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Management of Human and Organizational Error in Operational Reliability of Marine Structures

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ABSTRACT

Due to the high risks associated with the operation of offshore drilling and production platforms, the potential for catastrophic accidents are substantial. Over 80% of high consequence marine accidents are the result of compounded human and organizational error (HOE), and 80% of these accidents occur during operations. There are currently no structured quantitative analysis methods by which engineers can examine alternatives to better manage HOE in operating offshore platforms. Such methods could assist designers, operators and regulators in developing human error tolerant systems and identifying low tolerance critical paths which potentially result in catastrophic accidents. Through formal reliability analyses, the impacts of HOE and HOE management alternatives can be examined to determine how checks and balances can be assigned to reduce the incidence of HOE, and to take advantage of "early warning signs" to interrupt catastrophic compounding of these errors.

INTRODUCTION

The sources of a majority (generally more than 80%) of high-consequence offshore platform accidents can be attributed to compounded human and organizational errors (HOE) [1, 2]. These errors can occur in design, construction, and operations phases. HOE that occurs during the operations phase accounts for approximately 80% of the major incidents. Recent examples include the *Occidental Piper Alpha* North Sea platform explosions and fire (167 workers killed), and the *Odeco Ocean Ranger* capsizing off Newfoundland (84 workers killed).

Traditional engineering of marine systems has focused primarily on the structure and equipment aspects, ensuring the proper amount of structural materials is in place, suitable functioning equipment is provided, and the structure is constructible and serviceable for its intended purposes. Given that something in excess of 80% of failures of these systems are the result of human errors (Figure 1), it is timely for engineers and regulators to begin to formally engineer people and organizational considerations into design, construction, and operation of structures.

At the present time, there is no structured quantitative method to assist engineers in identification and evaluation of effective strategies to either design human error tolerant systems or include consideration of the potentials for human and organizational errors as an integral part of reliability assessments. Those critical of the use of reliability based methods in engineering structures cite the omission of consideration of the "human aspects" as a primary obstacle to meaningful applications of reliability methods [3].

This paper discusses the impact of human and organizational error on operational reliability of offshore platforms. It examine how probabilistic risk analysis (PRA) is used as a tool to evaluate the impact of HOE and HOE management alternatives. In addition, PRA modeling is a valuable tool in learning how to take advantage of "early warning signs" to interrupt catastrophic compounding through formal reliability modeling [4-6].

HOE PROJECT BACKGROUND

Two years ago, after completing a reliability study for the Occidental Piper Alpha replacement platform, the senior author in cooperation with Professor Elisabeth Paté-Cornell initiated a year-long pilot project to develop a first-generation HOE - PRA analysis procedure. The procedure addressed errors involved in design, construction, and operation of fixed offshore drilling and production platforms, with an emphasis on the organizational aspects and the design phase. The results of that work are summarized in reference [1].

During the past year, the authors have been conducting a research project that will further develop and verify an HOE - PRA analysis procedure directed at **operations** of marine structures, and specifically, floating marine structures (e.g. tankers and floating drilling and production systems). At the present time, the two-year project is sponsored by the California Sea Grant program and seven other government - industrial organizations that are acknowledged at the conclusion of this paper.

In the first year of the project, the effort is directed at identification, acquisition, and analysis of well-documented case histories of high consequence tanker and offshore platform accidents whose root causes are founded in **operations** HOE. The objective of this work is to develop an organization and classifcation of the sources of HOE, and to develop data bases that can be used to quantify the rates of HOE. An analytical framework is being developed that will allow evaluations of the interactions of HOE errors in causing accidents.

In the second year of the project, the effort is directed at the verification of the quantiatative analyses, and development of examples that will demonstrate the effectiveness (costs and safety benefits) of various alternatives to reduce incidents of high consequence HOE.

This paper summarizes some of the key observations, insights, and analytial procedures that have developed as a result of the first two years work. These observations, insights, and analytical procedures are based on the results of a large number of other researchers that have been studying this problem for the last 10 years (consult list of references). The authors have been given significant direction and HOE data by a number of individuals and organizations with extensive backgrounds in the field of marine safety, and in particular, the operations HOE related aspects of that safety (e.g. U.S. Coast Guard, National Transportation Safety Board, Human Factors Group at NASA Ames, High Reliablity Organization Project Group at the University of California at Berkeley). Their direction and assistance is gratefully acknowledged.

As this paper develops, it will be apparent that there are three major players in the HOE reliability problem: 1) humans (individuals), 2) organizations (groups of individuals), and 3) systems (structures, equipment). The field of "ergonomics" has largely developed to address the human - system interfaces. This work is an expansion of that focus to include the interactions of all three components.

The second observation that will develop during this paper is that there are two complimentary approaches to the evaluation and management of HOE in improving reliablity: 1) qualitative and 2) quantitative. Both of these approaches have benefits; our work indicates that they both should be mobilized to identify how and where to improve HOE management. One approach (qualitative) can and should form the framework for the other (quantitative).

A third observation regards the complexity of the problems of interactions of humans, organizations, and systems; this is not a simple problem. Further, there is little definitive or hard data to help engineers evaluate or analyze such problems. Data on human performance in different tasks under different constraints and environments is only beginning to be assembled.

Well then, is what we have to work with ready for applications? In the authors opinion and experience, the answer to that question is a demonstrable yes. The reason for this opionin is that in our experience it is the process of evaluation, assessment, analysis, and allocation of safety resources that can be dramatically improved with the present state of development in HOE reliability management procedures. **The principal objective of the explici introduction of HOE considerations into conventional reliablity analyses is to help identify critical weaknesses in the humann, organization, and systems that are being designed, constructed, and operated, and then to give one a basis to evaluate and justify alternatives to improve the reliablity of marine systems. Our record of marine safety attests to the fact that this must be done if the industry is to make major improvements in the reliability of its systems.**

ACCIDENT ORIGINS

As shown in Figure 1, high consequence accidents can be the result of a number of events. The first distinction is between *environmental factors* and *human factors*. Catastrophic accidents due to environmental factors can be the result of failures which exceed the "reasonable" demands of the structure during its lifetime. For example, observing the 1000-year wave during the lifetime of a structure which has been designed for the 100-year wave, or failure due to earthquake far in excess of the platform design capacity. These types of failures can be thought of as unavoidable "acts of god".

High consequence accidents resulting from human errors can be differentiated into *design*, *construction* and *operations*. Accidents can be the result of improper design and construction of the system. For example, primary contributors to the capsizing of the *Alexander Keilland* (123 workers killed) were the lack of redundancy (design) and cracks (construction) in the structure [7].

Accidents resulting from operations can be categorized into *societal* (cultural), *organizational*, *individual*, and *systems* errors. Societal values can substantially influence the frequency of human and organizational errors. Expedient offshore development in the United Kingdom, resulting from economic crises of the 1960's and 1970's, led to limited safety regulation and significantly high rates of accidents [8, 9]. Organizational structure has been found to impact on operational reliability for offshore platforms in previous studies [1, 10]. For example, errors in management decisions resulted in the loss of the *Odeco Ocean Ranger* and the excessive loss of life aboard the drillship *Glomar Java Sea* (82 workers killed) [6, 11]. Individual errors are those which are made by a single person which results in the accident. The chain of events which led to the *Occidental Piper Alpha* accident were initiated by an unfinished maintenance job in the gas compression module [12]. Errors can also be observed with human-system (equipment, structure) interfacing, these are described as system errors. System errors can be attributed to design errors and result in an operator making improper decisions. System errors led to the loss of the ballast control aboard the *Odeco Ocean Ranger* and emergency system failure aboard the *Occidental Piper Alpha* [6, 12].

HUMAN ERRORS

Human errors have been shown to be the basic cause of failures of many engineered systems [1, 2, 6, 13-17]. Figure 2 [2] summarizes the causes of severe accidents involving fixed and mobile offshore structures used in development of offshore hydrocarbons during the period 1970-1984 [16]. Less than 20% of the causes of severe accidents involving these marine structures can be attributed to the environment. The rest of the causes are initiating events such as groundings, fire, explosions, and collisions. In almost all of these cases, the initiating event can be traced to a catastrophic compounding of human and organizational errors [6, 15, 18, 19].

Table I shows a taxonomy of a number of factors which can result in human errors. The errors range from those of judgement to "ignorance, folly, and mischief" [17]. These errors are magnified and compounded in times of stress and panic [6, 15 , 18, 19]. As shown in Figure 3, optimal performance levels are observed at an "appropriate level of arousal" [12]. The human performance

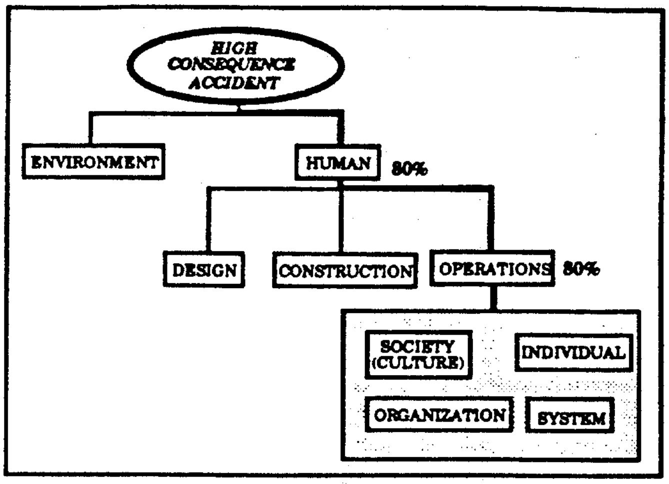
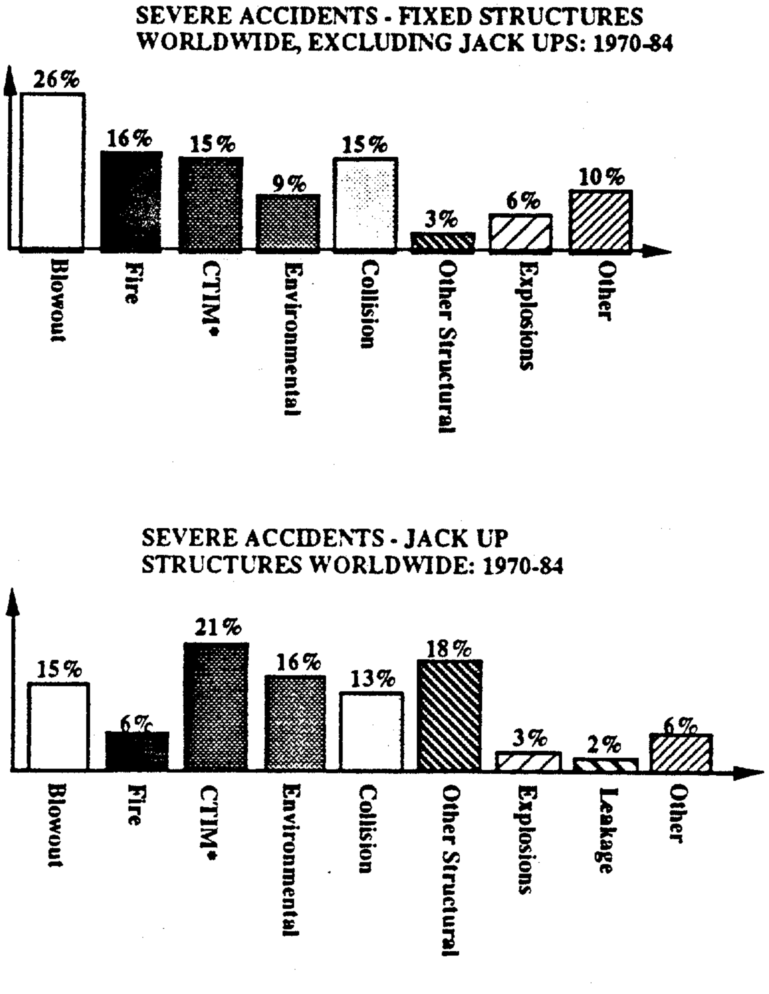


Figure 1: Breakdown of accident origins



* CTIM: Construction, Transportation, Installation & Mobilization

Figure 2: Severe Offshore Accidents 1970-1984

levels vary between individuals depending upon training levels, complexity of the operating system, and basic variability between individuals. Nevertheless, performance is observed to deteriorate when pressure levels are either too low or high. For example, times of high pressures could be effected by stress or panic while low human performances could be the result of boredom or laziness. Both extremes can contribute to increase the incidence of human errors.

Table I: Human Error Factors

Fatigue
Negligence
Ignorance
Greed
Folly

Wishful thinking
Mischief
Laziness
Drugs
Mischief

Bad judgement
Carelessness
Physical limitations
Boredom
Inadeqate training

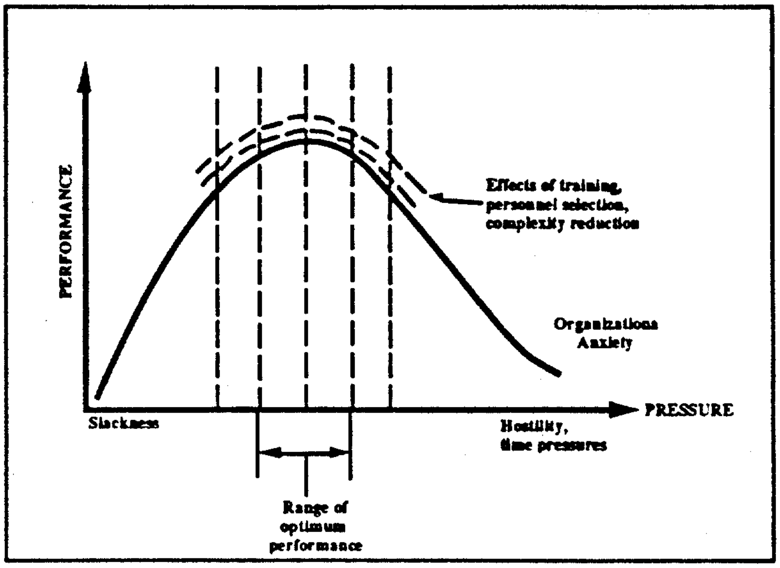


Figure 3: Human performance function [20]

Modeling a Simple Mishap

Studies of the role of human errors in the reliability of engineered structures indicates that human errors and imperfections basically are inevitable [2, 21, 22]. Figure 4 provides a schematic description of a simple mishap. Once a mishap has been initiated, the objective is to return the system to normal before it reaches a critical threshold.

A mishap is differentiated into three psychological factors: *perceiving*, *thinking*, and *acting*. The perception stage begins with initiation of the mishap. The initiation of the problem is followed by a warning signal (see Figure 4). The warning is then perceived and the source of the problem is recognized. The thinking stage begins with the identification of the problem and decisions regarding the proper course of action are evaluated. The mishap is aced upon with execution of a plan and the system is returned to a normal operating status or escalates to a critical state.

Though errors occur, they are influenced by cultural and moral values, corporate responsibilities and organizations, and individual training, craftsmanship, and integrity. The individual, organizations, and societies all play important roles in human errors which lead to dangerous states and can result in catastrophic consequences.

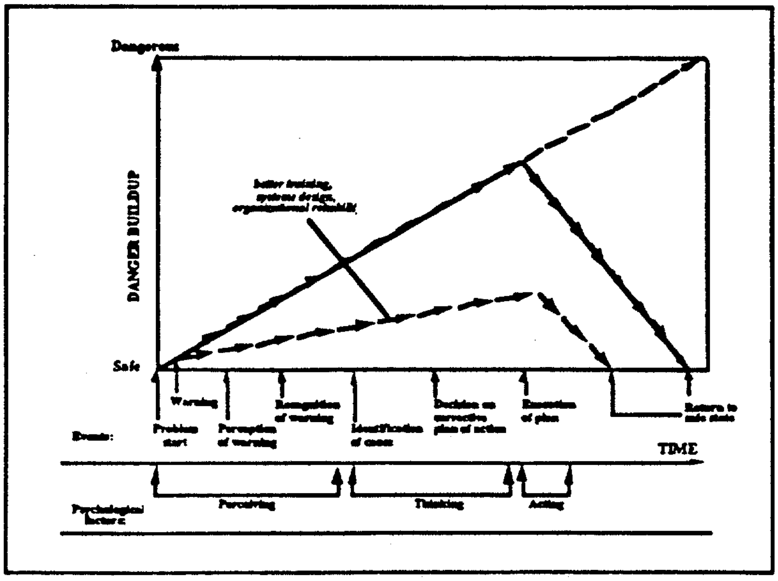


Figure 3: A simple model of a mishap

ORGANIZATIONAL ERRORS

The analysis of past decisions regarding the operations of offshore platforms provides numerous examples of instances in which organizational failures have resulted in failures of marine systems [1, 6, 14-16, 19]. Either collections of individuals (organizations, societies) or individuals (unilateral actions) contribute to accident situations. Failures can occur as a result of an organization's or an individual's willingness to take a calculated risk [23, 24]. Failures can result from different types of inevitable errors that can be corrected in time, provided they are detected, recognized as errors, and corrective action is promptly taken (see Figures 2 and 4). Failures can also occur as the result of errors or bad decisions, most of which can be traced back to organizational malfunctions. Table II shows a number of factors which can have negative effects on organizational reliability. For example, the goals set by the organization may lead rational individuals to conduct operations aboard a platform in a manner that corporate management would not approve if they were aware of their reliability implications [25-27]. Similarly, corporate management, under pressures to reduce costs and maintain schedules, unknowingly may not provide the necessary resources required to allow adequately safe operations.

Table II: Organizational Error Factors

Time pressures	Culture	Incentives
Cost - profit incentives	Morale	Communications
Regulatory requirements	Promotion - Recognition	Production orientation

Generally, two classes of problems face an organization in making collective decisions that result from sequences of individual decisions: information problems (who knows what and when?), and incentive problems (how are individuals rewarded, what decision criteria do they use, how do these criteria fit the overall objectives of the organization?) [24, 28]. In development of programs to improve management of HOE, careful consideration must be given to information (collection, communications, and learning) and incentives, particularly as they affect the balancing of several objectives such as costs and safety under uncertainty in operations of offshore platforms [17, 29].

The structure, the procedures, and the culture of an organization contribute to the safety of its product [26, 28] and to the economic efficiency of its risk management practices [17, 30]. The organization's structure can be unnecessarily complex and demand flawless performance. This can result in little or no credible feedback to the upper levels of management. The resulting safety problem is that there may be inconsistencies in the decision criteria (e.g. safety standards) used by the different groups for different activities. This can result in large uncertainties about the overall system safety, about the reliability of the interfaces, and about the relative contribution of the different subsystems to the overall failure probability [4, 14, 31].

Organization and management procedures that affect system reliability include, for example, parallel processing such as developing design criteria at the same time as the structure is being designed, a procedure that may or may not be appropriate in economic terms according to the costs and the uncertainties [1, 2].

The culture of the organization can also affect system reliability [17, 24, 29]. For example, the dominant culture may reward risk seeking (flirting with disaster) or superhuman endurance (leading to excessive fatigue), an attitude that in the long run may prove incompatible with the objectives of the organization. Another feature may be the lack of recognition of uncertainties leading to systematic biases towards optimism and wishful thinking [19, 32].

SYSTEM ERRORS

Errors can also be exacerbated by poorly engineered systems that invite errors. Such systems are difficult to construct, operate, and maintain [13, 14, 21]. As shown in Table III, system error factors include *latent errors* in design that do not surface until *active errors* are initiated in operations [33]. New technologies compounds the problems of latent system flaws. Complex design, close coupling (failure of one component leads to failure of other components) and severe performance demands on systems increase the difficulty in controlling the impact of human errors even in well operated systems [34]. Emergency displays have been found to give improper signals of the state of the systems [12, 15, 34]. Land based industries can separate independent subsystems whose joint failure modes would constitute a total system failure. System errors resulting from complex designs and close coupling are more apparent due to spatial constraints aboard platforms and other similar types of marine systems (e.g. ships).

Human performance is a function of the lead time available to respond to warnings in the system. Errors are compounded by the lack of effective early warning systems [5]. As observed in Figure 4, if the lead time is short, there is little time allowance for corrective action before the situation reaches a critical state. On the other hand, if the system is too sensitive causing frequent false alarms, operators will eventually cease to respond to the warning signals.

Table III: System Error Factors

Complexity	Latent flaws	Severe demands
Close coupling - non-redundancy	Small tolerances	False alarms

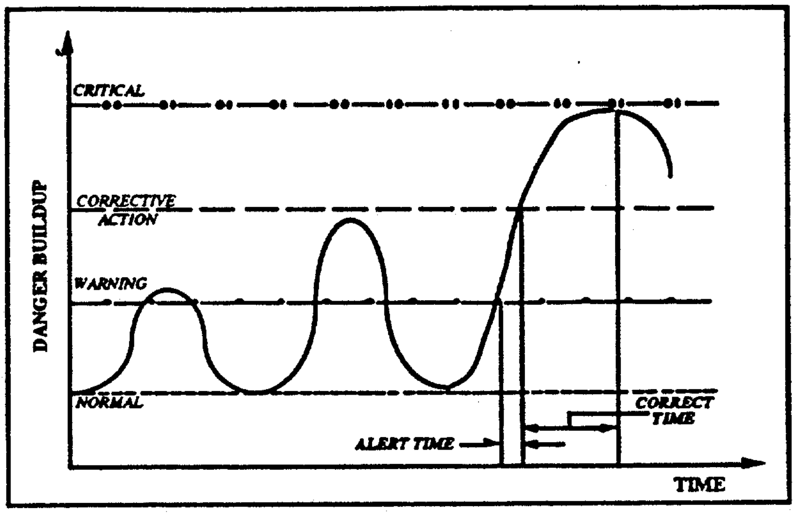


Figure 4: Danger buildup function [5]

ALTERNATIVES TO IMPROVE MANAGEMENT OF HOE

In many cases, a combination of human, organization, and technical (system), modifications can improve the overall safety level. Tables IV list some effective human, organizational, and technical factors which can benefit operational reliability.

Table IV: Error Management

HUMAN	ORGANIZATION	SYSTEMS
Selection	Resource allocation	Human tolerances
Training	Communication systems	Redundancy
Licensing	Decision making	Early warning systems
Verification	Process orientation	Damage tolerances
Incentives	Integrity	
Job design	Accountability	

Given a catastrophic failure, technical modifications are frequently proposed to "fix the problem." An example is the legislation requiring double-hull tankers following the Exxon Valdez disaster. Technical modifications, however, represent only one class of risk management strategies. When a system's failure is studied after it occurs, it is often obvious that what resulted in a technical failure was actually rooted in a functional failure of the organization and the human operators [24, 36]. Organizational modifications may address some of the reliability questions at a more basic level than strengthening the engineering design alone. They include, for example, improving communications, setting effective warning systems, and ensuring consistency of standards across the organization.

PROBABILISTIC RISK ANALYSIS

If HOE affect a subsystem whose functioning is not highly critical, their effect on the overall system reliability may be minor and may not justify profound human or system changes. However, complex interactions of relatively independent subsystems can substantially effect overall system reliability due to system complexities and tight coupling [34]. If deficiencies affect a subsystem or a complex interaction of subsystems whose failure constitutes a system failure mode, it is urgent to address the problem at its human and system origins. To permit evaluations of the interactions of the human and system components, it is desirable to organize and assess these features in a *probabilistic risk analysis* (PRA) [14] . This allows one to develop insights into the urgency of remedial measures, to evaluate alternative remedial measures to improve safety, and to set priorities among HOE problems to be addressed.

A PRA for engineering systems allows identification of the weakest parts of a system through qualification of the probabilities of the different failure modes [13]. Event tree modeling, a form of PRA, has been found to be an effective method to analyze contributions of individual accidents to risk associated with offshore operations [37]. This technique permits setting priorities among possible modifications aimed at the reduction of the failure risks and, therefore, optimal allocation of limited risk management resources.

The general method is to integrate elements of process analysis and organizational analysis in the assessment of the probability of system failure [1, 2, 32]. Figure 5 provides a schematic description of the structure of this integration model. The first phase (which does not appear in this diagram) is a preliminary PRA to identify the key subsystems or elements of the system's reliability. The second phase is an analysis of the process to identify the potential problems for each of the subsystems and their probabilities or base rates per time unit or per operation.

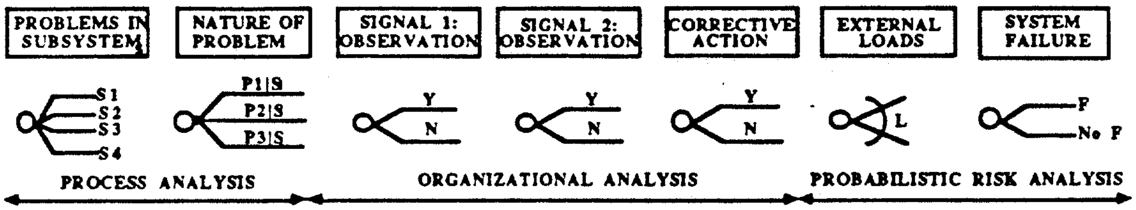


Figure 5: Event tree showing the structure of the generalized reliability model [1]

Given that a basic error occurs, the next phase is an analysis of the organizational procedures and incentive system to determine their influence on the occurrence of basic errors and the probability that they are observed, recognized, communicated, and corrected in time (i.e., before they cause a system failure).

The result of these three phases is a computation of the probabilities of the different systems' states corresponding to possible types of structural defects and, therefore, to different levels of systems' capacity. The fourth phase involves a return to the PRA for the physical system and a computation of the probability of failure for each capacity level corresponding to the different system states.

The overall failure probability is then obtained. It explicitly includes the possibility of weaknesses in the different subsystems due to organizational structure. These different models (process, organization, and final PRA) are integrated using an event tree [6, 35] or influence diagram [38] to compute the failure probability under different circumstances (e.g., occurrence and correction of a given problem in the process). We propose here to quantify the benefits of organizational measures using PRA as a starting point.

One can quantify the costs and benefits of HOE reliability management measures using PRA [6, 14, 35]. The analysis of a system's reliability allows identification of its failure modes and computation of their probabilities. It permits a decision maker to choose technical solutions that maximize an objective function (costs and reliability) under resource constraints [17, 29]. These solutions include, for instance, the choice of operating procedures and equipment that minimize the probability of failure during the lifetime of a structure under constraints of safety budgets, costs, time to completion, production level, structure location and general type. The results of the analysis can provide valuable insights into where scarce safety resources can best be deployed to achieve the largest improvements in safety.

Operations Example

An example will help illustrate the basic tenants of a HOE PRA. The example is the installation of an emergency shut down (ESD) valve in an existing pipeline. Three HOE management alternatives will be considered: Alternative 1 - using the present system, Alternative 2 - modest improvements in the planning, training, and supervision involved in the operation, and Alternative 3 - major improvements in planning, training and supervision.

It is of interest to note that in the recent past, a major fire developed and destroyed a Gulf of Mexico platform during the installation of an ESD into an existing pipeline [39].

Based on data that has been developed on the performance reliability of each of these three alternatives Table V summarizes the probabilities of a successful operation in each of the stages of installing the ESD.

Table V: Probabilities of Successful Operations

Phase of Operation	Alternative 1	Alternative 2	Alternative 3
Adequate Planning of ESD Installation	0.50	0.75	0.875
Adequate Purging of Pipeline	0.50	0.75	0.875
Detection of Hazardous Hydrocarbons	0.50	0.75	0.875
Suppression of Explosion and Fire	0.50	0.25	0.125
Extinguishment of Fire Before Significant Damage	0.50	0.75	0.875

The probabilities of successful operations of Alternatives 2 and 3 were based on one and two levels, respectively, of checking of the normal operation characterized as Alternative 1. The probability of successful detection and correction of error signals developed in each phase of the operation in Alternative 1 (no checking) was assigned a probability of 0.5 and in Alternative 2 (1 level of checking). The same probability of detection and correction was assigned in Alternative 3 (2 levels of checking).

In an actual PRA these probabilities would be based on results from studies of operations comparable to those of Alternative 1 and of the likelihoods of checking and corrective action given specified procedures for such actions. At the present time, such data is generally lacking for HOE PRA, and this poses one of the major hurdles to the performance of realistic quantitative analyses. Some organizations have begun to develop such information [e.g. 11, 16] and more will be developed in the course of the research work cited summarized in the Background section of this paper.

Figure 6 shows an event tree for the installation of an ESD valve in an oil pipeline. The event tree distinguishes between decisions and events at various states of the system. Table VI summarizes the results of the HOE PRA indicating the probabilities that fires caused by the ESD installation operation are not extinguished before there is significant damage to the platform. In addition, the estimated costs associated with the installation of the ESD using each of the operations alternatives is shown together with the expected total estimated costs associated with fires. The costs associated with the fires have been estimated at between $1 million and $2 million.

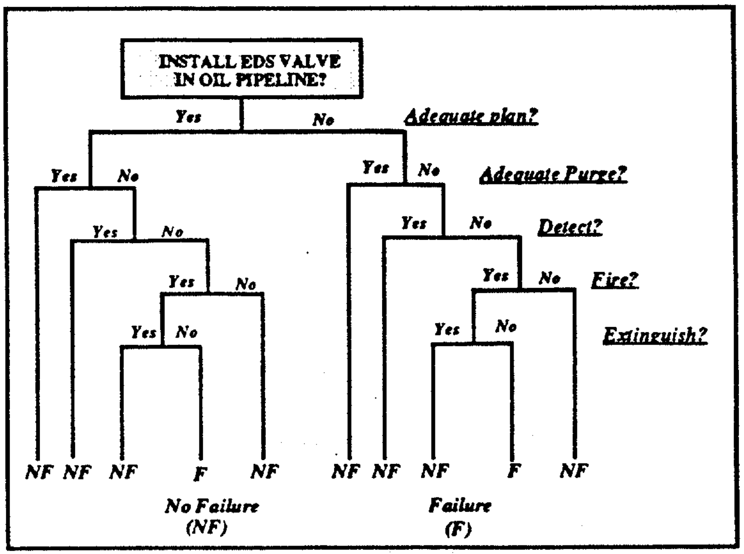


Figure 6: Event tree for installation of ESD valve in oil pipeline

Table VI: Probabilities for expected costs for operational alternatives

Operation Alternative	Probability of Fire During Operation	Estimated Initial Cost $ 1,000's	Expected Total Cost $ 1,000's ($1 million damage cost)	Expected Total Cost $ 1,000's ($2 million damage cost)
Present System	0.0625	50.0	112.5	175
Moderate Improvements	0.0081	60.0	68.1	76.2
Major Improvements	0.0001	80.0	80.1	80.2

As shown in Figure 7, the increase in initial cost to make radical improvements to the operations to reduce the probability of fire during the ESD installation ($30,000) does not apper to be economically justified. The $10,000 investment to make moderate improvements appears to be well justified by the range of reduction in expected total costs. Additional study could be performed to determine which of the changes in the operations phases are most effective at reducing the likelihoods of fires.

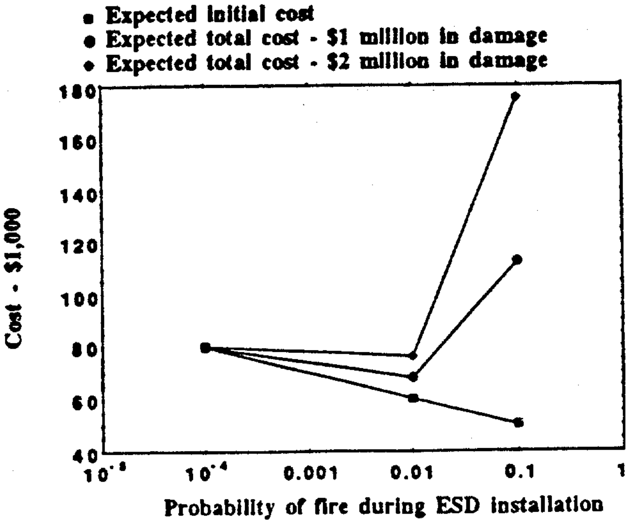


Figure 7: **Probability of fire during ESD installation vs. expected cost**

Influence Diagramming

Influence diagramming is a form of PRA modeling which allows flexibility in examining HOE and HOE management alternatives. There are distinct advantage for using influence diagramming for PRA. In standard decision tree analysis, decisions are based on all preceding aleotory and decision variables [40]. However, in not all information is available to a decision maker and information may come from indirect sources or not in the specific order in which the decision tree is modelled. When using influence diagramming all nodes need not be totally ordered. This allows for decision makers who agree on common based states of information, but differ in ability to observe certain variables in the diagramming [40].

Simple modeling an offshore operation

With the influence diagramming program *DAVID*©, the following example examines the impact of weather upon decisions to operate or evacuate a platform. There are costs associated with evacuating platforms which include lost production, the cost of evacuation, and most importantly loss of life. In regions where environmental conditions are highly variable during certain times of year (i.e. Gulf of Mexico, North Sea, South China Sea), it is important to use take advantage of weather information to make effective evacuation decisions.

Figure 8 is graphical representation of such a model. Oval nodes represent probability distributions while the square represents a decision node. The cost node represents the final expected value of the model.

Offshore weather condition influence four other sets of variables in the model. First, the offshore weather forecasts are dependent upon environmental events which are observed at some time before the weather pattern reaches the platform. Though it is impossible to predict exact weather conditions, the reliability of previous weather forecasts can be used to determine the their reliability. The reliability of weather forecasts can be easily determined using *Bayes' Rule*:

$$P[W|WF] = \frac{P[W] \ P[WF|W]}{P[WF]} \quad (1)$$

where, W is the observed weather, WF is the weather forecast. The probabilities of each the weather and weather forecasts are easily obtainable through hindcast data as well as the weather pattern probability given the forecast. For simplicity, three weather conditions are used for the model: *normal conditions*, *low severity storm*, and *high severity storms*. Table VII represents the weather patterns and reliability of weather forecasts in a specific offshore region.

Second, the cost of an accident is directly dependent upon offshore weather conditions. The cost of a platform failure is dependent upon the severity of the weather in which it failed. Failures due to severe storms are likely to have a greater loss in both manpower and equipment. Table VIII describes the failure costs representative of the events which can be observed for an imaginary platform.

Third, operational accidents are affected by weather patterns (e.g. mobile offshore drilling units which rely on humans to carry out stability procedures directly). For this example, operational accidents are separated into *blowouts*, *fires*, and *other*.

In addition, the operation of the rig is dependent upon the weather forecast. The choices at this decision node are to *operate* or *evacuate* the rig. Both the probability of an operational accident and cost of an accident are dependent upon the decision to operate the platform. These are represented by the arcs from the operate rig node to both the operational accident and cost nodes.

Operational accidents affect both the platform integrity and the cost of the accident. If the accident is severe enough it can cause a total platform failure. Table IX shows the probabilities of the types of operational accidents dependent upon the two conditioning variables: the weather and the decision to operate the rig. The cost of the accident is dependent upon the magnitude of the accident.

Finally weather conditions affect the platform integrity. It is presumed that normal weather conditions do not affect platform integrity though low and high severity storms can affect platform reliability. Platform integrity is distinguished between *operational* and *failure*. Table X shows the influences of both weather conditions and operational accidents on platform integrity.

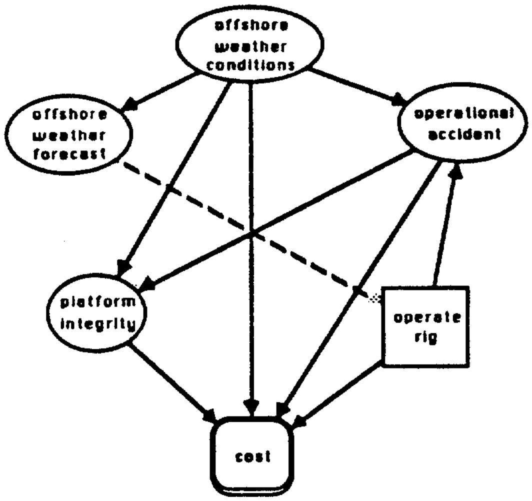


Figure 8: Influence Diagram of Rig Operations During Various Weather Conditions

Table VII: Weather and weather forecasting probabilities

Weather condition	Probability
Normal condition (NC)	P(NC)=.96
Low Severity Storm (LSS)	P(LSS)=.03
High Severity Storm (HSS)	P(HSS)=.01
NC forecast given NC weather	P(NC|NC)=.9
LSS forecast given NC weather	P(LSS|NC)=.09
HSS forecast given NC weather	P(HSS|NC)=.01
NC forecast given LSS weather	P(NC|LSS)=.3
LSS forecast given LSS weather	P(LSS|LSS)=.5
HSS forecast given LSS weather	P(HSS|LSS)=.2
NC forecast given HSS weather	P(NC|HSS)=.1
LSS forecast given HSS weather	P(LSS|HSS)=.4
HSS forecast given HSS weather	P(HSS|HSS)=.5

Table VIII: Cost of Failure Events

Event	Cost ($)
Evacuation(EV)	$ 100,000
Total loss of rig(TL)	$ 4,000,000
Blowout(BO)	$ 1,000,000
Fire(FR)	$ 1,000,000
Other(OTH)	$ 1,000,000
Loss of Life:	
NC	$ 1,000,000
LSS	$ 2,000,000
HSS	$ 3,000,000
Additional damage due to high severity storm	$ 500,000

Table IX: Conditional probabilities of operational accidents

Conditions	Probability
BO given operating rig (OR) and NC	P(BO|OR,NC)=.015
FR given OR and NC	P(FR|OR,NC)=.03
OTH given OR and NC	P(OTH|OR,NC)=.005
NO ACCIDENT (NONE) given OR and NC	P(NONE|OR,NC)=.95
BO given OR and LSS	P(BO|OR,LSS)=..03
FR given OR and LSS	P(FR|OR,LSS)=.06
OTH given OR and LSS	P(OTH|OR,LSS)=.01
NONE given OR and LSS	P(NONE|R,LSS)=.9
BO given OR and HSS	P(BO|OR,HSS)=.045
FR given OR and HSS	P(FR|OR,HSS)=.09
OTH given OR and HSS	P(OTH|OR,HSS)=.015
NONE given OR and HSS	P(NONE|OR,HSS)=.85
NONE given EV and NC	P(NONE|EV,NC)= 1
NONE given EV and LSS	P(NONE|EV,LSS)= 1
NONE given EV and HSS	P(NONE|EVHSS)= 1

Table X: Conditional probabilities of platform integrity

Condition	Probabilities
OPERATIONAL (OP) given NC and B	P(OP|NC,B)=.95
FAILURE (FA) given NC and B	P(FA|NC,B)=.05
OP given NC and F	P(OP|NC,F)=.93
FA given NC and F	P(FA|NC,F)=.07
OP given NC and OTH	P(OP|NC,OTH)=.95
FA given NC and OTH	P(FA|NC,OTH)=.5
OP given NC and NONE	P(OP|NC,NONE)=1
OP given LSS and B	P(OP|LSS,B)=.94
FA given LSS and B	P(FA|LSS,B)=.06
OP given LSS and F	P(OP|LSS,F)=.93
FA given LSS and F	P(FA|LSS,F)=.07
OP given LSS and OTH	P(OP|LSS,OTH)=.94
FA given LSS and OTH	P(FA|LSS,OTH)=.06
OP given LSS and NONE	P(OP|LSS,NONE)=.995
FA given LSS and NONE	P(FA|LSS,NONE)=.005
OP given HSS and B	P(OP|HSS,B)=.92
FA given HSS and B	P(FA|HSS,B)=.08
OP given HSS and F	P(OP|HSS,F)=.91
FA given HSS and F	P(FA|HSS,F)=.09
OP given HSS and OTH	P(OP|HSS,OTH)=.9
FA given HSS and OTH	P(FA|HSS,OTH)=.1
OP given HSS and NONE	P(OP|HSS,NONE)=.905
OP given HSS and NONE	P(OP|HSS,NONE)=.005

Results of the influence diagram

Through the influence diagram modeling, alternative decisions were evaluated regarding manning of the platform under various environmental conditions. The values given for weather and conditional probabilities resulted in the following decisions shown in Table IX.

Table IX: Decision to operate rig based upon weather conditions

Normal conditions	Operate rig
Low severity storm	Operate rig
High severity storm	Evacuate rig

Sensitivity analysis was performed on weather conditions resulting in variations in decisions to evacuate the platform. As the weather conditions more severe, decisions are made to evacuate the rig while observing both low and high severity storm forecasts due to uncertainties in forecasting storm severity (see Table 7). On the other hand, as the reliability of storm forecasting increases, more effective decisions to operate and evacuate can be made.

The expected cost of operating the platform under the given weather conditions $67,675.00. As shown in Figure 9, the expected costs increase as a function of the probability of normal conditions. Sensitivity analysis can assist decision makers in determining organizational policies regarding evacuation procedures for platforms to accommodate seasonal variations. Additional study can be performed to examine the reliability and expected costs of evacuation by surface vessel or helicopter.

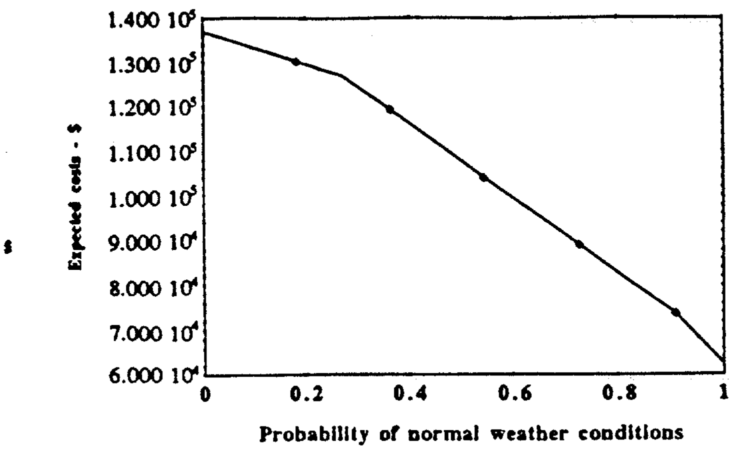


Figure 9: Expected cost of operating platform vs. probability of normal weather conditions

CONCLUSIONS

In traditional reliablity based studies of offshore platforms, HOE has been implicitly integrated into the background of accident statistics and experience on which such studies are often based. The principal focus of these studies has been the structural aspects or the equipment aspects, and how the design might be improved to improve reliablity.

In recent times, we have come to recognize that we may have been working on only a small part of the problem of the reliability of marine structures. Given that some 80% of major accidents can be directly traced to HOE, it would seem appropriate that engineers would begin to explicitly evaluate how the offshore platforms and the humans that are an integral part of these platforms from their design to their decomissioning can be better configured to improve safety.

Much of the previous work in this area has been directed at the design phase of engineered structures. Based on the available information on the reliablity of marine systems, it would appear that this is a secondary focus in comparison to HOE that is developed during construction and operations. Hence, the focus of our work on operations related HOE.

Hopefully this paper will help encourage other researchers and developers working in this field. Beyond researchers and developers, practicing engineers, operators, and regulators need to recognize the significant impact of HOE in the safe operations of offshore structures. It is time to create a basis which allows human and organization elements to be integrated into overall system reliability. This can be accomplished by developing methodologies to integrate HOE management considerations into design, construction, and operations of marine systems. Data and experience must be developed and provided to improve and verify these methodologies.

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