# HUMAN FACTORS: ROOT CAUSE FOR ERRORS ACROSS INDUSTRIES AND PRODUCT FOR REGULATORY CONCERNS

By

ANDREA S. LAWRENCE

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1992

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1994

OKLAHOMA STATE UNIVERSITY

HUMAN FACTORS: ROOT CAUSE FOR ERRORS

ACROSS INDUSTRIES AND PRODUCT

FOR REGULATORY CONCERNS

Thesis Approved:

James J. Lawler
Thesis Adviser

Kenneth K. Eastman

Franz A. von Sauer

Thomas C. Collins
Dean of the Graduate College

# PREFACE

This study was conducted to (1) analyze current oil spill legislation for the insertion of proactive strategies which encourage the prevention of marine accidents, if any; (2) illustrate the commonality of human error factors, the cause of most high-consequence low-probability accidents (e.g. oil spills), across industries; and (3) suggest the usage of influence diagrams as an effective preliminary tool for identifying causal relationships in accidents. These diagrams would then aid in error analysis and the eventual development of error management programs. Two case studies: the sinking of the London Valour and the Bhopal explosion were reviewed to illustrate the need for human error control from all levels of operations.

Since the human error element exists in almost all technological processes considerations must be developed for the actual compression of its frequency and the containment of its consequences.

I sincerely thank my masters committee -- Drs. James Lawler (Chair), Ken Eastman, and Franz Von Sauer -- for their flexibility and support in the completion of this research. I would also like to thank Mrs. Beth McTernan for her continued understanding, encouragement, and input during the compilation of my research.

## ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to the following individuals for their support, guidance, and inspiration during the construction of my thesis:

1) To the chairman of my committee, Dr. James Lawler, for his patience and commitment in encouraging my performance during the preceding months.
2) to Dr. Eastman and Dr. Von Sauer, my other committee members, for their successful brainstorming sessions, and insightful suggestions into the holistic construction of my research.
3) to David Jones, Robin Lacy, Will Focht, and Ken Bosma, personal friends and confidants, for their unique assistance, intuition, and humor.
4) to all the people who took time out of their schedules to discuss various opinions and ideas and to those who sent me piles of information without hesitation.

I would also like to extend my special appreciation to Mr. Zbigniew Karaszewski, of the United States Coast Guard. His assistance in motivating my efforts in the past few months was invaluable in addition to being a constant source of encouragement and enlightenment. I probably will not heretofore meet a more generous, reliable, or considerate person.

Lastly I would sincerely like to thank my parents for their emotional and financial backing for the many years of my life. I am confident that my college graduation will proudly justify their ongoing support.

## TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

## INTRODUCTION

Currently, the United States consumes approximately seventeen million barrels of oil daily and oil imports have increased almost 35% since 1986.[2] The increasing cargo capacity of transportation vessels coupled with the increasing demand for oil imports has expanded the potential for more frequent marine accidents. In 1965 the average size of an oil tanker was 27,000 deadweight tons (DWT.) a fraction of the Exxon Valdez's 214,000 DWT. and the 500,000-ton supertankers now plying the seas.[1] The world fleet of 1969 was comprised of 6,103 tankers, 1,416 of those tankers were having accidents.[1] Reports, as early as 1970, have estimated that 5.1 million gallons of oil were accidentally discharged from tanker ships in U.S. ports.[1] It was calculated in 1983 and 1984 that 11,250 oil spills occurred annually in the United States. And tankers, oil terminals, and other oil transportation-related sources were the cause of 2.1 million metric tons (635 million gallons) of petroleum discharge into the marine environment.

These reports demonstrate the accelerating frequency of marine accidents and a trend of increasing oil transportation and consumption. It has been realized that increases in the transportation of oil potentiates increases in the risks for future spills. Expanding the number of vessels transiting a highly congested waterway can only serve as a catalyst for marine accidents. The actual oil spill however, is not the fundamental problem.

It has been estimated that 60 to 80 percent of accidents in complex systems, such as the maritime transport of oil, are attributable to human error.[3] Every activity conducted in any organization involves the human element, and in most cases it is the human element that is identified as the causative agent of an accident. Simple omissions of responsibility, miscommunication, or employing individuals unacquainted with operational procedures or equipment may be the origin of such errors. For example, an overflow of a filling tank during a bunkering operation caused a spill of 500 gallons of bunker fuel (heavy oil used to fuel tankers). An inspection determined that the spill was caused by the opening of an incorrect valve and that the inexperience of the crew was identified as a causative factor.[61] To prevent or reduce the frequency of like accidents the human error element must be addressed as the fundamental cause of most marine casualties.

Unfortunately, concerted efforts from the government, industry, and public to minimize the human error element when transporting oil have been incremental at best. Currently, governmental and industrial organizations are spending about 90 percent of their time and resources to perpetuate the status quo: oil spill response - containment and recovery; and about 10 percent on spill prevention; the key for protecting marine environments and organisms and promoting spill abatement.[37] While containment and recovery operations justify development and implementation, the benefit to society cannot solely depend on post-spill responses. Government and industry must develop proactive measures to control the frequency of accidents perpetuated by human factors. Proactive measures should incorporate pre-spill preparedness such as enhanced training and education requirements, national certification of corporate maritime transportation procedures, and provisions which take in to account human nature. Studies must also be conducted to fully understand the implications of human errors in highly technical environments. The results of such studies would enable government and industry to redesign processes and procedures which will minimize the occurrence and the effects of human malperformance.

Therefore, the focus of this study is to illustrate human error as a significant obstacle in oil pollution control. For the ease of display the research will be presented in three phases. The first phase evaluates the effectiveness of current oil spill legislation in actually preventing (not just deterring) error-causing behavior. Next an analysis of human error types and frequencies in other highly technical industries will be conducted. The purpose of this phase is to illustrate the ubiquitous nature of human error in various technical operations. Lastly, this study will offer the use of an influence diagram as a cost-effective corporate technique to assist in error detection and control management.

Hopefully, this study will stimulate discussion of oil pollution abatement through proactive legislation, emphasizing preventive mechanisms, and increased industry involvement towards the minimization of human-based accidents and their adverse impacts on the natural environment.

# CHAPTER ONE

## OPA 90:
## A POSSIBLE DETERRENT FOR OIL SPILLS

### Introduction

The purpose of this chapter is to examine the effectiveness of the Oil Pollution Act of 1990 (OPA) in curtailing or *preventing* the frequency of marine accidents (e.g. oil spills). The intent of the legislation is apparent; to significantly reduce the impacts of marine accidents on U.S. industries and shores. Legislatively, OPA appears to make great strides in minimizing the *degree* of oil spilled and its impacts on both economic and ecologic environments. What is lacking in the legislation however, is an obvious effort to ***prevent*** spills from occurring.

The most productive method used to minimize the frequency of oil spills is to address the fundamental cause of the majority of marine accidents; human error. OPA fails at identifying and responding to the reality that human error is the primary cause of 80% of marine accidents. Instead, it incorporates provisions that marginally deter actions involved in marine accidents. Therefore, the act's effectiveness in preventing accidents such as the Exxon grounding is partial at best.

The author intends to demonstrate these points by analyzing several sections within OPA that have been proclaimed as highly effective implements for prevention of marine accidents. These provisions however, are only activated in response to an oil spill. Therefore, the preventative qualities of the Act cannot stand by themselves to foster proactive action. They maintain a supplemental position in the fight for pollution abatement in marine environments. It is suggested the efforts of the Oil Pollution Act would best serve the public interests if prevention was the focal point of the legislation rather than reaction.

**Behind the Act**

In August of 1990 both Houses of Congress unanimously enacted the Oil Pollution of Act of 1990(OPA).[15] Public pressure and ecological concerns sparked by the Exxon Valdez catastrophe in March of 1989, prompted the expediency of the act's decree. Ironically, however, Congress had been considering oil spill legislation since 1975.[15]

For approximately fifteen years Congress had been working to consolidate and rationalize oil spill response mechanisms under various federal laws, including §311 of the Federal Water Pollution Control Act (the Clean Water Act- (CWA), the Deepwater Port Act of 1974, the Trans-Alaska Pipeline Authorization Act of 1973 (TAPAA), The Outer Continental Shelf Lands Act Amendments of 1978 (OSCLA), and the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA or Superfund).[15]

In 1980 Congress came close to passing comprehensive oil spill provisions as part of CERCLA, only to have those provisions omitted in the lame duck session that finally enacted CERCLA.[15] Instead of oil spill provisions, CERCLA contained a petroleum exclusion to make clear that oil spills were to be governed by a different statutory scheme. Given these inclusions the Oil Pollution Act of 1990 has been deemed, by some, a comprehensive and thorough program to resolve the difficult political issues that had hobbled effective oil spill prevention and cleanup efforts under the previous uncoordinated legal regime.[15]

It took ten years of deliberation and a catastrophic event on U.S. shores to initialize strategies for protecting marine environments: aesthetic, economic, and ecologic. The question however, remains: does the current statutory scheme offer substantial security for the prevention of marine accidents? Some may argue that OPA is a watered down attempt to reduce the frequency of oil spills, but does focus on increasing the amount of oil recovered.[62] If this is proven so, then little has been done to protect the quality of U.S. marine environments from the intrusion of continual oil pollution.

Only through legislative review can regulations be evaluated and redesigned to better serve their intended purpose. Studying the contents and the tone of the Oil Pollution Act should satisfy this concern. Do the provisions within OPA actively promote the prevention of oil spills or do they simply enforce demands on spillers after a marine accident has occurred?

**TITLE I - LIABILITY PROVISIONS**

The liability provisions outlined in Title I of OPA are patterned closely to those of CERCLA and §311 of the Clean Water Act. Compared to §311 OPA makes it easier for the government to establish liability against a party responsible for causing or contributing to an oil discharge to a substantial threat of an oil discharge.[15]

Defenses and exclusions to liabilities under OPA are more limited than those under §311 of CWA and under §107(b) of CERCLA.[15] Section 1003(a) of the Oil Pollution Act, as with most environmental legislation, absolves the responsible party from liability imposed by §1002 (Appendix A) if that party proves by a preponderance of the evidence that the incident resulted solely from (1) an act of God; (2) an act of war; (3)an act or omission of a third party; or (4)some combination of (1),(2), or(3).[46]

Interestingly, OPA omits an important Clean Water Act defense. Under §311(f)(1)(C) of CWA, "negligence on the part of the United States Government" is a complete defense if the discharge resulted solely from that discharge.[15]

This defense was obviously inspired by the inadequate efforts of the Coast Guard in its employment of the Vessel Traffic System (VTS) during the Exxon Valdez disaster (Because of budget constraints the Coast Guard neglected needed upgrading of the Price William Sound VTS. This allowed for its 30% operability rate and failure to identify and respond to the Valdez approaching glacial obstacles in the traffic lane).[32]

In review of these liabilities no real incentive has been established within the legislation to actively promote preventive procedures. The monetary figures associated with liability issues must bear a significant penalty in order to foster prevention. If liability costs are marginal compared to the costs of compliance, deep pocket companies could simply choose to pay cleanup costs rather than redesigning their policies. For example, Ford Motor Company chose to compensate injured parties when the Pinto's gas tank exploded upon impact in a rear collision. Given this corporate nature it is the responsibility of the legislature to stimulate preventative behaviors before the accidents occur. Would unlimited liabilities pressure companies into increased awareness of neglectful activities?

Some dispute that liabilities in response to marine accidents should not carry any caps or limits (Table I). Those affected by the spill can see the importance of unlimited liability while those causing the spill are thankful for the limits imposed under OPA.

TABLE I.

**RESPONSIBLE PARTY LIABILITY LIMITS FOR TOTAL LIABILITY AND REMOVAL COSTS PER INCIDENT**

| Vessel Size | Dollar liability limit |
|---|---|
| * $1,200 per gross ton | or |
| greater than 3,000 gross tons | 10,000,000 |
| 3,000 or less | 2,000,000 |
| any other vessel | 600/gross ton or 500,000, whichever is greater |
| on shore facility & deepwater port | 350,000,000 |
| offshore facility other than (DWP)** | 75,000,000 |

* figures are first calculated using $1,200 per gross ton; the liability limit will be set at the greater of the calculations

** DWP = deepwater port

**Data generated from the Oil Pollution Act of 1990**

These limits do not apply if the responsible party fails or refuses to (1)report the incident as required by law, (2)cooperate with a responsible official in connection with removal activities, (3)comply, without sufficient cause, with an administrative or judicial order issued under §311(c) or (e).[54] The waiver of the liability limit assures that enforcement of the removal orders is not undercut by the limit.

Since the Oil Pollution Act does not preempt state legislation responsible parties may be subject to additional costs required by state measures. Contrary, to industry dogma the non-preemption clause may serve as an impetus for the prevention of spills. For example, the liability limit for tank vessels is set at the greater of (1)$1,200 per gross ton or (2)$10 million if the vessel exceeds 3,000 gross tons and $2 million if the vessel is less than 3,000 gross tons. If a company satisfied the $10 million liability cap and was then sued under state legislation an additional amount comparable to or possibly exceeding the liability cap imposed by OPA could economically devastate smaller companies.

Advocates of non-preemption argued that the 24 coastal states that have oil pollution liability and compensation laws have benefitted from increased assurance of additional cleanup and compensation provisions outlined in OPA.[15] Moreover, victims of oil spills need some way to get beyond the limits prescribed by federal law to be compensated for their damages.[46] For without these provisions impacted communities would have no means of recovering their cleanup costs from an accident they did not create. California and

Washington have successfully enacted more stringent compensation laws than federally mandated and many more coastal states are to follow.

The liability provision is a significant mechanism within the Act because it wakens spillers to the extreme monetary responsibilities of negligent behavior. If OPA, in its original design, preempted state and international laws the teeth would have been taken out of the provision. After federal liability requirements had been met spillers would be able to leave a state's shores contaminated with oil without further liability. Fortunately, for coastal states this is no longer a major concern.

## CIVIL AND CRIMINAL PENALTIES

Before passage of the Oil Pollution Act, the penalties available to the federal government under §311 to punish unpermitted discharges of oil and hazardous substances had not been significantly amended since the early 1970's.[15] In view of the damages inflicted by the Valdez spill, the available penalties looked too weak, especially in comparison with other portions of the clean Water Act and other environmental statutes. Other examples of inadequate penalty requirements can be found after reviewing previous penalty assessments. For example, In the five year span of 1983 to 1987, 110 oil spills occurred off the coast of the state of Washington alone. The cumulative penalty figure for those 110 spills barely reached over $400,000 (Table II).[11] Today one spill can produce fines well into the hundred thousands of dollars.

**TABLE II**

**STATE OF WASHINGTON'S OIL SPILLS & PENALTIES ASSESSMENT FROM 1979 To 1990**

| Calendar year | Oil Spills Number | Oil Spills Dollars Assessed |
|---|---|---|
| 1979 | 8 | 6,800 |
| 1980 | 2 | 500 |
| 1981 | 9 | 17,750 |
| 1982 | 4 | 2,350 |
| 1983 | 15 | 20,850 |
| 1984 | 20 | 79,250 |
| 1985 | 19 | 24,950 |
| 1986 | 30 | 233,750 |
| 1987 | 26 | 77,200 |
| 1988 | 2 | 14,500 |
| 1989 | 3 | 45,000 |
| 1990 | 7 | 23,000 |

**Adapted from the Department of Ecology: Washington State 1991 Data Book**

Currently, three types of penalties, administrative, civil, and criminal, may be imposed on the owner, operator, or person in charge of any facility or vessel from which oil or a hazardous substance is discharged. Administrative penalties can range from $10,000 to $125,000 per violation. Civil penalties include: (1)$25,000 per day of such discharge; or (2) $1,000 per barrel of oil discharged, or per unit of the reportable quantity of the hazardous substance discharged.[54] These penalties can be quite prohibitive in that they are directly imposed upon the individual at fault. The proverbial corporate shield no longer protects the negligent worker. Violators are held responsible for their own actions which should inspire preventative mind sets.

These two penalty schemes can also be an effective tool for encouraging better performance among managers and subordinates within any echelon of the corporate ladder. It is the opinion of the author that the threat of potential criminal investigation and prosecution motivates increased awareness to detail and indolent behavior. Severe criminal penalties are available to punish violators under section 311 of the Clean Water Act (Table III).[15]

For negligent violations, penalties include a $25,000 fine and one year of imprisonment. For knowing violations, the fines are $50,000 and a term of imprisonment not to exceed three years. For "knowing endangerment", a violation that places another person in imminent danger of death or serious bodily injury, the fine is $250,000 for an individual, $1 million for an organization, and a term of imprisonment of not more than 15 years.[54]

TABLE III

**PENALTIES IMPOSED FOR NEGLIGENT AND KNOWING VIOLATIONS OF THE OIL POLLUTION ACT OF 1990**

| Violation | Penalty |
|---|---|
| negligent behavior | $25,000 fine<br>1 year imprisonment |
| knowing violation | $50,000 fine and up to 3 years imprisonment |
| knowing endangerment | $250,000 fine for an individual, $1,000,000 fine for an organization, and up to 15 years imprisonment |

**Adapted from the Oil Pollution Act of 1990**

Until the 1990 amendments of the Clean Water Act, the only criminal charge that could be brought for discharges to navigable waters was for discharging without a permit.[15] These amendments give prosecutors much more to work with, and raise the stakes in criminal proceedings. Penalties of this magnitude coupled with other preventative measures could be a significant catalyst for promoting effective pollution abatement programs. Hopefully, the prospect of criminal prosecution for negligent discharges of oil will place a premium on diligent training and operations in the oil industry.

**Equipment Standards**

One of the most controversial topics of both legislative debates and the Valdez spill focused on the proposed effectiveness of double hulled vessels. Could the spill have been prevented if the Valdez was required to be a double hull vessel rather than a single hull? It has been speculated that the magnitude of the spill could have been largely minimized or even prevented with the insertion of a double hull.

Since the largest hole created by the grounding was sized at six feet in depth, the inner plating of the vessel would barely have been punctured (spacing between the inner and outer plates of twin skinned vessels is approximately six feet). Interestingly, however, before the Alaskan Pipeline was built an agreement had been made to Congress by the Interior Secretary, Roger Morton, that any newly built tankers used in the Alaska trade would have double bottoms.[8] The Valdez, a single skinned tanker would have been in violation of that agreement had it not been dropped as a result of pressure from the oil industry.

In support of the oil industry's goals, as with any industry, for yielding the greatest profit at least cost, tankers have been traditionally designed to carry as much cargo as possible into as little steel as possible. This idea has contributed to the manufacturing of ULCC's (ultra large crude carriers), such as Exxon Valdez, with a steel to cargo ratio of one to six.[8] Construction such as this perpetuates the vulnerability and increases the probability of tankers rupturing when coming in contact with stationary objects, hence illustrating the need for double bottom vessel design.

Documented incidents have proven that a second layer of steel on tanker bottoms significantly decreases the risk for loss of cargo when involved in a grounding, but do not prevent the accident from occurring. For example, in 1979 a double hulled tanker, El Paso Paul Keyser, ran aground in the Strait of Gibraltar at a speed of 17 to 18 knots.[8] The outer hull was torn out under four of the six cargo tanks, the inner hull however, only suffered a dent and retained all of its 95,000 cubic meters of cargo. In 1975 the Coast Guard determined that out of 30 oil tanker groundings resulting in spills 28 (96%) could have been prevented if the vessels were designed with double hull construction.[8]

As with any preventative measure required by governmental action, industries have several arguments discrediting the propositions. In this case the oil industry offered two objections to the twin skin design. The first is that an explosion could occur if gasses escaped into the vacant area between the inner and outer plating. As to date however, not one explosion has been attributed to twin skin design even though 530 tankers have them.[8]

Secondly, industry claims that if water by chance entered the space between the inner and outer plating it could cause the tanker to loose buoyancy, increase its difficulty for salvage (the actual removal of the ship from the accident site), and possibly cause it to capsize. In the case of Exxon Valdez it has been estimated that the Valdez would have lost 60% less oil had it been double hulled.[8]

Section 4115 of OPA establishes the double hull requirements for tank vessels.[54] Various designated vessel standards have been outlined for a timely, guideline for the phasing out of single hulled vessels (Appendix B). For example, if a vessel is of at least 5,000 gross tons but less than 15,000 gross tons and is 40 years or older with a single hulled bottom it may not operate in the navigable waters of the United States after January 1, 1995.

An inverse relationship exists between the tonnage increase of single hull vessels and the age of the vessels when determining the permissibility of operation in the navigable waters of the United States. In the case of a single hull vessel which is at least 30,000 gross tons and 28 years old it too may not operate upon the navigable waters after January 1, of 1995. All vessels that have a single hull will be restricted from operation upon the navigable waters by January 1, 2010.[54] Double sides and double bottom vessels, different from double hull, are to be completely phased out by 2015. The significance of the double hull design is that it requires the phasing out of unsafe vessels from sailing U.S. waterways.

Opponents of the double hull design offer the hydrostatic balance concept (HB) as a more economic and effective alternative to the costly double hull design required by OPA. This design reduces the size of the cargo in order to cause an ingress of water instead of an outflow of oil in the event of a breach in the vessel's skin.[42] More water pressure is exerted from the ocean onto the hull than is exerted from inside the vessel onto the ocean. This allows for an influx of sea water and prevents the vessel from losing its cargo. The reduced carrying capacity of this design would ultimately increase the amount of vessel traffic in an already congested transportation system; thereby, increasing the probability of more frequent marine accidents.

**Vessel Personnel Standards**

The vessel manning, equipment, and construction standards are imposed through amendments to numerous provisions of the navigation laws in Title 46 of the United States Code.[15] These provisions largely reflect the public's perceptions that alcohol problems, coupled with chronic understaffing on tankers contributed to the Exxon disaster. This also supports the idea that Oil Pollution

Act was largely enacted to satisfy austere public pressure for action.[15]

Under Title IV, OPA demands tighter controls on the licensing and acceptance of crewman and revamps traditional procedures involving vessel employment. As a result the Coast Guard's authority has been expanded to include checking the qualifications and performances of crewman and officers of vessels within U.S. jurisdiction. It is currently required that an individual applying for a license, if applicable, make available any information about drunk driving from the National Drivers Registry and about prior criminal records; the applicant must also submit to drug and alcohol testing. A five-year term limit, paralleling that also required for terrestrial transit, for licenses and certificates replaces the traditional indefinite licensing term. Periodic license renewals, retesting of licenses for drug and alcohol abuse, and rechecking for criminal records and drunk driving convictions is now required. Section 4102 makes it easier for the Coast Guard to suspend, revoke, and terminate, licenses and certificates for drug and alcohol abuse, negligence, misconduct, or incompetence.[32]

One of the major issues in the Valdez case was that the crew member attending the autopilot on the bridge was not properly licensed for his duty. How many other marine accidents were caused by unqualified under-the-influence crewman? To answer this question the Seattle Times and the Coast Guard conducted a timely study analyzing the number of crew members drunk on duty. It was found that of the 92 merchant ship-crew members involved in alcohol-related cases between 1984 to 1989, 86 (approximately 95%) were proven intoxicated.[1] Penalties included the suspensions and revocations of licenses, and probationary measures (Figure 1).

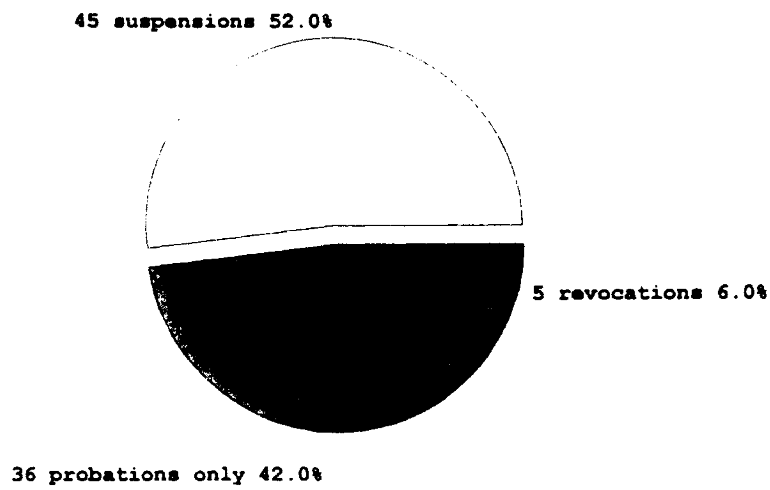


Figure 1. Penalties Imposed for Alcohol Related Cases Between 1984 and 1989. (Data Adapted from the State of Alaska Final Report, February 1990)

It is obvious that the insertion of the enhanced vessel manning requirements is fundamental to the safe passage of vessels.

**Discussion**

Most of the above provisions serve as mere deterrents to pollution, but are significant measures to inspire spill abatement activities. To be considered truly proactive, legislation must address problems at the fundamental level. What causes the need for regulation; the spill itself or the frequency of the event? These are questions that should be adequately answered prior to the construction of oil spill legislation. The Oil Pollution Act would seem to have covered all concerns regarding "what to do about oil spills". The ideas however, governing "what to do to prevent spills" have not yet been developed. Therefore, a few significant steps are missing from the process required to reduce the frequency and amount of oil spills.
Some suggestions follow:

(1) On a global scale, the unilateral actions imposed by the U.S. when designing OPA ultimately weaken efforts to promote consistency of international maritime trade. The unilateral decision to require a double hulled vessel in U.S. waterways could be construed as a discriminatory maneuver against developing countries. Their ability to compete in international trade would be significantly impeded. Should the United States be concerned with the ability of foreign countries to successfully compete in international import markets? Most certainly, the United States imports great quantities of petroleum annually. Most

of this resource comes from oil rich, but geographically poor countries. It would be in this country's best interest to maintain a positive international relationship between nations the U.S. depends on for oil. By excluding these countries from trade with the United States can only foster future ramifications.

It has been argued that U.S. law should provide for the protection of U.S. waters, resources, and regulatory standards regardless of whether international standards are consistent with them. While this point is acknowledged, foreign flag vessels violating U.S. standards frequent U.S. waters. It is far too easy for foreign flag ships to disregard U.S. labor laws regarding minimum competency standards for mariners operating on U.S. ships. The integrity standards for sea going vessels may also be compromised when allowing foreign flag vessels maintaining inadequate vessel performance standards into the ports of the U.S. The author believes it is congress' duty to remove isolationist views and accept the responsibility of promoting a global standard for transport. The United States can lead the global community by demanding universal standards of all vessels not only those frequenting U.S. waterways. For example, if international standards of training were developed crewmen would be held accountable for their own qualifications and performances. Competition would arise between qualified individuals and better standards of performance, from deckhands to controllers, could be achieved.

By implementing unilateral legislation that does not allow preemption by international compacts or promote an international standard of safety/competency only hinders the movement for increased participation both globally and nationally for pollution abatement during the transport of oil.

(2) Many of the provisions previously discussed in this chapter (e.g. liabilities, penalties, and vessel equipment) were designed with the assumption that a marine casualty had ensued. For the Oil Pollution Act to be considered a proactive piece of legislation it must require action prior to an accident. Liabilities and penalties would be mute issues for vessel owners if marine casualties did not occur. A more efficient and economic solution to the double hull controversy would be to focus on the reduction of collisions, groundings, and strandings rather than concentrating on providing extra protection for a damaged vessel. Simply requiring post-spill action does nothing to prevent the continual polluting of our marine environments.

(3) OPA does not address human error as a primary cause of marine accidents. Factors such as inattention, fatigue, and communication barriers when using crews of different nationalities create a range of conflicts that

undoubtedly lead to marine casualties. More regulatory emphasis must be attached to the reality of the human error element in high-consequence low-probability accidents. The focal point of the legislation must be directed toward the source of the problem; human error resulting from poorly qualified, inattentive, and inadequately trained crew members. Therefore, the implementation of advanced training programs and competency reviews/tests (including literacy tests) must be seriously considered.

Provisions are included in both the Occupational Safety and Health Act (OSHA) and the Superfund Amendments and Reauthorization Act (SARA) that require the development and implementation of programs for the education and training of employers and employees.[44,45] These programs are aimed at the avoidance and prevention of unsafe or unhealthful acts within the working environment. Special emphasis is also required for such training and education with respect to hazardous chemicals. For example, under section 408 of the Toxic Substances Control Act (TSCA), a lead abatement worker training and accreditation program is established.[4] Other environmental legislation governing hazardous materials and procedures understand the importance of well trained employees. The Oil Pollution Act misses the mark by failing to require any kind of training mechanism to curtail marine accidents perpetuated by human error.

In view of federal inefficiencies the responsibility of spill reduction must reside with the private industries and nonprofit organizations. Afterall, it is the private sector who must hire, supervise, and train the seamen. And it is private sector who must insist on the highest standards of operation from our seamen, our shore staff, and our governing organizations.

# CHAPTER TWO

# THE HUMAN ERROR FACTOR: A TECHNOLOGICAL REALITY

## Introduction

This chapter intends to cover a wide range of issues regarding the occurrence of human error. Until recently the attributability of human error as a cause of low probability-high consequence accidents, such as oil spills, had been scarcely acknowledged. Today fortunately, many states and other organizations are calling for the investigation of this issue. Studies are being conducted to identify the commonality of human errors across industries. And the ramifications of such accident events to the natural environment are becoming more prevalent to the average public. Hopefully, this will inspire a more active effort to redesign those operations that require individuals to perform beyond their capabilities (e.g. acquired knowledge and skill needed to perform desired tasks expediently) and the natural constraints of human abilities (e.g. extensive work hours and number of tasks in one duty).

Realistically, the human error element cannot be reduced to zero probability, but it can be significantly controlled. By addressing human error control using a systematic approach, the safety, efficiency, and motivation of personnel can be improved, which will reduce the frequency of accidents perpetuated by human error. The Exxon Valdez catastrophe is a primary example of what human malperformance can produce for society (Appendix C).

The most effective way to reduce the risk of oil spills, and other human related failures, is by raising the level of human performance in every day maritime practices. New and creative incentives must be developed to increase personal and corporate accountability in ways that will result in higher levels of human attentiveness at every stage of industry practice.

**Errors Across Technologies**

Our infrastructure is the envy of the world and the systems upon which our nation depends are vast, interactive, natural and artificial. Theses systems provide and facilitate energy, defense, nutrition, extraction, production, transportation, communication, and growing quality of life.[27] Their demonstrated reliability is high, but when they fail, costs exacted in human, environmental, and economic terms as well as in quality of life can be immense.

The primary cause of their failure is human error. Approximately 60 to 80 percent of accidents in complex systems are attributed to human error.[27] Each year, a significant number of the oil spills reported to state and federal officials are directly or indirectly caused by human error factors. Ironically, government and industry are spending about 90 percent of their time and resources on spill response, and only about 10 percent on spill prevention.[38]

What are the causes of human error? It varies slightly from one industry to another because of differences in task designs and procedures. But significant similarities can be found after thorough investigation of error events. The Institute of Nuclear Power Operations (INPO) conducted a study of 180 nuclear power plant accident reports issued in both 1983 and 1984; 387 root causes were identified (Figure 2). It was concluded that 92% of the root causes were man-made. Of that 92%, 52% were attributed to human performance and 33% were caused by design deficiencies. A breakdown of the human performance problems included: deficient procedures and documentation 43%, lack of knowledge or training 18%, failure to follow procedures 16%, miscommunication 6%, etc. (Table IV).[47]

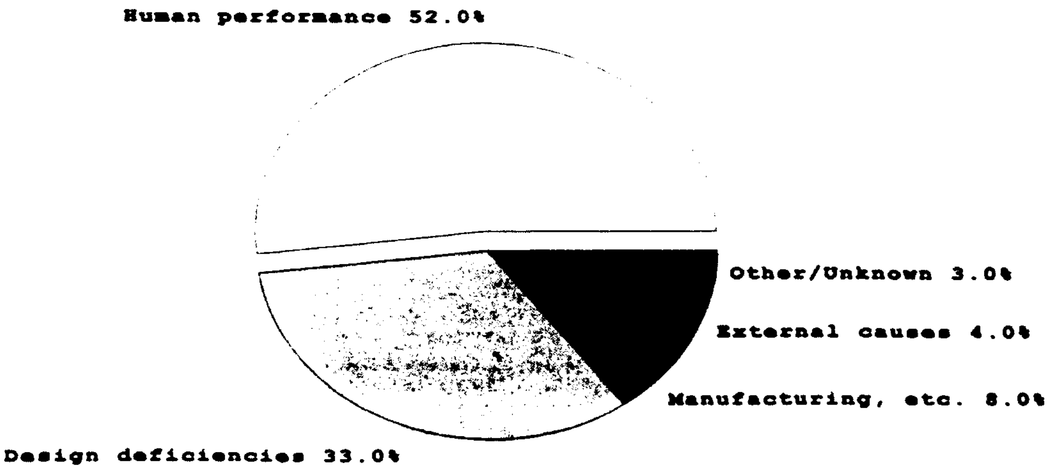


**Figure 2.** **INPO Analysis of 387 Root Causes Identified in 180 Significant Event Reports in both 1983 and 1984. (Generated from Human Error - J. Reason 1991.)**

**TABLE IV**

**A BREAKDOWN OF HUMAN PERFORMANCE PROBLEMS FROM THE INPO STUDY- 1983-1984**

| Human Performance Problems |
| --- |
| Deficient procedures or documentation: 43% |
| Lack of knowledge or training: 18% |
| Failure to follow procedures: 16% |
| Deficient planning or scheduling: 10% |
| Miscommunication: 6% |
| Deficient supervision: 3% |
| Policy problems: 2% |
| Other: 2% |

**Adapted from "Human Error", J. Reason - 1991.**

In an analysis of underground mining accidents, the listed causes of human error fell under six major categories: management, work itself, physical environment, social/psychological environment, equipment design, and worker/coworker.[27] Results of studies conducted from accident events during the transportation of oil in maritime operations yielded that 80 percent of high consequence accidents are caused by human error, with the remaining blame contributed to the environment. Of that 80 percent, approximately 88 percent were caused by operations which included society (culture), individual, organization, and systems.[23] Additionally, a pamphlet distributed by the State of Washington's Department of Ecology indicated that error factors were linked to insufficient training of personnel and included: inadequate knowledge of operations; or violations of procedures, poor communication during oil handling operations, improper monitoring designs, drug or alcohol abuse, overtired or overstressed employees, and lack of emergency preparedness.[10]

Most of these factors could certainly be ranked under the mining accident categories. For example, overtired and overstressed employees could be considered a viable listing under the "work itself" category. Studies have been conducted which indicate that workhours at sea are much more demanding and cause greater fatigue compared to working ashore. This heightened level of exhaustion is precipitated by the constant, almost imperceptible, movement of the working platform combined with external forces and internal vibrations.[62] This physical fatigue can be somewhat simulated through continuous physical activity under a hot sun. For example, a person working in the yard mowing, weeding, planting, etc. for several hours tires easily. The body becomes lethargic, reflexes dull, and mental attentiveness decreases. Crewman on board a vessel encounter similar physical reactions. Therefore, the relevance of fatigue as a common impetus for human malperformance should not be considered lightly.

Additionally, poor communication can be considered for the worker/coworker category and drug or alcohol abuse could fall under the social/psychological classification. These comparisons demonstrate that human error, ranging from simple fatigue and inattention to miscommunications from management, is a primary cause of accidents for all industries (Table V).

## TABLE V

## A COMPARISON OF CAUSES OF HUMAN ERROR AMONG THE NUCLEAR POWER, MINING, AND OIL TRANSPORT INDUSTRIES

| Industry | Error Causes |
|---|---|
| Underground Mining | management, work itself, physical environment, social/ psychological environment, equipment design, and worker/coworker |
| Oil Transport | society (culture), individual, organization, and systems, insufficient training, operations, procedure violations, poor communication, improper monitoring designs, drug/alcohol abuse, fatigue, inattention |
| Nuclear Power | procedural omissions, absent-mindedness, latent conditions not considered, lack of knowledge or training, deficient procedures and supervision |

**Adapted from "Human Error", J. Reason 1991.**

It has been mentioned that human error cannot be reduced to zero; we will always be victims of "normal accidents." This fact, however, cannot remit the worth of implementing vigorous programs of human error control aimed at reducing the frequency of human error and to contain its consequences. Human error should be able to be contained by designing, implementing, and managing effective, comprehensive error control programs that are also consistent with cost-effective demands.[27] Such applications are intended to improve plant performance by increasing safety, efficiency, and motivation of personnel; reducing the occurrence and consequences of human error; and reducing long-term operating costs. More specifically, human factors applications help ensure that personnel are not expected to perform with greater speed, accuracy, strength, or agility than they are capable of; can clearly sense, and can correctly perceive to interpret all information needed to perform assigned tasks; can remember relevant information not provided in the situation; can easily execute required actions; and are unburdened of needless mental or physical demands.[27] Therefore, serious accidents, like marine casualties, can be eliminated through the careful application of preventative countermeasures.

The best countermeasures for the prevention of human-based errors incorporate error control in disciplines of human engineering and human factors technology. This concentration is recognized to be essential for the control of human error in all modern systems; especially in the analysis of nuclear power plant failures like Chernobyl and

Three Mile Island. Error control reduces system operating costs and substantial paybacks can be realized through the reduction of costly catastrophic accidents. For example, the Chemical Manufacturers Association estimated that human error costs comprised $2 billion in property damage losses and severe injuries to hundreds of employees of the industry during 1985-1989.[27]

Efforts are being made which are changing attitudes toward the significance of controlling human related accidents and increasing knowledge about managing human and technical resources in an operational maritime environment. The U.S. Army in conjunction with the Department of Defense is working on methods to overcome human fatigue. The U.S. Coast Guard is also developing a total systems approach to the study of marine systems which will assist [illegible] the understanding of human factors that affect [illegible]mance and lead to marine casualties. Eventually [illegible]ledge gained will be applied to improve design, [illegible] staffing, licensing, and operational pr[illegible]

The Nuclear Regulatory [illegible]sion, however, has the greatest handle on the [illegible]. It believes that accident prevention is best ac[illegible]shed by analyzing, on a daily basis, every event th[illegible] occurred not just the errors. The significance of this procedure is to look for generic problems occurring within the system and determine the correctability of the errors. Series of events which falter the system are then more easily identified. For example, in the INPO analysis discussed at the beginning of this chapter only a relatively small proportion of the root causes (16%) were actually initiated by front-line personnel failing to follow procedures. By reviewing procedures on a daily basis failures such as these can be significantly controlled.

If it is impossible to guarantee the elimination of errors, then the development of more effective ways of minimizing their consequences in unforgiving situations is essential. By identify common or repetitious error events the consequence of the event can be somewhat predicted. Efforts can be efficiently tailored to reducing the impacts of the error event while the actual human error sequence is being analyzed. This step forward could stimulate similar activities on all levels of operations; governmental, industrial, public, and private.

**Latent and Active Errors**

Human error appears in many guises and has a variety of causes. It is not surprising that no single, universally applicable, error-reducing technique is available. But, by determining error types, patterns can be identified which will enable researchers to address workable solutions. Therefore, when considering the human contribution to system disasters it is important to distinguish two kinds of error: active and latent.[47]

*Active Errors*

Active errors are associated with the performance of the 'front-line' operators of a complex system: pilots, air/vessel traffic controllers, ship's officers, control room crews, etc. Their effects are felt and observed almost immediately after they occur. Therefore, it is presumed that the operators tend to be the inheritors of system defects created by poor design rather than main instigators of accidents.

Exceptions to this premise are violators of reasonably established standards, rules, or procedures. For example, when a competent individual in charge of operations makes a significantly poor judgement error the integrity of the system may still be intact, but adverse consequences may result given inadequate direction. This scenario can be epitomized in the decision events leading to the wreckage of the London Valour; April 9, 1970.[5]

**Case Study 1.** The London Valour was a modern steam powered bulk carrier of 15,947 gross tons and 593 feet long. She was registered in the United Kingdom and was equipped with the latest navigational gear including radar, all of which was operating satisfactorily. She was commanded by a competent and well regarded master aided by a chief officer, who had spent fourteen of his thirty years at sea and held a master's foreign-going certificate. The crew, which included fully qualified and competent officers and Chief Engineers, was deemed significantly seaworthy and dependable.

She was expected to anchor late in the day of April 7, off the coast of Genoa, and maintain her berth for the four following evenings. Only six shots of chain,(540 ft.), were paid out to port her anchor. At this point the Master should have considered lengthening the amount of chain, given the extended time she was to be at anchor, but to his remiss he omitted the action. Afterall, the weather was fine as she rode comfortably to her anchor; giving no cause for alarm.

Two days later, while the London Valour continued to ride peacefully to her berth, the Chief Officer noticed that the vessel had unexpectedly swung to a southerly heading. This change in direction brought the stern (rear) of the vessel closer to the nearby breakwater. The probability of the so far cooperative weather to deteriorate was noticed and expressed by the 2nd Mate. Later that afternoon the wind had picked up considerably and still nothing had been done about increasing the scope of the chain on the anchor.

Not long thereafter the Mate, noticed the ship had moved significantly in a manner at variance with her usual motion. It was found that the ship dragged its anchor onto the breakwater. The London Valour struck the breakwater and was driven along by the force of the wind and sea, opening large gashes in the hull causing her to sink within minutes.

The Court found great difficulty in understanding how a master with a distinguished record and vast experience could have failed to take the simple precautions that should have been second nature to him. As a result 20 of the 58 persons aboard the vessel lost their lives including the Master and his wife.[5]

The active errors in this instance were not caused by system failures. The ship's Master intelligibly misassessed the situation without any complications from technical or procedural failures. Therefore, the responsibility of human failure can often be attributed to individual negligence not just system inadequacies.

Active errors prompted by fatigue and inattention from crewman is another indication of personal malfunctions. Effectively reducing human errors of this type could significantly reduce the frequency of marine accidents when technical malperformance is not the root cause. Programs must be developed to analyze error events and determine root and subsequent causes of active errors. This procedure would enable management to differentiate the two primary causes of active errors, human malperformance and system inadequacies. As discussed, active errors are not the most prevalent nor the most troublesome of error types.

*Latent Errors*

Latent errors pose the greatest threat to the safety of complex systems.[47] The adverse consequences may lie dormant within the system for a long time, only becoming evident when they combine with other factors to breach the system's integrity. Errors of this type include poorly designed organizational policies, regulatory inadequacies, lack of performance reviews and reprimands from upper management, etc. The latter allows ill advised procedures to continually plague the systems' processes.

Most of the root causes of serious accidents in complex technologies are present within the system long before an obvious accident sequence can be identified (e.g. the active errors).[47] Operator's mistakes can be traced back to latent decision errors made in the higher echelons of the system long before an accident sequence even began. Therefore, analysts frequently give much misdirected attention to the occurrence of active errors in determining error sources.

By their nature, it is generally difficult to quantify the contribution made by latent errors to systems failures. An interesting exception, however, are those committed during the maintenance of nuclear power plants. Two independent surveys conducted by Rasmussen, 1980 and INPO, 1984 (previously discussed), indicate that simple omissions- the failure to carry out some of the actions necessary to achieve a desired goal - constitute the single largest category of human performance problems identified in the significant event reports logged by nuclear plants.[47]

Latent failures can also take many forms. They can be defined as an error or omission of responsibility that was committed prior to the start of the actual emergency and played a necessary (though not sufficient) role in causing the disaster. The Bhopal incident signifies this type of latency.

**Case Study 2.** On December 2nd or 3rd, 1984, a gas (methyl isocyanate MIC) leak from a small pesticide plant, owned by a subsidiary of Union Carbide Corp., devastated the city of Bhopal, India. At least 2,500 people were killed, and more than 200,000 were injured. Incompetent management, failed safety systems, and operator errors where a few contributing factors to the accident.

The obvious latent errors comprising this catastrophe are both disturbing and regrettably common. These errors are found in three primary categories: system, operator, and hardware (Table VI). The first, system errors, were those imbedded into the plant's processes long before the leak. For instance, management failed to update its safety program after encountering six prior accidents. This problem could have been controlled through the implementation of training programs to make the employees more aware of accident prevention. But, after reviewing the quality of the staff, advanced training would have been a waste of time.

The plant also employed and relied heavily on inexperienced operators and supervisors of a highly reduced staff. Even if the limited staff was highly qualified, the probability of them accomplishing all duties efficiently and correctly would be poor.

The internal make up of the Union Carbide plant in Bhopal, reinforces the idea that the greater the number of pathogens residing in a system, the more likely it will encounter the particular combination of triggering conditions sufficient to complete an accident sequence.[47]

**TABLE VI**

**ORIGINS AND LATENT FAILURES LEADING TO THE BHOPAL DISASTER**

| Selected Latent Failures | Origins |
|---|---|
| 1. **System Errors** | |
| Locating a high risk plant close to densely populated area | Government/Management |
| Poor emphasis on system safety; no safety improvements after adverse audits; poor evacuation | Management |
| No improvement in safety measures, despite six prior accidents | Government/Management |
| Safety measures not upgraded when plant switched to large scale | Management |
| Heavy reliance on inexperienced operators and supervisors | Management |
| Factory inspector's warning on washing MIC lines neglected | Management |
| 2. **Operator Errors** | |
| Reduction in operating and maintenance staff | Management |
| Using a nontrained superintendent for MIC plant | Management |
| Not operating warning siren until leak became severe | Management |
| Switching off siren immediately after starting it | Management |
| Failure to recognize that pressure rise was abnormal | Management/Operator |
| 3. **Hardware Errors** | |
| Refrigeration plant not operational | Management/Maintenance |
| No automatic sensors to warn of temperature increase | Design/Management |
| Pressure and temperature indicators did not work | Management/Maint. |
| Insufficient gas masks available | Management |
| No regular cleaning of pipes and valves | Maintenance/Mgt. |

**Data Generated from "Human Error", J. Reason 1991**

**Discussion**

The fact that accidents caused by human error are prevelent in most, if not all industries, should inspire added efforts to understand, manage, and possibly eliminate these causal factors. The challenge is not to just provide an account of how latent and active failures combine to produce accidents, but also to indicate where and how more effective remedial measures might be applied.

Through the study of human error events and consequences, better equipped designs for prevention management can be established. But where does the responsibility lie for requiring and enforcing human factor analysis?

Legislative, public, and private organizations must stimulate efforts in this direction to change the status quo: reaction to accidents that could have been prevented through simple alterations in function, methods, and programs. Until this concept is fully realized the natural environment and the health of living organisms will be adversely impacted by controllable error events.

# CHAPTER THREE

## INFLUENCE DIAGRAMS: A MANAGERIAL TOOL FOR ERROR DETECTION

### Introduction

To this point two key ideas have been discussed: the effectiveness or ineffectiveness of the Oil Pollution Act of 1990 in actively reducing the frequency of oil spills perpetuated by human error; and the commonality of human error accidents across industries. These two discussions have set the foundation for the contents of this chapter: the use of influence diagrams as a preliminary tool or a needs analysis for identifying common human and technical errors across similar accidents.

Research and expertise indicate that the majority of high-consequence low-probability marine accidents have one common theme: a chain of important errors made by people in critical situations involving complex technological systems.[47] By identifying the commonality of errors from accidents of the same magnitude analysts will be able to locate error patterns set within company procedures. Following the identification of these patterns the errors can be grouped into two categories: human/operational-based error and organizational/technical-based error. Human/operational errors can largely be corrected through well tailored training programs. Organizational/technical errors may respond better to system redesign or technical maintenance. After the review of such events solutions for error management can then be prescribed on a case by case basis.

Training can be a productive tool for error management if the error-training match is well researched, well designed, well implemented, and adequately reviewed for success. Failure in a training scheme can easily occur if the source and solution identified from the error analysis is mismatched. For example, if a bright, hard-working but functionally illiterate crewman fails to follow the correct company-designed safety policy and an accident follows, an advanced safety training program would be largely ineffective. However, enrollment into a literacy program usually offered by a city organization can vastly improve the performance of the individual and the safety of the crew.

Failures in performance may also stem from technical malfunctions. In cases such as these, training employees would do little to correct the fundamental cause of the accident. An analysis of the workings of the system must be conducted prior to addressing the human errors associated with the malfunction to overcome the obstacle.

Influence diagrams can be used successfully in the assessment of such errors. These diagrams are generic enough to cross industry barriers and simple enough to allow the nontechnical manager to actively contribute in the decision analysis.

### Influence Diagrams-Usage

Traditionally, influence diagrams are used to assess the probability of system failures given the presence of human and organizational errors. An example of users of influence diagrams includes studies conducted by Dr. W.H. Moore and Dr. R.G. Bea from the University of California at Berkeley. Their project team has developed a detailed statistical analysis which calculates probability values for system failures. A segment of this probabilistic model determines the set of possible initiating accident events ($in_i$) and final states ($fist_m$) of the system. The probability of lost components of the system can then be represented by the following equation:

$$p(lossk)=\Sigma_i \Sigma_m p(in_i)p(fist_m \backslash in_i)p(lossk \backslash fist_m).$$ [31]

The suggested use of the influence diagram for this research is to assist management in establishing the relevant contributing factors unique to specific accident sequences. This technique can identify a causal relationship between error events which may include errors solely caused by human malperformance, technical malfunctions or a combination of the two. A dependency relationship can then determine the degree to which errors, risks, and consequences may be successfully managed or controlled.

The diagram also gives insight to areas where more intensive study may be warranted. After an error sequence has been defined single error events along the sequence can be dissected to determine added error causes. Human error components can be identified as initiating or contributing to the accident sequence. For example, in the Chernobyl accident it was found that a valve malfunction was not detected because an indicator light had simultaneously malfunctioned. Was it the technician's responsibility to catch the operational malfunction or not. A summary of the accident indicated that it was a reasonable assumption that the technician or engineer should have tested the integrity of plant's safety operations. Without further investigation into this accident that human factor might have gone unchecked and might have remained in the system indefinitely, or until another catastrophe occurred. The detection of human-based errors can be more readily obtained through the use of influence diagrams.

The flexibility and generality of the diagram allows highly technical aspects to be removed as barriers for understanding causal relationships. This enables individuals from all disciplines of management to be included in the analysis and error management designs.

The diagrams should be constructed through the concerted efforts of various groups of specialists within the organization including: line managers, operators, engineers, top management, etc. These individuals should interpret and explain their incident reports in clear and unobtrusive language to facilitate a more user friendly diagram. The less diluted the description the easier the problem will be to identify across disciplines. Differences of opinions regarding the relationships between events and their causes inspire the development of more realistic and intelligible models.

**Modeling**

The first step in the analysis process is to identify the target event of the accident (for without one the analysis would be useless). The target event is the actual accident outcome (e.g. marine accident, vessel explosion, etc.). Secondly, dependencies must be identified between relevant events, decisions, and actions.[21] These dependencies include:

*Contributing/underlying* events, decisions, and actions:

- occur prior to the initiating accident event which contributes to the reduction of reliability or increase in risk for the system.

*Initiating/direct* accident events, decisions, actions:

- immediate accident events, decisions, and actions resulting in the casualty.

*Compounding or subsequent* events, decisions, actions:

- lead to subsequent errors which magnify accident consequences.

In the grounding of the Exxon Valdez these concepts can be readily presented. For example, the underlying and contributing factors of the disaster were caused by the vessel leaving the traffic lane to avoid collision with large pieces of glacial ice (Figure 3).[32] Secondly, the initiating or direct factor of the accident was the grounding itself. It was the immediate actions the crew and vessel engaged in prior to the loss of oil; the target event. Lastly, the compounding or subsequent events were those actions and decisions that increased the magnitude of the spill. Under Captain Hazelwood's command the crew attempted to pull the vessel from Bligh Reef after the grounding. (Its impact on the severity of the damage to the vessel however, is still disputed.)

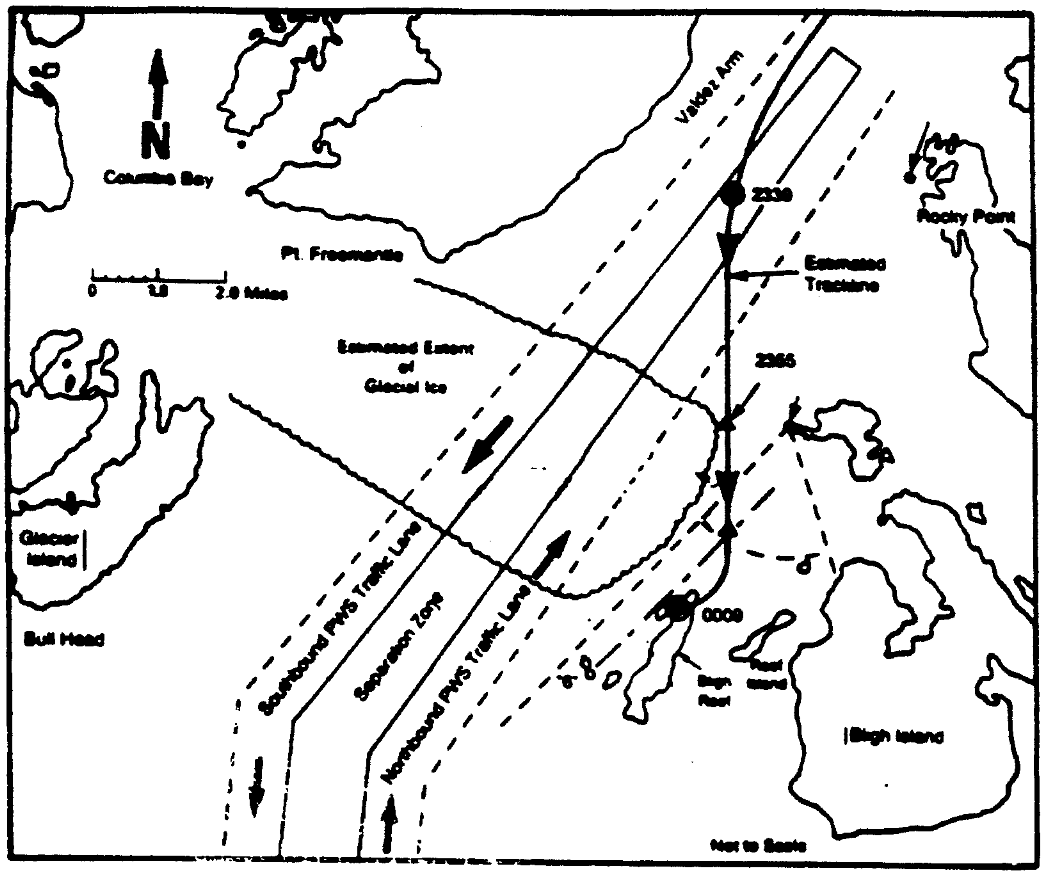


Figure 3. **An Adapted Mapped Version of the Exxon Valdez Tracking Around Glacial Ice**

## Components

The components of influence diagrams contain 1)decision and chance nodes, 2)arrows, 3)deterministic nodes, and 4)value nodes. Decisions are represented by square nodes in the diagram. Chance nodes are circles or ovals and are characteristic of uncertain events. Arrows indicate the relevance between the two nodes; event B was influenced by event A. Deterministic nodes, represented by double-lined ovals, depend deterministically upon their predecessors.[31]

The scattered nature of the diagram reduces the illusion of a sequentially patterned series of events. The interrelationships can be quite confusing at first, but logical after review. Each node may have many relationships within the diagram. For example, in the Piper Alpha diagram (Figure 4) the explosion, a deterministic node, depends solely on the system shutdown and ignition source nodes.[31] Since the shutdown oval is a deterministic node the explosion could not have occurred had the system remained operable. The degree to which the ignition source contributed to the explosion is however, unknown, but identifiable as a factor. Given the same example it is apparent that the explosion severity depended upon the event of the explosion and was regulated by the uncertainty of the leak size; a subsequent action.

**Discussion**

As illustrated, well documented case histories can give valuable insight into the interaction of causal relationships over an extended period of time. This assists in determining the sources of human and technical errors in various states and stages of accident scenarios. Once these error types have been identified management schemes can be developed to reduce the frequency of human-based errors and technical malfunctions.

The diagram discussed in this chapter can serve as a starting point for an error analysis. Patterns in behavioral and technical malfunctions can be shown in a graphical representation. Various causal relationships can

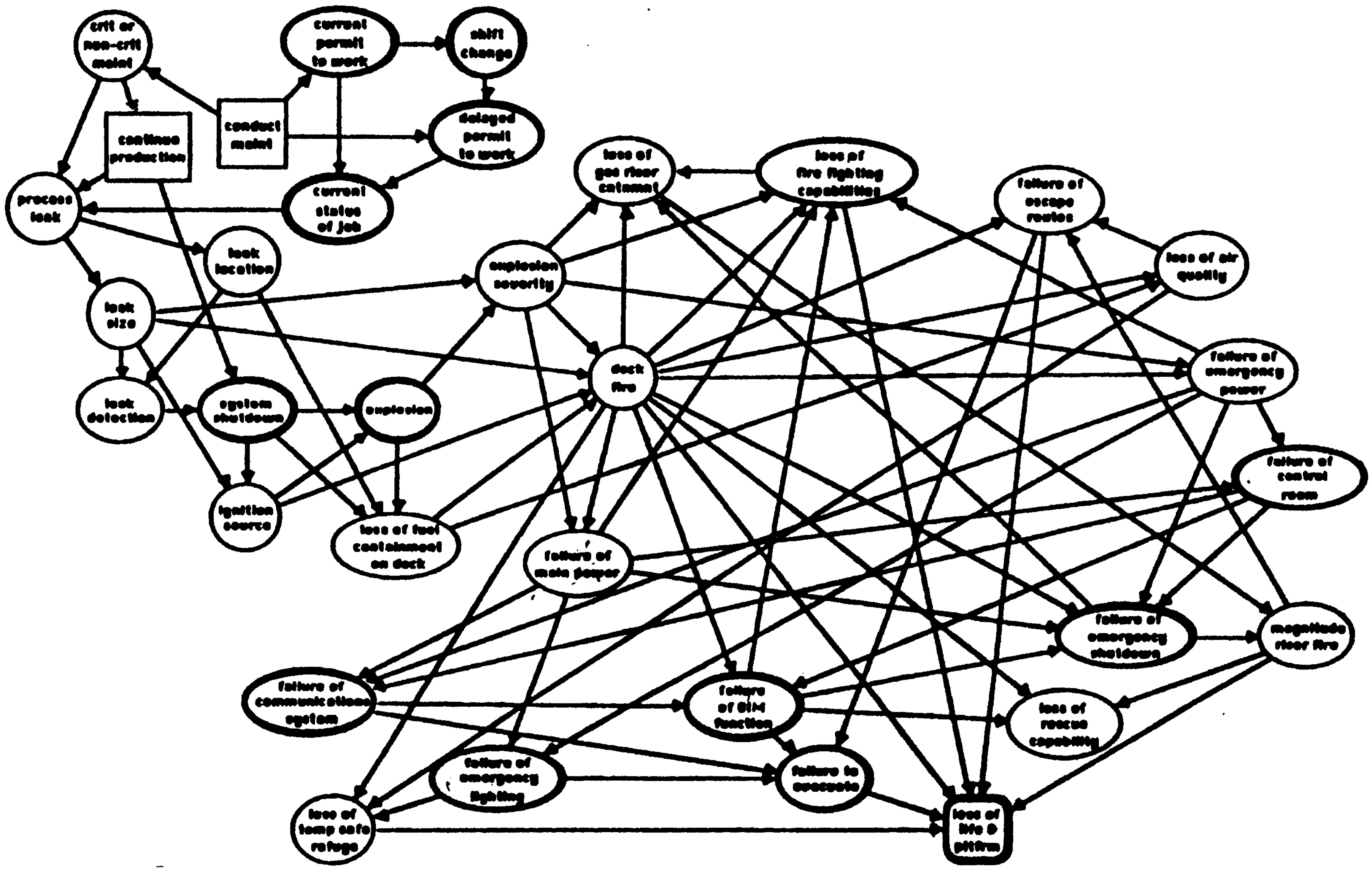


**Figure 4. An Example of the Relationships Between the Components of an Influence Diagram - Piper Alpha Accident**

be identified along an accident sequence which will enable researches to pinpoint root causes of an accident, human or technical. The question may arise: was a crewman's inattention to detail the cause of an accident or did the operational equipment falter? An influence diagram cannot answer this question directly, but can give specific insight to the decisions, actions, and events conducted prior to, during, and after the accident sequence. This insight will enable researchers to focus on human errors that can be eliminated and technical systems that cannot be properly managed given human limitations.

The influence diagram can also be expanded to incorporate a more comprehensive analysis for like error sequences encompassing a number of similar accidents. After all, similar accidents often yield reproduced errors. For example, collisions that occur when vessels sail too close to one another are often caused by misinterpretation or dismissal of the Collision Avoidance Regulations; misreading of the signals of approaching vessels; or inattention to duty and available technologies on the bridge.

In other words, deficiencies in human performance can be patternerized across similar accident scenarios such as vessel collisions. If a pattern can be identified by case-study review then companies can identify human and technical error patterns in their own organizations. Other companies of like operational make-up can draw from the experiences and analyses of competitors and design their systems to avoid human caused accidents. This would be a significant breakthrough for reducing the frequency of human-based accidents that adversely impact the natural environment.

# CHAPTER FOUR

## DIRECTIONS FOR FURTHER RESEARCH

Identifying the human element as a relevant regulatory concern is, in theory, ideal for fostering a preventative mind set in todays congress. Since human-based accidents are not predictable it is difficult and unrealistic for legislation to regulate an unpredictable phenomena. This research however, can initiate motivation towards the study and understanding of human error events and the construction of a networking link between organizations and legislators alike.

The indicating of error types among industries may illustrate the repetitive nature of human-based errors. If these repetitive characteristics can be identified then companies will be able to recognize warning signs within their operations and take action before the accident can occur. The influence diagram can be used to accomplish this task.

An influence diagram analysis of like accidents involving workers with limited work experience and education or operating under highly repetitive tasks, can indicate reproduced error behaviors. Similarities in performance may exist among individuals with comparable education levels or work-related training. If companies could identify performance problems on a somewhat generic basis they can combat the problem through quality control measures including: enhanced employee evaluation and training programs, job redesign, and industry wide training standards. These analysis findings can be reported and used by other companies within the same industry to assist in reducing the impacts and frequency of human-based errors.

Other areas that could benefit from using an influence diagram would be any organization, be it private, public, or not-for-profit, that find its employees causing accidents. Governmental organizations can evaluate their daily operations and determine areas that are slow in accomplishing tasks. What human factors are slowing progress and which human-based delays can be minimized?

On a natural environment scale, congress can use the diagram to evaluate industry practices that are plagued with human-related accidents and cause catastrophic environmental impacts. After the analysis is conducted congress can regulate industries by either requiring certified training programs or other means to ensure the safety of the environment from further industry perpetuated destruction.

Training can be an effective tool to foster the minimization of human errors in an organization. The influence diagrams can identify areas of needed reform and increased training, the type and duration of training however, must be prescribed by a knowledgeable professional. The influence diagram should be used to identify problem areas, but to utilize its full potential it must be used in conjunction with qualified individuals.

**Bibliography**


1. Alaska Oil Spill Commission, "Spill the Wreck of the Exxon Valdez Implications for Safe Transportation of Oil", State of Alaska Final Report, Feb. 1990.

2. American Petroleum Institute, "Guidelines for Developing Bridge Management Teams", API Recommended Practice 1140, 1st ed, Jan 1991.

3. Bea, R.G., Young, C. "Loading and Capacity Effects on Platform Performance in Extreme Condition Storm Waves and Earthquakes", Offshore Technology Conference - OTC 7140, Houston, Texas, May 1993.

4. Burdick, "Lead Exposure Reduction Act of 1991", Committee on Environment and Public Works, 102D Congress 1st Session, Senate, Rept. 102-179, Washington, D.C., Oct. 8, 1991.

5. Cahill, R.A. "Strandings and Their Causes", FairPlay Publications LTD., London, 1985.

6. Cahill, R.A. "Collisions and Their Causes", Fairplay Publications LTD., London, 1983.

7. Clay, W." Hearing on H.R. 3283, The Foreign Flagship Bill", Committe on Education and Labor, Washington D.C., Oct. 25, 1993.

8. Dane, A. "America's Oil Tanker Mess", Popular Mechanics. Nov. 1990.

9. Department of Ecology, "Rule Adopted: Oil Spill Prevention Plans", Washington State, F-CP-92-122, July 1992.

10. Department of Ecology, "Rule Adopted: Personnel Training and Certification", Washington State, F-CP-92-124, Dec. 1992.

11. Department of Ecology, "Washington State's Oil Spills & Penalties Assessed", Washington State 1991 Data Book, Washington State, Office of Financial Management, Table VT07.

12. Department of Transportation, "Report of the Chief Inspector of Marine Accidents into the Engine Failure and Subsequent Grounding of the Motor Tanker", Garths Ness, Shetland, Jan. 1993.

13. Department of Transportation, Federal Register, Oct. 17, 1989.

14. Donnellan, P. "Oil Pollution in the United States - A P&I Perspective", Hellenic American Chamber of Commerce Seminar on OPA 90, New York, Oct. 1993.

15. Environmental Law Reporter, "Oil Pollution Deskbook", Environmental Law Institute, Washington, D.C., 1991.

16. Gallagher, J.J. "Management Elements of Response to Major Maritime Oil Spills", Proceedings of the 1989 Oil Spill Conference, 1989.

17. Henn, G. "Coast Guard Responds to OPA 90", Proceedings of the Marine Safety Council, May-June 1992.

18. House of Represetatives, Subcommittee on Investigations and Oversight, Committee on Public Works and Transportation, "FAA's Training Programs for Air Traffic Controllers, Safety Inspections, and Maintenance Technicians", Washington, D.C. June 6, 1990.

19. Ingram, H.M., Mann, D.E. "Why Policies Succeed or Fail", Sage Publications, Beverly Hills, vol. 8. 1980.

20. International Maritime Organization, "Recommendation on Operational Guidance for Officers in Charge of a Navigational Watch", International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), Annex I, 1978.

21. International Standards Organization, "Performance Standards to Protect The Marine Environment", U.S. Tag Newsletter, International Standards, 01 12, 1994.

22. International Tanker Owners Pollution Federation Ltd. "Effects of Marine Oil Spills", Technical Information Paper, no. 10, 1985.

23. Jacobson, M. "The Notion of 'Pollution Damage' with Particular Regard to Damage to the Marine Environment", Proceedings of the Oil Spill Conference 1989, 1989.

24. Johnson, D.A. "Cost-Effectiveness Evaluation of Decentralized International Technical Training", Human Resources Development Quarterly, vol. 4, no. 3, Fall 1993.

25. Kende, B., "Managing Marine Pollution Claims", Insurance Claims for Envionmental Damage" Executive Enterprises Publications Co., Inc., 1989. Chapter 11.

26. Kimball, J.D. "OPA 90: The Hairy Palm of Chartering", Hellenic American Chamber of Commerce Seminar on OPA 90. Oct. 18, 1993.

27. Letaw, H. "Human Error and the Public Telephone Network: Part 1", Human Factors Society Bulletin, vol. 35, no. 5, May 1992.

28. Lynch, L.M. "Invited Reaction: Employer Training - Is a Mandated Tax the Only Solution?", Human Resources Development Quarterly, vol. 4, no. 3, Fall 1993.

29. Meurn, R.J. "Watchstanding Guide for the Merchant Officer", Cornell Maritime Press, Centreville, Maryland, 1990.

30. Mielke, J.E. "Oil in the Ocean: The Short- and Long-Term Impacts of a Spill", CRS Report for Congress, Congressional Research Services - The Library of Congress, July 1990.

31. Moore, W.H., Bea, R.G. "Human and Organizational Error in Operations of Marine Systems: Occidental Piper Alpha and High-Pressure Gas Systems on Offshore Platforms", Offshore Technology Conference - OTC 7121", Houston, Texas, May 1993.

32. Moore, W.H. "The Grounding of Exxon Valdez: An Examination of the Human and Organizational Factors" Marine Technology, vol. 31, no. 1, January 1994.

33. Murtagh, M. "Human Element, Halon, Uniformity are Priority Topics at IMO Session", Proceedings of the Marine Safety Council, Sept-Oct 1993.

34. The Nautical Institute, "Supplement to Seaways, Passage Planning", Nautical Briefing, Jan. 1994.

35. Nulty, P. "What We Should Do to Stop Spills", Fortune, July 16, 1990.

36. Office of Marine Safety, "Summary of Ogden Government Services Human Factors Contract", Washington State, June 30, 1993.

37. Office of Marine Safety, "Safe Passages", Washington's Oil Spill Prevention Agency, vol. 1, no. 3, Dec. 1993.

38. Office of Marine Safety, "Safe Passages", Washington's Oil Spill Prevention Agency, vol. 1, no. 4, Feb. 1994.

39. Office of Marine Safety, "Safe Passages", Washington's Oil Spill Prevention Agency, vol. 1, no. 1, Aug. 1993.

40. Oil Spill Planning Manual, "Industry Scrutinizes Coast Guard's Training Guidelines", Thompson Publishing Group, Inc., Washington, D.C., Oct. 1993.

41. Oliver, R.M., Smith, J.Q. "Influence Diagrams, Belief Nets and Decision Analysis" Wiley & Sons, 1988.

42. Papachristidis, B. "A Voice in the Wilderness", Hellenic American Chamber of Commerce Seminar on OPA 90", New York, Oct. 1993.

43. Pell, "Convention on Standards of Training, Certification and Watchkeeping for Seafarers", 102D Cngress 1st Session, Senate, Exec. Rept. 102-4, April 23, 1991.

44. Public Law 91-596, December 29, 1970.

45. Public Law 99-499, October 17, 1986.

46. Pyne, J.H. "New Oil Spill Law Will Affect All Americans Legislation Effective, But Riddled With Flaws", Proceedings of the 1990 American Merchant Marine and Maritime Industry Conference, Tacoma Washington, Oct 12, 1990.

47. Reason, J. "Human Error" Cambridge University Press, New York, 1991.

48. Small, W.A., Downey, E.A. "Technology Support for Managing Complexity", International Engineering Management Conference Proceedings, Eatontown, NJ, Oct. 1992.

49. Sleezer, C. "Training Needs Assessment at Work: A Dynamic Process", Human Resources Development Quarterly, vol. 4, no. 3. Fall 1993.

50. Somerville, R.D. "The Impact of OPA on Classification Societies", Hellenic American Chamber of Commerce Seminar on OPA 90, New York, Oct. 1993.

51. United States Coast Guard, "The Safety Imperative", Office of Marine Safety, Security, and Envionrmental Protection, American Petroleum Institute's Tanker Conference, South Carolina, June 1992.

52. United States Coast Guard, "Human Factors R&D (FY92-94)", U.S. Coast Guard Research & Development Center", Groton, CT, 1994.

53. United States Coast Guard, "Special Issue on Oil Pollution Act of 1990", Proceedings of the Marine Safety Council, vol. 49, no. 3, May-June 1992.

54. United States Coast Guard, OPA 1990 Staff. "Oil Pollution Act of 1990".

55. 33 U.S.C §1321, ELR Stat. FWPCA.

56. 33 U.S.C.§§1501-1524.

57. 43 U.S.C. §§1651-1655.

58. 43 U.S.C. §§1331-1374.

59. 42 U.S.C. §§9601-9675, ELR Stat. CERCLA 007-075.

60. 33 U.S.C. §2703.

61. Conversations with professionals including: Mr. Zbigniew Karaszewski - USCG, Mr. Edward Kelly AFL-ILO

# APPENDIX

# APPENDIX A

## ELEMENTS OF LIABILITY UNDER SECTION 1002 OF THE 1990 OIL POLLUTION ACT

**§1002.**
**Elements of liability**

*(a) In General.—Notwithstanding any other provision or rule of law, and subject to the provisions of this Act, each responsible party for a vessel or a facility from which oil is discharged, or which poses the substantial threat of a discharge of oil, into or upon the navigable waters or adjoining shorelines or the exclusive economic zone is liable for the removal costs and damages specified in subsection (b) that result from such incident.*

*(b) Covered Removal Costs and Damages.—*

*(1) Removal costs.—The removal costs referred to in subsection (a) are—*

*(A) all removal costs incurred by the United States, a State, or an Indian tribe under subsection (c), (d), (e), or (l) of section 311 of the Federal Water Pollution Control Act (33 U.S.C. 1321), as amended by this Act, under the Intervention on the High Seas Act (33 U.S.C. 1471 et seq.), or under State law; and*

*(B) any removal costs incurred by any person for acts taken by the person which are consistent with the National Contingency Plan.*

*(2) Damages.—The damages referred to in subsection (a) are the following:*

*(A) Natural resources.—Damages for injury to, destruction of, loss of, or loss of use of, natural resources, including the reasonable costs of assessing the damage, which shall be recoverable by a United States trustee, a State trustee, an Indian tribe trustee, or a foreign trustee.*

*(B) Real or personal property.—Damages for injury to, or economic losses resulting from destruction of, real or personal property, which shall be recoverable by a claimant who owns or leases that property.*

*(C) Subsistence use.—Damages for loss of subsistence use of natural resources, which shall be recoverable by any claimant who so uses natural resources which have been injured, destroyed, or lost, without regard to the ownership or management of the resources.*

*(D) Revenues.—Damages equal to the net loss of taxes, royalties, rents, fees, or net profit shares due to the injury, destruction, or loss of real property, personal property, or natural resources, which shall be recoverable by the Government of the United States, a State, or a political subdivision thereof.*

*(E) Profits and earning capacity.—Damages equal to the loss of profits or impairment of earning capacity due to the injury, destruction, or loss of real property, personal property, or natural resources, which shall be recoverable by any claimant.*

*(F) Public services.—Damages for net costs of providing increased or additional public services during or after removal activities, including protection from fire, safety, or health hazards, caused by a discharge of oil, which shall be recoverable by a State, or a political subdivision of a State.*

*(c) Excluded Discharges.—This title does not apply to any discharge—*

*(1) permitted by a permit issued under Federal, State, or local law;*

*(2) from a public vessel; or*

*(3) from an onshore facility which is subject to the Trans-Alaska Pipeline Authorization Act (43 U.S.C. 1651 et seq.).*

*(d) Liability of Third Parties.—*

*(1) In general.—*

*(A) Third party treated as responsible party.—Except as provided in subparagraph (B), in any case in which a responsible party establishes that a discharge or threat of a discharge and the resulting removal costs and damages were caused solely by an act or omission of one or more third parties described in section 1003(a)(3) (or solely by such an act or omission in combination with an act of God or an act of war), the third party or parties shall be treated as the responsible party or parties for purposes of determining liability under this title.*

*(B) Subrogation of responsible party.—If the responsible party alleges that the discharge or threat of a discharge was caused solely by an act or omission of a third party, the responsible party—*

*(i) in accordance with section 1013, shall pay removal costs and damages to any claimant; and*

*(ii) shall be entitled by subrogation to all rights of the United States Government and the claimant to recover removal costs or damages from the third party or the Fund paid under this subsection.*

*(2) Limitation applied.—*

*(A) Owner or operator of vessel or facility.—If the act or omission of a third party that causes an incident occurs in connection with a vessel or facility owned or operated by the third party, the liability of the third party shall be subject to the limits provided in section 1004 as applied with respect to the vessel or facility.*

*(B) Other cases.—In any other case, the liability of a third party or parties shall not exceed the limitation which would have been applicable to the responsible party of the vessel or facility from which the discharge actually occurred if the responsible party were liable.*

(Pub.L. 101-380, tit. I, §1002, Aug. 18, 1990, 104 Stat. 484.)

## APPENDIX B

## THE PHASING OUT SCHEDULE FOR SINGLE HULLED VESSELS OPERATING IN U.S. WATERS

Situation A - vessels of at least 5,000 gross tons but less than 15,000 gross tons -

- after January 1, 1995, if the vessel is 40 years old or older and has a single hull, or is 45 years old or older and has a double bottom or double sides;
- after January 1, 1996, if the vessel is 39 years old or older and has a single hull, or is 44 years old or older and has a double bottom or double sides;
- after January 1, 1997, if the vessel is 38 years old or older and has a single hull, or is 43 years old or older and has a double bottom or double sides;
- after January 1, 1998, if the vessel is 37 years old or older and has a single hull, or is 42 years old or older and has a double bottom or double sides;
- after January 1, 1999, if the vessel is 36 years old or older and has a single hull, or is 41 years old or older and has a double bottom or double sides;
- after January 1, 2000, if the vessel is 35 years old or older and has a single hull, or is 40 years old or older and has a double bottom or double sides;
- after January 1, 2005, if the vessel is 25 years old or older and has a single hull, or is 30 years old or older and has a double bottom or double sides;

Situation B - vessels of at least 15,000 gross tons but less than 30,000 gross tons -

- after January 1, 1995, if the vessel is 40 years old or older and has a single hull, or is 45 years old or older and has a double bottom or double sides;
- after January 1, 1996, if the vessel is 38 years old or older and has a single hull, or is 43 years old or older and has a double bottom or double sides;
- after January 1, 1997, if the vessel is 36 years old or older and has a single hull, or is 41 years old or older and has a double bottom or double sides;
- after January 1, 1998, if the vessel is 34 years old or older and has a single hull, or is 39 years old or older and has a double bottom or double sides;
- after January 1, 1999, if the vessel is 32 years old or older and has a single hull, or is 37 years old or older and has a double bottom or double sides;
- after January 1, 2000, if the vessel is 30 years old or older and has a single hull, or is 35 years old or older and has a double bottom or double sides;
- after January 1, 2001, if the vessel is 29 years old or older and has a single hull, or is 34 years old or older and has a double bottom or double sides;
- after January 1, 2002, if the vessel is 28 years old or older and has a single hull, or is 33 years old or older and has a double bottom or double sides;
- after January 1, 2003, if the vessel is 27 years old or older and has a single hull, or is 32 years old or older and has a double bottom or double sides;

- after January 1, 2004, if the vessel is 26 years old or older and has a single hull, or is 31 years old or older and has a double bottom or double sides;
- after January 1, 2005, if the vessel is 25 years old or older and has a single hull, or is 30 years old or older and has a double bottom or double sides;

Situation C - vessels of at least 30,000 gross tons -

- after January 1, 1995, if the vessel is 28 years old or older and has a single hull, or 33 years old or older and has a double bottom or double sides;
- after January 1, 1996, if the vessel is 27 years old or older and has a single hull, or 32 years old or older and has a double bottom or double sides;
- after January 1, 1997, if the vessel is 26 years old or older and has a single hull, or 31 years old or older and has a double bottom or double sides;
- after January 1, 1998, if the vessel is 25 years old or older and has a single hull, or 30 years old or older and has a double bottom or double sides;
- after January 1, 1999, if the vessel is 24 years old or older and has a single hull, or 29 years old or older and has a double bottom or double sides;
- after January 1, 2000, if the vessel is 23 years old or older and has a single hull, or 28 years old or older and has a double bottom or double sides;

* a vessel that has a single hull may not operate after January 1, 2010

** a vessel that has a double bottom or double sides may not operate after January 1, 2010

## APPENDIX C

## A SYNAPSES OF THE EXXON VALDEZ GROUNDING - MARCH 24, 1989

On March 24, 1989, at 12:04a.m., the largest U.S. oil catastrophe threatened a $150 million-a-year fishing industry, and scarred one of Alaska's most pristine environments - Prince William Sound. The Exxon Valdez was loaded with 1.2 million barrels of crude oil and was fitted with the latest safety equipment. Through the absence of qualified command and the inexperience of the crewmen left in charge, the Valdez, in seemingly perfect weather, literally skidded into a pinnacle of Bligh Reef.

The impact of this grounding brought the ship from a speed of 12 knots to a dead stop almost immediately. (it normally takes a tanker of its size three miles and twenty minutes to stop from a top speed of fifteen to sixteen knots). Damage reports indicated that eight of the eleven cargo tanks were ruptured releasing 10,836,000 gallons of crude oil at such a force that oil surged to the surface in 3ft. waves. The extent of damages to the body of the 246,000-ton supertanker included five huge gashes in the hull; the largest being 6ft. wide and 20ft. long.

Many factors contributed to the degree of destruction the spill created on Prince Williams' shorelines. The inadequacy of the Alyeska response plan, and the delayed disbursement, of bioremedial techniques ordered by the Coast Guard greatly magnified the impacts of the spill. Alyeska, a consortium for several oil companies with interests invested i the Alaskan region, had the first responsibility to respond to the spill.

Its clean up response plan was designed so that a team of workers employing a barge full of gear (containment devices such as booms, sorbents, skimmers, etc.) would reach a stricken ship within five hours after notification that a spill had occurred. Prior to March 24th however, the barge gear had been unloaded for repair and had not been restocked onto the barge. Additionally, of the 50 workers gathered for assistance only one knew how to operate the forklifts or cranes. As a result the barge did not arrive at the spill until fourteen hours after notification of the accident rather than the proposed five.

This oversight easily reduced the probability of effective containment efforts prescribed in the Alyeska Response Plan. The Coast Guard also reduced containment probabilities by significantly delaying the disbursement of bioremedial chemicals to be used as dispersants. these chemicals would have disaggregated the slick into droplets of ten microns in diameter to be dispersed and dissipated into the water column and metabolized by bacteria; and unfortunately other organisms as well.

The leading principle for use of such dispersants it to prevent the oil from stranding on sensitive shorelines. A critical factor which determines the effectiveness both economically and physically of dispersants is that the viscosity of oil increases rapidly with weathering and low temperatures. Since more viscous oil is more difficult to disperse, response within a few hours is essential to high effectiveness in the treatment or containment of oil spills.

Unfortunately, when the Coast Guard finally wavered its earlier decision a spring storm hit the Sound producing winds up to 73 miles per hour; grounding the planes. The following day the pilots discovered that the spill had spread over more than one hundred square miles. The spill had spread to such a degree that dispersants would have been an economical and ecological waste of time and money.

This distance however, covered only one quarter of the extent the oil eventually traveled.

On day eleven of the spill response efforts the spread of oil reached 140 miles; on day 30 it reached 280 miles; and on day 56 the spill contaminated 470 miles of coastal environments.

As the seas calmed and the impact reports were filed the of ecological and economical damages were phenomenal. Exxon however, made a valiant, largely voluntary effort to go above and beyond the clean up requirements imposed by regulators and relevant officials. Of the 1,090 miles contaminated by the spill Exxon managed to treat 1,087; leaving by their calculations 3 miles of contaminated shorelines. The state however, claimed that 1,000 additional miles still remained contaminated.

Among the costs of the clean up, workers were hired at $16.95 an hour to wipe off individual rocks with absorbent pads or blast oil out using high-pressure hoses. Exxon also shipped in free groceries for native villagers and made up the differences in economic losses for fisherman who caught less fish that season compared to the previous year. The total cost of Exxon's clean up efforts was estimated qat $1.28 billion with $400 million to be reimbursed by insurance companies. Of the 10,836,000 gallons of crude oil spilled approximately 2,604,000 gallons were recovered. The recovery process and clean up effort generated 24,000 tons of additional waste.

In addition to economic losses ecological damages of 33,126 dead birds including 138 dead eagles and 980 dead otters were reported. Exxon's animal safety and clean up programs helped many animals but a greater percentage still perished.

# VITA 2

Andrea S. Lawrence

Candidate for the Degree of

Master of Science

| | |
|---|---|
| Thesis: | HUMAN FACTORS: ROOT CAUSE FOR ERRORS ACROSS INDUSTRIES AND PRODUCT FOR REGULATORY CONCERNS |
| Major Field: | Environmental Sciences |
| Biographical: | |
| Personal Data: | Born in Rego Park, New York, on December 27, 1968, the daughter of Robert and Arlene Lawrence. |
| Education: | Graduated from Jenks High School, Tulsa Oklahoma in May of 1987; attended both University of Oklahoma, Norman, Oklahoma and Tulsa Junior College, Tulsa, Oklahoma prior to receiving a Bachelors of Science degree in Business Management and Administration from Oklahoma State in May 1992. Completed the requirements for the Master of Science degree with a major in Environmental Sciences at Oklahoma State University in May 1994. |
| Experience: | Participated in a summer long undergraduate Human Resources Management internship with Purolator, Inc., in Tulsa, Oklahoma, 1991. Acquired an assistantship in the University Center for Energy Research upon entrance into the Environmental Sciences masters program at Oklahoma State University, 1992 to present. |
| Professional Memberships: | National Society for Human Resources Management, Society for Environmental Scientists, National Association of Environmental Professionals. |