Presented at: Arctic and Marine Oilspill Program Technical Seminar (June 2000)

Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors

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Abstract:

Contingency planners, response officials, government agencies, and oil transporters share a keen interest in being able to anticipate oil spill response costs for planning purposes. Oil spill cleanup response costs depend on a variety of factors, most notably, location, oil type, spill size, and cleanup strategy, making it difficult to develop a universal per-unit cost factor.

This study analyzes marine oil spill cleanup costs on the basis of country, proximity to shoreline, spill size, oil type, degree of shoreline oiling, and cleanup methodology to determine how each of these factors impacts per-unit cleanup costs.

The results show that oil spill responses in different countries and regions of the world vary considerably in their costs most likely due to differences in cultural values, socio-economic factors, and labor costs. Location, oil type, and spill size also factor heavily in determining cleanup costs. Nearshore spills and in-port spills are 4-5 times as expensive to clean up as offshore spills. Responses to spills of heavy fuels are more than ten times as expensive as spill responses for lighter crudes and diesel fuels. Spill responses for spills under 30 tonnes are more than ten times as expensive, on a per-unit basis, as for spills of 300 tonnes.

The paper describes a cleanup cost estimation modeling technique that can be applied to marine spills of different types. The model is developed from updated cost data collected from case studies of over 300 spills in 40 nations. The model takes into account oil type, location, spill size, cleanup methodology and shoreline oiling to deduce a per-unit cleanup cost figure.

1.0 Introduction

The entire cast of players involved in oil transport – e.g., tanker owners, pipeline operators, insurers, spill contingency planners, spill responders, and government officials – would all benefit from "foresight" when it comes to oil spill cleanup costs. Many would like to be able to predict at the onset of a spill response or even in advance of spill incidents the amount of funds (on a per-unit-spilled basis) that might be required to remove the oil. Insurers and oil transporters would certainly like to develop a universal per-unit cleanup cost factor. While some officials have attempted to do this, the results have been unsatisfactory because such a universal cleanup cost factor does not take into account the many complexities of spill response and the fact that no two spills are ever alike. There are a host of factors that influence cleanup costs (Etkin, 1998b; 1998c; 1999b) and each of these factors is interrelated to some extent.

One approach to predicting oil spill cleanup costs in current or future spills is to rely on "hindsight," i.e., examine historical spill cost data to analyze the costs in past spills based on important factors which drive the costs, e.g., oil type, proximity to shoreline, location, cleanup methodology, and spill size. This analysis can then be used to develop an algorithm to estimate costs for hypothetical or actual marine spills based on these factors.

The analyses and data shown under each of the factor categories are based solely on that particular factor though the factors are interrelated. For example, spill costs are analyzed by oil type without regard to the cleanup methodology used, though clearly oil type influences response strategy and logistics, which are, in turn, dictated in large part by location. The final model pulls together the various factors to create a single method to predict costs.

While the spills occurred over the last two decades, all costs were normalized to 1999 US dollars by applying US Consumer Price Index change percentages. This corrects for any differences in monetary values due to inflation. (Currency conversions were done for the costs at the time of the incident.)

2.0 Cost Impact of Oil Type

The type of oil spilled significantly impacts cleanup costs. In conjunction with the amount of oil spilled and wind and current conditions, oil type determines the direct environmental impacts of the spill incident. The difference between a No. 2 diesel fuel oil spill and a heavy crude spill in terms of impact and the cleanup scenario are significant. While toxicity factors heavily in a gasoline or lighter refined fuel spill due to the higher proportion of lighter-end hydrocarbon components, persistence of the heavier oils and crudes presents the greatest challenge to cleanup crews. The cost increases in direct relation to the proportion of persistent oil fractions. Moller, et al. (1987) found that cleanup costs for lighter crudes and refined oils tended to be below the average spill cleanup cost.

An analysis of cleanup costs of US and non-US spills by oil type is shown in Table 1.

Table 1. Per Unit Oil Spill Cleanup Cost By Oil Type (1999 US$)

Oil Type	US Spills	Non-US Spills	All Spills
No. 2 diesel fuel	$3,607.38/tonne $3.24/liter	$1,699.32/tonne $1.53/liter	$2,307.90/tonne $2.07/liter
Light crude	$3,131.08/tonne $2.86/liter	$4,554.06/tonne $4.09/liter	$4,265.94/tonne $3.83/liter
No. 4 fuel	--	$23,893.38/tonne $21.47/liter	$23,893.38/tonne $21.47/liter
No. 5 fuel	$8,693.58/tonne $7.81/liter	$24,272.64/tonne $21.81/liter	$23,190.72/tonne $20.84/liter
Crude	$14,520.66/tonne $13.05/liter	$3,963.12/tonne $3.56/liter	$7,250.04/tonne $6.52/liter
Heavy crude	$21,091.56/tonne $18.95/liter	$6,447.42/tonne $5.79/liter	$8,540.70/tonne $7.68/liter
No. 6 fuel	$18,066.30/tonne $16.24/liter	$16,275.84/tonne $14.63/liter	$16,952.04/tonne $15.33/liter

No. 2 diesel fuel and light crude oil spills are significantly less expensive to cleanup up than spills of heavy crude or heavier fuel oil, which are more persistent. Mechanical containment and recovery are used to some extent, when possible to remove some of the oil, but these efforts often net little gain since the products begin to evaporate and dissolve very quickly after hitting the water surface.

Gasoline spills are not represented here because they often require little or no cleanup, since by the time responders can get to the spill scene most of the product has evaporated or dissolved. The response usually deals solely with mitigating the toxic and flammable hazards of this type of incident rather than an actual product removal.

Spills of more persistent products require more sophisticated cleanup strategies, which can include dispersant application when appropriate and when permitted by local statutes, or mechanical and manual recovery. Depending on the location and degree of shoreline impact, spills of persistent oils generally require the most expensive spill response operations. Responses to spills of persistent oils that are near shorelines can result in prolonged and laborious shoreline cleanup responses if offshore dispersant or mechanical containment and recovery operations are ineffective or incomplete.

3.0 Shoreline Oiling Factors

In nearly any oil spill, the most expensive component of the oil spill cleanup response is the shoreline cleanup. This is generally the most labor-intensive and time-consuming part of the operation. Cleanup response strategists, by and large, will do whatever is possible through dispersant application, when appropriate and permitted by local regulations, and/or offshore mechanical containment and recovery operations to minimize shoreline oiling to reduce the impacts on the coastline.

With a greater awareness of the potential ecological impacts of aggressive shoreline cleaning tactics such as hot-water washing and use of heavy machinery, response officials are moving towards gentler manual approaches, or in more and more cases, towards "natural cleansing" options in shoreline locations that have exposure to intensive wave action.

Shoreline cleanup operations that rely primarily on manual techniques are relatively expensive compared to the much lower costs of natural cleaning methods, which often require only careful monitoring. While the "do-nothing" approach is certainly attractive from a cost perspective and often from an ecological perspective as well, especially on exposed shorelines, response officials and responsible party decision makers need to heed local and federal regulations, as well as respond to the values and needs of local communities and stakeholders before choosing this option. The "How clean is clean?" concept is most applicable to shoreline cleanup operations. Often, local interests press for aggressive cleanup responses on oiled shorelines despite evidence that such operations can cause greater long-term environmental damages. The public often demands that the beach "look clean," which influences decision makers.

An analysis of cleanup costs as they relate to shoreline oiling is shown in Table 2 and Figure 1. The costs shown in Table 2 represent *the average costs for the entire cleanup operation* (offshore, nearshore, and shoreline response), not just the shoreline cleanup operations. This would explain why cleanup operations in which there is virtually no shoreline cleanup would still have costs (associated with offshore recovery, monitoring, and logistics.)

Cleanup costs for spills with an average of 1,000 km of oiled shoreline were not analyzed due to the small sample size involved. These incidents are rare and generally represent highly complex situations. For example, the total cleanup costs associated with the 1989 Exxon Valdez spill which oiled over 1,200 km of shoreline in Prince William Sound, Alaska, USA, resulted in cleanup costs of over $93,568.74/tonne ($84.08/liter). This spill had extremely high unit costs associated with it due to the complexity of the cleanup operations, which were greatly influenced by the highly political nature of the entire incident.

Table 2. Per-Unit Cleanup Costs By Degree of Shoreline Oiling (1999 US $)

Shoreline Length Oiled	**US Spills**	**Non-US Spills**	**All Spills**
0-1 km	$2,644.11/tonne $2.37/liter	$5,530.66/tonne $4.97/liter	$5,086.00/tonne $4.57/liter
2-5 km	$5,991.33/tonne $5.38/liter	$6,150.37/tonne $5.53/liter	$5,793.00/tonne $5.21/liter
8-15 km	$10,540.42/tonne $9.47/liter	$6,304.60/tonne $5.67/liter	$5,876.00/tonne $5.28/liter
20-90 km	$15,164.62/tonne $13.63/liter	$6,863.19/tonne $6.17/liter	$6,612.00/tonne $5.94/liter
100 km	$27,303.53/tonne $24.54/liter	$9,061.36/tonne $8.14/liter	$11,398.00/tonne $10.24/liter
500 km	$51,962.94/tonne $46.70/liter	$10,404.21/tonne $9.35/liter	$16,443.00/tonne $14.78/liter

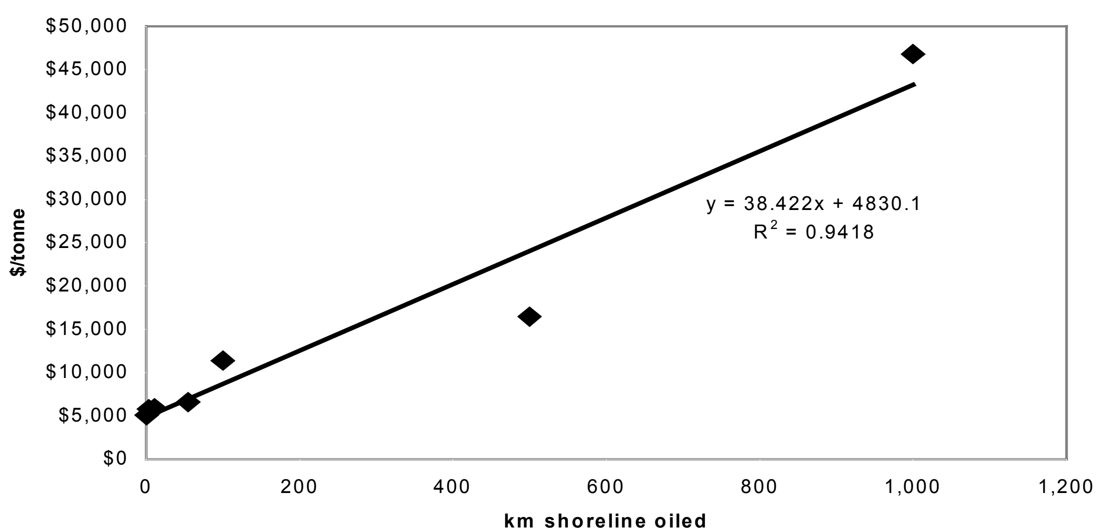

Figure 1. Per-Tonne Cleanup Costs vs. Shoreline Oiling (1999 US $)

An analysis of shoreline cleanup vs. offshore cleanup costs as presented by Peck, et al (1996) showed that for five US spills, offshore cleanup costs per gallon recovered were 26-55% of costs associated with recovering oil on shoreline.

4.0 Cost By Location Type

The degree of shoreline oiling is related to oil type (i.e., non-persistent oils evaporate before impacting the shoreline), wind and current conditions that might drive the oil away from or towards the coast, and the actual location of the spill in terms of proximity to the shoreline.

Oil spill incidents were grouped according to their proximity to shore into "offshore", "nearshore (within 5 km of shoreline)", and "in-port" locations. The associated cleanup costs are shown in Table 3.

Table 3. Per-Unit Marine Oil Spill Cleanup Costs By Location Type (1999 US $)

Location	US Spills	Non-US Spills	All Spills
In-Port	$34,089.30/tonne $30.63/liter	$12,983.04/tonne $11.67/liter	$19,674.25/tonne $17.68/liter
Nearshore	$25,066.44/tonne $22.53/liter	$17,931.06/tonne $16.11/liter	$22,442.69/tonne $20.17/liter
Offshore	$6,873.72/tonne $6.18/liter	$8,570.10/tonne $7.70/liter	$8,292.94/tonne $7.36/liter

Oil spills that occur in nearshore locations or in ports are significantly more expensive to clean up than offshore spills (Etkin, 1998d). This is due to the higher probability for shoreline impact, particularly for persistent oils.

5.0 Spill Size Cost Correlation

An analysis of 96 oil spills (Etkin, 1999b) showed that cleanup cost/tonne was significantly negatively correlated with spill size. This correlation was also shown by Monnier (1994). Monnier found that spills of under 10 tonnes had average per-unit cleanup costs of $345,000/tonne, whereas spills of over 50 tons had costs of $12,000/tonne.

Smaller spills are more expensive to clean up than larger spills on a per-unit basis because of the costs associated with setting up the cleanup response, mobilizing the equipment and personnel, as well as bringing in the experts to evaluate the spill response and damages.

In the current study, spill responses for spills under 30 tonnes were found to be more than ten times as expensive, on a per-unit basis, as for spills of 300 tonnes (see Tables 4 and 5; Figures 2-3).

Table 4. Per-Unit Marine Oil Spill Cleanup Cost By Spill Size for Non-US Spills (1999 US $)

Spill Size	US $/tonne	US $/liter
0.34-3.4 tonnes 379-3,785 liters	$77,896.33/tonne	$70.00/liter
3.4-17 tonnes 3,785-18,925 liters	$31,035.34/tonne	$27.89/liter
17-34 tonnes 18,925-37,850 liters	$10,687.65/tonne	$9.60/liter
34-340 tonnes 37,850-378,500 liters	$9,757.86/tonne	$8.77/liter
340-1,700 tonnes 378,500-1,892,500 liters	$6,390.95/tonne	$5.74/liter
1,700-3,400 tonnes 1,892,500-3,785,000 liters	$3,686.74/tonne	$3.31/liter
3,400-34,000 tonnes 3,785,000-37,850,000 liters	$2,367.69/tonne	$2.13/liter
>34,000 tonnes >37,850,000 liters	$357.56/tonne	$0.32/liter

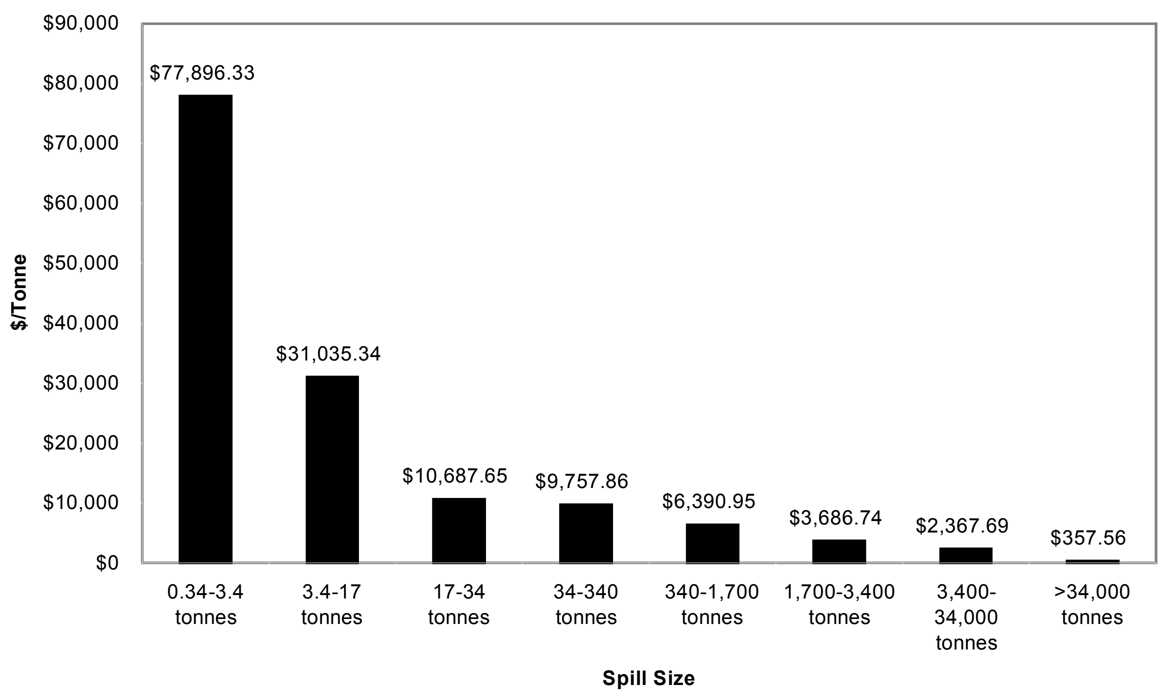

Figure 2. Per-Unit Marine Oil Spill Cleanup Costs for Non-US Spills (1999 US $)

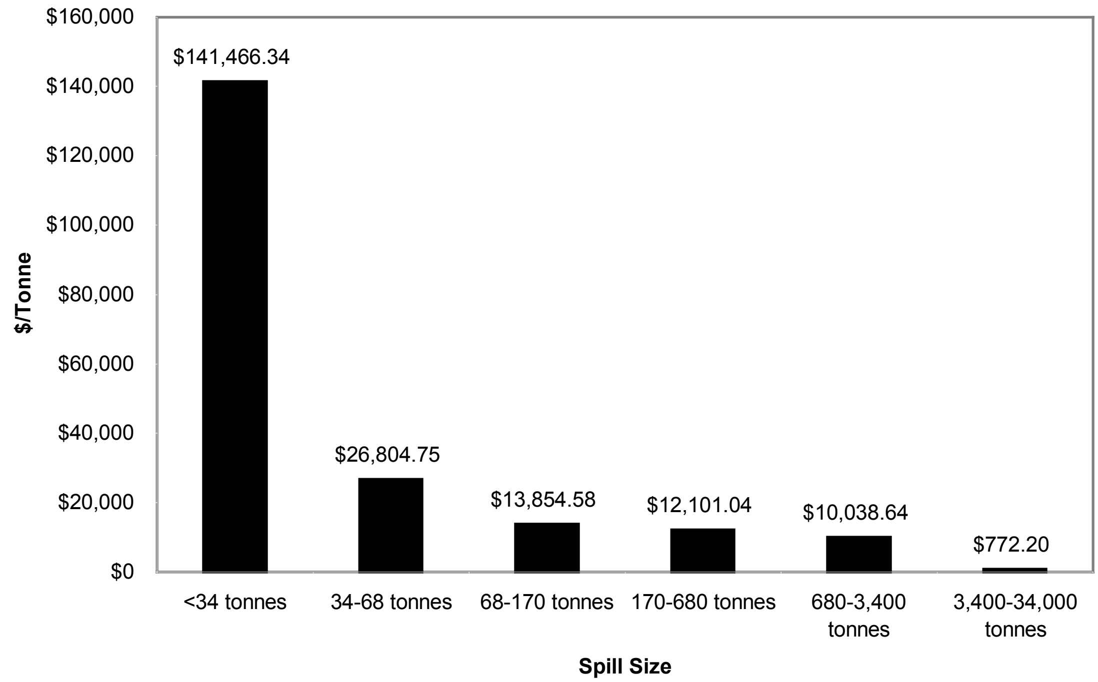

Figure 3. Per-Unit Marine Oil Spill Cleanup Costs for US Spills (1999 US $)

Table 5. Per-Unit Marine Oil Spill Cleanup Cost By Spill Size for US Spills (1999 US $)

Spill Size	**US $/tonne**	**US $/liter**
<34 tonnes <37,850 liters	$141,466.34/tonne	$127.13/liter
34-68 tonnes 37,850-75,700 liters	$26,804.75/tonne	$24.09/liter
68-170 tonnes 75,700-189,250 liters	$13,854.58/tonne	$12.45/liter
170-680 tonnes 189,250-757,000 liters	$12,101.04/tonne	$10.87/liter
680-3,400 tonnes 757,000-3,875,000 liters	$10,038.64/tonne	$9.02/liter
3,400-34,000 tonnes 3,785,000-37,850,000 liters	$772.20/tonne	$0.69/liter

The amount of oil spilled clearly influences the logistics of a spill operation as well as its ultimate impact. Often the first questions that spill responders and officials ask is “How much oil spilled?” But, again, location and oil type are key factors that work in tandem with spill size in determining actual impact and the requirements of a spill response operation.

It would follow that the larger a spill, the more expensive the response. This is generally true, but when analyzed on a per-unit basis, spill size also has an impact on costs. By and large, response operations for smaller spills are more expensive on a per-unit basis than larger spills. This is generally due to logistical considerations.

A small spill of a tonne or less often requires the same amount of monitoring and personnel as a spill of ten times that amount. Mobilization of personnel and equipment, which are often mandated by local or federal contingency planning and response requirements, can result in astronomical costs. Labor crews and rented equipment, whether they are actually used or just standing-by on the shoreline cost the same amount of money. There are, of course, anecdotal cases in which large amounts of equipment are mobilized for what turns out to be a non-event. While the threat of a spill, maybe even a major spill, exists, the incident never results in any spillage. The crews need to be paid and the equipment rentals need to be covered.

But beyond these "non-incidents," smaller spills that require a response are more expensive. Coast guard or other official monitoring is often required along with the aforementioned labor and equipment. The cost of spill supervisors can factor heavily in the relative costs of smaller incidents.

6.0 Cost Implications of Cleanup Strategy

Cleanup strategy also plays a very large role in determining cleanup costs. The use of dispersants in particular has been shown to significantly reduce the overall cleanup costs (Etkin, 1998a; see Table 6). The cost reduction can be attributed to the lower labor costs (fewer personnel for a shorter period of time) and even lower overall equipment costs (even when factoring in planes and dispersant application equipment) that are required with dispersant application compared to mechanical containment and recovery operations. The lower labor costs are even more dramatic when manual cleanup compared to dispersant application.

Table 6. Oil Spill Cleanup Cost Comparison By Technique (1999 US $)

Cleanup Technique	Mean Cost/Tonne	Mean Cost/Liter
Dispersants only	$2,184.40/tonne	$1.96/liter
Dispersants Primary method	$2,556.98/tonne	$2.30/liter
Dispersant Secondary/tertiary method	$14,233.17/tonne	$12.79/liter
Other methods only (No dispersants)	$12,802.94/tonne	$11.51/liter
Adapted from Etkin 1998a.		

Lower costs associated with cleanup responses centered on dispersant application are also due to the often dramatic reduction in shoreline impact, which reduces the need for expensive manual shoreline cleanup.

The cost data on the over 200 spill cases in the current study that occurred outside the US were analyzed for costs by primary cleanup methodology as shown in Table 7. US spills were excluded in this analysis since dispersant application has generally not been an option in US spills response until very recently. National and local regulations determine whether or not dispersants are even an option even when the situation makes their use the most cost-effective and ultimately the most environmentally beneficial (Etkin, 1998a).

Table 7. Per-Unit Marine Non-US Oil Spill Cleanup Costs By Primary Cleanup Methodology (1999 US $)

Primary Method	US $/tonne	US $/liter
Manual	$23,403.45/tonne	$21.03/liter
Mechanical	$9,611.97/tonne	$8.64/liter
Dispersants	$5,633.78/tonne	$5.06/liter
In Situ Burning	$3,127.87/tonne	$2.81/liter
Natural	$1,286.00/tonne	$1.15/liter

In-site burning is another attractive option in terms of costs, though this option is not often used due to concerns over air pollution risks. Allen and Ferek (1993) indicated that spill responses involving *in-situ* burning would cost on average $162.29-$402.34/tonne burned, as opposed to $402.34-$804.68/tonne per tone dispersed in responses using dispersants, and $804.68-$1,207.02/tonne per tonne mechanically recovered and disposed of. [All costs converted to 1999 US $.] These calculations were based on theoretical cost estimates since there is little data on actual *in-situ* burning incidents. Improving technologies and re-evaluation of the relative risks and effectiveness of this strategy may change the pattern of usage in the future. Again, as with dispersant use, *in-situ* burning is heavily regulated in most nations because of the real and perceived risks associated with the particulate and polycyclic aromatic hydrocarbon emissions associated with burning oil.

When the effectiveness of the various cleanup strategies is considered (see Table 8), the use of dispersants and even *in-situ* burning can be viewed as even more cost-effective options (Allen and Ferek, 1993). The actual effectiveness of any cleanup methodology depends, of course, on the actual application methods, the individual circumstances of the spill (location, oil type, amount of oil), and such unpredictable variables as weather.

Table 8. Reported Effectiveness of Cleanup Methodologies

Method	Reported Field Effectiveness
Dispersants	80-90%
In-Situ Burning	90-98%
Mechanical Containment and Recovery	10-20%
Natural Cleansing	Up to 90% (under right conditions)
Manual Removal	Varies

7.0 Regional Cost Differences

Perhaps the most important factor in determining the impact and response costs for an oil spill is the *location*. As mentioned earlier, the location of a spill determines, to a large degree, its impact in terms of shoreline oiling. The spill's proximity to environmentally, economically, and politically sensitive locations can greatly impact its response costs. The political regime of the spill location can determine the standards of "how clean is clean?," options in non-mechanical/manual cleanup methodologies such as dispersants (see Etkin, 1998a), labor costs, equipment costs, and response logistics, not to mention insurance, liability, and compensation factors. Social and economic values play a large role in determining standards.

Table 9 gives a synopsis of spill costs based on nation and region. The costs given represent only cleanup costs and do not reflect third-party damage claims or natural resource damage costs which may be incurred in addition to cleanup costs depending on state, national, and international liability regulations.

Table 9. Average Per-Unit Marine Oil Spill Cleanup Costs By Nation/Region (1999 US $)

Nation/Region	US$/liter	US$/tonne
North America		
Canada	$5.85	$6,508.14
United States	$23.02	$25,614.63
Average	**$17.81**	**$19,814.63**
Latin America		
Argentina	$2.08	$2,316.61
Brazil	$5.03	$5,600.72
Chile	$0.82	$910.42
Mexico	$0.76	$850.32
St. Kitts/Nevis	$2.77	$3,085.81
Uruguay	$3.03	$3,368.25
Venezuela	$10.62	$1,817.83
Average	**$2.75**	**$3,055.76**
Africa		
Egypt	$3.98	$4,428.90
Morocco	$8.69	$9,675.07
Mozambique	<$0.01	$6.09
Nigeria	$1.59	$1,766.75
South Africa	$2.62	$2,917.54
Average	**$2.84**	**$3,163.93**
Europe		
Denmark	$10.05	$11,180.41
Estonia	$6.13	$6,820.62
Finland	$1.90	$2,115.29
France	$2.07	$2,301.58
Germany	$9.62	$10,702.67
Greece	$7.67	$8,530.29
Ireland	$4.32	$4,807.49
Italy	$5.88	$6,541.19
Latvia	$8.28	$9,212.35
Lithuania	$0.07	$78.12
Netherlands	$5.98	$6,655.37
Norway	$20.77	$23,118.08
Spain	$0.39	$438.68
Sweden	$14.06	$15,642.36
UK	$2.77	$3,082.80

Yugoslavia	$1.36	$1,541.40
Average	**$9.71**	**$10,807.83**
South Pacific		
Australia	$5.38	$5,991.33
New Zealand	$2.51	$2,791.35
Average	**$5.12**	**$5,698.88**
Middle East		
Israel	$2.08	$2,313.60
United Arab Emirates	$0.57	$636.99
Average	**$0.95**	**$1,057.50**
Asia		
Hong Kong	$4.00	$4,452.94
Japan	$31.11	$34,619.92
Malaysia	$68.93	$76,589.29
Philippines	$0.61	$676.51
Singapore	$0.35	$390.61
South Korea	$11.52	$12,814.96
Average	**$24.71**	**$27,495.83**

Not surprisingly, the US ranks as one of the most expensive locations for spill cleanup responses. The high spiller liability, cleanup standards and labor costs of the US contribute to the higher cleanup response costs. Spills in Asia are also relatively expensive. Much of this has to do with the need for high "how clean is clean" standards necessitated by the vast aquaculture in the region.

The spill costs in Table 9 are based on relatively small numbers of spills in some of the nations and regions. Cost data is not widely available in all regions and therefore, cost estimations have to be extrapolated from the limited historical data that is available. In general, spills in more highly developed nations with high labor costs, complex regulations for spill response, and high standards for environmental protection rank as the most expensive.

8.0 Cleanup Cost Estimation Technique

Integrating all of the above cost factors into a single algorithm can be done with the following formulae and methodology.

$$C_{ui} = C_{li}\, t_i\, o_i\, m_i\, s_i$$

$$\textit{and}\ \ C_{li} = r_i\, l_i\, C_n$$

$$\textit{and}\ C_{ei} = C_{ui}\, A_i$$

where,

C_{ui} = response cost per unit for scenario, *i*

C_{li} = cost per unit spilled for scenario, *i*

C_n = general cost per unit spilled in nation, *n*

C_{ei} = estimated total response cost for scenario, *i*
t_i = oil type modifier factor for scenario, *i*
o_i = shoreline oiling modifier factor for scenario, *i*
m_i = cleanup methodology modifier factor for scenario, *i*
s_i = spill size modifier factor for scenario, *i*
r_i = regional location modifer factor for scenario, *i*
l_i = local location modifier for scenario, *i*
A_i = specified spill amount for scenario, *I*

To apply the formulae, begin with C_n, which can be found in Table 9. Regional and/or local adjustment factors can be applied. For example, if it is known that labor costs or costs, in general, are more 15% expensive in a particular state or locality, the general per-unit cost can be increased by this percentage.

The various cost adjustment factors or "modifiers" that are applied to this per-unit cost can be found in Table 10. These factors are derived from the relative costs for the different factors found in the tables for each section above. The factors are based on the percentage difference of the average factor cost relative to the median costs for the data in each cost factor category. For example, spills of No. 2 diesel fuel cost only on average 18% of the median costs as calculated for all oil types.

Table 10. Cleanup Cost Factor Modifiers

Cost Factor	Modifier
Oil Type	
No. 2 fuel (diesel)	0.18
Light crude	0.32
No. 4 fuel	1.82
No. 5 fuel	1.82
Crude	0.55
Heavy crude	0.65
No. 6 fuel	0.71
Spill Size	
< 34 tonnes	2.00
34-340 tonnes	0.65
340-1,700 tonnes	0.27
1,700-3,400 tonnes	0.15
3,400-34,000 tonnes	0.05
>34,000 tonnes	0.01
Location Type	
Nearshore	1.46
In-Port	1.28
Offshore	0.46
Primary Cleanup Method	
Dispersants	0.46
In-Situ Burning	0.25

Mechanical	0.92
Manual	1.89
Natural Cleansing	0.10
Shoreline Oiling	
0-1 km	0.47
2-5 km	0.54
8-15 km	0.54
20-90 km	0.61
100 km	1.06
500 km	1.53

This model is similar to modification made by the US Minerals Management Service (MMS) to an empirical model developed by the US National Oceanic and Atmospheric Administration (NOAA) (US Department of Commerce, 1983) from data collected during the Amoco Cadiz spill. The NOAA model assumes that oil spill control (containment and recovery/removal) comprised 15% of total cleanup costs and shoreline cleanup and oil removal accounted for the remaing 85% of costs. MMS then further modified this model by considering factors that could influence total cost on the basis of percentages that the costs would increase or decrease (US Department of the Interior/Minerals Management Service, 1992). For example, use of dispersants would decrease costs by 10%, water temperature could increase or decrease costs of removal by 15%, and the proximity of effective response organizations and response equipment could increase or decrease the costs by 15%. At the same time, shoreline cleanup cost could likewise be increased or decreased by 45% depending on the shoreline type, by 20% in either direction depending on regional operating costs, and by 10% in either direction depending on wave energy at sea.

The current proposed model considers other factors and is based on over 200 spill cases as opposed to a single case study which was then analyzed theoretically to determine these factors.

9.0 Discussion

The actual spill costs in a particular incident are completely dependent on the actual circumstances of the spill. By and large, these costs – even on a per-unit basis -- are influenced by a variety of interrelated factors, such as geographical location (proximity to the shoreline and sensitive resources), political regime, oil type, amount spilled, and cleanup technologies employed. The actual costs incurred can only be examined in the aftermath of the spill once the predictable and unpredictable circumstances play themselves out.

The average costs outlined above for the different cost factors and regions are indicative only of *general trends* in historical spills. These trends and the estimation modeled described above can therefore only be used as general indications of predicted costs. These estimations should always be used with caution. They are presented as a method for estimating or predicting per-unit costs without knowing all of the actual circumstances that will occur in a particular spill situation. As such, they are only intended as an improvement over universal per-unit spill cost estimates for planning or evaluation purposes. With increased data collection and analysis, the estimation technique will be refined and improved in terms of its descriptive and predictive properties.

10.0 References

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