ELSEVIER

Journal of Hazardous Materials 107 (2004) 51–58

Journal of Hazardous Materials

www.elsevier.com/locate/jhazmat

A high-level synthesis of oil spill response equipment and countermeasures

Nikolaos P. Ventikos*, Emmanouil Vergetis, Harilaos N. Psaraftis, George Triantafyllou

School of Naval Architecture and Marine Engineering, National Technical University of Athens (NTUA), Athens, Greece

Abstract

This paper presents an operational synthesis of major oil spill response methods (mechanical, chemical, etc.) and the corresponding oil response equipment for sea context (booms, skimmers, etc.). We focus on important features of oil spill response, in order to formulate a decision-based database, capable of supporting the development of a complete oil spill response operation. Moreover, we classify these findings and introduce simple formatting and standards to supply predictive tools for oil spill models. The actual goal of this paper is to come up with a decision-driven process, which can provide for a realistic choice of oil spill response equipment in the design of the primary oil response phase. This is intended to lead to a prompt, logical, and well-prepared oil spill response operation satisfying time and cost criteria and protecting the marine environment.

Keywords: Oil pollution; Operational planning; Oil spill response; Response equipment; Oil spill countermeasures

1. Introduction

Marine pollution, including oil spillage from vessels, has become a major issue in the protection of the aquatic environment over the past decades. After the first world war, there was a gradual increase in the amount of hazardous substances entering the marine environment. The following factors contributed to this situation, Vergetis [1]:

- the population increase in various parts of the world, e.g., third world countries, and the resulting urbanization;
- the increase in industrial activities using petroleum as a primary source of energy;
- the high consumption in the western countries, e.g., Europe and the United States; and
- the increase in marine transportation of oil and other hazardous materials.

Marine pollution can be actually met in various forms depending on the nature of the incoming substances. This means that sea pollution is characterized by a vast spectrum of occurrences and features; such a fact points to complicated needs and circumstances and to different means of confrontation. Thus, marine pollution is categorized into six major types, Vlahos and Alexopoulos [2]:

- organic;
- metal;
- chemical;
- radioactive;
- oil (this paper covers aspects of this type of pollution); and
- mechanical—this is a relatively new type of marine pollution resulting from human-related projects, such as the building of a dam, Ventikos [3].

A comprehensive view of oil pollution leads to a number of interesting observations. It has a variety of possible sources that make it difficult to select the appropriate oil spill response. Hydrocarbon marine input may come from the atmosphere, tanker accidents, natural sources, vessel operations, industrial and urban discharges, or offshore exploration and production. This variety of sources shows the complexity of the specific problem along with the given diversity of oil spill response methods.

The strategic/tactical planning implemented in order to minimize oil spillage can be divided into two major parts, Ventikos [3]:

- preparedness (including prevention) for operational and accident oil pollution; and

---

* Corresponding author. Tel.: +30-210-6527341; fax: +30-210-7721408.

E-mail address: niven@deslab.ntua.gr (N.P. Ventikos).

0304-3894/$ – see front matter © 2003 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhazmat.2003.11.009

- control and recovery of a spill to mitigate its consequences.

Dealing with oil spills is a major task. Terms such as “cleanup” or “countermeasures” do not have their usual and literal sense. In the case of oil pollution, only its visible part can be dealt with. For example, oil can penetrate vertically into a pebble shore to a depth of more than 3 m. The corresponding cleanup operation will be limited to dealing only with the patches of surface oil, ignoring most of the remaining oil. Moreover, cleanup operations should generally be cautious, well planned, and balanced because they can cause more damage than the pollution itself, e.g., by the use of heavy machinery in sensitive spill sites, such as in marshes.

Therefore, it is important to compile and categorize oil response equipment in the spill response plan to protecting the marine environment. This effort is being undertaken and its results can actually map the current situation that applies to all respective operations.

This paper is structured as follows. Section 2 includes findings on oil spills generated from marine vessels. Section 3 briefly describes the major oil spill response methods and gives a corresponding review of oil response equipment. The formulated generic synthesis of common response methods (along with an example) are presented in Section 4. Section 5 gives the compatibility framework for the use and combination of oil spill response equipment and the relevant guidelines for an efficient oil spill response operation in case of an actual spill. Section 6 closes the paper with a discussion on selected points of the invoked tasks.

2. Oil pollution from maritime transport

Oil pollution resulting from numerous maritime transportation sources is considered an important threat to the marine environment. This type of pollution can take the form of massive spills coming mostly from tanker cargoes (collision, grounding, etc.) or frequent small spill occurrences due to various ship operations (bunkering, loading/unloading, etc.). Examples of oil spill accidents accompanied by large-scale oil spill cleanup operations are the grounding of the *Torrey Canyon* (1967), the grounding of the *Amoco Cadiz* (1978), the explosion of the *Irenes Serenade* (1980), the grounding of the *Exxon Valdez* (1989) and the grounding of the *Sea Empress* (1996).

In the last two to three decades, the introduction of a new regulatory regime and the sub-consequent development of new technologies have certainly ameliorated the number of ship-generated incidents. Table 1 depicts the quantitative improvement in the number of oil pollution “sources” from 1981 to 1989 worldwide, Vlahos and Alexopoulos [2], Ventikos et al. [4].

Table 1 shows the quantitative reduction in oil pollution resulting from vessel operations and accidents. More specifically, it seems that there is an aggregate cutback of about 250% that shows that maritime community’s intervention is effective. This is especially true in case of tankers, where the enforcement of strict regulations (MARPOL) and the implementation of upgraded cargo specific equipment (COW, inert gas system, etc.) has led to an impressive reduction in hydrocarbon marine pollution. It must be noted that most of MARPOL’s current clauses for operational oil pollution spills were not in force in 1981.

Table 1
Oil marine pollution from maritime transport procedures (1981 and 1989)

	Year 1989 (t)	Year 1989 Total (t)	Year 1981 (t)
Tanker operations			
Ballasting/deballasting			
Crude tankers	65,900	158,600	700,000
Product carriers	92,700		
Dry-dock		4,000	30,000
Terminals		30,000	20,000
Bilge and bunkers			
M.E. bilge	64,400	252,600	300,000
Fuel residuals	186,800		
Tank fuel ballast	1,400		
Naval accidents			
Tanker accidents	114,000	121,000	420,000
Non-tanker accidents	7,000		
Scrap		2,600	–
Total		568,800	1,470,000

Responding to oil spills is a complex and often costly task; in particular its cost can be proven as a significant player in regard to the feasibility and conclusion of an oil spill response operation. Oil spills usually have a substantial economical burden on liable companies and local authorities, a fact that points out the need for pro-active strategies on issues of oil pollution.

Table 2 presents some interesting fiscal and operational data for the *Exxon Valdez* spill, Vlahos and Alexopoulos [2]. As can be seen, the *Exxon* suffered lawsuits that reached the astronomical amount of $ 145,000,000,000; they had to mobilize 12,000 people, 1400 vessels and 85 aircraft and managed to clean up about 25% of the initial amount of

Table 2
Fiscal and operational analysis of the *Exxon Valdez* spill (1989)

Exxon Valdez (Alaska, 1989)	
Amount of spilled oil (gal)	10,836,000
Polluted shore-length (miles)	1,090
Exxon operational shore-length (miles)	1,087
Cleanup cost ($)	1,280,000,000
Cleanup human resources	12,000
Cleanup vessels	1,400
Cleanup airplanes	85
Amount of oil recovered (gal)	2,604,000
Cleanup debris (t)	24,000
Lawsuits against *Exxon* ($)	145,000,000,000

spilled oil. Thus it is only logical to support, even in the interest of all stockholders, the prevention of oil spills or to act rapidly towards its mitigation, rather than to have to pay enormous amounts in lawsuits.

3. Oil spill countermeasures: critical review of marine oil response equipment

Contingency planning is a crucial feature of oil spill abatement. The type and quantity of oil spill response equipment are important features of the cleanup operation. The outcome of the respective effort depends highly on the type of equipment used a fact that accentuates the need for fast and sound in situ deployment. When an oil spill occurs, the very first environmentally-friendly action is to stop pollution at its source. Subsequent actions can be containment, recovery and disposal of the oil. Cleanup processes can be divided into marine and shore operations, Tsocalis et al. [5]. Oil spills have the potential to cause serious problems for marine and coastal activities, e.g., for those who depend on the sea resources, or on the fauna and flora of a local reef, etc. Oil spills must therefore always be efficiently dealt with using a variety of oil response methods and equipment.

3.1. Conventional cleanup methods

These are the most commonly implemented techniques (e.g., during the primary response phase) and consist of three dominant groups, according to the type of response equipment used.

3.1.1. Mechanical cleanup methods

These methods include containment and recovery of oil that remains on the sea surface. There are numerous characteristics concerning this cleanup equipment. These include high capital investment, the direct need for logistics support, the consequent need for disposal, its effectiveness depending on weather and sea state conditions, and on the type of spilled oil and the encounter rate that can give an estimation of the response capability, etc.

The following are the actual methods used in the mechanical cleanup approach, Vergetis [1]:

- Barriers/booms: Booms are mechanical barriers capable of controlling the motion and spreading of floating substances, e.g., oil. Containment booms can be divided into four categories:
    - ○ curtain booms: often used in offshore situations with a good wave response;
    - ○ fence booms: used in high-current areas with no or limited wave profile;
    - ○ shore sealing booms: used as a barrier in inter-tidal zones; and
    - ○ fire-resistant booms: used in conjunction with in situ burning techniques.
- Skimmers: These are mechanical specialized devices to recover oil (including oil–water mixtures) from the sea surface, without changing either the physical or the chemical properties of the oil, ITOPF [6]. Almost all existing skimmers use one of the following oil recovery methods:
    - ○ Recovery by suction: This category includes vacuum skimmers, weir skimmers, vortex skimmers, and the dynamic inclined plane with belt known as DIP.
    - ○ Recovery by adhesion (*surface skimmers*): This category includes drum skimmers, belt skimmers, disc skimmers, rope mop skimmers, and brush skimmers.
- Heavy oil skimmers, Hvidback [7]: These use the same methods to deal with oil from the sea as ordinary skimmers, but they are specifically designed to remove high viscosity oil and emulsified oil–water mixtures.
- Skimmer vessels: These are vessels designed to remove oil from the sea surface. Most of them have one or more of the aforementioned skimming devices embodied in their hull. Skimmer vessels can operate well in open sea and some designs also function adequately in rough seas.
- Sorbent materials, Tsocalis et al. [5]: These materials are manufactured to recover oil from water using either absorption or surface adhesion. They are frequently used close to shores and ports in dealing with small oil spills. This type of cleanup method includes:
    - ○ natural organic sorbent materials;
    - ○ mineral or natural inorganic sorbent materials;
    - ○ synthetic sorbent materials.

3.1.2. Chemical methods

A variety of chemical approaches are used to treat oil spills or to act complementary to mechanical oil recovery. The main feature in their capability is to change the physical and chemical properties of oil. Chemical treatment includes the following methods, Vergetis [1]:

- Dispersants: These are surfactant mixtures, which reduce the interfacial tension between oil and water; thus oil breaks into fine droplets and is distributed in the water column. It must be noted that the usage of dispersants is a “sensitive” subject due to the ecological damage it may cause, e.g., in Greece they are considered as the final option in an oil spill response operation. Generally, they are applicable in cases of large oil spills. There are three main types of dispersants in use:
    - ○ conventional dispersants;
    - ○ concentrated undiluted dispersants;
    - ○ concentrated diluted dispersants.
- Other chemicals: These chemical combinations may include the following agents/additives:
    - ○ emulsion breakers (implemented to break water–oil mixtures);
    - ○ gelling agents;

- ○ bioremediation chemicals (they accomplish the acceleration of oil's biological degradation);
- ○ burning agents;
- ○ neutralizing agents;
- ○ sinking agents;
- ○ other (e.g., herders, viscoelastic additives, etc.).

3.1.3. Natural degradation
Ventikos [8]: This is equivalent to the do-nothing approach; in this case no action is taken apart from monitoring the movement of the spill.

3.2. Alternative/advanced cleanup methods

Additionally, there are methods that are considered as backup options for use in special circumstances, or they are still experimental.

3.2.1. Bioremediation
Tsocalis et al. [5]: This is an environmentally-friendly method which in some cases involves the addition of various special additives to accelerate the natural course of biodegradation.

3.2.2. In situ burning
Bellantoni et al. [9]: This method involves the application of a controlled ignition of spilled oil. It is suitable for massive spills and for Arctic water pollution.

3.2.3. Advanced cleanup methods
This group of techniques refers to numerous efforts that are able to deal with (at least on experimental basis) oil spills through advanced technology. All conventional methods for oil pollution confrontation are characterized by certain problems, e.g., low performance in adverse weather conditions, limited efficiency in oil recovery, etc. These advanced methods focus on these disadvantages using improved know-how in the context of an oil spill response operation. One of these methods is *cleanmag*, a new oil-absorbing "magnetic" material that presents very high cleanup capability. It has magnetic properties that prevent spills from spreading, Nicolaides [10].

4. Commonly-used oil response equipment

Oil spill response is primarily based on the so-called conventional cleanup methods. The use of the appropriate equipment is limited by the following three basic parameters:

- wave height;
- current velocity;
- viscosity of spilled oil.

The key objective of this effort was to gather all appropriate information about oil spill equipment in order to determine the limitations regarding their use. In this way, a guideline is formulated including acceptable sea state, current velocity, type and weathering phase of spilled oil, etc. The results of this are shown in Tables 3–8 that refer to booms, skimmers, heavy oil skimmers, skimmer vessels, sorbent materials, and dispersants, respectively, Vergetis [1]. Using these tables one can easily and quickly decide whether a specific piece of equipment can be operated in certain sea conditions and types of spilled oil. One can also judge the effectiveness of the selected package/choice. The main factor is to present a straightforward method that can realistically pinpoint what equipment and methods should be deployed in a given spill situation from an operational point of view. As already mentioned, the only ad hoc data needed is the wave height, the velocity of local currents, and the viscosity of the spilled oil.

Tables 3–8 present the operational limits of selected oil countermeasure techniques. More specifically, information is provided in these tables on numerous relevant and necessary features in the outline of an oil spill response operation, such as equipment efficiency, performance, nominal operational standards, etc.

For example, in Table 4, the mechanical-vacuum skimmer can be used in a sea state up to 2 (which is translated in wave height from 0 to 0.4 m and wind velocity up to

Table 3
Detailed operational limit data for barriers/booms (A)

Boom category	Boom type	Sea state				Shear strength (kg/m^2)
		Wind velocity (knots)	Current velocity (knots)	Wave height (m)	Sea state	
Fence (1)	Flexible (a)	20	1.5	1.5	3–4	50–600
	Semi-rigid (b)	20	1.5	1.5	3–4	50–600
	Rigid (c)	15	2.0	1.2	3	50–600
Curtain (2)	Flexible (a)	20	1.5	1.5	3–4	50–600
	Semi-rigid (b)	20	1.5	1.5	3–4	50–600
	Rigid (c)	15	2.0	1.2	3	50–600
Shore sealing (3)		8	0.6	0.4	2	50–600
Fire resistant (4)		20	1.5	1.5	3–4	50–600

Table 4
Detailed operational limit data for skimmers (Bi)

Skimmer category	Skimmer type	Wind velocity (knots)	Current velocity (knots)	Wave height (m)	Sea state
Mechanical (b)	Vacuum (1)	3	0.7	0.4	2
	Weir (2)	6	0.7	0.4	2
	Vortex (3)	6	0.7	0.4	2
	DIP (4)	6	0.7	0.4	2
Oleophilic (c)	Drum (2)	10	1.0	1.2	3
	Disc (3)	10	1.0	1.2	3
	Belt (1)	6	1.0	1.2	2
	Rope mop (4)	10	1.0	1.2	3
	Brush (5)	16	1.0	1.5	3–4
		Oil viscosity (cSt)	Sensitivity to debris	Recover efficiency (% of oil)	Nominal recovery rate (m^3/h)
Mechanical (b)	Vacuum (1)	50,000	High	0–60	5–200
	Weir (2)	30,000	High	0–60	1–50
	Vortex (3)	1,000	Medium	40–60	5–700
	DIP (4)	50,000	Low	40–60	1–300
Oleophilic (c)	Drum (2)	30,000	Medium	50–90	1–60
	Disc (3)	3,300	Medium	50–90	1–400
	Belt (1)	1,000	Medium	50–90	10–400
	Rope mop (4)	20,000	Medium	50–90	1–50
	Brush (5)	20,000–50,000	Medium	50–90	1–120

Table 5
Detailed operational limit data for heavy oil skimmers (Bii)

Skimmer type	Skimmer name	Wind velocity (knots)	Current velocity (knots)	Wave height (m)	Sea state
Rot. drums (1)	LORI	16	1.0	1.5	3–4
Incl. belt (2)	MARCO	6	1.0	0.4	2
Belt (3)	ERE	10	1.0	1.2	3
H.O. belt (4)	AXION HOBS	3	1.0	0.1	1
Incl. belt (5)	Tar Hawg	6	1.0	0.4	2
Rotating net drum (6)	UNISEP	10	1.0	1.2	3
Rot. drum (7)	KLK	6	1.0	0.4	2
Rot. disc (8)	Sea devil	6	1.0	0.4	2
		Oil viscosity (cSt)	Sensitivity to debris	Recover efficiency (% of oil)	Nominal recovery rate (m^3/h)
Rot. drums (1)	LORI	50,000–100,000	Low	50–90	1–80
Incl. belt (2)	MARCO	50,000–300,000	Low	40–60	1–300
Belt (3)	ERE	1,500,000–2,000,000	Medium	50–90	10–300
H.O. belt (4)	AXION HOBS	1,500,000–2,000,000	Low	50–90	10–300
Incl. belt (5)	Tar Hawg	100,000–200,000	Low	40–60	10–300
Rotating net drum (6)	UNISEP	>1,000,000	Medium	50–90	1–60
Rot. drum (7)	KLK	2,000,000	Medium (to High)	50–90	1–60
Rot. disc (8)	Sea devil	1,000,000	Low	50–90	1–60

3 knots). The local current velocity should not exceed the value of 0.7 knots for adequate functioning. The viscosity limit on the oil is 50,000 cSt and the device is vulnerable to floating debris. Its recover efficiency can reach 60% and the nominal recovery rate would be a value of 200 m^3/h. It is also noted that short period waves and swells may reduce the performance of mechanical-vacuum skimmers, Vergetis [1].

5. Compatibility analysis for oil spill response methods: development and guidelines

The above effort is complemented with a thorough compatibility analysis related to an operational framework of all selected oil spill response equipment. This is done in order to objectively determine what response “packages” should be selected under certain sea

Table 6
Detailed operational limit data for skimmer vessels (C)

Skimmer type	Vessel type	Wind velocity (knots)	Wave height (m)	Sea state	Recover velocity (knots)	Tank residue capacity (m^3)
DIP (2)	Valdez star	50	4.6	7	3	208
	Shearwater	50	4.6	7	3	208
	Sea truck	50	4.6	7	3	0
Vacuum system (1)	Oil skimmer	50	1.5	3–4	4	12
	Piranha III	50	1.5	3–4	4	10
	Oil jet	50	1.5	3–4	4	4
Multi-type adapter (3)	Multi-use vessel I	26	4.0	5	3	6
	Multi-use vessel II	26	4.0	5	3	10
	Cosens	26	4.0	5	3	27
Self-propelled barge (4)	Egmopol	3	0.1	1	1.5	100

Skimmer type	Vessel type	Sensitivity to debris	Oil viscosity (cSt)	Recover efficiency (% of oil)	Nominal recovery rate (m^3/h)
DIP (2)	Valdez star	Low	50,000	99	207
	Shearwater	Low	50,000	99	207
	Sea truck	Low	50,000	99	207
Vacuum system (1)	Oil skimmer	Medium	50,000	90	3
	Piranha III	Medium	50,000	90	5
	Oil jet	Medium	50,000	90	1
Multi-type adapter (3)	Multi-use vessel I	Medium	50,000	90	12
	Multi-use vessel II	Medium	50,000	90	15
	Cosens	Medium	50,000	90	50
Self-propelled barge (4)	Egmopol	Low	30,000–1,000,000	90	200

Table 7
Detailed operational data for sorbent materials (D)

Sorbent type	Sorbent material	Wind velocity (knots)	Wave height (m)	Sea state	Oil viscosity (cSt)	Recover capacity (absorption to weight)
Natural organic (1)	Drizit	6	0.4	2	>1500	3–15
	Neococal	6	0.4	2	>1500	
Mineral (1)	Koperl 33	6	0.4	2	>1500	4–20
	Fiberplre	6	0.4	2	>1500	
Synthetic	Pah (1)	6	0.4	2	>1500	70
	Norscpol (1)	6	0.4	2	>1500	
	Boultane (1)	6	0.4	2	>1500	
	Rubber needles (2)	10	1.2	3	>1500	
Towels (3)	Eleophilic	10	1.2	3	250	>15
Pillows (3)	Polypropylene	10	1.2	3	250	>10
Rolls (3)	Eleophilic	10	1.2	3	250	>15
Booms (4)	Eleophilic	16	1.5	3–4	250	>10
Materials (3)	Polypropylene	10	1.2	3	250	>30

conditions, local characteristics, and types of spilled oil.

The outcome of this in-depth analysis constitutes the sub-base of a realistic and promising decision support tool that will be able, depending only on three basic and easily accessible parameters, to produce environmentally-friendly and efficient "packages"; these are possible combinations of oil spill countermeasure. These parameters are sea state, referring mainly to wave height, resultant velocity of local currents, and the viscosity of spilled oil. Tables 9–11 depict the incorporation of data into the implemented methodology, Vergetis [1]. Thus, the actual selection of appropriate oil spill response equipment is done in a structured and reliable way rendering the initial oil countermeasure procedures as a sum of event-oriented and logical steps.

Equipment in Tables 9–11 is coded with a capital letter that indicates the generic anti-pollution method, and with an accompanying letter and/or number representing its specific type (Tables 3–8). For example, code A1a indicates the *flexible fence-type boom*. Furthermore, for sea state 4 in Table 9 shows that skimmer vessels, and more specifically equipment types C1 and C2, along with dispersants E1–E3, are the only suitable ones recommended for usage.

Table 12 is the last output derived from the endorsed task, in the context of effective implementation for oil spill response equipment, Vergetis [1]. It presents the qualified equipment (e.g., booms, skimmers, etc.) as a dynamic

Table 8
Detailed operational data for dispersants (E)

Dispersant type	Oil viscosity and application ratio (dispersant/oil) (cSt)			Oil pour point
	<1000	1000–2000	>2000	
Conventional (1)	1:2–1:3			Above air temperature
Conventional (1)		1:1–1:2		Above air temperature
Conventional				
Undiluted (2)	1:10–1:20			Above air temperature
Undiluted (2)		1:10		Above air temperature
Undiluted				
10% dilution (3)	1:1–1:2			Above air temperature
10% dilution (3)		1:1		Above air temperature
10% dilution				
	Wind velocity (knots)	Wave height (m)	Sea state	Effectiveness
Conventional (1)	7–33	0.5–6	3–6	Appl. rate: 10 m^3/h, conventional (1:2)
Conventional (1)	7–33	0.5–6	3–6	
Conventional	7–33	0.5–6	3–6	
Undiluted (2)	7–33	0.5–6	3–6	Appl. rate: 1 m^3/h, conventional (1:20)
Undiluted (2)	7–33	0.5–6	3–6	
Undiluted	7–33	0.5–6	3–6	
10% dilution (3)	7–33	0.5–6	3–6	Dispersants are more effective when applied undiluted
10% dilution (3)	7–33	0.5–6	3–6	
10% dilution	7–33	0.5–6	3–6	

Table 9
Compatibility framework of oil spill response methods—sea state features

Sea state	Booms	Skimmers	H.O. skimmers	Skimmer vessels	Sorbing materials	Dispersants
0	A	Bi	Bii	C	D	
1	A	Bi	Bii	C	D	
2	A	Bi	Bii	C1, C2, C3	D	
3	A1, A2, A4	Bic2, Bic3, Bic4	Bii1, Bii3, Bii6	C1, C2, C3	D2, D3, D4	E1, E2, E3
3–4	A1a, A1b, A2a, A2b, A4	Bic5	Bii1	C1, C2, C3	D4	E1, E2, E3
4				C2, C3		E1, E2, E3
5				C2, C3		E1, E2, E3
6				C2		E1, E2, E3

Table 10
Compatibility framework of oil response means—current velocity limits

Current velocity (knots)	Booms	Skimmers	H.O. skimmers	Skimmer vessels	Sorbing materials	Dispersants
0.6	A	Bi	Bii	C	D	E1, E2, E3
0.6–0.7	A1, A2, A4	Bi	Bii	C	D	E1, E2, E3
0.7–1.0	A1, A2, A4	Bic	Bii	C	D	E1, E2, E3
1.0–1.5	A1, A2, A4			C	D	E1, E2, E3
1.5–2.0	A1c, A2c			C	D	E1, E2, E3

Table 11
Compatibility framework of oil response means—oil viscosity limits

Oil viscosity (cSt)	Booms	Skimmers	H.O. skimmers	Skimmer vessels	Sorbing materials	Dispersants
<1,000	A	Bib, Bic1, Bic2, Bic3, Bic4		C1, C2, C3	D3, D4 (maximum 250 cSt)	E1, E2, E3
1,000–2,000	A	Bib1, Bib2, Bib3, Bic2, Bic3, Bic4		C1, C2, C3	D1, D2 (minimum 1500 cSt)	E1, E2, E3
2,000–3,300	A	Bib1, Bib2, Bib3, Bic2, Bic3, Bic4		C1, C2, C3	D1, D2	
3,300–20,000	A	Bib1, Bib2, Bib4, Bic2, Bic4		C1, C2, C3	D1, D2	
20,000–30,000	A	Bib1, Bib2, Bib4, Bic2, Bic5		C1, C2, C3	D1, D2	
30,000–50,000	A	Bib1, Bib4, Bic5		C	D1, D2	
>50,000	A		Bii	C4	D1, D2	

Table 12
Qualified (recommended) oil response equipment

	A	Bi	Bii	C	D	E
Sea state results						
Current velocity results						
Oil viscosity results						
Qualified equipment						

combination of the results from the three selected operational parameters: sea state, current velocity, and spilled oil viscosity.

The following are the basic steps implemented in the outline of the given methodology.

- *Step 1*: recording of the local sea state (wave height, wind velocity, etc.), current velocity and spilled oil viscosity.
- *Step 2*: implementation of Tables 9–11 incorporating spill data and operational codes derived from Tables 3–8.
- *Step 3*: integration of Table 12, in order to have a coded list of the qualified (recommended) oil spill response equipment for each spills incident (priority is given to methods that cover all three basic parameters).
- *Step 4*: decision-making procedure concerning the equipment and techniques that are to be deployed to a spill site. This decision should additionally take into account the availability and needed capability of the recommended oil response equipment, the quality of the responsible personnel, the actual volume of spilled oil, and the existence of undesirable circumstances, e.g., floating debris, etc.

6. Discussion

The best possible strategy for oil spill response is without doubt spill prevention. It is much safer to avoid a polluting incident/accident than to deal with all the undesired consequences deriving from it. This is not always possible, however rendering numerous direct oil response methods as the primary option for preserving the aquatic environment. These methods, e.g., mechanical, chemical, alternative, etc., are integrated in order to mitigate oil pollution damage. This equipment is used and specially designed for this purpose (e.g., booms, skimmers, etc.). Experience and historic data prove that protecting shorelines is often the main goal of oil spill response operations. It is easier and less expensive to deal with oil in open sea than once it reaches the shore, Ventikos [3].

The most common oil spill countermeasure is the use of mechanical methods/equipment, as long as the weather conditions are suitable. This method provides an extensive variety of devices with satisfactory performance and user-friendly practices. Nevertheless, the success of the specific option is dependent on deployment time along with the proper selection of equipment. Moreover, the use of certain mechanical means (e.g., heavy trucks, powerful vacuums, etc.) can substantially damage coastal environment and transform a spill countermeasure operation into an inefficient if not harmful process.

Therefore, the incorporation and utilization of adequate and suitable countermeasures requires a selection procedure. As already mentioned, sea state, local current velocity and spilled oil condition (viscosity) are the basic limitations governing the selection, deployment, and usage of oil spill response equipment. Using the data/tables in this paper, the mechanical response can select appropriate combinations of equipment, e.g., skimmers in sea state 3 with spilled oil viscosity from 1000 and 2000 cSt. Therefore, a major part of the initial decisions/actions of a contingency plan can derive from the proposed methodology.

Tables in this paper show that oil response methods/equipment should be used in a structural and uniform framework. Thus, they are required to develop cooperation slots with each other, in order to diminish the required deployment time as well as the costs. In this way, efficient oil response operations can be initiated.

References

[1] E. Vergetis, Oil pollution in Greek seas and spill confrontation means-methods, National Technical University of Athens, Greece, 2002.

[2] G.P. Vlahos, A.V. Alexopoulos, in: G.P. Vlahos (Ed.), Techno-economical Aspects Concerning Maritime Transport and the Protection of Marine Environment, 1st ed., Stamoulis Publications, Piraeus, 1995.

[3] N.P. Ventikos, Development of an evaluation model for the importance, the causes and the consequences of oil marine pollution: the case of maritime transport in the Greek seas and in the Gulf of Saronikos, National Technical University of Athens, Greece, 2002.

[4] N.P. Ventikos, K.P. Dilzas, H.N. Psaraftis, in: I. Theotokas (Ed.), Proceedings of the Second International Conference of Safety of Maritime Transport 2001, Chios, Greece, University of the Aegean, Greece, 2001, CD-Rom.

[5] E.A. Tsocalis, T. Kowenhoven, A. Perakis, Mar. Technol. Sname News 31 (1994) 79–93.

[6] ITOPF, Use of skimmers in combating oil pollution, ITOPF, Technical Information Paper No. 5, London, UK, 1999.

[7] F. Hvidback, in: J.R. Gould (Ed.), Proceedings of the International Conference on Oil Spill 2001, Sheattle, Washington, API, Washington, DC, 2001, pp. 577–584.

[8] N.P. Ventikos, Oil spill control program, National Technical University of Athens, Greece, 1994.

[9] J. Bellantoni, J. Garlitz, R. Kodis, A. O'Brien Jr., A. Passera, Deployment requirements for US coast guard pollution response equipment, vol. 1, US Department of Transportation, Washington, DC, 1979.

[10] G. Nicolaides, in: B. Tselentis (Ed.), Proceedings of the First International Conference on Shipping Technology and Environment 2001, Piraeus, Greece, University of Piraeus, Greece, 2001, CD-Rom.