

## Offshore Oil Spills Emergency Response: a Method for Response Gap Analysis

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A methodology to conduct the Response Gap Analysis (RGA) for offshore oil spill emergency activities was developed, able to identify, for a given area and a given time period, if the response, which depends on the combination of the environmental factors affecting the performance of the contingency actions, is favourable, impaired, or ineffective. The necessity for offshore oil and gas operators to perform a RGA derives from the provisions of the Directive 2013/30/EU on safety of offshore oil and gas operations. In this Directive, “oil spill response effectiveness” means the effectiveness of spill response systems in combating an oil spill, on the basis of the “analysis of the frequency, duration, and timing of environmental conditions that would preclude a response. Furthermore, the assessment of oil spill response effectiveness is to be expressed as a percentage of time that such conditions are not present and is to include a description of the operating limitations placed on the installations concerned as a result of that assessment”. Firstly, a gap analysis was conducted, aimed at highlighting the state of the art of RGA. The various literature reports on RGA are based on different environmental factors, as well as on different response strategies. A detailed analysis of the available information allowed identifying 9 environmental factors to be included in RGA: the wind speed, the wave height, the air temperature, the wind chill, the superstructure icing, the daylight / darkness conditions, the horizontal visibility, the cloud ceiling, and the sea ice coverage. In addition, also the shoreline distance and the bathymetry, which are location specific factors, could impair the response. Thus, a total number of 11 “environmental factors” is taken into account in the new RGA methodology. The definition of threshold values to be applied to each environmental factor was also addressed. In literature, usually two limit values are adopted and three zones are identified: a green zone, where the factor is favourable to the response; a yellow zone, where it is marginal, and a red zone, where it is unfavourable. Technical reports were analysed in order to retrieve the limit values of the environmental factors mentioned. Thus, a set of threshold values was proposed for mechanical recovery, application of dispersants by vessel and by aircraft, and in-situ burning. As a further step, the criteria adopted to combine the environmental factors in order to evaluate the effectiveness of the response were investigated. All the most recent studies identify for the response a green zone for the favourable response, a yellow zone corresponding to the impaired response, and a red one, where the response is ineffective. This criterion is adopted in the RGA method developed in the present study. The RGA methodology was implemented in a software code, which was applied to a case study area, allowing the validation of the RGA procedure.

### 1. Introduction

The Directive 2013/30/EU on safety of offshore oil and gas operations and amending the Directive 2004/35/EC [Directive 2013/30/EU] has the aim of reducing “as far as possible the occurrence of major accidents relating to offshore oil and gas operations and to limit their consequences”, improving the response mechanisms in case of an accident. In the text of the Directive there is a specific focus on the spills of oil and

oily products into the sea, that is on the accidents with the potentiality to cause damage to the environment. Furthermore, it is reported that, in order to ensure effective response to emergencies, “operators should prepare internal emergency response plans (...) based on risk and hazard scenarios identified in the report on major hazards (...). The adequate availability of emergency response resources should be assessed against the capacity to deploy them at the site of an accident. The readiness and effectiveness of emergency response resources should be assured and regularly tested by the operators”. It is further explained that “oil spill response effectiveness” means the effectiveness of spill response systems in combating an oil spill, on the basis of the “analysis of the frequency, duration, and timing of environmental conditions that would preclude a response. Furthermore, the assessment of oil spill response effectiveness is to be expressed as a percentage of time that such conditions are not present and is to include a description of the operating limitations placed on the installations concerned as a result of that assessment” (Directive 2013/30/EU).

The evaluation of the oil spill response effectiveness requires performing a so-called RGA – Response Gap Analysis, with emphasis on the time gaps during which the environmental conditions preclude the possibility to respond to an oil spill. RGA studies have received a substantial increase with the beginning of the offshore hydrocarbon exploration and production in the Arctic, where on one side there is a unique and precious environment, on the other the weather conditions could very often be particularly harsh, so to preclude any response to an oil spill.

First of all, an extensive analysis of the state of the art about RGA methodologies was performed. As a result, it has been possible to identify several references presenting a RGA methodology and applying it to one or more case studies (NUKA, 2006; NUKA, 2007; NUKA, 2008; SLRoss, 2011; Terhune, 2011; NUKA, 2012; NUKA, 2014; Laborde et al., 2015; Spansvoll et al., 2015; NUKA, 2015; NUKA, 2016; Spansvoll et al., 2016; EPPR, 2017a; EPPR, 2017b; Dahlslett et al., 2018). Each method considers a different set of environmental conditions, usually without justifying why some factors are not taken into account. There are also differences in the degree of detail adopted to describe the oil spill emergency techniques for which the response gap is evaluated. Generally, the presentations of the fundamental concepts underlying the different procedures is rather incomplete. Furthermore, a critical review of alternative procedures is never provided. As a consequence, a full comprehension of the theoretical fundamentals of the different methods is rarely possible. Thus, the present study focused on the development of a new RGA method overcoming the limits of the existing ones (DICAM, 2019). After the present introduction, section 2 contains the description of the key aspects of the procedure, while section 3 reports its application to a case study. Lastly, section 4 is devoted to the conclusions and to future research developments.

## 2. The Response Gap Analysis method

The proposed RGA method is based on 9 metocean conditions related to the wind, the sea state, the temperature effects, the visibility, and the sea ice. In addition, 2 location specific factors - the bathymetry and the shoreline distance - are included. Differently from the metocean conditions, the location specific factors do not vary with time; though, they might have a negative effect on the response. The list of the 11 environmental factors taken into account by the RGA procedure is reported in Table 1.

*Table 1: Environmental factors included in the RGA method*

Wind	Wind speed
Sea state	Significant wave height
Temperature effects	Air temperature
	Superstructure icing
	Wind chill
Visibility	Daylight / darkness
	Horizontal visibility
Sea ice	Cloud ceiling
	Ice coverage
Bathymetry	Bathymetry
Shoreline distance	Shoreline distance

The response strategies available to combat oil spills at sea are mechanical recovery, application of dispersants and in-situ burning. Generally, each strategy can be mounted by means of different tactics. The baseline tactics to implement the different strategies are listed in Table 2.

Table 2: Baseline tactics for oil spill emergency intervention

Response strategy	Baseline tactics	
Mechanical recovery	T1	Vessels with booming and skimming systems
Application of dispersants	T2	Application of dispersants from a vessel
	T3	Application of dispersants from an aircraft
In-situ burning	T4	Vessels with booming and ignition system

Each tactic requires the combination of different components. Rather obviously, the environmental factors affect the performance of the components of the response equipment adopted within each tactic. Thus, the definition of the set of the environmental factors influencing the response, as well as of the threshold values for each of them, has necessarily to consider the single tactics.

An accurate analysis of the threshold values reported in the technical literature was performed, considering the studies presenting an RGA method and the main bibliographical sources concerning operational limits cited by them. Generally, these values reflect literature review, considerations extracted from oil spill contingency plans, restrictions imposed by regulatory standards, guidelines developed by industry and government agencies, best professional judgement of experts and academics, and, ultimately, the authors' opinion. Hardly ever limits refer to specific commercial equipment or derive from experimental activities. Again, it was possible to acknowledge lack of completeness and poor homogeneity in the limit values adopted for the factors within each tactic. Generally, thresholds are organized into three categories, corresponding to conditions which are favourable, or marginal, or not favourable for the deployment of the tactic. For daylight / darkness, and here and there also for some other environmental factors, only two categories are defined: favourable and marginal, if the factor never makes the response ineffective, or favourable and not favourable, if the available limits are so scarce that is difficult to define the intermediate marginal class.

Thus, basing on values documented by authoritative references and already adopted in RGA studies, typical threshold values of the environmental factors were proposed for mechanical recovery, application of dispersants, and in-situ burning, assuming that each strategy is mounted by means of the baseline tactics. As an example, the set of values proposed for tactic T1 is reported in Table 3.

Table 3: Tactic T1: typical threshold values for the environmental factors

Environmental factors	Conditions		
	Favourable	Marginal	Unfavourable
Wind speed	< 10 m/s	10 m/s ÷ 15 m/s	> 15 m/s
Wave height	< 1 m	1 m ÷ 2 m	> 2 m
Air temperature	> -18 °C	not used	< -18 °C
Superstructure icing	< 0.7 cm/h	0.7 cm/h ÷ 2 cm/h	> 2 cm/h
Wind chill	> -31.7 °C	-37.2 °C ÷ -31.7 °C	< -37.2 °C
Daylight / darkness	daylight	darkness	not used
Horizontal visibility	> 900 m	200 m ÷ 900 m	< 200 m
Cloud ceiling	.....not limiting.....		
Ice coverage	< 10%	10% ÷ 30%	> 30%
Bathymetry	> 3.6 m	1.8 m ÷ 3.6 m	< 1.8 m
Shoreline distance	.....not limiting.....		

In all the most recent RGA studies a common criterion has been adopted to combine the environmental factors, i.e. to establish if their combination makes a response tactic favourable, impaired, or ineffective. This criterion has been used also in the new RGA method, as shown in Table 4.

Table 4: Criterion to combine the environmental factors

Description	Response Outcome
All factors green	Response favourable
One or more factors yellow and all the remainders green	Response impaired
One or more factors red	Response ineffective

As a last step, the new RGA methodology was implemented in a custom software is written in MatLab (version R2017b), in order to elaborate the huge amount of input data and to produce detailed results [Mathworks, 2020].

### 3. Case study application

The code implementing the RGA procedure was applied to a sea area off the Northern coast of Norway, including parts of the Norwegian Sea, of the Barents Sea, and of the Greenland Sea, as shown in Figure 1.

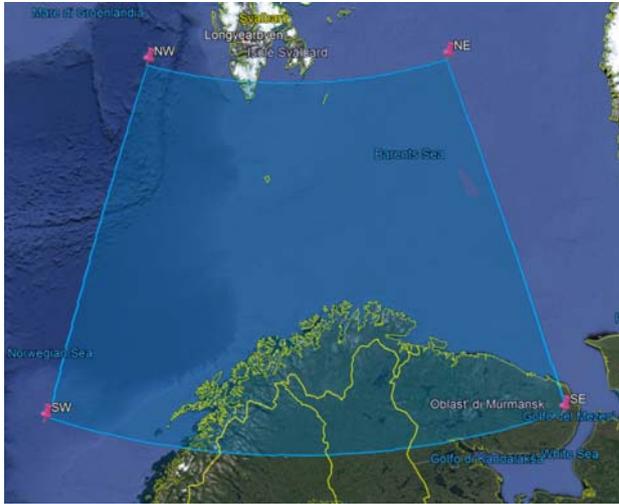


Figure 1: Case study: map view of the area

The ERA 5 database was used to retrieve the data about the wind speed, the wave height, the air temperature, the sea temperature, the dew point temperature, and the ice coverage (ECMWF, 2020); a ten-years period - from 2009 to 2018 - was adopted. Since no data for the wind chill, the superstructure icing, and the horizontal visibility are present in the ERA 5 database, these factors were calculated as a function of the wind speed, the air temperature, the sea temperature, and the dew point temperature, by applying empirical equations of technical literature (DICAM, 2019). Information about the daylight / darkness conditions was obtained for all points of the area through a model developed by the Institut de Physique du Globe de Paris, basing on the date and the latitude and longitude coordinates of each point (IPGP, 2020). Lastly, information about the bathymetry and the shoreline distance was extracted, respectively, from the General Bathymetric Chart of the Oceans (GEBCO, 2020) and the Global Self-Consistent Hierarchical High-Resolution Geography database (GSHHG, 2020). As in all previous RGA methods, the cloud ceiling was excluded, because of the unavailability of data. Since for the case study area the data of most environmental factors have a space resolution of  $0.25^\circ \times 0.25^\circ$ , it was decided to perform the RGA with this spatial step. Instead, the time resolution was set to 2 hours, because the value of 1 hour, which is the time resolution of most data, would require an excessive computational time. All the baseline tactics were considered. Information was made available on specific boom models and oil skimmers available in the case study area. Thus, for the wind speed and the wave height thresholds values derived from the technical documents of these emergency components were used, as shown in Table 5. For all the other factors, the typical limits reported in Table 3 were adopted.

Table 5: Case study area, tactic T1: specific threshold values for the wind speed and the wave height

Environmental factors	Conditions		
	Favourable	Marginal	Unfavourable
Wind speed	< 20 m/s	20 m/s ÷ 25 m/s	> 25 m/s
Wave height	< 1.5 m	1.5 m ÷ 3.5 m	> 3.5 m

In Figure 2 and 3 an example of the results of the RGA for the tactic T1 is reported; the letters on the horizontal axes are the initials of the months of the year. Looking at Figure 2b), it can be noticed that for the tactic T1 the percentage probability of a favourable response on a yearly basis is equal to 22%, the percentage probability of an impaired response is equal to 59%, while the percentage probability on an ineffective response is equal to 19%. However, Figure 2a) shows that these probabilities are quite variable over time: for instance, the probability of a favourable response is maximum in June, while it is minimum in December, when it is null. Thus, the yearly value of 22% for the favourable response is an average of rather different weekly percentages.

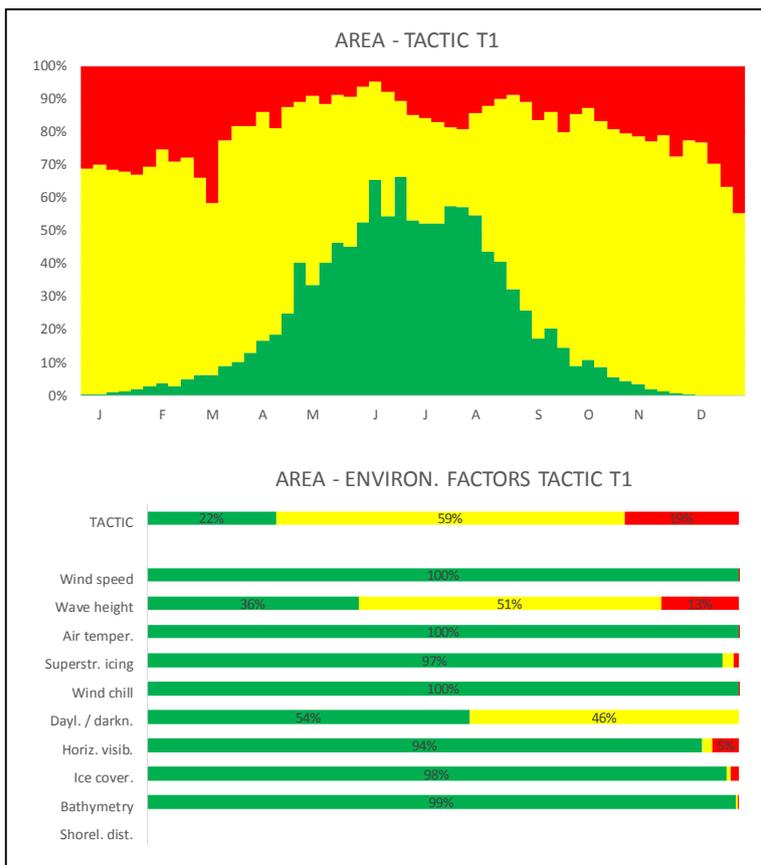


Figure 2: Case study, tactic T1: a) percentage probabilities of favourable, impaired, ineffective response for each week; b) yearly contributions of each environmental factor to the favourable, impaired, ineffective response

Figure 2b) shows which environmental factors determine that, for the tactic T1, the response is ineffective: these factors are, primarily, the wave height, for which the percentage probability of unfavourable conditions is equal to 13% and, secondarily, the horizontal visibility, for which the percentage probability of unfavourable conditions is equal to 5%. All the other factors, that is the wind speed, the air temperature, the superstructure icing, the wind chill, the daylight / darkness, the ice coverage, and the bathymetry are never or hardly ever unfavourable. However, the conditions of two factors are often marginal to the response: the wave height, with a percentage probability of 51%, and the daylight / darkness, with a percentage probability of 46%. Thus, these two factors determine the high value of the percentage probability of the impaired response, which is equal to 59%.

#### 4. Conclusions

After an in-depth analysis of the RGA procedures available in technical literature, it was possible to set up a new RGA methodology and to implement it in a custom software. The method was applied to a case study area, in order to validate the RGA procedure. The validation test was totally positive.

Though, it is necessary to highlight that RGA is aimed at evaluating a “theoretical” maximum effectiveness of the response, basing only on the values of the environmental factors. In fact, the real effectiveness of the response depends also on the location of the spill, the amount and duration of the release, the properties of the oil, its fate and trajectory, the number and features of the emergency equipment available in the area. For this reason, it may be useful for a more effective response to oil spills to complement the RGA with a “practical effectiveness” and to set up a procedure to assess it, taking into account all the additional elements mentioned above together with the environmental factors.

The evaluation of the “practical effectiveness” would allow to thoroughly understand and to express in quantitative terms the oil spill risk reduction due to the deployment of emergency actions, in the framework of the Directive 2013/30/EU, which has the object “to reduce as far as possible the occurrence of major

accidents relating to offshore oil and gas operations and to limit their consequences, thus increasing the protection of the marine environment and coastal economies against pollution” (Directive 2013/30/EU).

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