



## Developing an expert system and fuzzy-based model for the oil spill environmental risk assessment

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### Abstract

Nowadays, risks arising from the rapid development of oil and gas industries are significantly increasing. As a result, one of the main concerns of either industrial or environmental managers is the identification and assessment of such risks in order to develop and maintain appropriate proactive measures. Oil spill from stationary sources in offshore zones is one of the accidents resulting in several adverse impacts on marine ecosystems. Considering a site's current situation and relevant requirements and standards, risk assessment process is not only capable of recognizing the probable causes of accidents but also of estimating the probability of occurrence and the severity of consequences. In this way, results of risk assessment would help managers and decision makers create and employ proper control methods. Most of the represented models for risk assessment of oil spills are achieved on the basis of accurate data bases and analysis of historical data, but unfortunately such data bases are not accessible in most of the zones, especially in developing countries, or else they are newly established and not applicable yet. This issue reveals the necessity of using expert systems and fuzzy set theory. By using such systems it will be possible to formulize the specialty and experience of several experts and specialists who have been working in petroliferous areas for several years. On the other hand, in developing countries often the damages to environment and environmental resources are not considered as risk assessment priorities and they are approximately under-estimated. For this reason, the proposed model in this research is specially addressing the environmental risk of oil spills from stationary sources in offshore zones.

**Key words:** Oil spill, stationary sources, environmental risk assessment model, expert system, fuzzy logic.

### Introduction

Risk assessment defines the undesirable events or situations, determines the likelihood of their occurrence, and estimates how severe the consequences may be. A formal risk assessment process offers several advantages to the management of oil spills. Firstly, it enables managers to identify the likely causes of oil spills for a specified area and to compare the relative risk between different geographical regions. Secondly, it provides a basis for the identification of appropriate management strategies to reduce the overall risk for a given region, either through preventative or preparedness strategies<sup>3</sup>.

As a result, risk analysis has become a powerful tool for identifying technical solutions and operations with high risk, and it is extensively used in the offshore industry<sup>1</sup>. Risk analysis is also used to identify, assess and compare risk-reducing measures. For events where a database exists, the risk figures estimated in a quantitative risk analysis can be considered to represent the risk involved when carrying out said operations. For special operations where little previous experience exists, one has to rely on the experience of experts in order to establish probability figures<sup>4</sup>.

Several studies have been carried out on risk assessment of oil spills worldwide and different methods have been presented accordingly. The Oil Spill Risk Analysis (OSRA) model is considered as one of the progressive methods in this way. OSRA

model was developed in 1975 by the Department of the Interior (DOI) of the Federal Government of the United States of America (USA) for the analysis of possible oil spill impact from offshore oil and gas operations<sup>5</sup>. The OSRA model produces probabilistic estimates of oil spill occurrence and contact to biological and economic resources using historical records of oil spills, winds and ocean currents<sup>6</sup>.

It is worth mentioning that the later model, like most of the represented models and methods for environmental risk assessment of oil spill, is based on precise data bases. Considering the fact that in most of the regions especially in developing countries, the above-mentioned data is not accessible and hence, applying these models would not be possible. Also in most of these countries, relevant researches and studies are mostly focused on the consequences of oil spills on equipment and human whereas the negative effects of oil spills on environmental resources are underestimated.

Due to the aforementioned points, the main purpose of this research was to develop an appropriate model for environmental risk assessment of oil spills in such countries. The mentioned model has been designed on the basis of expert system using the knowledge and experiences of experts who have been working in petroliferous areas for several years. As with any kind of risk, oil

spill risk assessment is inherently judgmental and no analytic method can eliminate the need for judgment <sup>7</sup>.

### Methodology

In this research, basic definition of risk has been used for risk assessment of oil spills from stationary sources including the oil wells, platforms and pipelines. According to this definition, risk is calculated through multiplying probability of occurrence by severity of consequences.

Oil spill is divided into two general groups of small oil spill (less than 50 tons per incident) and large oil spill (more than 50 tons per incident) in this investigation. For the purpose of determining the probability of oil spill occurrence, it was required to identify the most significant incidents that could result in oil spill from each of the stationary sources. To do this, Delphi method has been used. These incidents are hierarchically shown in Fig. 1. It is noteworthy that the identified incidents represent the most common factors resulting in oil spill. However, considering technical characteristics and natural conditions of each site, some other incidents may also be added to the above list. It is self-evident that the probability of occurrence for a specific incident differs based on the groups of oil spill; small or large.

It should be mentioned that the incidents are independent; however, simultaneous occurrence of two or more of these incidents is also possible. For calculating the probability of oil spills in a specified site, the probability of occurrence of the lowest (last) level of the incidents hierarchy must be determined through a checklist. A sample of such a checklist completed by experts for the research case study is represented in the next section. As shown, the checklist includes seven alternatives as follows: improbable (occurs once per 10,000 years), very low probability (occurs once per 1000 years), low probability (occurs once per 100 years), medium probability (occurs once per 50 years), high probability (occurs once per 10 years), very high probability (occurs once per year) and extremely probable (occurs once per month).

All the presented qualitative alternatives will then be quantified using Triangular Fuzzy Numbers (TFN) method <sup>8</sup>. Then the probability of higher levels incidents will be calculated by incorporating the probabilities of the relevant lower level incidents. As the number of factors (incidents) entering the equation is variable, the induction axiom should be used <sup>9</sup>. In other words, Equation 2 has been used instead of Equation 1.

$$P(A_1 \cup A_2 \cup A_3 \cup \dots \cup A_{n-1} \cup A_n) = P(A_1) + P(A_2) + \dots + P(A_{n-1}) + P(A_n) - P(A_1 \cap A_2) - \dots - P(A_{n-1} \cap A_n) + P(A_1 \cap A_2 \cap A_3) + \dots + P(A_{n-2} \cap A_{n-1} \cap A_n) - P(A_1 \cap A_2 \cap A_3 \cap A_4) - \dots - P(A_{n-3} \cap A_{n-2} \cap A_{n-1} \cap A_n) + (-1)^{n+1} P(A_1 \cap A_2 \cap A_3 \cap \dots \cap A_{n-1} \cap A_n)$$

Equation (1)  $P(A)$ : Probability of Incident A

$$P(A_1 \cup A_2) = P(A_1) + P(A_2) - P(A_1 \cap A_2) \quad n=2$$

$$P(A_1 \cup A_2 \cup A_3 \cup \dots \cup A_{n-1} \cup A_n) = P(A_1 \cup A_2 \cup A_3 \cup \dots \cup A_{n-1}) + P(A_n)(1 - P(A_1 \cup A_2 \cup A_3 \cup \dots \cup A_{n-1}))$$

Equation (2)- Induction Axiom  $\forall n > 2$

In the course of severity of consequences, first the environmental resources should be categorised. In this investigation spatial environmental resources are considered and plant and animal

species should be studied as a part of such resources. The list of mentioned earlier environmental resources is represented in Table 1. First the existing environmental resources of the region should be identified and prioritized. Second the damages to each of the resources in the site should be determined.

**Table 1.** List of identified environmental resources in marine ecosystem.

Muddy shore	without coverage	-
	with coverage	Mangrove swamps Salt marshes
Rocky shore	without coverage	-
	with coverage	Seaweed beds
Sandy shore	without coverage	-
	with coverage	Sea grass beds
Coral reefs		

Weight or the level of significance of environmental resources present in the site should be determined considering their significance. In other words, significance factor represents the value of the resource. Table 2 can be used for the determination of the level of significance for environmental resources.

**Table 2.** Determination of the level of significance of environmental resources.

Level of significance		Type of ecosystem
Internationally significant	0.9166	Unique ecosystem
Regionally significant	0.6250	Rare ecosystem
Nationally significant	0.3750	Relatively rare
Rather significant	0.0833	Wide-spread ecosystem

In the next stage, the determining variables for the severity of consequences have been identified. The volume of oil reaches to the coast, type of oil, the rate of oil weathering and the level of success of management plans are the most significant indices in accordance with expert's judgment. Since the proposed model has been designed on the basis of fuzzy logic <sup>1</sup>, it was necessary to make fuzzy rules considering the mentioned variables. Some of the rules recommended by experts are shown in Table 3.

The severity of environmental consequences made to each environmental resource will be calculated through the rules and should be multiplied by the relevant significance factor (Table 2) of each environmental resource. The total oil spill environmental risk is calculated through Equation 3:

$$\text{Oil Spill's Environmental Risk} = \sum P C_i S_i \quad i=1 \text{ to } n$$

P: Probability of occurrence (large/small)

C: Consequences severity

S: significance of environmental resources

n: Number of damaged environmental resources

Generally, the probability of oil spill in small or large level and the severity of consequences are subsets of [0,1]. Thus the environmental risk of the oil spills for each resource can also be considered this range. As the site can contain the maximum of eight resources, the total risk is a member of [Minimum potential risk when the site contains only one resource, Maximum potential risk when the site contains eight resources]. The value of the risk should be interpreted. So the final risk is defined in three levels (Table 4).

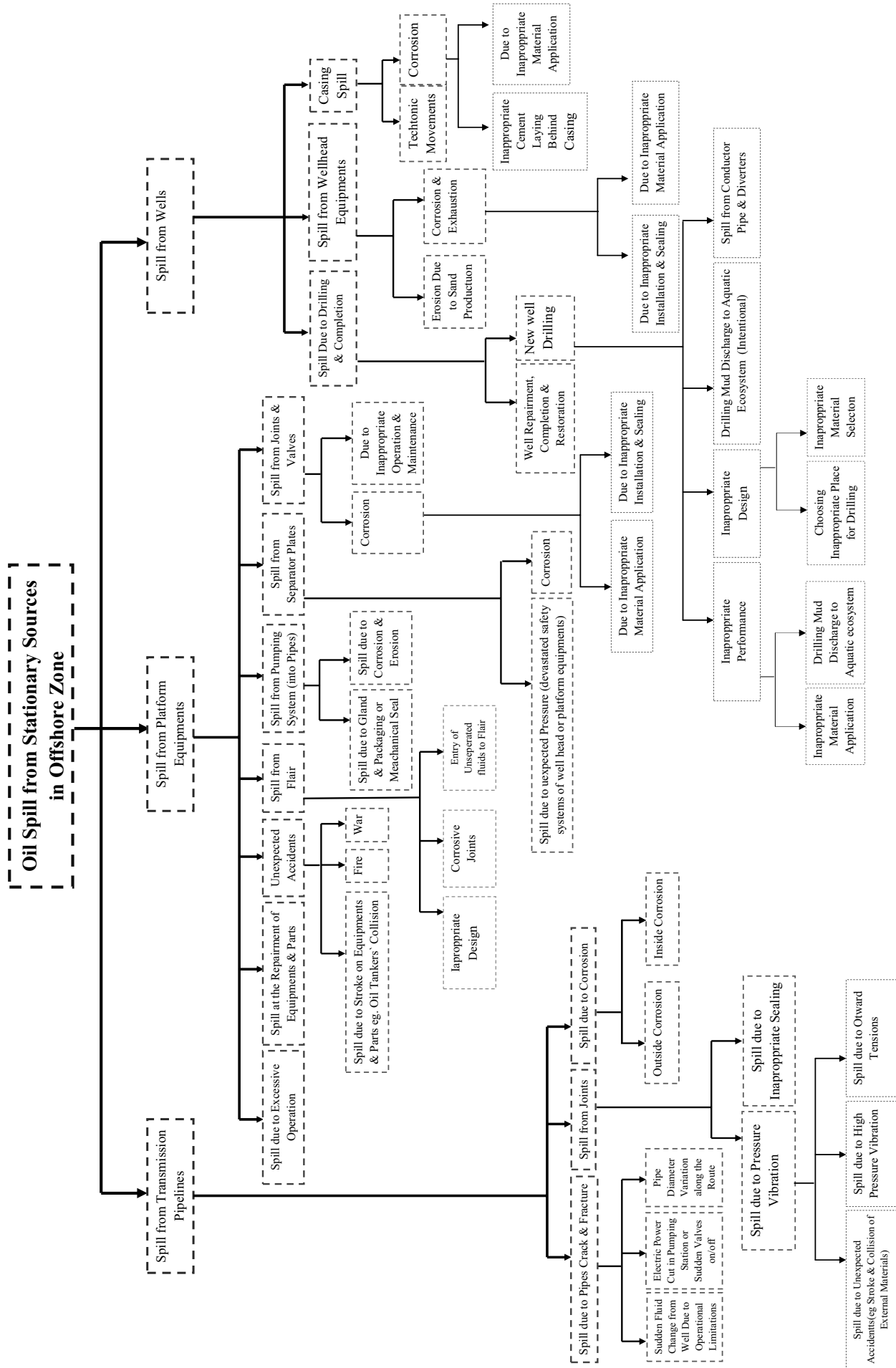


Figure 1. Incidents resulting in oil spill from stationary sources.

**Table 3.** Some of the rules set for the consequence assessment (severity of damage).

Factors affected	Volume of oil		Type of oil		Rate of weathering			Management plan			Severity of damage				
	Small	Large	Light	Heavy	Low	Medium	High	Weak	Medium	Good	Very low	Low	Medium	High	Very high
Environmental resource															
Coral reef		*		*	*			*							*
Mangrove		*	*			*		*							*
Seaweed	*		*				*			*	*				
Salt marsh	*		*			*				*		*			

**Table 4.** Total risk interpretation.

Risk level	Definition	Numerical range
1	Negligible risk- No certain management measures are required	Minimum calculated risk, Product of low probability of spill in low severity
2	Tolerable risk - Limited management measures are required	Product of low probability of spill in low severity, Product of high probability of spill in high severity
3	Unacceptable risk - Extensive management measures are required	Product of high probability of spill in high severity, maximum calculated risk

### Results and Discussion

The represented model in this research has been run for a part of an offshore zone in ROPME (Regional Organization for the Protection of the Marine Environment) sea area. The ROPME sea area covers eight states that joined forces in 1978 to adopt the Kuwait Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution. The above-said zone consists of an oil well, an oil platform and pipelines which transfer oil from the platform to the shore. As mentioned, the checklist for determining the probability of occurrence of incidents was completed by experts. Table 5 shows some parts of the completed checklists.

Each incident can result in small and large levels of oil spills with different probability. Thus, in this stage there are two values of probability for each site. According to the checklist results, the small and large level of oil spills probabilities for the case are  $7.7 \times 10^{-4}$  and  $6.2 \times 10^{-4}$ , respectively (using Equation 2).

In the course of the severity of consequences, first the site was studied in order to determine the present resources and their level of significance. Studies revealed that muddy shores, sandy shores, sea weeds and sea grass beds exist in the mentioned site. These resources are represented in Table 6 according to their level of significance.

**Table 5.** Probability of occurrence of large oil spill and small oil spill due to different incidents.

Incidents	Probability of occurrence	Improbable	Very low probability	Low probability	Average probability	High probability	Very high probability	Extremely probable
		Casing spill due to application of inappropriate materials for casing	Large oil spill		*			
	Small oil spill		*					
Casing spill due to inappropriate cement laying for the back of casing	Large oil spill			*				
	Small oil spill			*				

**Table 6.** Level of significance of environmental resources available within the site.

Environmental resources	Level of significance			
	Internationally significant	Regionally significant	Nationally significant	Rather significant
Muddy shore	*			
Sandy shore				*
Salt marshes	*			
Sea grass beds	*			

The produced oil in the mentioned site is of the light type and the rate of weathering considering the climate condition (high temperature), ocean currents (relatively intensive), large distance of the installations to the coast is great. The management plan was stood the medium level. Therefore, fuzzy rules selected for this case study are expressed in Table 7.

According to the points and equations explained in methodology, Table 8 shows the final results. The final environmental risk of stationary sources in offshore zone is

**Table 7.** Applied rules for determining consequence severity.

Severity factors	Volume of oil		Type of oil		Rate of weathering			Management plan		Severity of damage						
	Small	Large	Light	Heavy	Low	Medium	High	Weak	Medium	Good	Very Low	Low	Low	Medium	High	Very High
Environmental resource																
Muddy shore		*	*				*	*							*	
Sandy shore		*	*				*	*					*			
Salt marshes		*	*				*	*								*
Sea grass beds		*	*				*	*								*

**Table 8.** Final results.

Environmental resources	Consequence severity (C)	Significance factor (S)	Total consequence (S × I)	Probability of occurrence		Environmental risk	
				Small	Large	Small	Large
Muddy shore	High	0.7174	0.9545	0.6848		5.3×10 <sup>-4</sup>	4.2×10 <sup>-4</sup>
Sandy shore	Medium	0.5217	0.3636	0.1897	7.7×10 <sup>-4</sup>	6.2×10 <sup>-4</sup>	1.5×10 <sup>-4</sup> 1.2×10 <sup>-4</sup>
Salt marshes	Very high	0.9348	0.9545	0.8923		6.9×10 <sup>-4</sup>	5.5×10 <sup>-4</sup>
Sea grass beds	Very high	0.9348	0.9545	0.8923		6.9×10 <sup>-4</sup>	5.5×10 <sup>-4</sup>
Total environmental risk						2.06×10 <sup>-3</sup>	1.64×10 <sup>-3</sup>

the sum of different resources risk. In accordance with Table 8, the small and large oil spill risks are 2.06×10<sup>-3</sup> and 1.64×10<sup>-3</sup> for the case study and both of the values belong to level 2 along with Table 4 which means that the site is faced to tolerable risk and limited management measures are required.

### Conclusions

Oil spill from stationary sources in offshore zones is one of the accidents resulting in several adverse impacts on aquatic ecosystems and irrecoverable damages to the environment. Considering a site's current situation and relevant requirements and standards, risk assessment process is not only capable of recognizing the probable causes of accidents but also of estimating the probability of occurrence and the severity of consequences. In this way, results of risk assessment would help managers and decision makers create and employ proper control methods.

Most of the represented models and methods for oil spill environmental risk assessment have been developed based on precise data bases. Considering the fact that in most of the regions especially in developing countries, the aforesaid data is not accessible and hence, applying these models would not be possible. Also in most of these countries, relevant research and studies are mostly focused on the consequences of oil spills on equipment and human whereas the negative effects of oil spills on environmental resources are underestimated.

The model attempts to emphasise on the most significant and effective parameters on probability of occurrence and severity of consequences and this would result in making the model user friendly. Moreover, this can cause the model to be widely applied. Using fuzzy logic for demonstration of variables that do not have certain nature is considered as one of the advantages of the model.

Due to the aforesaid points, the main purpose of this research was to developing an appropriate model for environmental risk assessment of oil spills in such countries. Considering that the oil

volume that reaches to the coast is one of the significant factors on the severity of environmental consequences, it is recommended to accurately measure this volume using trajectory models. To this end, it is advised to carefully study the mentioned models to identify the model that best suits the studied region.

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