Distribution of oil spill response capability through considering probable incident, environmental sensitivity and geographical weather in Vietnamese waters

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ABSTRACT
Various occurrences of marine incidental oil spills in the Vietnamese waters require effective high response system. The probability of oil spill, environmental sensitivity, and geographical weather conditions were simultaneously considered to calculate the distribution of the oil spill response capability (OSRC). In this contribution, 13 important factors (3 priority protected areas, marine traffic, max. amount spill, industrial installation, offshore activities, historical spill, distance to spill, sea state, tidal current, visibility and sea-water temperature) of 8 oil spill response (OSR) areas were investigated and calculated by using Fuzzy Analytic Hierarchy Process (Fuzzy AHP). The results were reflected the highest OSRC in Vung Tau area, peaking about 1,457 tons of the amount of Vietnam national marine OSRC. The study suggested the new scientific platform for the distribution of areal OSRCs to mitigate the damage of future marine incidental oil spills to marine ecosystems, coastal resources, humans, and socio-economy.

Introduction
Oil as an important factor impacting on economic development and human's life, global seaborne trade of oil by tankers, oil exploration and production industries has been increasing (EIA 2017; UNCTADStat n.d. 2017; Reynolds 2014; Behmiri et al. 2013), contributing to great benefits to various localities, regions and nation (Alidi and Al-Faraj 1994; Garrett et al. 2017; PetroVietnam 2017). However, the risk of oil spill influence on marine ecosystems and coastal resources (Carla et al. 2015) gave rise to losses of the fisheries, aquaculture and tourism industries and consequences on social and environmental values that concerned by researchers and policymakers (ITOPF, The International Tanker Owners Pollution Federation Limited 2014a, 2014b; Alvarez et al. 2014; Garza-Gil et al. 2006). In order to minimize damage from oil spill incident, various contingency plans, policies, legislation, and effective countermeasure would be established.

Vietnam is located on the East Sea where more than half of the world’s annual merchant tonnage, one-third of the global trade in crude oil and over half of the LNG passed through. The oil and gas exploration and production activities in Vietnam are increasing sharply and playing a vital role in national economy, about 16–18% of the State budget (petroVietnam 2017). The demand for national energy consumption to support economic development has been sharply climbing (Le et al. 2016). It is well-known that characteristics of Vietnamese sea are various and complex such as Ha Long Bay, Cat Ba Island with many marine and coastal ecosystem (Hong et al. 2008; Nguyen, Jacobson, and Ross 2017).

The Neptune Aries pollution incident in 1994, the tanker Formosa One pollution incident in 2001 and the mystery oil spill in 2007 are important lessons in preparing and responding to large oil pollution accidents (ITOPF 2017), resulting in the establishment of Circular 2262/TT-MTG and a series of laws and policies. Vietnam’s Government has built three National Oil Spill Response Centers. There are 24/28 Oil spill contingency plans of Coastal Provinces and various Contingency plans in-house level that considering about historical spill have approved. There were some solutions that have been proposed to improve oil spill response capability such as response measures for oil spills in Da Nang City (Phung 2005), enhancing local capacities in oil spill preparedness and response (Nguyen 2009; Nguyen et al. 2014). Oil spill response capability (OSRC) is defined as the resources to deal with the oil spill incident, including three categories: equipment, response personnel, and additional support (IPIECA-IOGP 2015). However, oil spill response equipment, facilities, materials, and manpower resources and additional support in Vietnam still cannot be reasonably allocated and used, and there is a lack of scientific basis for allocating oil spill response resources to combat oil spills. Therefore, the scientific and systematic researches on factors impacting on the distribution of OSRC to
comprehensively evaluate national OSRC are necessary to be performed. Hence, it provides scientific basis and guidance for the distribution OSRCs and gives rise to scientific suggestions in process of construction of national oil spill response capability.

In this study, 13 important factors were investigated that were divided into three categories: oil spill sensitive areas, the probability of oil spill incident, and geographical environment conditions. It is well known that fuzzy – AHP model is good decision-making method that was applied to solve the different managerial problem (Asghari et al. 2017; Isai et al. 2011; Shaverdi, Heshmati, and Ramezani 2014). The fuzzy linguistic approach can take into account the optimum and pessimism rating attitude of decision makers. The membership functions are characterized by fuzzy triangle number and are assessed preference ratings instead of conventional numerical equivalence measures (Shaverdi, Heshmati, and Ramezani 2014). Therefore, Vietnam response capability (VRC) model was developed by using Fuzzy AHP technique to calculate performance weight of important factors. These weight and statistics are unified into one value to suggest new areal OSRC for each region.

**Research methodology**

**Identifying factors and development of hieratical VRC model**

According to the current situation of marine oil spill response capability in Vietnam and the experience of developed countries in marine oil spill response capability in-house and oversea, including Guidance on Oil Spill Risk Evaluation and Assessment of Response Preparedness of IMO, Sensitivity mapping for oil spill response of IPIECA, Guidance to State and Local Governments in oil spill response of USA, Geographic Response Plan Oil spill Sensitive Sites, the Regulations of Vietnam National Assembly on Environmental Protection, the Law on Petroleum, the Law on Resources and Environment of Sea and Islands, Vietnam Maritime Code, the Law on Inland waterway traffic, the Law of the Sea of Vietnam, Law on Water resources, the Decision No. 02/2013/QD-TTg of Prime Minister, dated 14 January 2013, to promulgate the regulation on oil spill response as well as other Laws, regulations, standards and guidelines of Vietnam on marine oil spill pollution, we set up an evaluation important factor system, which includes 3 factors in the upper level and 13 factors in the lower level (Figure 1 and Table 3).

This hierarchical model is developed to analyse and estimate the OSRC with Fuzzy-AHP methodology. The VRC model can calculate separately probability of oil spill incident, oil spill sensitive area to marine and coastal ecosystems, and geographical weather conditions according to season. Then in the lower level of the model, the oil spill sensitive area has been divided into three main factors: high priority protected areas, medium priority protected areas, and low priority protected areas. The probability of oil spill incident has been divided five main factors: the number of vessels enter and depart from area, estimation of the maximum amount of oil spill in the areas, industrial installation, offshore operational ports and historical oil spill incidents. Moreover, the geographical weather

![Figure 1. Hierarchical VRC model.](image-url)
conditions have been divided five main factors: distance to spill site, sea state (wind, wave), tidal current, visibility, and sea-water temperature.

The aim of this study is providing the best balance of important factors for the distribution of OSRC in Vietnamese waters that support policymaking, planning, response personnel to mitigate impacts of an oil spill.

### Fuzzy AHP methodology

In order to avoid various failures when defining new precise of approximation and vague characteristics of decision-making issues Zadeh (1965) first proposed on the generalization of standard set theory to fuzzy sets, which oriented the rationality of uncertainty due to vagueness (Kahraman, Cebe, and Ruan 2004). In this study, F-AHP method is found that will be used to find the final weight factors for distribution of areal OSRCs.

The analytic hierarchy process (AHP) is one of the most frequent techniques for decision-making, a multi-criteria decision-making tool (MCDM) was initially introduced by Saaty (1972, 1987), and has been used to solve multiple criteria decision issues in different fields such as political, socio-economic and management sciences, planning, resource allocations, optimization, etc. (Lee, Chen, and Chang 2008; Vaidya and Kumar 2006). Using a systematic hierarchy structure, complex estimation criteria can be represented clearly and definitely (Chou et al. 2001). However, this technique is inability to assign exact numerical values to the comparison judgments and effective when applied to unstructured and ambiguous problems. Generally, the conventional AHP still cannot provide full guidance on the highly vague world. Therefore, AHP has been integrated with various techniques such as linear program, quantity function deployment, fuzzy logic, etc. (Saaty and Vargas 2001). In order to achieve the desired goal in a better way, the benefits of all methods should be combined. In this case, some scholars have combined the Fuzzy theory with AHP method to handle fuzzy comparison matrices such as Chang’s extend analysis method (Chang 1996).

### Fuzzy numbers and fuzzy synthetic extent

The fuzzy set is a class of objects with a continuum of grades of values ranging from 0 to 1. Complete non-membership is represented by 0, and complete membership as 1. The values lie between 0 and 1 belongs to the fuzzy sets (Zadeh 1965). Fuzzy number \( m \) on \( R \) to be a triangular fuzzy number (TFN) with three points if its membership function of \( m \) is equal to Eq. (1).

\[
fm(x) = \begin{cases} 
0, & x < l \\
\frac{x-l}{m-l}, & l \leq x \leq m \\
\frac{u-x}{u-m}, & m \leq x \leq u \\
0, & x > u 
\end{cases}
\]

Considering two triangular fuzzy number \( m_1 = (l_1, m_1, u_1) \) and \( m_2 = (l_2, m_2, u_2) \) that can be operated according to their laws as below:

**Addition**: \( m_1 + m_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \) (2)

**Subtraction**: \( m_1 - m_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \) (3)

**Multiplication**: \( m_1 \times m_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \) (4)

**Division**: \( m_1^{(-1)} = (1/u_1, 1/m_1, 1/l_1) \) (5)

The value of fuzzy methods has considered as a linguistic value that the definite values are converted to fuzzy numbers according to the definitions in Table 1.

### Algorithm of fuzzy AHP

The steps of FAHP that the extent of FAHP is utilized, which was originally introduced by Chang as below.

Let \( X = \{x_1, x_2, \ldots, x_i\} \) be an object set and \( U = \{u_1, u_2, \ldots, u_n\} \) be a goal set. And then, each object is taken and performed extent analysis for each goal, respectively. Hence, \( m \) extent analysis values for each goal can be gotten with the following signs:

\[
M_{(g_i)}^1, M_{(g_i)}^2, \ldots, M_{(g_i)}^m, \quad i = 1, 2, \ldots, n, \quad (6)
\]

where all the \( (j = 1, 2, \ldots, m) \) are triangular fuzzy numbers and \( g_i \) is the corresponding to the goal.

**Step 1.** The value of fuzzy synthetic extent with respect to the ith object is defined as:

\[
\sum_{j=1}^{m} M_{g_i}^j \text{ perform the fuzzy addition operation of } m \text{ extent analysis values for a particular matrix such as}
\]

\[
\sum_{j=1}^{m} M_{g_i}^j = \left( \sum_{j=1}^{m} l_j \sum_{j=1}^{m} m_j \sum_{j=1}^{m} u_j \right)
\]

(8)

In order to obtain \( \left( \sum_{j=1}^{m} M_{g_i}^j \right) \), the fuzzy addition operation of \( M_{g_i}^j \) (\( j = 1, 2, \ldots, m \)) value is performed as follows:

\[
\sum_{j=1}^{n} \sum_{j=1}^{m} M_{g_i}^j = \left( \sum_{j=1}^{n} l_j \sum_{j=1}^{n} m_j \sum_{j=1}^{n} u_j \right)
\]

(9)
Table 1. Linguistic responses and fuzzy scale transformation chart (Saaty 2008; Buyukozkan, 2004).

| Linguistic scale | TFN scale | TFN reciprocal scale |
|------------------|-----------|----------------------|
| Just equal       | (1,1)     | (1,1)                |
| Equal Importance | (1/2,1,3/2) | (2/3,1,2)           |
| Weakly more important | (1,3/2,2) | (1/2,2,3,1)         |
| Strongly more important | (2/3,2,5/2) | (2/5,1/2,3/2)     |
| Very strongly more important | (2,5/2,3) | (1/3,2/5,1/2)      |
| Absolutely more important | (5/2,3,7/2) | (2/7,1/3,2/5)      |

And the inverse of the vector in Equation. (9) is computed as

\[
\left( \sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij} \right)^{-1} = \left( \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{m} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right).
\]

(10)

Step 2. As \(M_1, M_2\) are two triangular fuzzy numbers, the degree of possibility of \(M_1 = (l_1, m_1, u_1) \leq M_2 = (l_2, m_2, u_2)\) is defined as (Kahraman, Cebe, and Ruan 2004)

\[
V(M_1 \leq M_2) = \sup_{x,y} \min(\mu_{M_1}(x), \mu_{M_2}(y)) \tag{11}
\]

\[
V(M_1 \leq M_2) = \text{hgt}(M_1 \cap M_2) = \mu_{M_d}(d) \tag{12}
\]

where \(d\) is the ordinate of the highest intersection point between \(\mu_{M_1}\) and \(\mu_{M_2}\), and \(\text{hgt}\) is height. The numbers \(M_1\) and \(M_2\) should be compared calculating both, \(V(M_1 \leq M_2)\) and \(V(M_1 \geq M_2)\) values.

Step 3. The degree possibility of a convex fuzzy number to be greater than \(k\) convex fuzzy \(M_i (i = 1, 2, \ldots, k)\) numbers can be defined by

\[
V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots \text{ and } (M \geq M_k)]
\]

\[
= \min V(M \geq M_i), i = 1, 2, 3, \ldots, k. \tag{13}
\]

Assume that

\[
d'(s) = \min V(S_i \geq S_k) k = 1, 2, \ldots, n; k \neq i. \tag{14}
\]

And then the weight vector is given by

\[
W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \tag{15}
\]

Where \(A_i (i = 1, 2, \ldots, n)\) are \(n\) elements.

Step 4. Via normalization, the normalized weight vectors are

\[
W = (d(A_1), d(A_2), \ldots, d(A_n))^T, \tag{16}
\]

where \(W\) is a non-fuzzy number.

Saaty (1977) has proposed a consistency index (CI), which is related to the eigenvalue method applied in matrix, for which:

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}, \tag{17}
\]

where \(n\): dimension of the matrix and \(\lambda_{\text{max}}\) = maximal eigenvalue

Saaty (1980) suggested that if \(CI/RI < 0.1\), the pairwise comparison matrix is characterized by an acceptable level of consistency. RI is a random index (the average CI of 500 randomly filled matrices), the values of which have been predefined by Saaty (Saaty 2001) for problems with \(n \leq 10\) as indicated in Table 2.

From the theoretical basis above, a pair-wise comparison tool is set up by using the Visual C # tool programing (see Figure 3). In order to check the consistency the matrix, it is required to calculate the consistency ratio:

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1} \quad \text{and} \quad CR = \frac{CI}{RI} = 0.0209 < 0.10. \tag{18}
\]

It means that FAHP sequencing result is of high consistency, the distribution of weight coefficient is very reasonable. Figure 2 shows the flowchart of this study.

Results and discussion

Calculating weight factor using F-AHP

In this study, we conducted questionnaires to “pool experts” as advisory group, consisting of individuals with expertise in the following areas: navigation, ship technology, naval architecture, chemical hazards, marine biology, physical and chemical oceanography, dispersion modeling, spill response, and firefighting who have at least over 5-years experiences. These experts are asked to compare two main criteria and 13 important factors in the range of this study as the table above. The results of the survey are analyzed by using FAHP measures that are presented as below. The first step of the analysis, set up the pair-wise comparison matrix to compare the relative importance between various factors that obtains the relative importance of criteria factor from the result of questionnaires, the definite values are converted to fuzzy numbers (see Table 1). Table 3 shows the fuzzy evaluation matrix, local weights and pair-wise comparison of factors, including 3 factors: OSS, POS, GEO in the upper level, 13 important factors: HPA, MPA, LPA, VED, EMO, IND, OSP, HOS, DIS, SSW, TID, VIS, and TEM in the lower level. These fuzzy values are compared (for example in Figure 3).
The weight factor was determined as \( W_p = (0.300, 0.273, 0.156, 0.151, 0.120) \). In the five factors, VED is the most preferred factor when compared with the other factor. The other main factors and sub-factors are calculated in a similar way. The weight of upper evaluation and local weight were multiplied to produce the global weights, as shown in Table 4.

**Regional status and normalization**

**Probability of oil spill incident**

The five factors used to estimate probability of oil spill incident in Table 5 are the number of vessel enter and depart from area (2015), estimation of maximum amount of oil spill in the area (2017), industrial installation (2017),

![Figure 2. Flowchart of setting up OSRC.](image)

![Figure 3. Sample pair-wise comparison matrices.](image)
offshore operational oil port (2017) and historical oil spill incident (1995–2016). Generally, the five factors showed the highest point in S1 (Binh Thuan – Ba Ria Vung Tau –

| Table 3. Detailing important factors for evaluation of VRC Index. |
|---|---|---|---|---|---|
| Goal | Upper level | Lower level | Detail |
| VRC | Oil spill sensitive area protected level: OSS | High priority protected areas (HPA) | Marine protected areas (World heritage sites, national park, marine nature reserves, etc.) Wildlife protected include marine bird (wetlands as waterfowl habitat in Ramsar site), marine mammals and sea turtles (Sea turtles spawning ground and habitat area). Coastal habitat (consists of mangrove and mudflat forest, coral reefs, seagrass beds) Aquaculture (fish stocks, fish and shellfish farming, seaweed cultivation, water intakes for hatchery, etc.) Oil port area |
| Medium priority protected areas (MPA) | Beach, tourism and recreation areas |
| Low priority protected areas (LPA) | National park, nature reserves, habitat on land, industrial land |
| Probability of oil spill incident: POS | No. Vessel enter and depart from area (VED) |
| | Estimation of maximum amount of oil spill in the areas (EMO) |
| | Industrial installation (IND) |
| | Offshore operational oil port (OSP) |
| | Historical oil Spill incident (HOS) |
| Geographic condition (seasonal, meteorological condition): GEO | Distance (DIS) |
| | Sea state (Wind, wave) (SSW) |
| | Tidal current (TID) |
| | Visibility (VIS) |
| | Temperature (TEM) |

| Table 4. Weighted scores for each factor by Fuzzy-AHP. |
|---|---|---|---|---|---|
| Upper evaluation | Lower evaluation | Local weight | Global weight |
| POS | 0.619 | VED | 0.300 | 0.186 |
| | | EMO | 0.273 | 0.169 |
| | | IND | 0.156 | 0.097 |
| | | OSP | 0.151 | 0.093 |
| | | HOS | 0.120 | 0.074 |
| OSP | 0.236 | HPA | 0.521 | 0.123 |
| | | MPA | 0.312 | 0.074 |
| | | LPA | 0.167 | 0.039 |
| GEO | 0.145 | DIS | 0.325 | 0.047 |
| | | SSW | 0.263 | 0.038 |
| | | TID | 0.231 | 0.033 |
| | | VIS | 0.082 | 0.012 |
| | | TEM | 0.059 | 0.009 |

| Table 5. Present status of areal probability factors. |
|---|---|---|---|---|---|
| Region | Area | VED (No.) | EMO (Tons) | IND (Tons) | OSP (No.) |
| NOSRCEN | N1- Hai Phong | 26810 | 6000 | 2362100 | 5 | 10 |
| | N2- Thanh Hoa* | 7643 | 45000 | 1125400 | 3 | 3 |
| | N3- Ha Tinh+ | 2202 | 2700 | 158000 | 4 | 2 |
| SOSRCEN | C1 – Da Nang | 7160 | 4500 | 409500 | 8 | 12 |
| | C2 – Quang Ngai | 8030 | 22500 | 1281900 | 5 | 15 |
| | C3 – Khanh Hoa | 4894 | 22500 | 1124900 | 6 | 2 |
| NASOS | S1 – Vung Tau | 41405 | 45000 | 3513860 | 116 | 66 |
| | S2 – Ca Mau+ | 591 | 18000 | 65000 | 4 | 7 |

Tien Giang – Ben Tre – Tra Vinh – Soc Trang), which is the central area in which oil and gas exploration and largest sea-ports system of Vietnam are concentrated. The summed data values of area and region are shown for each factor through average normalization step (see Table 8).
**Oil spill sensitive area**

The three factors used to estimate oil spill sensitivity area are the high priority area, medium priority area, and low priority area (see Table 6). The high priority is estimated through the marine protected area (2016–2017), aquaculture (2016), and oil port (2017). The medium priority includes beach, tourism and recreation areas (2016), salt field (2017), intensive land of rice and vegetables coastal area (2016), subsistence, artisanal and commercial fishing, and fishing villages (2016), main port and marinas (2017), urban residential area, rocky beach, sandy beach for many users (2016). The low priority area was estimated through the national park, nature reserves, habitat on land, industrial land (2016), land for planting industrial trees, perennial trees, coastal area a little used (2017), small port and marinas (2017). These factors reflect the sensitive characteristics of each area and used in the normalization step (see Table 8).

**Geographical weather conditions**

The five factors used to estimate geographical weather conditions according to tropical monsoon weather area distance from OSR center to spill site (2015–2017), sea state, tidal current, visibility (hours of daylight/year), and temperature of surface seawater (<10 m) according to QCVN 02: 2009/BXD. The average normalization of these data is shown in Table 7.

The result of each distribution was determined by a total of multiplying the normalization valuation and global weight of each factor of each area by fuzzy AHP (formula 17). The final weight of each area to oil spill response capability in Vietnam are shown in Table 9 and Figure 4. Practically, new OSR bases (N2, N3, C2, S2) reach the important percentage of national OSRC. The highest of OSR base in national OSRC is available OSR in S1, accounting for 31.67%. It means that Vung Tau area has the highest level of oil spill response capability in the country. This reflects the fact that the highest number of vessels entering and departing Vung Tau – Ho Chi Minh City area as the biggest economic center, concentrating most of the oil and gas exploitation activities of the country. In addition, it is also an area of high environmental sensitivity with priority protected areas such as Con Dao Island, Can Gio Mangrove, Hon Cau – Vinh Hai, Binh Chau – Phuoc Buu, etc.

\[
A_i = \sum_{j=1}^{13} N_{ij} \times GW_{ij} \quad (20)
\]

where:
- \(A_i\): Result of Area \(i\)
- \(N_{ij}\): Normalization evaluation of factor \(j\) of area \(i\)
- \(GW_{ij}\): Global weight of factor \(j\) of area \(i\).
The statistics of recovery capacity of oil skimmer in three OSR centers (VINASARCOM 2017; PCDN 2016; PCVT 2016) combined with applying Korea’s formula (Lee 2001; Min-Jae 2014) to calculate the existing capabilities in Vietnam:

\[
Q = \frac{T}{C_{20}} \left(\frac{C_{24}}{C_{28}}\right) / C_{0}
\]

\[
T = 4600 \text{ tons}, \quad 1764 \text{ tons}, \quad 961 \text{ tons}, \quad 1875 \text{ tons}.
\]

Looking on Table 10, the results of OSRC are absolutely different from the existing capabilities. Because of the areal OSRC are more sensitive and effective to areal protected priority compare with the existing standard. The existing excessive OSRC of some areas was adjusted to areal protected priority and to the central areas. Therefore, the results of OSRC reflect the impacts of an oil spill considering cause of incident, impacts of geographical weather condition and are more balanced than the existing capability.

### Validity of OSRC

According the results of areal OSRC on water, we verified by simulating the distribution of oil spill response equipment. It was assumed 2000 tons of oil, the target recovery amount of oil spill in Thanh Hoa at 13:00. In Thanh Hoa, there is a high risk of oil spill and most disadvantage in term of mobilization of response resources (Figure 4). Because of the fact that the OSR equipment is not available at Thanh Hoa area. In this simulation, marine OSR equipment was dispatched to spill site with the speed vessel was assumed to be 11 knots, weather conditions were assumed to be good. The daytime working period was assumed to be 8 h (07:00 to 17:00). The response operation was started immediately upon OSR equipment entering at spill site. In cases of equipment arrived on spill site at night, operation was assumed to start at 7:00 the following day.

In this scenario, the actual OSRC is estimated about 2,327 tons/h when considering the dispatching OSRC of other areas to Thanh Hoa area (Table 12). It is really satisfy with the existing OSRC of NOSRCEN, about 1764 tons (Table 11).

### Conclusion

This paper proposed the new criteria for the distribution of OSRC that is a platform in order to establish...
Vietnam national OSRC. The present status of 8 areal OSR according to 13 important factors was investigated and normalized. The global weight was calculated by using fuzzy AHP approach that helps to choose the best decision – making strategy using a weighting process through pair-wise comparison matrices. The global weight for each factor was combined with the results of normalization step to produce the final weight for each OSR area. Interestingly, Vung Tau area (S1) of southern region is estimated to be around 1457 tons, ranking the first of national OSRC. In the northern region, Hai Phong area (N1) is made up of 633 tons, followed by Thanh Hoa area (N2) and Ha Tinh area (N3), about 476 tons and 196 tons, respectively. In Quang Ngai (C2) and Da Nang (C1) account for 392 tons and 362 tons, respectively. The result of this research is the balanced probability of oil spill, sensitive environment of OSR area, and geographical weather conditions according to tropical monsoon to the central high risk of marine pollution areas.

It is expected that this research would make any contribution to improving the efficiency of OSRC, supporting to OSR responders, policy-making, contingency plan–making, and the damage of marine pollution incidents petering out.

Table 10. Final weight and OSRC (4 days).

| Region | Area | Final weight | OSRC (tons) | Current capability (tons) | Difference |
|--------|------|--------------|-------------|---------------------------|------------|
| NOSRC  | N1   | 0.1376       | 633         | 1764                      | (1131)     |
|        | N2   | 0.1035       | 476         | 0                         | 476        |
|        | N3   | 0.0426       | 196         | 0                         | 196        |
|        | Sum. | 0.2837       | 1305        | 1764                      | (459)      |
| SOSREC | C1   | 0.0786       | 362         | 961                       | (599)      |
|        | C2   | 0.0852       | 392         | 0                         | 392        |
|        | C3   | 0.0756       | 348         | 0                         | 348        |
|        | Sum. | 0.2394       | 1101        | 961                       | 140        |
| NASOS  | S1   | 0.3167       | 1457        | 1875                      | (419)      |
|        | S2   | 0.1602       | 737         | 0                         | 737        |
|        | Sum. | 0.4769       | 2194        | 1875                      | 318        |
Table 11. Regional OSRC for the worst case discharge in North Region.

| Region       | Area                  | Distance (NM) | Time dispatching (hour) | Time operating (hour) | OSRC Simulation (tons) | Existing capability |
|--------------|-----------------------|---------------|-------------------------|-----------------------|------------------------|---------------------|
| NOSRCEN      | N1- Hai Phong         | 100           | 9                       | 28                    | 554                    | 1764                |
|              | N2-Thanh Hoa*         | 0             | 0                       | 32                    | 476                    | 0                   |
|              | N3- Ha Tinh+          | 60            | 5                       | 28                    | 171                    | 0                   |
| SOSRCEN      | C1 – Da Nang          | 241           | 22                      | 21                    | 237                    | 961                 |
|              | C2 – Quang Ngai       | 295           | 27                      | 17                    | 208                    | 0                   |
|              | C3 – Khanh Hoa        | 506           | 46                      | 13                    | 141                    | 0                   |
| NASOS        | S1 – Vung Tau         | 690           | 63                      | 8                     | 364                    | 1875                |
|              | S2 – Ca Mau+          | 850           | 94                      | 2                     | 46                     | 0                   |

Table 12. Gathering OSRCs in Thanh Hoa area.

| Hour working | Day 1 | Day 2 | Day 3 | Day 4 |
|--------------|------|------|------|------|
| Day 1 15     | 30   | 45   | 60   | 101  |
| Day 2 287    | 351  | 415  | 479  | 543  |
| Day 3 799    | 863  | 938  | 1013 | 1088 |
| Day 4 1434   | 1555 | 1676 | 1797 | 1918 |

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