Chapter 6

The Marriage Between Science and Technology

Oil spill response management is quite often impacted by the lack of available real-time and historical data which impacts the ability to make a rapid decision. Rapid decision making and the selection of effective response technologies can significantly minimize the environmental impact and subsequent total costs of oil spill response and clean-up. For use of dispersants and in-situ burning technologies in spill response, decisions needs to be made immediately in order to respond within the first 2–24 hours after a marine oil spill has occurred. Remote sensing data have become an important factor in the decision-making system in order to identify and monitor oil spills and to provide an operational downlink (real time) for night-time operational direction of resources (ships) in clean-up.

6.1. Failures of Present Oil Spill Contingency Planning, Response, Education and Training Strategies

A global review of national arrangements to enhance oil spill capabilities was conducted by the International Tankers Owners' Pollution Federation Fund (ITOPF) and published by the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO). It reported disparity among nations and regions and states that oil spills from marine sources, particularly tanker accidents, continue to pose a risk to coastal nations and island countries (MEPC, 1995). Actions taken by ITOPF since this report have reduced the number of large tanker spills.

Over time, contingency planning and spill response (clean-up) have been better integrated to strengthen response capabilities. Because we are using knowledge and experience learned from each previous spill to respond to the next one, this trial and error works, except when the oil or the environmental conditions are different. The critical elements that are still currently missing in oil spill contingency planning and best response are:

- An understanding of oil properties;
- Changes in these properties (weathering) over time; and

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- The subsequent influence of these properties on technology effectiveness.

Given the consistent number of oil spills today (1.3 spills per 10^9 barrel transported), and the lack of a scientific basis for spill response decision making, the technology window-of-opportunity concept may provide the best tool for oil spill contingency planning and response available. It is a highly targeted system, in which the selection of response technologies will be more efficient, cost effective, technically correct, and environmentally sensitive and appropriate. In addition, the windows concept by being scientifically based may provide decision makers with greater legal protection in the selection of the best response.

6.2. The Need for a Scientifically-Based Decision-Making Tool

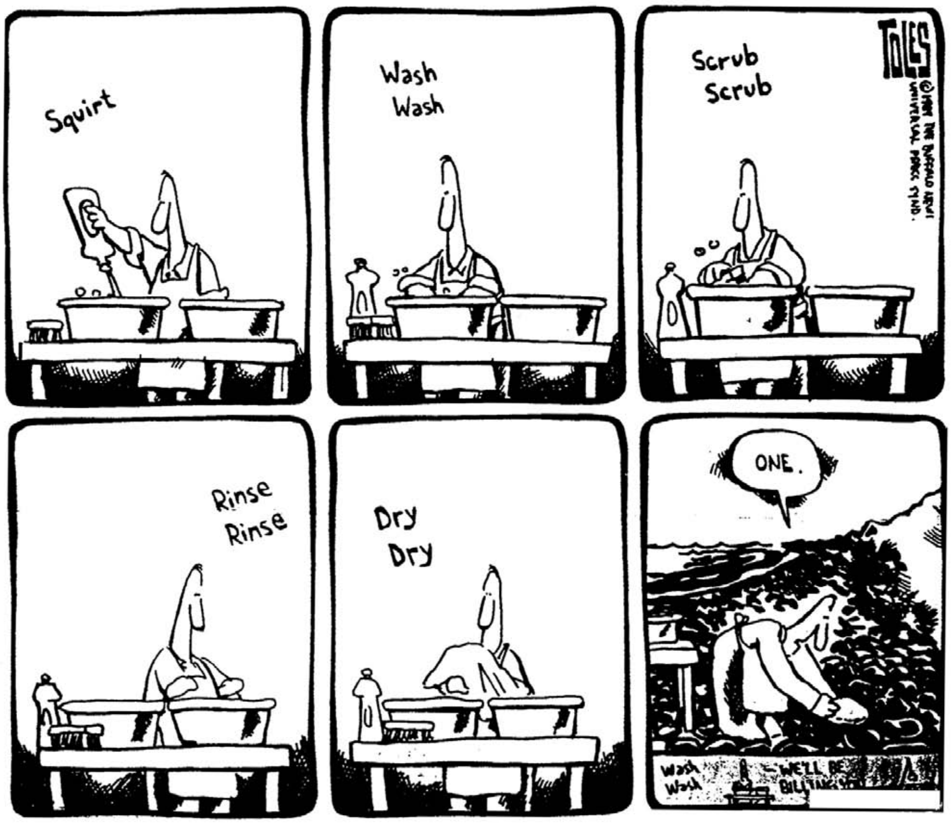
There is a need for a scientifically-based decision-making tool to assist in the decision-making system in oil spill contingency planning and response. The technology windows-of-opportunity concept, by utilizing the combined (projected weathering under specific environmental conditions) determined from dynamic oil weathering model with performance technology data, are a unique planning and decision-making tool in oil spill response because it identifies and defines the windows of effectiveness of different response methods and technologies (equipment) for specific oils under given environmental conditions and weathering of the oil following the spill. In addition, the integration of spill trajectory and environmental assessment with the windows concept provides a significant improvement in oil spill response and clean-up capabilities.

The technology *Windows-of-Opportunity Oil Spill Concept* is an oil spill response decision-making tool with a scientific and engineering basis. It integrates a wide range of real-time and historical data and information to achieve *Best Response*. The purpose of "Windows" is to provide policy and decision makers with recommendations for "how and when" response methods and technologies (i.e., dispersants, bioremediation in-situ burning, and mechanical recovery technologies) should be used in marine coastal waters.

Response management (local, state, federal agencies, response planners, clean-up organizations (responders), insurance companies, tanker owners, and transporters) using this tool will minimize the economic, environmental and social impacts from oil spills, and conduct clean-up operations in a most cost effective and efficient manner.

As technology evolved from mechanical clean-up (booms and skimmers) to treatment with dispersants, emulsion breakers, adsorbents and in-situ burning, it has become more apparent that physical and chemical properties of weathered oil have on the influence of the success or failure of a given technology, when combined with a wide range of environmental conditions.

In the past decade advanced *in-situ* automated measurement technologies (weather, winds, rain, currents, tides, salinity, remote sensing, etc.) have evolved to be able to collect real-time data and information and to transmit these data directly to the *user*.



By Tom Toles, *Buffalo News*, April 17, 1989.

However, these data have not been integrated into a system for utilization by oil spill response decision makers.

The impact of the *Exxon Valdez* oil spill would have been greatly reduced if decision makers had in place at the time of the spill, a real-time operational oil spill response management or advisory system that would enable them to identify "Best Response" for decision making.

6.3. Best Response

Highly effective oil spill response decision making for Best Response (see also Appendix III) requires the development of a system that integrates data from many different sources:

- Existing spill contingency response plans, (strategies and tactics);
- Multiple spill remote sensing images, from single sensors and processes;

- Environmental databases (distribution of environmental sensitive and recreational areas);
- Historical weather analysis (general planning purposes);
- Weather forecast (for operational planning and response);
- Physical oceanographic conditions (tides, currents, winds);
- Local current, wind and temperature (for input to regional and local spill trajectory predictions);
- Spill trajectory predictions;
- Dynamic oil weathering model (prediction of changes of oil properties);
- Oil weathering rates and physical properties;
- Available and equipment and technologies;
- Shipping traffic lanes (location of response capabilities);
- Timing for delivery of response technologies;
- Windows response method and technology selections;
- Emergency offloading equipment; and
- Temporary storage capabilities.

In the past, the lack of a scientific basis for selecting oil spill response technologies promoted "Reasonable" or "Best Available Response". However, today, the public, policy and decision makers, responders, oil companies and tanker owners desire "Best Response". Best Response (which is *Best Response*) mandates that decision making in oil spill response be:

- Scientifically based;
- Technically and environmentally the correct response;
- Able to integrate in real time a wide array of data and information; and
- Reflective of a process of extensive preplanning and training at all levels.

Oil spill response is an extremely complex and challenging cross-disciplinary experience. In the operational decision-making process, it combines a wide range of issues and activities under emergency response conditions that include: the nature of the material spilled, which undergoes changes in physical and chemical properties (weathering) and biodegradation over time, local environmental conditions, sensitivity of impacted natural resources, and selection and effectiveness of response/clean-up technologies.

Planning and decision making in oil spill response requires an understanding of oil weathering processes and the subsequent changes in an oils characteristics and the effect of these changes on response technologies over time. These changes have an important influence on the usefulness and effectiveness of response methods and technologies. Four major categories of response (clean-up) technologies are available:

- Chemical treatment (dispersants, emulsion breakers);
- In-situ burning;
- Mechanical recovery (booms, skimmers, oil-waster separators, adsorbents; and

- Bioremediation (including chemical).

6.3.1. Technology Windows-of-Opportunity Concept

The delineation of technology windows-of-opportunity is a new approach where science and engineering data and information are integrated to provide a scientific foundation for rapid decision making in oil spill planning and response, to optimize environmental and cost benefits by the selection and use of different oil spill response technologies and methodologies. The concept utilizes the following datasets: (1) dynamic oil weathering data for selected oils; (2) actual (real time) environmental data; and (3) dynamic performance data of oil spill clean-up technologies. (For more details see Chapter 7 of this book.)

Recent studies have found, that the time period available for response within a window-of-opportunity, will vary with environmental conditions, oil type, and the degree and rates of changes in oil properties (Nordvik, 1995). Changes in oil properties as a function of time can be measured by use of a stepwise oil weathering method. This weathering method determines changes in evaporation, density, viscosity, pour point, flash point, and emulsification at different degrees of distillation, (weathering) representing different time intervals of spilled oil. A graphical presentation of these data can be plotted by the IKU Dynamic Oil Weathering Model (Aamo et al., 1993).

The two dominant processes that cause changes in oil characteristics over time are evaporation and emulsification, which significantly increase the viscosity of spilled oil. In this book, viscosity is used as a time reference for estimating the window-of-opportunity for dispersants and mechanical recovery equipment including sorbents. Density is used as time reference for density differential oil water separators and emulsification (water content) is used for booms and in-situ burning.

Evaporation of the more volatile components and the formation of a water-in-oil emulsion during weathering occur simultaneously during and after a spill. The rate and extent to which they proceed depends on the chemical composition of the oil and prevailing environmental conditions (such as wind speed, seawater and air temperature, and sea state). The relationships between these factors and the changes in key properties during weathering have to be well understood as well as the effectiveness of specific response technologies under these conditions, in order to estimate and delineate windows-of-opportunity for specific clean-up methodologies and technologies. Therefore, to achieve maximum environmental and cost benefits in implementing response strategies, response tactics and technologies must be chosen to fit the time periods of the technologies windows-of-opportunity.

Recent studies of oil weathering, and the influence of such weathering on performance and effectiveness of specific response technologies (equipment), provide the necessary data to make it possible to identify time periods of windows-of-opportunity. The delineation of these time periods then facilitates the optimization of different response technologies and strategies.

Methods and technologies in each of these categories are limited by environmental conditions both operationally and as a result of the changes in oil characteristics over time. Effective use of dispersants, in-situ burning and some mechanical technologies is limited in time and governed by changes in oil properties. The most efficient, environmentally preferred, and cost effective spill response is dependent on the following factors:

- Chemistry of the spilled product;
- Quantity;
- Location;
- Response time;
- Environmental conditions; and
- Effectiveness of available or pre-positioned response technologies

6.3.2. Oil Weathering and Technology Performance

To enhance the effectiveness of clean-up operations, decision makers need a rapid and accurate tool for predicting changes in oil properties, and a dynamic database containing data and information on the capabilities, capacities, effectiveness, and limitations of response technologies and methodologies. Dynamic oil weathering models have been developed for use in contingency planning and response decision-making. Their reliability and operational output values have greatly improved over the past several years. This progress is a result of advances in model development, data quality and quantity.

Decision-making in oil spill response requires an understanding of oil weathering processes and subsequent changes in the characteristics of the spilled oil over time. These changes have an important influence on the usefulness and effectiveness of response methods and technologies. Three major categories of response (clean-up) methods are available: (1) mechanical recovery; (2) chemical treatment; and (3) in-situ burning. Methods and technologies in each of these categories are limited by environmental conditions both operationally and as a result of the changes in oil characteristics over time.

Dynamic oil weathering models have been developed to predict changes in oil properties over time and have been used as a decision-making tool in actual spill and spill scenario over the past several years in particular to assess use of dispersants. Integration of a technology database, using changes in specific oil characteristics as a time reference has further improved decision-making capabilities.

In addition to dispersants, effective use of in-situ burning and some mechanical technologies is limited in time and governed by changes in oil properties. The most efficient, environmentally preferred, and cost effective spill response is dependant on the following factors: chemistry of the spilled product, quantity, location, response time, environmental conditions, and effectiveness of available response technologies (given the first five factors). Utilization of multiple response technologies requires a rapid and scientifically-based decision-making tool and an integrated system of response capabilities.

6.3.3. The Dispersant Window-of-Opportunity

The operational limitations of dispersant applications are dependent on application methods, equipment, average droplet sizes of the dispersant, environmental conditions (such as wind speed, sea state, salinity, and temperature), oil thickness and dosage rates, and the distribution of the oil on the sea surface at the point of application. The use of a dispersant is considered to be a rapid response method and has the potential to greatly enhance the degree of natural dispersion. Dispersants also have logistical advantages compared to contained in-situ burning and mechanical clean-up (no waste to process). Effective use of dispersants is for some oils very limited in time.

Four factors are believed to have a major impact on the effectiveness of dispersants: pour point, viscosity of the oil and emulsion, emulsion water content, and emulsion stability. Most crude oils and heavier refined products will form emulsions. Weathering causes an increase in the viscosity of oil, raises its pour point, and increases the water content and the degree of stability of an emulsion. All of these changes tend to make oil less dispersible as the viscosity of the oil or emulsion approaches its limiting value. The value of this limiting viscosity depends on the type of the spilled oil and the prevailing environmental conditions.

For a given oil emulsion, dispersant treatment windows-of-opportunity can be estimated by combining emulsion viscosity data from effectiveness testing data with IKU Oil Weathering Model prediction of emulsion viscosity as a function of time. The data plotted in this figure cover three windows of defined dispersibility as defined from the MNS and IFP test criteria (dispersible, reduced dispersibility, and non-dispersible).

Laboratory effectiveness results for dispersants can not be directly transferred into performance data during spill response. However, laboratory results are of value for guiding the selection of an appropriate dispersant during contingency planning and response. Recent dispersant field-testing has established a relationship between laboratory and field effectiveness data for good, medium and poor dispersants.

6.3.4. The Window-of-Opportunity for In-Situ Burning

The window-of-opportunity for ignition and burning will vary, depending on environmental conditions, physical properties and chemical composition of the spilled oil. The rate of evaporation and emulsification and the subsequent changes in flash point, viscosity, water content, and stability of an emulsion have a major influence on ignition technologies and the usefulness of in-situ burning. In addition, sea temperature, wind speed, thickness of the oil layer, heat transfer from the burn to the surface of the oil or emulsion, and the loss of heat through the oil to the underlying water limit the use of in-situ burning as a response method (Guénette et al., 1994). The removal effectiveness under experimental conditions has been reported from zero percent for emulsified and weathered oils and up to 99% for fresh oils.

The method of calculating in-situ burning effectiveness is based upon a volumetric reduction of oil from a closed system. In comparing data for burning operational effectiveness with a fire resistant boom to mechanical or dispersant operational effectiveness data, one must consider the loss of oil from the towed boom system which under environmental and operational conditions can vary widely, and the release of soot and smoke which can account for 10–15% of the removed mass of oil.

The preliminary and valid arguments for considering in-situ burning as a response measure are that it extends the options for response by providing a useful supplemental tool, while decreasing the dependency on recovered oil and water storage needs. The latter remains a limiting factor for large catastrophic spills, especially for response systems built for vessels of opportunity.

Ignition and combustion are dependent on the flash point and release of ignitable and combustible vapor. It is the vapor released from the oil that burns and not the oil as a liquid. Thus, the mechanism for maintaining a sufficient amount of vapor for continuous burning is vital to in-situ burning. When the flash point temperature of the oil exceeds the sea temperature, the surface of the oil needs to be heated by an external source to promote the release of flammable vapor that can be ignited. Ignition and burning is also restricted by increased water content, heat transfer to the under lying seawater, viscosity and stability of the emulsion. When water-free oil is burning on the top of a layer of emulsion, the temperature within the emulsion can not exceed approximately 100 °C. A limit for ignition may also occur if the flash point of the oil is above the temperature that can be created or maintained on the surface of an emulsion.

For most crude oils, approximately 25% evaporation and or a 50% water content restrict a time window for ignition and sustained burning of weathered oil using conventional ignition technology. The estimated time window-of-opportunity for ignition and in-situ burning of ANS and Bonnie Light crude oils based upon 5 m/s wind speed, water temperature of 15 °C, and the time to reach 50% water content is presented in Table 6.1. Also included is the time it takes for 25% of the oil to evaporate,

Table 6.1

Estimated time windows for ignition based upon predicted 25% evaporation and 50% water content at 15 °C and a wind speed of 5 m/s using data from the IKU Oil Weathering Model.

Oil	25% Evap. (hours)	50% Emulsified (hours)	Evap. at 50% Water (%)	Viscosity at 50% Water (cP)	100 °C Flash point (hours)
ANS	72	36	22	1500	160
Bonnie Lt.	12	1	10	200	70

percentage of oil evaporated when the water content is 50% plus corresponding viscosity, and time estimate to raise the flash point to 100 °C. After this time it will be almost impossible to ignite an emulsified oil slick with conventional ignition technologies. A case example for in-situ burning of ANS is presented in Appendix V.

6.3.5. Integrating Data and Information for Spill Response Management

Utilization of multiple response technologies requires a rapid and scientifically-based decision-making tool and an integrated system of response capabilities. Rapid oil spill response decisions are of vital importance to mitigate and reduce environmental damage. Remote sensing data have become an important factor in the decision-making process in order to determine the extent of the spill (satellite images) and level of response needed and for operational direction of resources (aircraft images) in clean-up. For dispersant and in-situ burning, decisions needs to be made immediately in order to respond within the first 2–24 hours after a marine oil spill has occurred.

Highly effective spill response requires the integration of data from many different sources:

- Environmental databases (distribution of environmental sensitive and recreational areas);
- Historical weather analysis (general planning purposes);
- Weather forecast (for operational planning and response);
- Physical oceanographic conditions (tides, currents, winds);
- Local current, wind and temperature (for input to regional and local spill trajectory predictions);
- Spill trajectory predictions;
- Dynamic oil weathering model (prediction of changes of oil properties); and
- Oil weathering rates and physical properties.

Oil spill response management in the past decade has evolved advanced remote and mobile systems to collect data and information and to transmit them directly from the spill to response policy and decision makers. These new scientifically based tools, can integrate several data sources, to bring together the impact of weather, sea state, wind, current and water temperature, the physical and chemical properties and characteristics and trajectory of the spill oil for identification of the time periods that specific response methods and technologies are most effective.

Oil spill response decisions (or lack of) made immediately (and in the first 4–48 hours) after a marine oil spill has occurred can be the single largest factor that will influence the total cost of oil spill response and the degree of environmental impact.

Major oil spill incidents over the past decade have led to development of more specific and stringent requirements and regulations in many countries around the world, followed by establishment of response organizations using clean-up methods, ruled by governmental policies and environmental concerns. Response methods are therefore quite varied among the countries around the world, even for the same spill of oil. The ability of a spill responder to use the best science and the most effective response methods in dealing with oil spills has been quite limited.

Ideal marine oil spill response strategy and tactics should focus on the use of the most rapid, efficient and cost-effective response methods and technologies. Use of the most effective response method and technologies require access to reliable, national and international accepted data, based upon a scientific and engineering approach. The windows-of-opportunity concept, with the combined information from dynamic oil weathering model and performance technology databases can become a decision-making tool identifying and defining the window of effectiveness of different response technologies (methods and equipment) under given environmental conditions.

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