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Prevention of oil spills by tankers - Feasibility study of a Safety and Environmental Index (SEI)

by

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Submitted to the Department of Ocean Engineering
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Abstract

Oil spills are among the most threatening events for the environment.
Since the grounding of the *Exxon Valdez* in 1989, many studies have been conducted to analyse the impact of spills on the environment, but also to investigate the means to reduce this threat by the use of sophisticated designs of ships and other technologies.
The present study attacks the problem of oil spills by assuming that preventing a spill is better than mitigating it. For this purpose, the concept of a Safety and Environmental Index is described. This index should assist the choice of best solutions to prevent spills among a set of alternatives, and it would also provide bases for policy-making, since this problem has political, economic as well as legal implications.

Thesis Supervisor: Judith T. Kildow
Title: Associate Professor

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I would like to thank all the people that have supported me: they know who they are.

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Chapter 1

Introduction: the causes of oil spills

1.1 Accidents, spills, impacts

In 1989, the *Exxon Valdez* grounded on the shores of Alaska, spilling some 267,000 barrels of oil in the ocean. This was not the first oil spill in history, but its tremendous impact on the environment and on public opinion induced a strong reaction from the US Government. The Oil Pollution Act was passed in 1990 (from now on, it will be referred as OPA 90), and the National Research Council of the US National Academy of Sciences was given the task to analyse the means to prevent such spills. The results of this study are detailed in *Tanker spills - Prevention by design* [5], and showed that the double hull was at that time the most cost-effective tanker design to prevent oil spills.

Nevertheless, many unknowns remain, and the oil tanker industry does not unanimously agree with some of the points of OPA 90. First, the double hull is not the perfect design (even if it is currently more cost-effective, according to *Tanker spills - Prevention by design* [5]), because under some conditions, it is as inefficient as a single hull[1].

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[1] In high-energy groundings (the ship hits the ground with a substantial speed), both hulls of a double hull tanker may be damaged, with the same consequent spill as in the case of the same tanker

Moreover, implementation is a crucial problem. For instance, it is well-known that the inert gas system invented in 1938 by Sun Oil is an efficient means of preventing explosions in tankers. Nevertheless, this technology was actually installed only in the early 70's on tankers which did not belong to Sun Oil. In 1974, the United Nations adopted a recommendation for inert gases in larger tankers, but it was not a requirement. It became mandatory under IMO in 1983. This shows that acknowledging that a device is efficient to prevent accidents is not enough: it has to be actually installed. And the decision to install a system is not only driven by safety considerations, but also by costs and benefit estimations. It should also be mentioned that about 30 tankers exploded despite this inert gas device (Eric Nalder, [9]). The reason is that the system was not turned on when the accident occurred, or because the maintenance of the system was poorly carried out. This emphasizes the problems with the interaction between technology and human behavior.

It has been shown before that many factors can contribute to an accident, and not only a failure in the structural design of the ship. The following section will develop the analysis of those factors, and describe what can be done to reduce the risks associated with them.

1.2   Explanation of the failures

Among all catastrophes involving high technology and natural resources, oil spills have tremendous effects on the environment, as well as on the economy. It is possible to identify several explanations for this.

First, the environment itself, the oceans and coastal zones, is not well-understood. Therefore, having no precise understanding of all the mechanisms involved, it is dif-

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with only a single hull.

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Name	Spillage (in 1,000 barrels)	Cause
Atlantic Empress	1,890	Collision
Castillo de Bellver	1,760	Fire/Explosion
Amoco Cadiz	1,628	Structure/Machinery Failure
Odyssey	925	Fire/Explosion
Torrey Canyon	909	Grounding/Stranding
Exxon Valdez	267	Grounding/Stranding

Table 1.1: The five major oil spills by tankers, and the *Exxon Valdez*

ficult to analyse the impact of an accident, and even more to predict this effect a-priori. For instance, whereas the *Exxon Valdez* accident with 267,000 barrels of crude oil spilled in the waters of Alaska is only the 28th largest spill in history as regards the amount of oil spilled (see Table 1.1 for a comparison with the largest spills), it is one of the most expensive[2]. The reason is that the environment in Alaska is actually more sensitive to a spill, due to the temperature of the water among other factors[3].

Second, the prediction of consequences is a real challenge because of the time scales one has to deal with. In fact, the evolution of the environment during and after the spill is unknown because of a whole set of chemical, biological and physical parameters that depend on sites, weather conditions, and human interactions. Moreover, once natural resources are damaged, it is hardly possible to determine the time needed for the environment to return to its initial state, if, in fact it can. For instance, according to Reilly and Skinner [12], in the case of the *Amoco Cadiz*, a spill six times larger than the *Exxon Valdez*, the environment largely recovered from the

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[2] According to Alan Strudler [13], in 1991 Exxon agreed to pay $900 million in damages to the federal government and the state of Alaska. Also, at the beginning of the trial, plaintiffs (fishermen and other Alaskans who have suffered losses from the spill) were awarded $286 million in compensatory damages (More recently, Exxon was also ordered to pay $5 billion in punitive damages, because Exxon and the tanker captain were convicted of negligence).

[3] Due to lower temperatures, rates of physical weathering and biodegradation are slower than in temperate regions, and therefore allow the oil to persist.
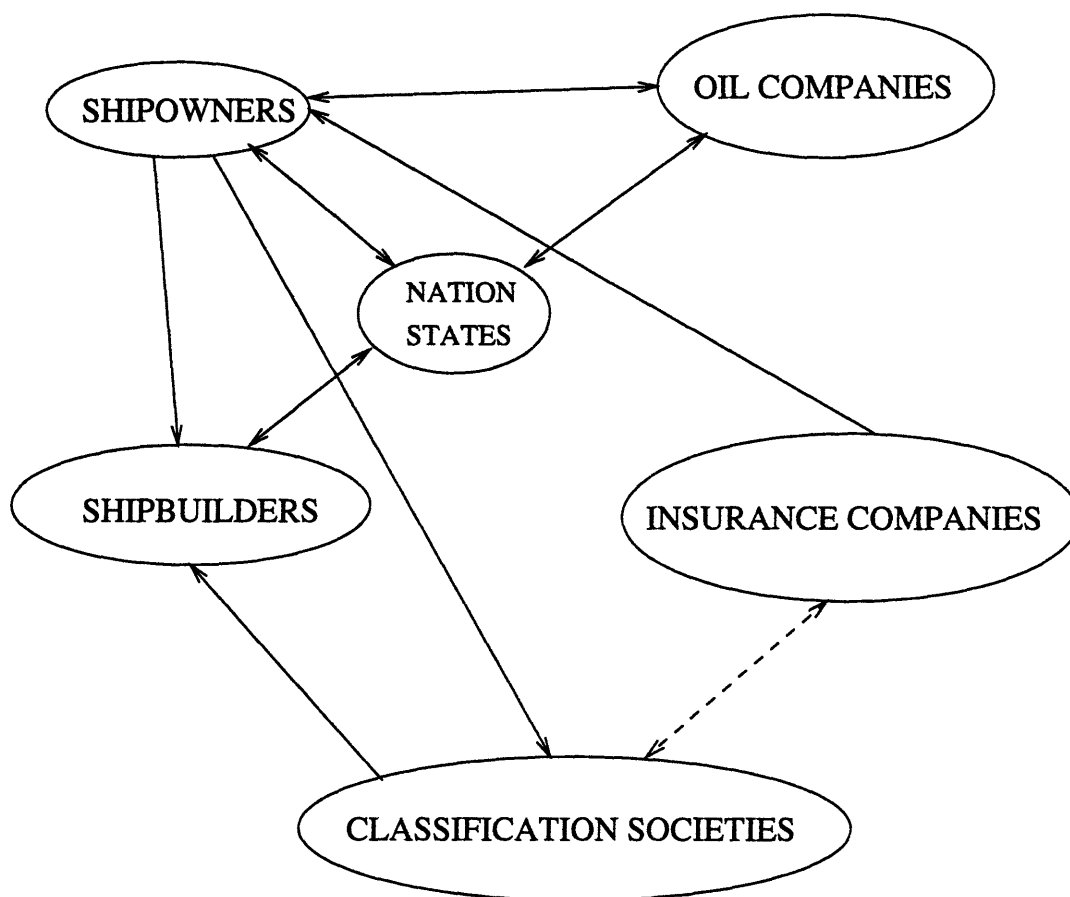
Figure 1-1: Stakeholders

spill within three to eight years. In the case of the *Exxon Valdez* it is very unlikely that the Alaskan ecosystem will return to its normal state within this same time period.

Third, beyond the difficulties encountered in the assessment of environmental damages (and therefore costs), there is the problem of determining social consequences, such as the loss of income for recreational areas and fishermen.

Fourth, the international landscape of the oil industry, the number of stakeholders involved, and the complexity of the linkages among them, make it difficult to draw a scheme of actions. Figure 1-1 tries to describe very roughly the system. In this

	Basic compensation provided by shipowners	Supplementary compensation provided by cargo owners
International Conventions	Civil Liability Convention	Fund Convention
Voluntary Agreements	Tovalop Standing Agreement Tovalop Supplement	Cristal

Table 1.2: The Compensation Process

Figure, the main stakeholders are represented, and an arrow going from a stakeholder to another signifies the influence of the first one on the second one. Many of those arrows go in both senses, because it is sometimes hard to tell who influences whom. But a more complete description of these linkages is made in Chapter 3.

The linkages among the stakeholders are not clear enough to be sure of the consequences of any decision. The point is that there is no well-defined hierarchy among the stakeholders. For example, on the one hand the nation-states implement regulations concerning the management of ships, but on the other hand they might be influenced by shipowners and oil companies. Therefore, it is difficult to reach a consensus among all the stakeholders, regarding their respective interests. This will be developed further in a later section.

Another aspect of this complexity is that compensation for losses is not an easy task to calculate effectively, and determining who is responsible for paying the bill of a spill is controversial. According to the *Marine Pollution Bulletin*[2], in 1978 although the clean-up costs for the *Amoco Cadiz* spill were not precisely calculated, it was already obvious that they would go beyond the £20 million maximum insurance cover at that time. The compensation system is described in Table 1.2. This system of compensation partly reflects the international/private partition of the oil industry.

Although those four points are not an exhaustive list of explanations for the failure to build a prevention process for oil spills, they definitely emphasize the toughness

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of the task of predicting the costs and the effects of an oil spill on the environment. Thus, it seems more sensible to address the problem in a different way; that is, not to act a-posteriori but a-priori. It is probably worth it to prevent an incident rather than to try to mitigate the damages it causes[4]. In order to create an efficient prevention process, an accurate analysis of the system (its dynamics and its stakeholders) must be done.

In the past, the decision-making process often did not go deeply into the details of the problem of oil spills, or avoided some of the major points, resulting in inadequate regulations and practices. For instance, although it is one of the first attempts[5] to enforce a set of regulations aiming at the reduction of oil spills[6], OPA 90 is not as efficient as it could be. OPA 90 requires that:

- All newbuildings and/or major conversions of 5,000 gross tons and over, contracted on or after June 30, 1990 or delivered after January 1, 1994, must have double hulls, and double containment systems.

- Existing ships of 5,000 gross tons and over, without double hulls, are to be fitted with a double hull or phased out from 1995 until 2015 depending on their age and tonnage, and are required to have double containment systems only after January 1, 2015.

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[4]In an article in the Boston Globe of Saturday April 22, 1995, Jessica Mathews, a Senior Fellow at the Council on Foreign Relations, states that clean-up is generally 10 to 100 times more expensive than avoiding damage to begin with.

[5]The 1978 Tanker Safety Act was an earlier attempt to deal with the problem.

[6]OPA 90 states (Beghin, [4]):

The Secretary of the Department of Transportation shall determine, based on recommendations of the National Academy of Sciences or other qualified organizations, whether other structural and operational tank vessel requirements will provide protection to the marine environment equal to or greater than that provided to double hulls, and shall report to Congress that determination and recommendations for legislative action.

Therefore, even with OPA 90, non-safe tankers are likely to be shipping in the US waters until 2015. Until now, nothing serious has happened, but the worst may happen yet.

1.3 The decision process

In order to avoid mistakes in decision-making processes (which is one of the main causes for the great impacts of oil spills), all the analytical methodologies available should be compared and used in the evaluation of the impact of the different choices that could be made to reduce risk. In *Decision science and social risk management* [8], a review of the existing decision techniques is done, the implications of risk assessment and management are defined, and the tools to deal with them are described. Different strategies for modifying risk are presented, each of them being used depending on the types of measures that can more easily be taken:

Implement different risk-management strategies: This could be done through regulations (mandatory requirements), financial incentives (taxes, licenses, insurance), or information dissemination (governmental research or warnings);

A. Modify the risk sources: For instance, establish new performance standards for structure against fatigue;

B. Modify the effects process: Require new equipment on ships;

C. Modify consequent utility: Offer government-subsidized liability insurance. This might be a way of promoting initiatives of the shipowners in matters of safety.

The above categorization can be explained as follows: implement different risk-management strategies is an overall approach of the problem, whereas modify the risk sources, the effects process, or the consequent utility are precise actions, well-determined in time. Establish new performance standards as well as require new

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equipment are mainly related to the enforcement of regulations; offer liability insurances might be considered as a financial incentive.

Considering the three risk-management strategies mentioned above (regulations, financial incentives, information dissemination), one must understand what their efficiency is, and how difficult it is to implement them.

First, regulations are the most obvious way to reduce risk. But, the studies leading to the regulations must provide sufficient information so these regulations are neither ineffective nor incomplete. Besides, the enforcement part of the regulations must be taken care of in order to actually implement them.

Second, financial incentives are a manner of modifying risk, which decision-makers are more likely to be less reluctant to consider, contrary to the enforcement of regulations. The reason is that they are a more positive approach than regulations: some stakeholders decide to make trade-offs so that an agreement can be reached. But, although it is a more efficient process, it is difficult to implement because the price of those trade-offs has to be paid by some stakeholders.

Third, information dissemination is the best way to use public opinion to put some pressure on some stakeholders. Another aspect of information dissemination is also to promote actions or research programs from the part of outside institutions such as universities. But in any case, this strategy can only be a complement to the two previous ones, and not a strategy by itself.

Therefore, the use of regulations or financial incentives are the two major strategies to reduce risk that will be considered in this study. Nevertheless, as pointed out previously, they have limitations in the extent to which they can be implemented as well as in their efficiency. This is due to several factors [8]: limited knowledge, disfunctions in human perception of risks, social consent, and conflicting interests

among stakeholders. Moreover, although there are already new solutions available in matters of design or equipment, their implementation might be a problem, because they involve too high an investment compared to their actual benefits. Therefore, each alternative has to be evaluated so that it may be possible to know whether or not it is worth implementing. The tools to do this assessment are the following:

Cost-benefit theory: It consists of the maximization of aggregate values. The willingness to pay (WTP) for all considered items is determined: this theory uses market values. The efficiency criterion in this method is the "Pareto optimality", which states that an improvement in the system is equivalent to having one or more individuals better off without at least one worse off. The underlying problem in using aggregate values is that it is a global consideration, and there is no distinction among the groups of individuals.

Decision theory: It is based on the maximization of expected outcomes among several alternatives. The concept of rational behavior is one of the bases of this theory.

Social choice theory: This theory is based on the rational synthesis of preferences of all individuals affected by the decision, rather than the preferences of decision-makers only. There are two aspects to this method: first, the game theory (there are individuals who are pursuing self-interest and personal values against other that are doing the same), and second, ethics (which is the rational pursuit of the interests of the group as a whole).

All these theories differ in the method of analysis, and the concepts of value and uncertainty. The cost-benefit theory relies on the idea of economic efficiency, and monetary values are determined by economic actors in a free market, and the environment is characterized objectively, with no intervention of individual considerations. Moreover, the US Executive Order 12291 of February 17, 1981 states that the US Government cannot promulgate any regulation before having demonstrated benefits

to society greater than the costs. Therefore the cost-benefit theory is essential to any economic evaluation.

Nevertheless, this theory should be integrated into a broader scheme to improve the existing decision-making process. This will be described hereafter by the introduction of a new concept: a safety and environmental index.

Chapter 2

A new strategy to prevent oil spills: a safety and environmental index

2.1 Complexity

As pointed out in the previous chapter, a first overview of the problem of oil spills emphasizes two important stages:

The first step to understand the system is to identify the actors or stakeholders. Considering the problem of oil spills, one must keep in mind that the oil business is very complex. Strictly speaking of oil transportation, oil companies, ports, shipowners (plus ship operators and crews) have to be studied. Then one must add to this list insurance companies and certification societies, which are parts of the system. Finally, going further, one has to think about the role of ship builders and states (whether as oil companies or shipowners, or as endangered locations where an oil spill could have huge consequences).

The second step is to understand the links among all the parts of the system. This

is the crucial issue here. In fact, the actors are not well-separated, and it is therefore difficult to isolate them and to treat their own problems and needs respectively. This complexity of the system is the major obstacle to building an efficient prevention process, because a single action on one particular stakeholder is not likely to be enough to provide a major change in the current situation.

2.2 Dynamics

Being a complex system, the problem of prevention of oil spills should be addressed by an evolutive scheme of actions. As described above, it is likely that any decision will affect more than one stakeholder. Therefore, it will make the system evolve globally. This demonstration of the low control decision-makers have on the system leads to the idea that with no cooperation of all the actors, no complete solution will be reached, only partial trade-offs. More than a principle of balance among all participants, the scheme should be fair, setting an acceptable distribution of responsibility and accountability in the prevention process, as well as in a litigation if an accident occurs. To reach this state, the creation of an index of safety is the first stage. The purpose of this is to have sound bases for the evaluation of potential risks. For instance, the assessment of ports and ship equipment and maintenance procedures, the level of training of crews and port staff are some of the points one would like to investigate. Finally, by assessing the capability of a ship-system[1] to respond to several situations (collisions, groundings, etc.), it could be possible to locate this ship-system on a safety scale. A high grade on this scale would signify that the ship-system is capable of avoiding an accident. Given a minimum acceptable grade on this scale, it would be easier to identify risky situations. For instance, having a tanker with poor communication equipment entering a port where the traffic is known to be important, would indicate the risk of collisions is high. Thus, the creation of this safety index

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[1]The ship-system is the system formed by the design of the ship, the pieces of equipment installed on it, and the crew.

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might be a real improvement in the prevention of oil spills. Moreover, by setting such an international standard of perfomance, sound bases would be given first to insurance companies and certification societies for their evaluation processes, then to shipowners and port operators in order to bring them guidelines for future operations and improvement measures. As a conclusion, all actors should be part of this process, so that nobody's needs would be forgotten or underestimated.

2.3   A checklist for action

In order to have safer tankers carrying the oil across the oceans, a global approach such as a safety and environmental index described above is an important step. Now that the concept is introduced, the purpose of this study will be to evaluate its feasibility, what it should do, and what will be required to make it efficient. In order to study this feasibility, many areas must be assessed. This work takes two important aspects to examine:

- The efficiency of the alternatives[2] concerning the prevention of oil spills in given situations. This is related to the creation of efficient regulations.

- The costs and benefits of those alternatives for the investors. This is an economic approach. The creation of financial incentives is correlated to the analysis of the financial efforts required to implement different solutions.

Those two aspects are complementary, because even if an alternative is found to be the most efficient in a given situation, it might not be used because of cost or implementation constraint. Therefore the analysis should reveal incentives for the implementation of efficient solutions, at a reasonable cost.

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[2]The alternatives are different designs, equipment, training of crews, port and ship management strategies.

The following problems have been identified in the previous chapter:

Characteristics of the shipping route vis-a-vis risk of damages: The environment is an important parameter which is usually not accounted for, or at least not enough: carrying oil from one terminal to another across the open sea is not the same thing as transporting cargo along a coast, close to natural reserves. Therefore, different solutions must be applied, depending on the characteristics of the route of the ship; that is, if along the route there are locations where there is a risk of accident or where a spill will have huge consequences.

Strategies, equipment, and design to overcome risk: Given that the risks and the potential impact are identified, it is possible to determine what equipment or ship design is more efficient. That is, for example, if the tanker is to travel near unsafe coasts, a double hull is evidently safer than a single hull.

Calculation of risk: By comparing the features of the route and what alternatives can be used on the ship, it may be possible to evaluate the risk of the situation.

Those three elements are the beginning of a sketch of what a "safety checklist" can be. This notion will be refined all along the present study. Besides, it remains very simple for the moment. In Ozkaynak and Murphy [10], the same kind of approach has been taken: the route of the ship is analyzed, and a calculation of the probability of a spill is done. In this study, some relations are drawn among the geographic location of the ship, the generic probability of particular types of accidents, and the likelihood of a spill. These are based, among other factors, on the analysis of statistical data. The purpose of the present study is not to calculate probabilities of spill occurrence, because using historical data suggests that trends in spill frequency remain constant. But, since technological change affects probabilities (with a safer design, the probability of accident is likely to decrease), and because regulations and financial incentives are recommended to help implement new alternatives, promoting one or both of these strategies and basing them on static probabilities are two incompatible things.

This checklist should be used when investigating any particular situations. The outcome is the evaluation of the nature of the risk inherent to the situation, and the relative efficiency of the alternatives in this situation. The final objective of the SEI will be then to designate what level of efficiency is required, given the risk of the situation. The very last step will be the implementation of this minimum requirement by the way of one of the two risk-management strategies described in Chapter 1: regulations or financial incentives.

In Chapter 3, this implementation stage is described. Then, in Chapter 4, a way of determining the efficiency of alternatives is explained.

Chapter 3

Study of the interactions among the stakeholders - Implementation of risk-management strategies

The Safety and Environmental Index (SEI) relies on a reasonable understanding of as many of the linkages among the stakeholders as can be identified in the tanker business, the oil industry, and several economic, political, and social parameters. Thus, a preliminary requirement to building the SEI is to identify the variables from which decisions will flow, and the entities that are likely to influence these variables.

In order to determine that basic information, the systematic approach of an Analytical Hierarchy Process could be used.

3.1   Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process is a decision tool that enables the visualization of the objective that is to be reached, the alternatives to reach it, and the criteria upon which the decision among the alternatives will be based.

The AHP for this study is represented in Figure 3-1.

The final objective of the study is the prevention of the spill, or at least the reduction of the amount of oil spilled. But the goal the AHP will try to reach is an intermediate stage: it is the implementation of alternatives in order to prevent spills. The problem of implementation is closely related to the agreement of the stakeholders considering the alternatives. Therefore, the risk-management strategies described previously will be incorporated in the process, in a manner that will be explained later.

The alternatives are the different possible designs of ships, the equipment that can be used on board and in the ports, and particular training strategies for the crews. They stand for what financial incentives or regulations would aim to implement as performance standards or minimum requirements.

The criteria are classified below in 3 categories:

- Economics: This section includes some subcriteria reflecting the interests of the shipowners, shipbuilders, oil companies, and the locations likely to be affected by a spill.

- Politics: The subcriteria will be the problems of implementation, and the public opinion (its perception of environmental risks), and the interests of nation-states.

- Legal/Financial: Here will be put the definition of liability, and the insurance/certification concerns.

The difference between financial and economic criteria is defined as follows: economic aspects are strictly related to costs and benefits of operations, whereas the

OBJECTIVE

IMPLEMENT SOLUTIONS

CRITERIA

ECONOMICS   POLITICS   LEGAL / FINANCIAL
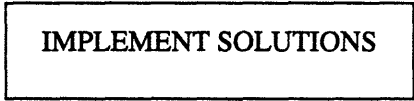
SUB-CRITERIA ────────▶ SATISFACTION OF STAKEHOLDERS

OIL COMPANIES   SHIPBUILDERS   CLASSIFICATION SOCIETIES

SHIPOWNERS   INSURANCE COMPANIES   PORTS   STATES

ALTERNATIVES

DESIGN   TRAINING   EQUIPMENT
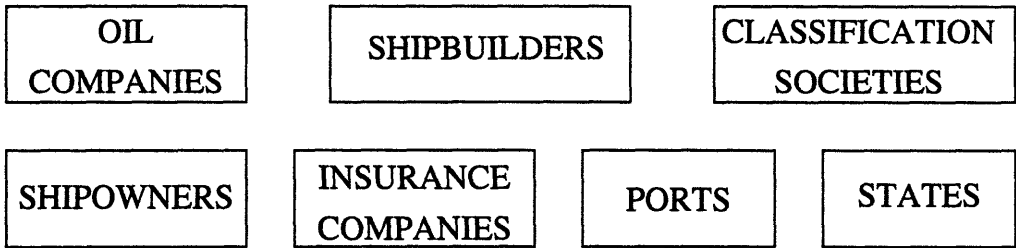
Figure 3-1: Analytical Hierarchy Process

-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
Dissatisfied					Indifferent					Enthusiastic

Table 3.1: Satisfaction of stakeholders

financial side takes into account the external movement of funds for purpose of insurance cover or legal mitigation.

The subcriteria reflect the degree of satisfaction of each stakeholder mentioned on the diagram. These subcriteria are parts of more general aspects that fit into economic, political, legal and financial considerations. Satisfaction is a hard notion to define, but a scale such as the one described in Table 3.1 can be a sufficient quantification of satisfaction.

As mentioned in Chapter 1, the cost-benefit theory relies on the "Pareto optimality" criterion. Therefore, decision-makers would prefer to avoid a situation where some stakeholders' satisfaction is located on the negative part of the scale.

The next step is to compute the level of satisfaction S brought to the whole ensemble of stakeholders by each alternative. Given the set of S_i (S_i: satisfaction of stakeholder i), S is calculated by:

$$S = \sum_i (w_i * S_i)$$

where w_i is the weight of stakeholder i. The stakeholders with the highest w_i are the ones whose influence is the greatest in the decision-making process (this is equivalent to say that the satisfaction of the group of stakeholders is mainly the satisfaction of those who will win the decision).

To each alternative is associated a calculated satisfaction of the group. Thus, it is possible to estimate the alternatives that will be easier to implement (i.e. those with the highest level of satisfaction).

The use of the AHP enables the decision-maker to identify the most advantageous solution among a set of alternatives for the different stakeholders. This is a necessary step in order to understand what trade-offs will have to be made to reach some agreement. Nevertheless, the linkages remain complicated.

The way to obtain the S_i will be discussed at the end of the following section. But another question remains to be addressed: what are the w_i? As mentioned above, they stand for the influence of the stakeholders. But to understand how to calculate those w_i, it is necessary to discuss the relationships among the stakeholders.

3.2 Discussion

In this section, the study of the interests at stake will be developed. Two layers of interests can be identified: "obvious" actors, who are directly related to the tanker and the cargo, and more complex entities, that is aggregates of several actors.

3.2.1 Basic actors

Oil companies: The oil companies own the cargo. They are responsible for the choice of the ship that will carry the oil. But, in many cases, they actually own the tanker too. Their concern is to get as much oil carried as possible, as quickly as possible, and at the lowest price. Besides, oil companies also show an increasing interest for safety and environmental issues. For instance, according to *Petroleum and the marine environment* [1], British Petroleum has developed a service of environmental audit since 1970 with its Environmental Control Center; Shell, too, has a department of Health, Safety, and Environmental

Conservation; finally, the Gulf Area Oil Companies Mutual Aid Organisation (GOACMAO) aims to pool the resources of all members for joint capability to clean up oil spills.

Shipowners: According to Eric Nalder [9], the largest tanker fleets are owned by national governments (the former USSR: 200, China: 92, Brazil: 71, the US: 68, Indonesia: 47, and India: 44). Among the largest private fleets are Exxon: 60, Shell; 46, Chevron: 42, Mobil: 36, Texaco: 28, BP: 25, Arco: 10, and Amoco: 10. Therefore, among shipowners there are the states, the oil companies, and private shippers: The interests are not the same for those three groups.

In the US, shipowners are liable for spilled oil removal cost and damages in amounts up to $1,200 per gross ton. Thus, they have to make trade-offs between their competitiveness on the market for oil transportation and the risk of a spill with all the financial consequences that may follow.

Shipbuilders: Building a tanker is a complex task. In the actual market of ships, shipyards are fighting one another to get contracts to build tankers. Therefore the economic situation of the market is a direct input to the ship itself.

Port operators: Since the route of a ship goes from one port to another, the characteristics of those ports are important parameters of the problem. One has to consider the management of the port, as well as the human factor involved in port operations (pilots, etc.), and the equipment used (navigation, mapping, monitoring). Moreover, the geographic location is important, because of the characteristics of the shipping channels, the natural resources near the location, and the traffic patterns.

3.2.2   More complex stakeholders

States: States may belong to many categories: they can be shipowners, potential victims of spills, or flag states. A flag state imposes domestic legal requirements for ships using its flag. According to the International Maritime Organisation

(IMO) Conventions, penalties for non-compliance to requirements are imposed by the flag states. Some countries like Panama or Liberia impose low taxes and fees, and do not enforce strict regulations so that their flags attract many shipowners. Besides, states can be considered as port-states. For instance, in the United States, the Coast Guard administers the vessel Certificate of Financial Responsibility (COFR) Program: all vessels coming into US ports must have a certificate providing evidence of sufficient financial resources to cover the vessel's liability limit.

P&I Clubs: The P&I Clubs (Protection and Indemnity Clubs, also called Hull Clubs) are maritime insurance groups in which members agree to share each other's liabilities on a non-profit-making basis. They are composed of owners, charterers, managers, ship operators. Each member pays a premium that is established in accordance with the claims that he is likely to bring on the club. There are 17 P&I Clubs. They are strongly influenced by the shipowners.

Insurance companies: Tankers usually carry from four to six separate insurance policies covering hull, cargo, and other liability exposures. Therefore, insurance companies play an important role.

Certification societies: There are 42 Classification Societies in the world. 11 of them are grouped in the International Association of Classification Societies (IACS) (*Tanker spills - Prevention by design* [5]). They are: the American Bureau of Shipping, Det Norsk Veritas, the Lloyd Register of Shipping, Germanischer Lloyd, Nippon Kaiji Kyokai, Registro Italiano Navale, Bureau Veritas, the Korean Register of Shipping, the China Classification Society, Polski Rejestr Statkow, and Yugoslavian Register Brodova. In fact, they are easily manipulated by the shipowners, because if a classification society does not want to issue a certificate for a tanker, the shipowner will ask another classification society whose requirements are not as difficult to meet as those of the first society. Thus, classification societies are likely to be less exigent in order to satisfy their customers: the shipowners.

3.3 The hierarchy of alternatives

In this section, the AHP will be applied to two different alternatives, in order to show how the ranking of satisfaction is done. Since, as pointed out in a previous section, the concept of satisfaction by itself is somehow too vague, it is easier to get relations such as "according to stakeholder i, alternative 1 is this more satisfying than alternative 2" (for instance, going back to Table 3.1, alternative 1 is at +4 and alternative 2 at +1). That is to say that pairwise comparisons are usual and practical ways to make those kinds of judgements. Therefore, the demonstration of the AHP with two alternatives is sufficient to show the way it works. As an example, in the following, single and double hulls will be compared.

Single hull: The single hull is the most widely used design. It could be considered as a reference in this example.

Double hull: The double hull consists of adding another hull (bottom and sides) to a single hull tanker. The implications for the stakeholders are now to be examined.

Adding another hull is expensive: more steel is needed. Moreover, the useable space is reduced, due to the void between the two hulls[1]. Therefore, the following conclusions can be drawn:

- For the oil company, the problem is that less cargo will be transported.

- For the shipowner, the problem remains the same, except for the maintenance of the ship, which is a little more complicated (inspecting the space between the hulls for corrosion problems might be difficult, due to problems of accessibility).

- For the shipbuilder, the only change is that a double hull is far more complicated to build than a single hull. Therefore, the cost of building such a tanker is higher.

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[1]The distance from one hull to the other is about 2 meters.

- For the P&I Clubs, the owner of a double hull tanker is likely to bring less claims to the Clubs than the owner of a single hull tanker. Thus, it is a better design as far as they are concerned.

- For the insurance companies, the double hull design is considered to be safer, therefore it seems to be less risky to insure a double hull tanker than to cover the operations of a single hull tanker. Nevertheless, the insurance premium will be higher than for a single hull, because this premium is calculated on parameters such as the weight of the ship (and the weight of a double hull tanker is obviously greater than the weight of the same tanker with one hull less).

- For the certification societies, the double hull is definitely a good alternative, because even if it is not efficient in high-energy impacts, it is still at least as good as the single hull.

- For the states, as potential plaintiffs in an accident, the double hull is an improvement. As an element of the previous items (oil company owned by the state, operator of a fleet), the conclusions had already been drawn.

Thus, for each stakeholder the double hull is or is not an improvement compared to the single hull: satisfactions (as described on Table 3.1) would vary for instance from -2 for the shipowners to +3 for the certification societies. Therefore, the decision for the implementation of the design is merely a question of who is the strongest in the group. Actually, in that case, OPA 90 obliges tankers coming to the US to have a double hull in the long term. But, this is not an international requirement. Therefore, it seems that for OPA 90 the US Government (pushed by the pressure of public opinion) has been the strongest stakeholder, and has won the decision despite the opposition of the others. Yet, this case is special, due to the trauma of the *Exxon Valdez* accident, the urgency of the situation, and the size of the US market. This shows that even the relative strengths of the stakeholders may change due to particular situations: the ranking of the influence of each stakeholder relative to the others is very subjective. But it is possible to perform this ranking in a non-crisis situation

by the means of a war game-type exercise: representatives of each stakeholder may gather together, and play their own role in a comparison exercise such as the previous one concerning single and double hulls.

The conclusion is that performing the AHP is not a valid process when the implementation of regulations is responding to a crisis situation. Nevertheless, the AHP may and must be used in a preventive approach: this is the only way to take advantage of its results.

As a conclusion, it seems that reaching an agreement among all the stakeholders is not an easy task, and that most of the times regulations are enforced rather than agreed on. Thus, consistent policy-making must take into account some interests that in the end are incompatible. At this point, trade-offs must be made, and they require incentives. For instance, any effort on the part of a shipowner to purchase and use new equipment or attempt different crew management should be supported by a financial compensation such as a reduction in the insurance premium, if those measures of course give clear evidences of their effectiveness in reducing risks of failure. In the AHP, this is equivalent to changing the relative weight of the stakeholders, or increasing their level of satisfaction: the estimation of the impact of any incentive is part of the Analytical Hierarchy Process, and therefore this tool, if used adequately, is likely to give good estimations of the political and economical measures that must be taken.

Chapter 4

Ranking the alternatives

In the previous chapters, it has been shown first that prevention is the keyword to solve the problem of oil spills. Then, two different risk-management strategies have been identified: implement regulations, and create financial incentives. Besides, it has been demonstrated how to use an Analytical Hierarchy Process to find the way to an efficient establishment of those strategies. But one point is still unclear: is it the way to estimate the efficiency of the alternatives? This problem is addressed in this chapter. This efficiency will be assessed, regarding particular situations. In this chapter, the general concept of this assessment is described, the term "situation" remaining a generic notion. In Section 6.2, the way a situation may be described is demonstrated in an example.

4.1 Building scenarios - Toward a global simulation

Given that the concept of a safety index seems to be a reasonable way to solve the problem, one has to study how this could be efficiently built. One fact everybody can easily notice is that what had basically guided policy makers in the past was more some kind of reaction to catastrophic events rather than a real prevention process.

OPA 90 is a good example of this type of precipitous decision. Moreover, in the past, studies were usually done to find cause and effect relations between circumstances of the accidents and volume of oil spilled, on an historical basis. The problem with this kind of approach is that it does not take into account the input of new technologies and new understanding of risk. In one word, it tries to forecast the future by looking at the past, using outdated scenarios.

This study, contrary to the methods used in the past, intends to use a more systematic methodology, with the application of the checklist described in Chapter 2 to as many situations as could be identified, rather than a compilation of statistical data collected during the past x years. The reason is that with the evolution of newly adopted technologies and the changing international environment, as well as the emergence of new technologies, those data could be irrelevant for a precise risk study.

The main difference between a statistical approach and the one that is presented in this study is illustrated by the concept of time shown in Figure 4-1: the time sequence of events is split into the events leading to a spill and those led by it. This Figure suggests that there are two types of events related to a spill: tractable and intractable events. This characteristic is mainly related to the time of occurence of a spill, and to the possibility the decision-maker has to influence it. Given that the behavior of intractable parameters such as weather conditions is difficult to predict, it is sometimes reasonable to think about the worst possible case, and to focus on the tractable parameters, on which the decision-maker can have an influence. This is developed in the categories cited hereafter:

The prevention part: The elements in this part deal with parameters that are defined before the incident: the design of the vessel, the equipment (communication, fire prevention, etc.) on board, the level of training of the crew, the ports the ship is visiting (special characteristics and management), and to what
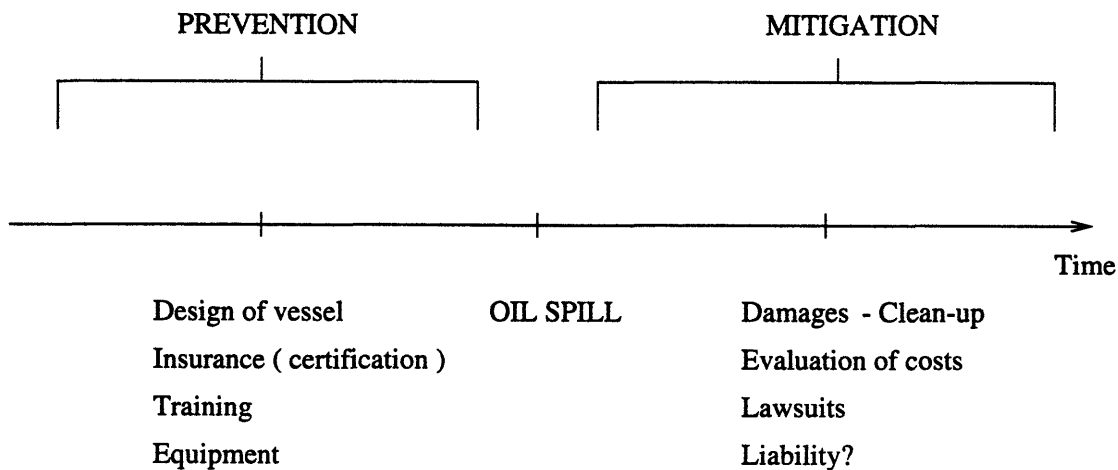
```
         PREVENTION                        MITIGATION
      ┌───────────┬───────┐          ┌───────────┬───────┐
      │                   │          │                   │

   ───────────────┼───────────────────┼───────────────────┼──────────────────►
                                                                        Time

      Design of vessel         OIL SPILL      Damages - Clean-up
      Insurance ( certification )            Evaluation of costs
      Training                               Lawsuits
      Equipment                              Liability?
```

Figure 4-1: Time scale

extent the shipowner is covered by insurance companies. If one wants to pre-
vent a spill, it is on those parameters that one must focus. By changing their
relative importance, and by setting minimum standards for them, it could be
possible to at least minimize the risk of pollution.

The mitigation part: In this part, the consequences of the spill are described.
They include all the damages caused to the environment and to human activ-
ities at the site of the spill, the clean-up process, and the lawsuit and claims
that are taking place (these of course involve the determination of who or what
is responsible for the spill). The study of those elements is crucial, even to
establish a prevention scheme, because the evaluation of the real cost of a spill
to society as a whole is relevant to the determination of the investment required
to reduce the risk of incidents.

Nevertheless, this approach is not complete, because it somehow puts aside the
actual causes of the spill. Thus, one must not forget that all the parameters cited
before in the prevention part might be called "internalities", and are also subject to

some "externalities". Those externalities include the given conditions at the location and moment of the spill, conditions upon which no control can be exercised. Figure 4-2 summarizes this other way to study the system, and points out once again what happens if a preventive approach is taken, rather than a mitigation approach: if one waits until the spill occurs, one will have to deal with problems in the environment and disturbance of human activities; if one chooses to build a prevention process, one will have to think about modifying internal parameters, being aware that external and unpredictable variables may perturb the forecast of the consequences of the spill.

In order to investigate the concept of a safety index, and to cope with the problem existing in the time sequence described before, a systematic model will be developed hereafter, so that the evolution of the parameters can be simulated, and their influence on the system may be assessed. It consists of the building of scenarios. The building of a scenario will involve different steps:

4.1.1 Identify the actors

The first step of the process is to understand who are the stakeholders, and moreover to estimate their relative weight of importance concerning their influence on the parameters. A sort of pair-wise comparison could be appropriate. For a first approach to the problem, only a rough picture of the system will be drawn, in order to have a basic tool for the purpose of this study. Yet, it would be possible in the future to refine the model to integrate new parameters.

The basis for the scenario is summarized in Figures 4-3 and 4-4. Figure 4-3 shows the route of the ship, and Figure 4-4 the location of the spill. In fact, one can designate Figure 4-3 as the "macro-situation", and Figure 4-4 as the "micro-situation".

The macro-situation displays the route of the ship, that is the departure point (port P1), and the destination (port P2). The parameters one would want to take

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                    ┌─────────────────┐
                    │  SPILL: CAUSES  │
                    └─────────────────┘
                      ╱             ╲
                     ╱               ╲
                    ╱                 ╲
       ┌─────────────────┐       ┌─────────────────┐
       │  INTERNALITIES  │       │  EXTERNALITIES  │
       └─────────────────┘       └─────────────────┘

           Training                   Weather
           Structure                  Contingency
           Equipment
```

───

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                                    Recreational Activities
           Ecosystem                Commercial Fishing

       ┌─────────────────┐       ┌─────────────────┐
       │   ENVIRONMENT   │       │  HUMAN ACTIVITY │
       └─────────────────┘       └─────────────────┘
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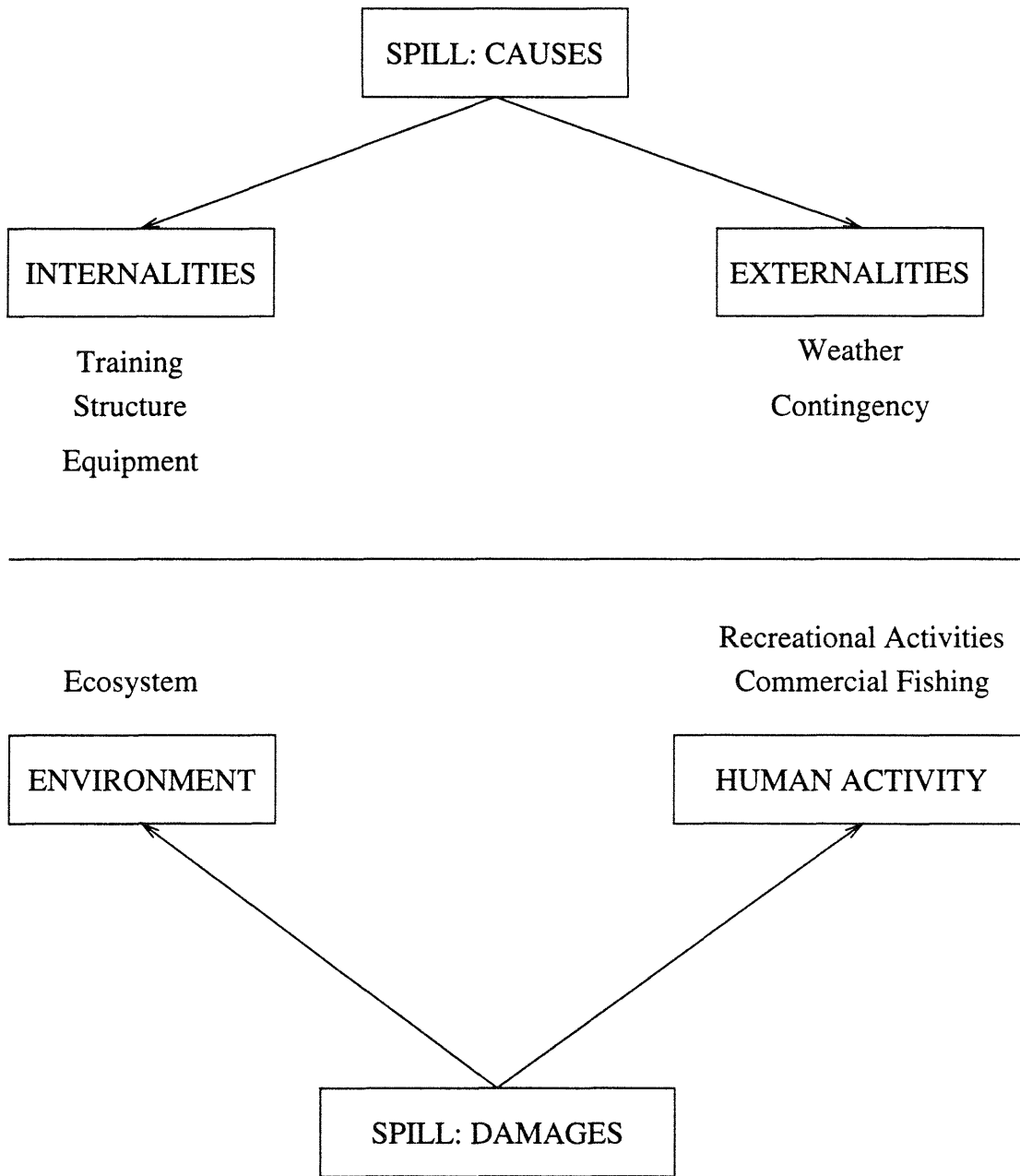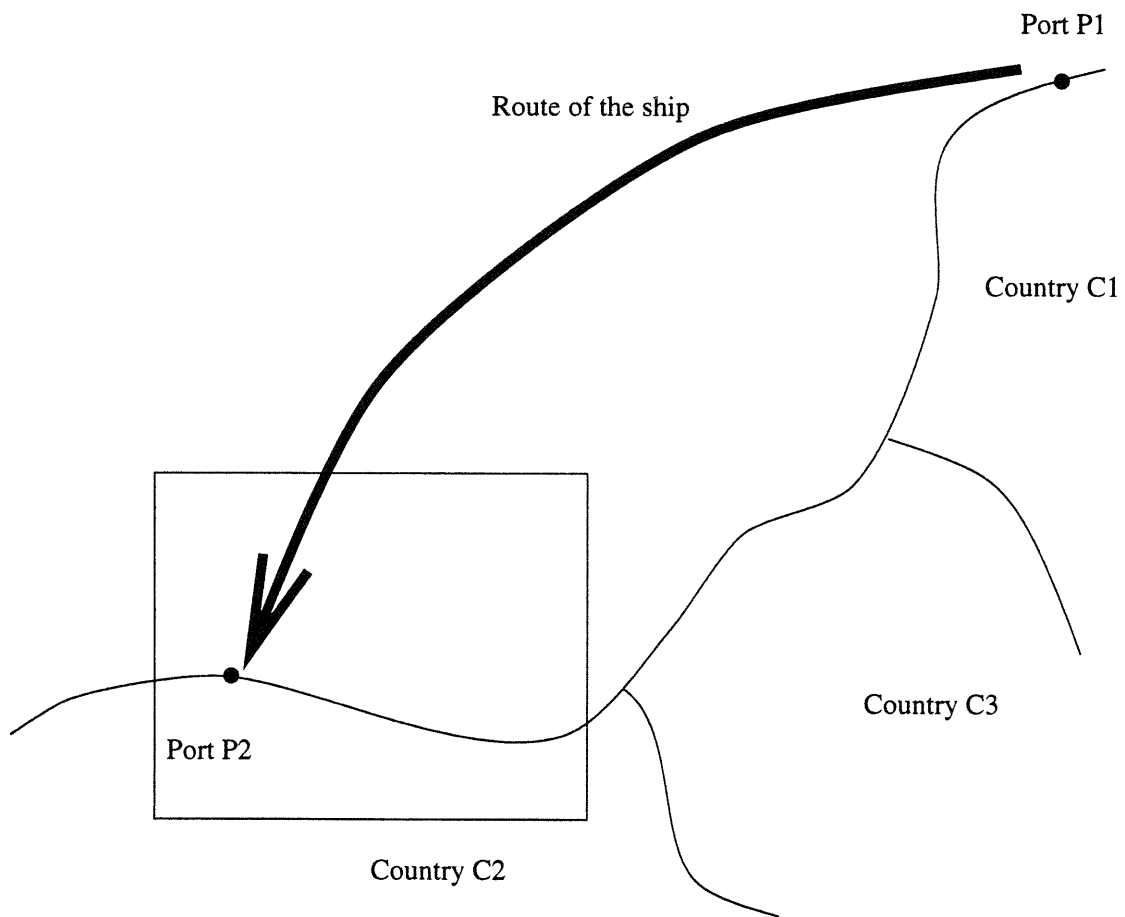
Figure 4-2: The problem of oil spills

Figure 4-3: Macro-situation

into consideration are the countries whose waters the route crosses (and especially the countries of departure and arrival), the ship, and the locations of the sensitive sites along the route. Sensitive sites may be recreational areas, or whatever locations are valuable for human activities or may have existence value (a natural reserve for instance is valuable only because it is known to be there and people can visit it at will). When dealing with the ship, some sub-parameters will have to be looked at carefully, for instance the design of the ship, its age, the level of training of the crew, the communication equipment on board, and of course some data like its insurance coverage, and the financial statement of its operator. Concerning the countries, the parameters one should want to consider are for instance the legal framework (in case of lawsuit), and the existence of contingency plans.

The micro-situation displays the location of the spill, and the sensitive sites affected by the incident. For the purpose of this study, the following parameters will be considered: the recreational activities associated with the site, the commercial activities in the area (for instance commercial fishing), and the ecosystem as a whole. The ecosystem includes the fisheries (marketable or non-marketable species), all non-marketable species (fauna and flora), and the global quality of the site, that is all the factors such as water quality, state of the beaches, etc. In fact, the ecosystem value will be split into marketable value, and non-market value. The reason for this is to reasonably simplify the analysis, because with this approach it will be possible to figure out the value of the marketable part of the ecosystem, and the non-market value will be computed as a single figure for the whole site, and not for each of its components. In Section 6.2 and Appendix A, the description of several methodologies is made. Yet, this approach might easily be criticized, because the impact of the oil spill is not equivalent for each of the sub-systems of the ecosystem. But the present analysis should allow the possibility to refine the model by going to a more detailed level. Again, this is only a first approach.
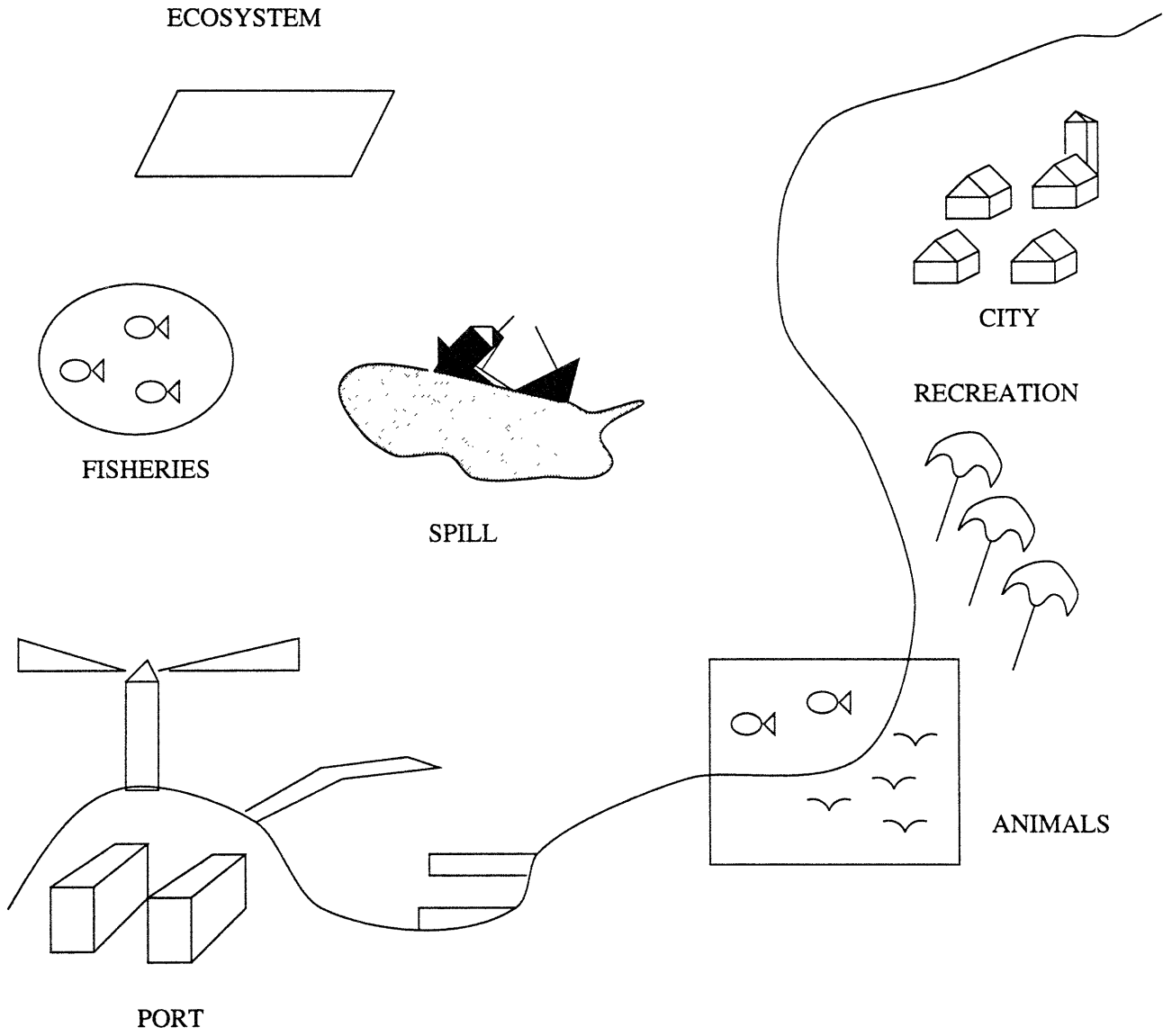
ECOSYSTEM

FISHERIES

SPILL

CITY

RECREATION

ANIMALS

PORT

Figure 4-4: Micro-situation

4.1.2 Evaluate the risks (weaknesses of the system, and possible outcomes)

Once the actors have been identified, the links between them must be established. This will involve the use of different economic theories, and valuation techniques. This step will be developed further later.

4.1.3 Do a sensitivity analysis

Since the parameters the analysis is based on may only be approximations or subject to random variations, it is necessary to estimate the relative impact of those fluctuations as regards the outcome of the model. For instance, it could be of interest to know the influence of a significant change of one or more parameters such as the age of the ship on the outcome of the model. This would be plugged into the process of simulation that will be described later. This analysis would allow a better understanding of the way the system works, and also it could provide justifications for focusing on several variables rather than others (for example, it is possible to determine levels of improvement (for instance: the thickness of the hull) above which no significant benefit can be drawn in the studied situation).

4.1.4 Adapt the model for different situations

Even if the model presented before seems to be simplistic, it can easily be upgraded by the addition of new parameters or by the use of other valuation techniques. The main advantage of the scenario is to be as compartmentalized as possible, so that one can modify one parameter at a time in order to get a more precise result.

4.2 Integration of the scenarios in the process

Now that a situation (or scenario) has been defined, the following section will describe the point of this chapter: a proposed methodology to measure the efficiency of the alternatives in a given situation. For the concept of scenarios, the following method will be used: for a given scenario, the relative efficiency of the different alternatives will be measured. By efficiency, it is assumed that no economic consideration will be taken into account, only the amount of oil spilled in the scenario[1]. Besides, scenario in this section means what happens to the ship (i.e. the cause of the spill), and not the location of the incident.

At first, it is necessary to define a four-dimension space with the following variables:

x_1: Type of design.

x_2: Type of equipment.

x_3: Level of training.

x_4: Amount of oil spilled.

We have the following relation:

$$x_4 = f(x_1, x_2, x_3)$$

Function f depends, as mentioned before, on the given scenario.
Nevertheless, at this point it must be understood that the efficiency of the equipment on board depends also on the level of training of the crew. Therefore, a relation of the form

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[1]The cost of the spill is only a function of the amount of oil spilled. This cost may vary due to external conditions such as the sensitivity of the environment, but those factors will be taken into account only in a later step
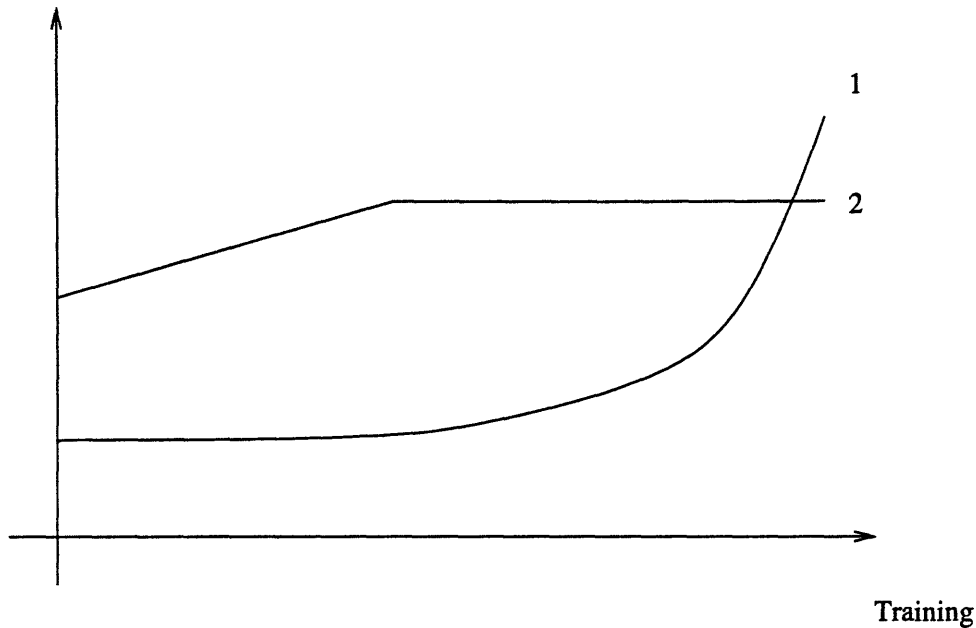
Efficiency of equipment

Figure 4-5: Level of training

efficiency of equipment=g(x_3)

can be derived. In Figure 4-5 are shown some possible curves for function g. Curve 1 might describe a high technology equipment, for which efficiency is low and remains constant at the beginning, and then increases faster after a certain level of training. Curve 2 might represent a more basic technology, for which efficiency increases fast, and then remains constant over a certain level of training.

Or, it is possible to adapt a piece of equipment to the way it is used by the crew (which does not mean the reliability of the equipment is not taken into account). Thus, the problem is redefined as follows:

Y: Amount of oil spilled.

y_1: Type of design.

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y_2: Efficiency of the equipment, as a function of the level of training.

This relies on the fact that training and design are not related. And, if only one type of equipment is considered at a time, the problem is reduced to a three-dimension space with the equation:

$$Y = h(y_1, y_2)$$

where y_1 and y_2 are independent variables. y_2 is a continuous variable. y_1 is a simple designation of the type of design, therefore it is possible to simplify the notation by using the following formula:

$$Y(design, equipment)(x_3) = g(x_3)$$

where x_3 is still the level of training, and Y the amount of oil spilled.

Note that $g(0)$ is the amount of oil spilled if no equipment is used, that is the efficiency of the design by itself.

As a conclusion, Y for a given design and a given piece of equipment is a function of the training only (a function which is different for each scenario).

Then, it is possible to compare all the combinations of designs and equipment in a given situation (i.e. for a given scenario), and the results will be summarized in a table like Table 4.1.

The amount of oil spilled Y is the bottom line for each scenario. The assumption is that given the design of the ship and the equipment on board, in a given situation[2] Y is a function of the training only.

The amounts figuring in Table 4.1 are calculated by simulations and theoretical models. For instance, in Lenselink, Thung, Stipdonk, and van der Weijde [7], a

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[2]A situation consists of a type of accident (collision, etc.), and a set of externalities (weather, etc.)

	Single Hull	Double Hull	Double Bottom	...
Communication System	x tons			
Fire Prevention System				
...				

Table 4.1: Effectiveness of alternatives

numerical methodology for the simulation of the dynamic events of collisions where a double hull tanker is struck by another ship is studied. [7] focuses on several scenarios:

- Collision between two tankships;

- Collision between a tugboat and a tankship;

- Collision of a tugboat with a rigid structure (bridge pile).

In the first two cases, four different experiments were conducted (with different collision angles and ship speeds). One of the conclusions of this study is that the extrapolation of computational results to other scenarios is difficult if not impossible. It shows that in this case, full scale experiments are the most reliable. Yet, they remain very expensive.

Finally, such devices as the Global Positionning System (GPS), and other navigation systems have to be evaluated, and integrated into the ranking process.

4.3 Other parameters

In this section, the parameters that are external to the ship will be studied. Those are of importance, because they may have an external influence on the probability of occurence of a spill (for instance, a pilot guiding a tanker in a port, and running it

aground), or they may be significant for the response to a spill (for example, clean-up procedures, and contingency plans).

4.3.1 Clean-up operations

Clean-up operations are part of the mitigation process. Many studies had been done on the efficiency of the numerous existing clean-up techniques. Past accidents have provided useable information on what technique should be used, and where. The only question remaining is the speed of reaction when a spill occurs, and the means that are within reach. Real simulations should be a good way to answer those questions, and therefore to evaluate what might be the actual impact of a spill in any location.

Besides, incentives should be provided to nation-states and tanker operators in order to promote the implementation of contingency plans to respond to an accident. This is a part of the prevention process, which is envisioned to be crucial in this issue.

4.3.2 Ports

The port system is a possible location for a spill, and therefore it could be included in what has been called a scenario. Nevertheless, because there are some important parameters involved in the port system that could be of importance in the determination of the probability of a spill, the port system is studied separately.

First, ports use equipment to help ship navigation, and therefore the reliability of the devices that are in operation is an element of the risk of having an accident.

Second, accurate mapping of the port surroundings is essential for precise and safe navigation. Regular updates are necessary to prevent groundings.

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Third, when a ship arrives into a port, it is then guided by a pilot. Captains are required by law to tell the pilot about any unusual handling conditions on the ship. But the pilot has no such obligation. Nevertheless, the captain remains the ultimate authority over the vessel. In each geographic area, pilots belong to associations, which hold the exclusive right to guide ships that enter and leave. In the US, there are two types of licenses for pilots:

- A federal license is required for piloting US-flagged vessels;

- A state license is needed to guide foreign-flagged ships.

The skill of the pilot is therefore an essential part of the navigation inside a port.

Fourth, inside the port, the tanker is escorted by tugboats in order to avoid problems of steering. There are two types of tugboats:

- Ordinary tugboats, which can only push the tanker;

- Tractor tugboats, which are more efficient, because they are able to control the moves of the tanker in case of emergency.

Thus, the type of tugboat a port is using could be either a kind of prevention measure, or a cheap but risky alternative.

Finally, for the US, a ship entering a port must provide a certificate of financial responsibility. This certificate declares who will pay the bill, in case of a spill. This is also a prevention measure, but it is only required in the US.

4.4 Conclusion

In this section, the process of ranking alternatives in different situations has been described. This is a necessary step in the implementation of the index. To be efficient, this process must include a definition of the typical locations where a spill may occur

(regarding the usual natural conditions, and the resources that can be potentially threatened), and it must also be performed in each different port, because of the specific characteristics of each port system. Finally, local infrastructure, and existence of contingency plans in any particular location are parameters of importance, because as part of the mitigation those plans can enable a reduction in the requirements needed to travel through the location.

Chapter 5

The future

In this section, the way the index should be implemented and evolved will be described.

5.1   Using the index

The use of the index involves different steps that are summarized below: it is a development of the basic concepts introduced since the beginning of this study, and particularly the "safety checklist" sketched in the second chapter.

Check the route: The first thing to know is the departure and arrival ports of the tanker.

Identify risks: Knowing the route, it is possible to identify the locations where a spill is more likely to occur (special geographic features for example), and the places where, if a an accident happens, a spill will have tremendous environmental effects.

Rank alternatives: Given that the situation is defined, then the ranking of alternatives can be performed. A better alternative may then be chosen.

Set a minimum grade: After an overview of the external factors such as the existence of contingency plans, a minimum requirement for the route can be defined.

An example of the use of this checklist is described in Section 6.1: the risk of the route is assessed, and some ideas about the kind of alternatives that should have been used are given. But, this remains an a-posteriori analysis: this should have been done before any accident could occur.

The next step is the real enforcement of this decision, which may be done by issuing permits for the route to approved tankers. This idea integrates many of the types of regulations already implemented: for instance, Certificates of Financial Responsibility and design requirements (such as those set by OPA 90) may be part of a list of requirements needed to travel to a location. In fact, each location should provide "packages" of requirements for the tankers.

The enforcement is a difficult task, but it seems necessary to provide some organizations (like the Coast Guard in the US) with adequate means to force compliance, and also to track non-compliance.

Moreover, it is at this stage that the definition of adequate risk-management strategies described in Chapter 3 comes into play: policy-makers will have to choose the best way to implement the alternatives suggested by the results of the checklist, and the way to do that is to use the AHP described previously.

5.2 Evolution of the index

5.2.1 Integration of new parameters

Nevertheless, as technology is always evolving, as well as the relative strength of the stakeholders, the index should be able to change.

The integration of new parameters can simply be done by the comparison process described in the previous chapter: once a new alternative is identified, it should follow the process previously described, and ranked among the other possible alternatives.

New technologies

Concerning the evolution of technology, the following fields must be investigated:

Navigation systems   Among the current devices that are under development or about to be installed are the Electronic Chart Display and Information System (ECDIS), and the Differential Global Positioning System (DGPS). Those will probably improve safety because of more precise navigation parameters, and will also have a low cost of operation, due to increased automation. Nevertheless, they will require special training of the crews. In terms of the tractable/intractable parameters approach described in Chapter 4, those devices will lower the risk associated with the intractable variables.

Communication systems   Satellite communication is currently being developed, and it will enhance communication between ships and between ports and ships.

Vessel traffic control   Controlling all the ship's navigation patterns within an area is a way of preventing collisions. Thus, systems that can enable a port operator to do this are important factors of reduction of risk.

Terminal operations   Automation, or new techniques in terminal operations are likely to prevent mistakes in the oil charging-discharging processes.

Structure and design   Intermediate decks and other particular features may prove to be efficient in the future, therefore, those types of design must be studied as well.

5.2.2 International trends in the oil industry

Besides, another point of view (a far broader view in fact) is the prediction and analysis of the future trend in the oil and tanker market, in order to provide information to orient the decision-making process.

According to Drewry Shipping Consultants Ltd [3], the volume of trade will experience a rise in Middle Eastern crude exports. Over the next years, the increased demand for crude oil will be reflected in refinery rises in the Middle East, South East Asia, Far East, and North America. The declines in crude output from the US and the former USSR will be compensated by an increase in the output from the countries of OPEC.

In terms of trade, long haul movements from the Middle East will assume greater importance: 58% (935 million tonnes) of total world export in 1997 compared to 53% (791 million tonnes) in 1992.
Imports to South East Asia will rise by 45% between 1992 and 1997, 16% to North America, 15% to Japan and 11% to Western Europe.

In 1992, the largest crude oil trades were:

- From the Middle East to Japan, South East Asia, US East coast, Europe;

- From the Caribbean to the US East coast;

- From North Africa to North and South Europe.

The main growth in trade through 1997 will be seen in movements from the Middle East to Japan and South East Asia; and from West Africa to the US East coast and South Europe.

This kind of information may be useful to elaborate decisions in the long-term. Besides, as knowing the route of the ship and analyzing it is an essential task, the knowledge of what the oil industry will look like in the future is completely part of the idea of preventing oil spills rather than responding to them. Moreover, this fits into the definition of risky locations, as regards vessel traffic, and port operations. Thus, this an important input for building the safety index.

Chapter 6

Examples of use of the index

In this chapter, the index (and especially the checklist described in the previous chapters) will be used first in the case of the *Exxon Valdez*, and second in a general description of a scenario.

6.1 The *Exxon Valdez* case revisited

In this section, the checklist described previously will be used in the case of the *Exxon Valdez* accident, in order to show some of its advantages.

The different informations concerning the case where found in Reilly and Skinner [12].

The route: When the accident happened, the *Exxon Valdez* was leaving the port of Valdez, Alaska, on March 24, 1989.

Evaluation of the risk: The Alaskan waters are located at a high latitude. Prince William Sound is a semi-enclosed body of water. With more than 2,000 miles of shorelines, it is one of the largest tidal estuarine system on the North American continent. Besides, clean-up operations are difficult, due to the remoteness and features of the coastlines.

In the area are located the Chugach National Forest, and the Kenai Fjords National Park, two major natural reserves. There could be found many species of birds and marine mammals (23 species). Also, there are rich commercial fisheries (Pacific herring, Salmon,...).

The human activity within the area is mainly fishing. Two ports were the most affected by the spill: Cordova (third port in Alaska (for the $ value of fisheries), ninth in the US), and Kodiak (first in Alaska, second in the US). Cordova and Kodiak together represent $174 million in 1987: 18% of Alaskan catch, 6% of US catch.

About one third of the Alaskan fishermen (which represents about 12,000) were working in the area at the time of the disaster. Moreover, from 3,000 to 4,000 people are employed by the fish processing industry. Therefore, the destruction of the ecosystem is also an economic catastrophy for the local community.

The next step in the index is to choose the best alternatives. Given that the contingency plans could not be as efficient as in other areas, due to the remoteness of the site, high standards of performance should have been required. Besides, the particular geographic situation of the port of Valdez seems to ask for precise navigation: mapping is here an issue of importance.

As a conclusion, this combination of a fragile environment, and the difficulty to respond adequately to a spill is a good reason to require high safety measures on the ships traveling in the Alaskan waters. This analysis could have prevented one of the worst spills in the history of tanker operation.

6.2 Illustration

In this section, the principles developed in the previous chapters are going to be illustrated by the building of an example. This example will remain very simple, but complexity is not an issue for the moment, the objective here is to show how the model works. The goal of this section is mainly to show what kind of parameters can be found in the description of a situation. It will also provide tools to assess the risk of this situation.

As explained in Section 4.1.1, the study is split into two sub-scenarios: the micro- and macro- situations. This separation will be kept, and the links between them will only be drawn at the end.

6.2.1 Description of the accident

In this section, we are going to focus on the spill itself.
Here is the scenario:

The facts

A single hull tanker, on its way to a port terminal suffers a violent storm, and grounds near the shore of a little recreational station. A spill then occurs. Clean-up operations are organized almost immediately.

The location of the spill

The little city next to the location of the spill is mainly known for its beatiful beaches, and the diversity of its fauna and flora. This is a place far from industrial areas. Moreover, it is a good place for boating and fishing. For all those reasons, many tourists come there each year to spend their vacations.

Aside from the recreational activities (which take place mainly during the summer), the local community takes benefit from the prosperous fishing grounds near the shores (fish and shellfish).

6.2.2 Impact of the spill - Qualitative approach

Before doing any qualitative study of the problem, one has to identify the variables that are playing a role in the assessment of the damages. The following is the list of these relevant parameters:

l_i: number of inhabitants during winter (i.e. local community)

l_t: number of tourists (during summer)

l_l: number of tourists after the spill - lower bound

l_h: number of tourists after the spill - upper bound

I_t: average income to the station per tourist

I_f: annual income of the fishing community as a whole

T_t: time to return to a stable level of tourism

T_f: time to return to a stable level of commercial fishing

Impact on recreational activities

The first assumption that will be made is that the local community does not change after the spill, that is l_i remains constant. The impact of the spill on recreational activities will be shown by the evolution of l_t and I_t. Also, the determination of T_t is crucial for the study.
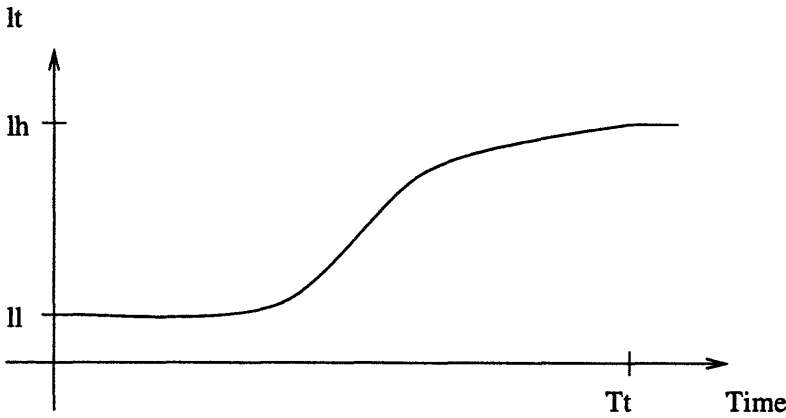
Figure 6-1: Level of tourism

The total income of tourism per year is given by $l_t * I_t$. The level of tourism l_t, as well as the average income per tourist I_t are subject to fluctuations, due to the occurence of the spill.

For the purpose of this study, the following assumptions will be used:

- At $t = 0$, that is just after the spill, the level of tourism falls to l_l.

- After $t = T_t$, the level of tourism remains constant at l_h, and the income per tourist is stable at I_{tf}.

- $l_h \leq l_{t0}$, l_{t0}: level of tourism before the spill.

On Figure 6-1 one can see the suggested level of tourism after the spill. The shape of the curve models an increase in tourism that starts slowly the first years, then grows a little faster, and finally reaches a plateau around T_t. After T_t, l_t remains stable at l_h.

The evolution of I_t is modelled as follows (see Figure 6-2): the willingness to pay of a tourist for the site decreases rapidly at the beginning, and reaches a lower bound I_{tl}. Then it starts to increase, and reaches an upper bound I_{th}. This shape of curve can be justified by the fact that just after the spill tourists are not willing
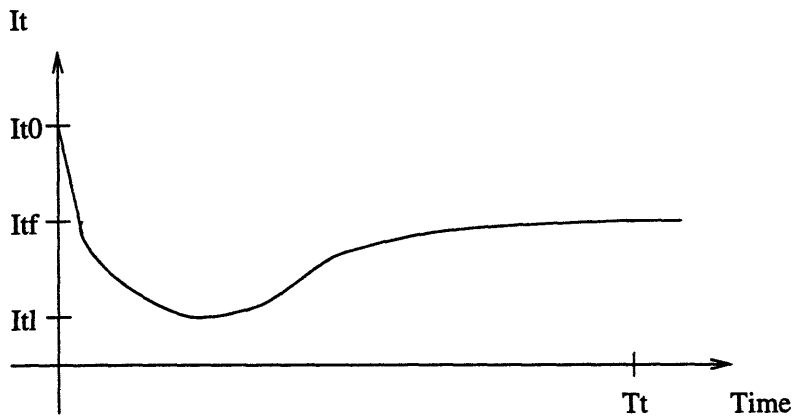
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Figure 6-2: Average income to the station

to spend as much time and money on the site as before, because it no longer offers as many services as it was able to, due to the pollution. Besides, as for the level of tourism, the upper bound is lesser than I_{t0}, average income per tourist before the spill.

Impact on commercial fishing

Similarly, on Figure 6-3 is represented the evolution of the total income of the fishing community after the spill. This curve should model the increase in the distance to reach new fishing grounds, and also the scarcity of fish. It is assumed that after T_f the income is stabilized at I_{fh}, which is lesser than I_{f0}, income before the spill.

Giving values to the parameters

All the parameters that have been previously defined must now be estimated. A way to do it is to look at historical data. It has been shown previously that the use of historical data is not a pertinent approach in building the index. Nevertheless, by comparing the situation described in this study to similar accidents in the past, it is possible to get estimates of the parameters needed in the calculations.
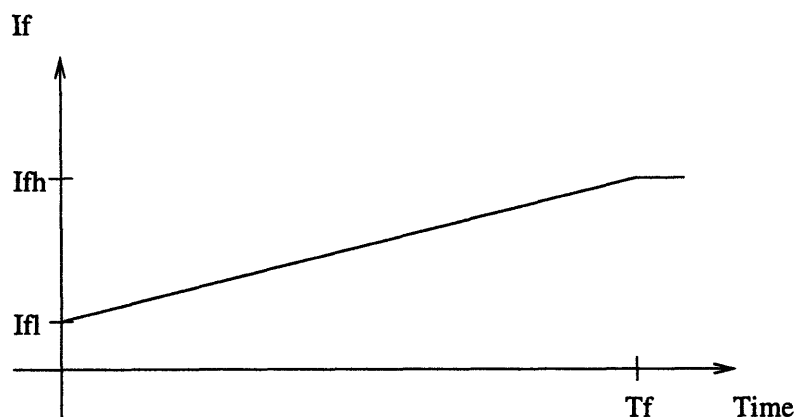
Figure 6-3: Income of the fishing community

Therefore, a first step should be to categorize past events in matters of locations and damaged resources, and then each new incident could be related to a similar spill in matter of impact. For example, assume that the situation described in this chapter is similar to the *Amoco Cadiz* spill in Brittany (France) in 1978 (same type of environment and recreational facilities). Then, all the informations that can be obtained can be used for the present case, after having been "resized" to fit into the scenario. For instance, in the *Marine Pollution Bulletin* [2] it is said that by the end of July 1978 the region of the spill had suffered a deficit of 1.5 million visitors out of an annual average of 5 million, that is a decrease of 70% in the level of tourism. Thus, it could be stated that in first approximation $l_l = 0.3 * l_{t0}$.

6.2.3 Estimation of costs

Writing a global formula

Now that the impact of the spill is somewhat determined, the next step is to integrate all the results in a single formula to obtain a figure for the estimation of the global cost of the spill.

The global cost is defined as follows:

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global cost = clean-up cost + loss in tourism income + loss in commercial fishing + overevaluation

The clean-up cost is a function of the volume of the spill, and some other factors like the methods employed, the time response of the clean-up teams, and the level of difficulty of the task.

To find the loss in tourism, one must first draw the curve of total income $(l_t * I_t)$. The loss in income is the area between this curve and the line $l_{t0} * I_{to}$ for $0 \leq t \leq T_t$. Yet, a discrete approach should be more appropriate, in order to be able to apply discounting methods.

The same method is applied for the loss in commercial fishing, by calculating the area between the curve I_f and the line $I_f = I_{f0}$ for $0 \leq t \leq T_f$.

The term "overevaluation" is used to take into account what happens after T_t and T_f. one can put under this term the valuation of the "moral prejudice" caused by the incident, or the loss of existence value of the site (this concept will be discussed later). Here is the way this overevaluation will be estimated in this study:

The terms calculated before at $t = T_t$ and $t = T_f$ are taken in perpetuity, that is divided by the discount rate r, and discounted back to $t = 0$. This term may be calculated, even though in the very long-term the situation returns to what it was before the spill.

But, with this approach another concept has been introduced: the discount rate. And in fact, this is a real problem, because the determination of this discount rate is very difficult. The solution suggested here is to make the calculation for different discount rates (i.e. a sensitivity analysis), and find an adequate average of the values that are obtained.

Discussion

The global cost formula According to Pearce [11], the economic value of a natural resource is the sum of use and non-use values. The use value includes the direct, indirect, and option values. The non-use value is the existence value.

The direct value is basically the monetary benefit derived from the resources (in our case the income from commercial fishing and recreation). It is more or less easy to estimate.

The indirect value is the valuation of the resource as playing a role in the environment (that is having special functions, because being a subsystem within a larger environmental unit).

The option value is the willingness to pay to conserve the site for future use.

Finally, the existence value is what the resource is worth, if one thinks about it as an "environmental asset".

Therefore, in the previous analysis, the term "overevaluation" covers the indirect, option, and existence values. Their determination is difficult, and implies the use of questionnaires to assess the willingness to pay of consumers, or some other similar methods. The approach taken in the previous section seems to be simplistic regarding those complicated notions, but once again, the goal here is not to have precise figures, but to get first approximations to include in the model. The next step will be to refine the analysis to reach a higher level of accuracy.

The determination of the discount rate David W. Pearce states in [11] the problem of setting an appropriate discount rate.

In fact, discounting discriminates against future generations, because in this concept $1 in t years is worth $1/(1 + r)^t$, where r is the discount rate. But, when dealing with environmental resources, the problem is different from the question of the opportunity cost of capital for a firm: the environment has always the same value in

time. Thus, using a discount rate is like saying that the quality of the environment for future generations is worth nothing (or at least far less than this quality for us now) for us, when we are allocating our money.

Nevertheless, setting a zero discount rate (and therefore accounting for future generations) is not a satisfying method. An approach explained in Pearce [11] is to build a composite discount rate by taking into account some consumer and producer discount rates. This relies on the use of contingent valuation techniques.

Back to the scenario

The previous discussion should lead to a cost for the spill. This figure should be adjusted, because the approach used before is very simplistic.

In fact, this is what happens without the index. Now, what the use of the index can change will be described.

6.2.4 Improvement brought by the Index

In the previous sections, the route of the ship has been studied, and the risk presented by the location described is in fact evaluated by the figure that has been obtained at the end: the natural resources near the arrival port cannot be neglected.

The use of the index would have required a look at different alternatives concerning the ship. For instance, it seems reasonable to think that near the port an improved communication system, or an accurate mapping of the coastline is necessary. It is likely that the ranking of alternatives should have showed those would have reduced the risk of spill.

But, there is no certainty, and it is not possible to say that such a piece of equipment would have prevented the spill for sure. Nevertheless, the use of the index has at least the advantage of showing where the risk is (that is to make people think about it), even if it cannot make it disappear completely.

6.2.5 Conclusion

In this section, a very simple illustration of how the index works has been made. The economic assumptions that have been used are very simple and do not describe reality accurately. In Appendix A, some economical theories already developed will be explained. A more precise study should of course require the integration of the concepts described in those.

Chapter 7

Conclusion

This study has shown that although oil spills are a real threat to the environment, the decision-making process involved with the problem has demonstrated serious flaws. No real long-term strategy has been built yet, and huge spills have only led to precipitous and less than efficient regulations. Moreover, the complexity of the oil industry with its numerous stakeholders makes it difficult to target the necessary actions for the prevention of spills. Finally, since the environmental response to a spill is highly variable, the assessment of the potential threat a spill can represent in any area is difficult, if not impossible.

The suggested approach to cope with all those difficulties is the Safety and Environmental Index described in this study. The two advantages of this tool would be to:

- Simplify decision-making for the operators of ships and ports regarding the alternatives that are offered to them, and the improvements that can be made. This will be done by the systematic use of cost-benefit analysis, as well as the setting of minimum efficiency requirements.

- Allow consistent policy-making for governments and international organizations by the rationalization of the linkages among the stakeholders, and the understanding of the means to control those stakeholders.

Nevertheless, in order to work efficiently, the index must be an international standard, and as so, it must be agreed on by all the stakeholders. If it is to be only a local experiment (such as OPA 90 for the US), it is also likely to work, but it would create an imbalance such that the countries enforcing it could become isolated in the oil industry.

Appendix A

Some economists' points of view

In the literature, many examples of valuation of natural resources can be found. Two studies have been chosen for their relation to the subject, and are described below. The first one shows what can be done when one wants to study a specific site: accurate measurements, and the use of well-adapted resources (databases, numerical models, etc.) are the main characteristics of this type of study. In fact, this approach fits well into the concept of situation described in Chapter 4, because it is obvious that the most efficient alternatives to prevent a spill in a given situation are really found when the methodology is applied to the real case itself, and not to a situation that is supposed to be equivalent.

The second study is a more theoretical one: economic methodologies are explained. In theory, they are perfect, becausethey address the most extensive set of parameters that can be imagined. But the problem is that going from theory to practice is difficult, and it is sometimes better to have less precise theories but readily available rather than complete theories that are too difficult to apply.

- In Wilman [14], a case study of the valuation of the cost of oil pollution is done. The situation described in the case is the probable impact of a spill on recreational areas, a spill likely to occur because of offshore oil development and

production nearby.

The case study presents an interesting approach to the problem of oil spills. it is stated that for the problem of the estimation of costs the use of statistical dose-response models are very practical, because they treat the natural system as a black box. But they are really difficult to implement, because their major drawback is the absence of appropriate and sufficient data to estimate the changes in the system.

Therefore, the author takes another approach: a hedonic model combined with an oil spill risk analysis model. The hedonic model[1] is primarly concerned with the determination of the magnitude of external costs from pollution, whereas the oil spill risk analysis model simulates the probable occurence of the pollution.

The hedonic model is used because it appears that the market for tourist accomodations fits the theoretical structure of the hedonic model, and the type of data needed for the model are available at a reasonable collection cost.

The oil spill risk analysis model consists of a computerized model that analyzes the probability of oil spill occurrence and of paths a spill may take (in this case study, the model is designed for Georges Bank, off New England coasts). The estimation is based on data on the anticipated level of oil production and the method and route of transport.

All this leads to the building of consumer and producer functions in market equilibrium, which are used to obtain quantitative results for the costs of pollution.

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[1]The hedonic price method is an attempt to estimate an implicit price for environmental attributes by looking at real markets in which those characteristics are effectively traded.

- In Freeman [6], a whole set of valuation techniques are described. To estimate the recreational use of natural resource systems, it is stated that a travel cost model should be used. This model is based on the recognition that the cost of traveling to a site is an important component of the full cost of a visit, and therefore any change in the quality of the site (for example, due to pollution) will be reflected in this cost.

But, this is not a simple methodology, and it implies calculation of willingness to pay and many other parameters.

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