AIDIC *Conference Series*, Vol. 9, 2009
Editor Sauro Pierucci
DOI: 10.3303/ACOS0909019

ISBN 978-88-95608-10-5 ISSN 2036-5969

APPLICATION OF AHP METHOD IN SELECTION OF BEST AVAILABLE TECHNIQUES FOR OIL SPILL CONTAINMENT AND CLEAN-UP

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An oil spill is the accidental or intentional discharge of petroleum products into the environment due to human activities (drilling, manufacturing, storing, transporting, waste management). Albeit oil spills are actually just a little percent of the total world oil pollution problem, they represent the most visible form of it. The impact on the ecosystem in an area can be severe as well as the impact on economic activities. The cleaning-up of oil spills is a very difficult and expensive activity. This work suggests criteria for BAT (Best Available Techniques) selection weighted by means of AHP (Analytical Hierarchy Process) method.

1. BEST AVAILABLE TECHNIQUES USED FOR OIL SPILLS CONTAINMENT AND CLEAN-UP

This work concerned a research activity about the marine environmental defence and the loss of biodiversity as a consequence of spills in maritime oil transport, in collaboration with the Italian Ministry of Environment. Recently a review has been carried out on Best Available Techniques (BATs) currently used for oil spills response by Guidi et al. (2007). Containment and clean-up techniques must be employed when a marine oil spill occurs in order to limit its spreading on water surface; spreading phenomena depends on many factors such as the quantity of oil, its viscosity and the weather conditions (Bilardo and Mureddu, 2004). It is crucial to contain the spills as quickly as possible in order to minimize danger to human beings, environment and property. The most used containment technique is based upon floating barriers called booms. They are used for concentrating oil in thicker surface layers, making its recovery easier, as well as for keeping oil out of sensitive areas or for diverting oil into collection areas. There are many kind of booms but all of them are greatly affected by conditions at sea: the higher the waves swell, the less effective booms become. Usually booms are less effective with waves higher than one meter or currents faster than one knot per hour. New technologies, such as submergence plane booms and entrainment inhibitors, have been developed with the aim of allowing booms to operate at higher speeds while retaining more oil (U.S. Environmental Protection Agency). Straight after oil spill containment, oil removing operations can start. A number of techniques have been recently promoted as alternative or complementary measures (Guidi et al., 2008). Six types of techniques are currently used to physically recover oil from water surface:

1) booms;
2) skimmers;
3) sorbents;
4) dispersants;
5) in-situ burning;
6) bioremediation.

Skimmers are mechanical devices used to remove floating oil from water surface. They may be employed from shore or operated from vessels. The skimmer's efficiency hinges on weather conditions: in moderately rough or choppy water, skimmers tend to recover more water than oil.

Sorbents are insoluble materials or mixtures of materials used to soak up liquids by means of the mechanism of absorption, adsorption, or both. Absorption allows to pick up and retain liquid throughout the molecular structure of the material (oil can penetrate into pore spaces in the absorbent material) while adsorption involves only the surface of the material (adsorbents attract oil to their surfaces but don't allow it to penetrate into the material). To be useful in fighting oil spills, sorbents need to be both oleophilic and water-repellent. Even though sorbents may be used as the only clean-up technique in small spills, they are most often used to remove final traces of oil, or in areas hardly reached by skimmers.

Dispersing agents, also called dispersants, are a group of chemical products designed to be sprayed onto oil slicks with the aim of accelerating the process of natural dispersion (International Tanker Owners Pollution Federation Limited). They contain surfactants or compounds acting to break oil into small droplets. In an oil spill, these

Please cite this article as: Guidi G., Gugliermetti F. and Violante A.C., (2009), Application of ahp method in selection of best available techniques for oil spill containment and clean-up, AIDIC Conference Series, 09, 159-166 DOI: 10.3303/ACOS0909019

droplets disperse into the water column, where they are subjected to natural processes, such as waves, currents and wind, that help to break them down further. Dispersants are often used when mechanical recovery is not feasible. Their effectiveness hinge on the oil composition and on the method and rate at which the dispersant is applied. Heavy crude oils don't disperse as well as light to medium weight oils. Dispersants are most effective if applied straight after a spill, before the lightest oil components have evaporated.
Factors such as water salinity, temperature and conditions at sea, influence the effectiveness of dispersants. Even if dispersants can work in cold water, they work best in warm water. While some countries lean almost exclusively on dispersants to combat oil spills, because rather frequently rough or choppy conditions at sea make mechanical containment and clean-up difficult, some other countries don't use them even because of concerns about the toxicity of the dispersed mixture. Dispersant used today are definitely much less toxic than those used in the past.
In situ burning of oil entails the ignition and controlled combustion of oil slicks (fig. 1). It can be used when oil is spilled on a water body or on land and is typically used in conjunction with mechanical recovery on open sea. Fire resistant booms are often used to collect and concentrate the oil into a slick that is thick enough to burn. Factors such as water temperature, wind direction and speed, wave amplitude, oil type and slick thickness, influence the decision to use or not in situ burning. For many spills there is only a short window of opportunity during which in situ burning is a feasible option. This technique enables to remove great amounts of oil from water surface, but there are a number of problems limiting the feasibility of this technique such as the generation of huge quantities of black smoke and possible sinking of viscous and dense residues. The major issues for in situ burning is undoubtedly the proximity to human populations. Because the technique involves the release of pollutants into the air, it requires careful air quality monitoring. Even though it can be effective in some situations, in situ burning is not often used on marine spills because of widespread concern over atmospheric emissions and uncertainty about its impacts on human and environmental health. Despite its drawbacks, in situ burning could be an efficient clean-up technique under certain conditions when there are few negative effects on human populations or the environment such as remote areas, water covered with snow or ice. Under these conditions, burning can quickly prevent the movement of oil to other areas and provide a clean-up means for affected areas with restricted access for mechanical or physical removal methods, or provide an additional level of clean-up when other methods become ineffective. When oil is spilled into water containing a layer or chunks of ice, burning can often remove much more oil than other techniques.

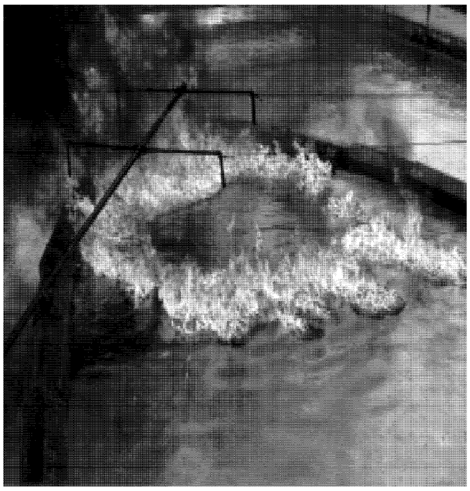

Fig. 1 In situ burning

Oil as well as many natural substances biodegrade over a period of time into simple complex such as carbon dioxide, water and biomass. Bioremediation is the term referred to a series of processes used to accelerate natural biodegradation (U.S. Environmental Protection Agency). Biodegradation of oil is a natural process that slowly removes oil from the environment. Bioremediation technologies can help biodegradation process work faster. Bioremediation refers to the act of adding materials to the environment, such as fertilizers or microorganisms, that will increase the rate at which natural bioremediation occurs. Here the physical, chemical and biological factors affecting bioremediation can be controlled in order to offer optimum conditions for biodegradation. Bioremediation

should not be used on oil on the sea surface because any materials added are likely to be quickly diluted and lost from the slick. Natural biodegradation can be most usefully accelerated when bioremediation is used on land.
Many different problems arise during the clean-up phase. For example, booms are helpful in spill containment in good weather conditions but they are not so effective in rough sea. After the skimmers have completed their work, there is still a small quantity of oil left which needs to be dispersed using for example chemical dispersants. Extra pollution is produced when using dispersants: although they are efficient in breaking up the oil slick, they contribute to the accumulation of oil products on the sea bed, thus contaminating the food chain of marine life (Guidi et al., 2007).
A promising method for oil spill clean-up is based on a magnetic separation technique using the material "CleanMag" (Nicolaides et al., 1998). The material has been developed by Prof. George Nicolaides at the Technology Education Institute of Piraeus in Greece. It is a nanocomposite magnetic material, with oleophillic and porous characteristics and has an apparent density lower than water. It is a non toxic, recyclable and environmental friendly material. Because of its oleophillic properties, oil is right away adsorbed upon contact with the material at a ratio that can go up to 1:9. Depending on the size of the oil spill, the material can be dispersed by pneumatic systems placed on small vessels or it can be sprayed in granular form over the spill by aeroplanes and helicopters. Once the oil has been absorbed, the material forms aggregates, because of its residual permanent magnetisation. This helps slow down the rate of expansion of the surface of the spill and therefore gives more time for the clean-up operation to be carried out before the spill reaches the shoreline. The material and the oil can be collected and recovered by using a magnetic conveyor belt (fig. 2) mounted onto the collecting vessel (fig. 3). Powerful magnets are placed inside the lower drive drum of the conveyor belt, which is submerged half way into the water. The material is attracted to the drum and the viscosity of the oil helps it to stick onto the conveyor belt, made of synthetic rubber. The material moves to the top of the conveyor and, since the upper drum is not magnetic, it falls off the belt into a container due to gravity. The main environmental benefits of this material are:

- full recovery of oil without leaving any residual oil pollution;
- development of an environmental friendly technology, since the material is non-toxic and can be also recycled;
- alternative option to the use of chemical dispersants which are very often toxic.

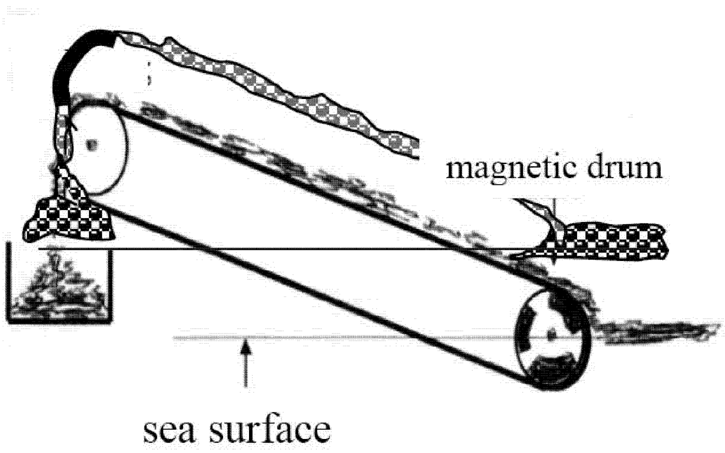

Fig. 2 Schematic view of the conveyor and magnetic drum

Fig. 3 Prototype vessel for the collection of oil spill

Chemical analyses of water samples taken from the area where experimental investigation have been carried out showed that the residual oil pollution, which was left into the sea after using the CleanMag technology, was less than 8 ppb. This is a very outstanding result since there is no other technology available today able to collect oil from the sea at this level. The result is even more noteworthy when compared with MARPOL 73/78 regulated limits (15 ppm). As a matter of fact MARPOL 73/78 states that in order for a boat's functional disposal water to be released into the sea, it has to contain no more than 15 ppm of oil.

2. PROPOSED CRITERIA FOR BAT SELECTION

Many techniques can be used in order to reduce oil spills damages. When a oil spill occurs and lots of techniques are available, it is worthwhile to choose the technique which turns out to be the most suitable in the context situation. Simple and user-friendly criteria will be helpful in making this choice. Guidi et al. (2007) proposed a methodology based on three different kind of criteria, to be applied in sequence, to come to the most satisfactory technique. These criteria have been called:

- main criteria;
- technical criteria;
- impact criteria.

This paper aims at improving the method, based on main, technical and impact criteria, by developing a more structured analysis and, above all, introducing a weight to each impact criteria by means of Analytical Hierarchy Process (AHP). Parameters such as:

- time of intervention (prompt or next);
- typology of the spilled oil (light, medium or heavy);
- conditions at sea (calm, choppy or icy);

are assumed as main criteria in the BAT selecting process. A very important factor when choosing the best available techniques to face an oil spill, is the time of intervention. In situ burning, for example, should be used straight after a spill, before the lighter volatile and inflammable fraction in the oil has evaporated. Other important factor is the typology of spilled oil, that is its physical-chemical characteristics. The main oil typologies are: light, medium and heavy oils. Some techniques, such as those based upon the use of dispersants have small effect on heavy oils, while if a spill occurs in water containing a layer or piece of ice, in situ burning can often take away much oil than conventional techniques. The third factor is represented by the conditions at sea where the spill occurred: calm sea, choppy sea, water covered with snow or ice. For example when spill occurs in water containing a layer or chunks of ice, in situ burning can often remove much more oil than conventional techniques. In rough and choppy sea the use of dispersant is not recommended because the oil will be submerged by breaking waves, preventing direct contact between the dispersant and the oil.

For the main criteria it is possible to sketch out a table showing the relationship between them and both the main containment and clean-up BATs , as reported in Table 1. When a BAT satisfy each criterion, an X is marked in the corresponding box.

Table 1: Main criteria.

		Booms	Skimmers	Sorbents	Dispersants	In-situ burning	Bioremediation	Clean-Mag
Time of intervention	Prompt	X	X	X	X	X	X	X
	Next	X	X	X	X	X	X	X
Typology of spilled oil	Light	X	X	X	X	X	X	X
	Medium	X	X	X	X	X	X	X
	Heavy	X	X	X		X	X	X
Conditions at sea	Calm	X	X	X	X	X		X
	Choppy							X
	Icy	X	X			X		

BATs overcoming this screening phase should fulfill the technical criteria such as:

- actual availability;
- feasibility;
- compatibility with other techniques.

It is essential to verify if the technique is available in the area where oil spill occurred or if it must reach the area from a considerable distance. Another important characteristic to take into account is the technique's feasibility, in term of logistics and other operational aspects. It is important to verify the presence of specialized workers and facilities in support of the technique, essential to the technique's carrying out. Finally should not be neglected the compatibility of the technique under examination with the other ones used in the context of the operations implemented to face out the oil spill.

Finally BATs should meet with the impact criteria, for instance the impact on human health, on environment and the economic one. These criteria consider:

- the proximity of built-up areas;
- the presence of economic activities (such as fishery and tourism);
- the presence of environmental protected areas and submerged archaeological sites;
- the loss of biodiversity;
- the cost of the technique.

Near built-up areas clearly it is not possible to use in situ burning because it produces huge quantities of black smoke, possibly causing danger to human beings, environment and property. In the areas, where the presence of economic activities such as fishery and tourism is very important, it is crucial to use techniques acting quickly, preventing the oil spill to reach the shoreline. A good technique satisfying this parameter is the one based upon the use of magnetic material, capable of absorbing oil rapidly.
In areas with presence of submerged archaeological sites it is not impossible to use aggressive techniques such as dispersants or in situ burning, that could cause irreparable damage to these sites. In areas where loss of biodiversity could occur it is not recommended the use of aggressive techniques, while it is suggested the use of booms and magnetic material. The economic impact of the BAT takes into account not only the material cost of technique, but also the cost for training of response workers.

3. ANALYTICAL HIERARCHY PROCESS METHOD

BATs accomplishing main and technical criteria, should also satisfy impact criteria. These three criteria may be weighted according to AHP (Analytical Hierarchy Process) method, a well-known mathematical technique for prioritizing and ranking alternatives (Saaty, 1980). This method has been developed by Thomas Saaty in the 1970's, at the University of Pittsburgh in Pennsylvania; it is regarded as one of the most successful techniques to solve decision making problems involving multiple criteria (Saaty, 1987). AHP is very useful when teams of people are working on complex problems involving human perceptions and judgments. It has incomparable advantages when important elements of the decision are difficult to quantify or compare or when communication among team members is hindered by their different specializations, terminologies or perspectives. The method has been validated with a large number of examples in applications that have been reported in the literature. In this approach the problem is decomposed into levels of factors or elements. Elements at any level are directly related to, or influence, elements at the level immediately below them. The strength of influence of elements at a particular level over those in the succeeding level is measured by a procedure of paired comparisons. The procedure is repeated by moving downwards along the hierarchy, computing the weights of each element at every level and using these to determine composite weights for succeeding levels. The final set of weights relate to the alternatives under evaluation and give a measure of their overall relative importance.

The AHP method can be conducted in three steps:

- pairwise comparisons;
- assessment of consistency of pairwise judgement;
- calculation of relative weights.

The core of Saaty's method is an ordinal pair-wise comparison of all criteria. In other words, it addresses in particular preference statements and allows to convert the qualitative judgments into numerical values. Per pair of criteria the decision-maker is asked to which degree a criterion is of more importance than the other. By means of these comparisons the method defines the relative position of one criterion in relation to all other criteria.

By using an eigenvalue matrix technique, quantitative weights can be assigned to the criteria. The Saaty method employs a semantic 9-point scale (Table 2) for the assignment of priority values. This scale relates numbers to judgements, which express the possible results of the comparison in qualitative terms. In this way, different elements can be weighted with a homogeneous measurement scale.

Table 2: Semantic scale of Saaty.

Value	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Through this method, the weight assigned to each single criterion reflects the importance which every party/agent/group involved in the project attaches to the objectives. In addition, the method verifies the fit between the components of the weight vector and the original judgements. From the pair-wise comparison a 'comparison matrix' is derived out of which, through the eigenvector approach, it is possible to calculate the weight vector to be used for a subsequent evaluation and investigation. Finally, the method is able to check the consistency of the matrix through the calculation of the eigenvalues. AHP allows inconsistency, but provides a measure of the inconsistency in each set of judgements. The consistency of the judgemental matrix can be determined by a measure called the consistency ratio (CR) defined as:

$$CR = \frac{CI}{RI} \tag{1}$$

where CI is the consistency index and RI the random index. Saaty (1980) provided average consistencies (RI values) of randomly generated matrices (Table 3).

Table 3: Average consistencies of random matrices (RI values).

	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Normally, a consistency ratio of 0.1 or less is considered acceptable. If the value is higher, the judgment may not be reliable and should be elicited again.

4. RESULTS

The evaluation criteria are defined in relation to the concept of BAT's acceptability in the Mediterranean Sea, notably through the identification of three main classes of impacts: human health, environment and economic impact. A scientific group of experts with different fields of specializations was asked to compare pair-wise the relative importance of each impact criterion on the basis of the Saaty scale (Guidi et al., 2009). From the pair-wise comparisons, a judgemental matrix was formed for each expert. This matrix was used for computing the priorities and the consistency index was carried out. The priorities expressed by experts have been combined using the geometric mean. The results are shown in Table 4.

Table 4: Comparison matrix.

	Human Health	Environment	Economic	Geometric mean	Weight	K Eigenvalues
Human Health	1.00	5.73	7.97	3.57	0.76	0.99
Environment	0.17	1.00	2.63	0.77	0.16	1.17
Economic	0.13	0.38	1.00	0.36	0.08	0.89
Total	1.30	7.11	11.60	4.71	1.00	3.05

Each weight value is obtained by dividing the geometric mean of each line by the total sum of the geometric means. K eigenvalues are deduced by multiplying each weight, calculated for human health, environment and economic, by the corresponding total: for example the first K eigenvalue is obtained multiplying 0.76 by 1.30.
Once known the K eigenvalues, it was possible to define the consistency index (CI):

$$CI = \frac{(K_{tot} - n)}{(n-1)} \tag{2}$$

where n is the number of components (Table 5). Then, the consistence ratio (CR) is calculated as the ratio of consistency index and random consistency index (RI). The RI is the random index representing the consistency of a randomly generated pair-wise comparison matrix. It is derived as average random consistency index calculated from a sample of 500 of randomly generated matrices based on the AHP scale. In our case (3 components), RI has the 0.52 value, taking into account three elements.

Table 5: Index values.

N° of components	Consistency index	RI	CR
3	0.02	0.52	0.04

It is interesting to note that the consistence ratio is < 0.1, so the pair-wise comparison matrix should be regarded as consistent enough. The expert group gave the highest weight (0.76) to human health criterion, followed by environment while the less important was judged to be the economic one.

5. CONCLUSIONS AND FURTHER DEVELOPMENTS

The relative weight of impact criteria was assessed by means of Saaty method. Findings from the use of this method highlighted the importance of human health criterion for the expert group. In a further development the AHP method will be applied to technical criteria in order to define their relative weight. The expert group will be asked to compare pair-wise the relative importance of each technical criterion. Consequently this is the first part of a more complex work aiming at providing a helpful, user friendly and quick tool to authorities in charge of facing the response to oil spills.

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