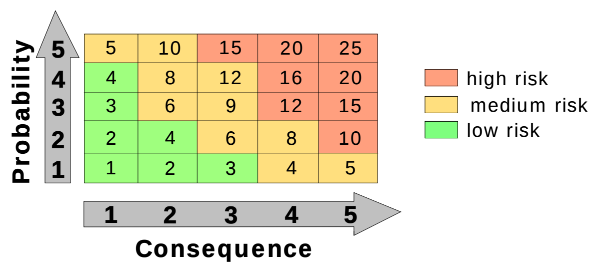

Fig 3: Probability-consequence table

The probability-consequence table technique is applied for every risk in all oil spill scenarios. The scenarios used in this process are the ones that have been used for the consequence assessment. The 168 scenarios of the probability assessment are integrated in the consequence scenarios.

Some indicative results of the analysis performed for risk R3 in five random scenarios are presented below (table 5).

Scenario	Descriction	Probability class	Consequence class	Risk class
C1	S1-W1-L1-O1-T1	2	2	1
C255	S1-W5-L4-O2-T3	2	1	1
C589	S2-W3-L4-O1-T4	1	2	2
C1050	S3-W3-L6-O1-T2	3	5	3
C1341	S3-W8-L7-O2-T1	5	3	3

Table 5: Risk assessment results for risk R3

6. Conclusions

- A methodology for probability and consequence assessment is developed which is based on Analytic Hierarchy Process. After some appropriate modifications, Analytic Hierarchy Process is transformed from a decision-making technique into a tool for risk prioritization and qualitative risk analysis.

- The risk prioritization is achieved through the comparative evaluation of the problem parameters and their values, and not through a direct risk assessment. A rationalization of the risk assessment stages is attempted with this approach, which facilitates the discrimination of uncertainties imposed to the analysis.

7. Recommendations

- The developed methodology refers to an oil spill risk analysis. Appropriate alterations of the problem parameters enable its application in other kinds of hazards as well, such as flooding, failure of structures and nuclear accidents.
- An objective evaluation of the methodology through a validation is necessary. This can be achieved with application in a real area by experienced analysts. Such a procedure can indicate elements that need to be reconsidered.
- The methodology indicates the sources of uncertainty in the risk analysis. Further research on the deviation of the final results caused by the imposed uncertainties would highly contribute to the reliability of the analysis.
- The possibility of transforming the method to a quantitative analysis tool is interesting to be examined. This can be possibly realized by correlating the qualitative probability and consequence classes with real probabilities and damage costs respectively.

8. Acknowledgements

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9. References

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