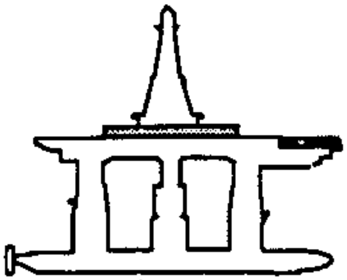
CALIFORNIA SEA GRANT
(Bea; R/OE-17)

MANAGEMENT OF HUMAN ERROR IN OPERATIONS OF MARINE SYSTEMS



DECISION MODELS FOR EVACUATING OFFSHORE PLATFORMS UNDER STORM CONDITIONS

by
William H. Moore

Supervised by
Robert G. Bea

Report No. HOE-91-2
August, 1991

Department of Naval Architecture & Offshore Engineering
University of California, Berkeley

TABLE OF CONTENTS

	Page
TABLE OF CONTENTS	1
LIST OF FIGURES	2
LIST OF TABLES	2
1. INTRODUCTION	3
2. EVACUATION DECISIONS BASED ON UNCERTAINTIES	5
3. MODELING OF EVACUATIONS	8
3.1 Model Systems and Variables	8
3.2 A Decision Tree Model	10
3.3 An Influence Diagram Model	13
4. EVALUATION OF INFLUENCE DIAGRAMMING MODEL	22
4.1 Sensitivity Analysis	22
5. CONCLUSIONS	26
REFERENCES	27

LIST OF FIGURES

Page

Figure 1: Danger buildup function 6

Figure 2: Severe offshore accidents 1970 - 1984 9

Figure 3: Decision tree for operating semisubmersible MODU under various weather conditions 12

Figure 4: Influence diagram of rig operations during various weather conditions 15

Figure 5: Figure 5: Sensitivity analysis - probability of weather conditions vs. expected profits 23

LIST OF TABLES

Page

Table I: Annual mean forecast position errors for Northwest Pacific typhoons 5

Table II: Probability of weather conditions and operational accidents under these weather conditions for decision tree 10

Table III: Probabilities of evacuation accidents during averse storm conditions and operational accidents 13

Table IV: Costs of evacuations and accidents 13

Table V: Weather and weather forecasting probabilities 17

Table VI: Cost of failure events 18

Table VII: Probability distributions for operational accident events 19

Table VIII: Conditional probabilities of platform integrity 20

Table IX: Conditional probabilities of operational accidents 21

Table X: Decision to operate rig based upon weather conditions 22

Table XI: Evacuation decisions for weather conditions and forecasts 25

1. INTRODUCTION

The impact of storm conditions on offshore operations can create potentially hazardous for work crews. Averse weather has resulted in compounding a number of catastrophic accidents which could have been avoided if effective evacuation procedures were in place. For example, the *Ocean Ranger* catastrophe on February 15, 1982 was the result of operator errors by untrained personnel during a storm and compounded by latent system flaws in the ballast control system. However, the *Ocean Ranger* and support vessels were not properly prepared for an evacuation if one should be necessary and the capsizing of the MODU led to the loss of 84 crew members [1,2].

The sinking of the *Glomar Java Sea* was similar in origin. Facing typhoon LEX in the South China Sea, both ARCO and Glomar management aboard the vessel chose not evacuate non-essential personnel when the opportunity was available and all 82 crew members were lost. Excessive loss of life could have been avoided if the evacuation and proper storm preparations were made [3].

In November 1989, the drillship *Seacrest* was lost while operating in the Gulf of Thailand in an area where typhoons were not normally developed or were observed. The ship capsized and resulted in the loss of the entire 92 man crew [4].

In wake of accidents such as these, it has become important to establish and examine decision criteria for platform evacuations. Weather conditions can deteriorate rapidly and timely decisions are critical to reduce the potential consequences of a platform failure. This is particularly crucial in areas with high storm intensity and low predictability (i.e. North Sea, Gulf of Mexico, South China Sea, etc.).

To limit the exposure of personnel to these risks, evacuations must be conducted within a reasonable time before storm conditions deteriorate such that an evacuation would be hazardous. Developing frameworks for modeling these operational and evacuation systems for various weather conditions can assist in creating decision criteria for evacuations. This paper addresses the development of such a framework and evaluation of various decisions using *probabilistic risk analysis* (PRA) modeling techniques.

2. EVACUATION DECISIONS BASED ON UNCERTAINTIES

Proper evaluation of a storm's early warning signals are important to safe and effective evacuation of platforms. However, weather forecasting reliability has left much to be desired due to large uncertainties in calculating storm paths and intensities [4, 5]. For example, the annual mean forecast position errors for Northwest Pacific typhoons for the past thirty years vary substantially as shown in Table I:

Table I [5]
Annual mean forecast position errors for Northwest Pacific typhoons

24-hour forecasts	**110-140 miles**
48-hour forecasts	**210-260 miles**
72-hour forecasts	**300-420 miles**

These are the mean errors in forecasts and individual errors can be substantially larger [5].

Forecasters are continually updating hypotheses and developments resulting in decreasing uncertainty levels over time. However, these uncertainties create a number of problems for decision makers. Uncertainties in storm intensity and direction compounded with pressures to not evacuate unless absolutely necessary can result in indecision by management. Management may be reluctant to evacuate due to incurred costs and loss of work time. For example, the *Glomar Java Sea* was not evacuated of non-essential personnel partially due to ARCO and Glomar managers decisions that evacuation would delay the work schedule.

As a result of these uncertainties, it is important to determine the criteria for platform evacuations. Evacuation criteria can be based upon a number of factors:

a.) wave heights and periods,
b.) wind speeds and gust factors,
c.) storm distance,
d.) storm direction,
e.) storm velocity,
f.) type of platform (fixed structure, semi-submersible MODU,

drillship, etc.),
g.) availability of evacuation vessels and helicopters,
h.) and, the number of personnel to evacuate.

The reliability of the warning systems are dependent upon the ability to forecast danger and to effectively respond to it. In a paper by Paté-Cornell, she examines human performance as a function of the lead time available to respond to warnings in the system [6]. Errors are compounded by the lack of effective early warning systems. As observed in Figure 1, 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 resulting in frequent false alarms, operators will eventually cease to respond to the warning signals.

For offshore operations, early warning signals come in the form of storm forecasting. If the lead time to respond to a storm is too short, evacuations are more hazardous and the potential for accidents are more prevalent. If evacuations are made too early, they may have been in error resulting in unnecessary costs and loss of work time. Operating under high intensity or unpredictable weather conditions, effective weather forecasting is an essential factor to operational reliability. Good weather forecasts at early stages allow sufficient alert time for preparation and evacuation ahead of oncoming storms.

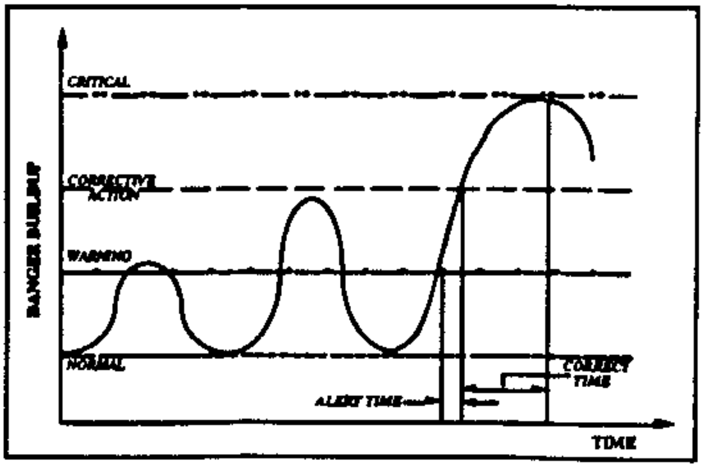


Figure 1: Danger buildup function [6]

Preparation for platforms involve constant monitoring of weather conditions, crew evacuation procedures (both platform and support vessels and/or helicopter), securing active equipment and supplies (i.e. drill pipe, cranes, etc.), shutting down non-critical operations and so on. For MODU's, additional mooring and stability calculations and procedures must be addressed and preventative measures fulfilled.

3. MODELING OF EVACUATIONS

In order to examine evacuation procedures and decisions, it is important to develop models of these operations. An exhaustive model the evacuation systems would be quite complex. These models should be simple enough to understand, yet detailed enough to include the important factors involved in the operation. For platform evacuations, two PRA models are used to model platform evacuations. First is an event tree model distinguishing decisions and events at various states of the system. The second model uses influence diagrams allowing for greater flexibility in that decisions and variables are not totally ordered.

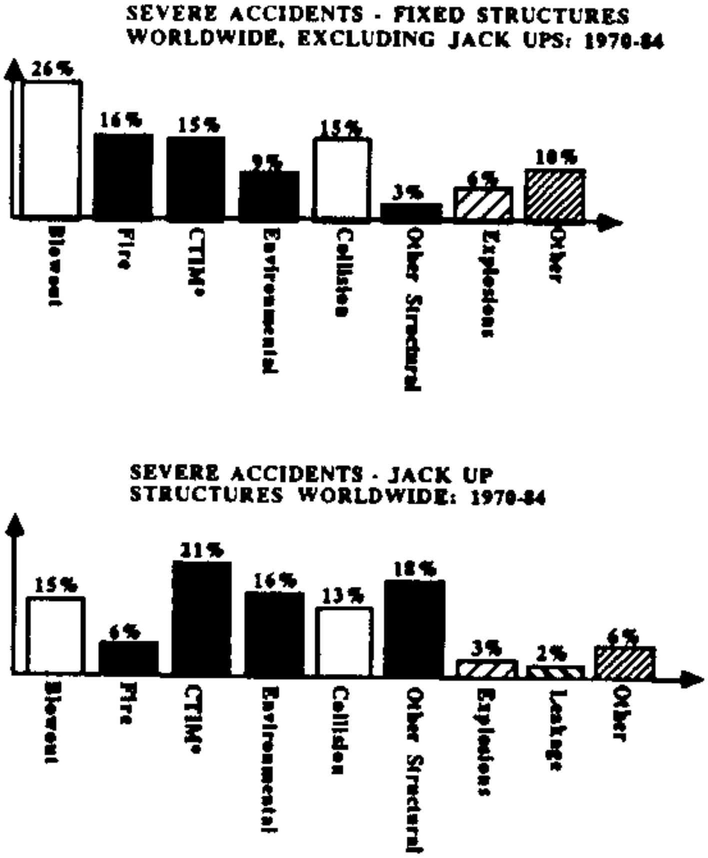
3.1 Model Systems and Variables

Personnel evacuation of platforms can be achieved by means of either support vessel or helicopter. However, manning and demanning of platforms are subject to environmental conditions which effect the transportation method reliability. Transport is evaluated under three platform operating conditions: (1) *normal*, (2) *low severity storm*, and (3) *high severity storms.*

During normal weather conditions, transport by stationed support vessels would be both economical and reliable while helicopter transport would be expedient. While operating under storm conditions, the reliability of both transport methods become dependent upon storm severity. Low and high severity storms allow for limited interfacing between surface vessels and platforms for evacuations, while helicopter operations would experience higher risks due to difficulties of flying in high wind conditions. High severity storms limit reliability of both transportation methods.

Extreme conditions imply evacuation of the platforms facing oncoming severe storms or hurricanes. Decisions regarding evacuation of the platforms are time, storm path, dependent. If the decision to evacuate is made before conditions deteriorate beyond a point where safe evacuation is feasible, the risk is limited. However, indecisions can result in delaying evacuations and increasing the risk as weather conditions worsen. Nevertheless, the evacuation decisions are only as reliable as the weather forecasts available.

It is important to examine the unique characteristics of each type of platform to determine its operational and structural reliability under various weather conditions. As mentioned previously, mobile structures such as semi-submersibles and drillships must take into account stability factors to either ride out or operate during storm conditions. Mobile structures possess a greater chance of failure than do fixed structures [7]. As shown in Figure 2, higher probabilities of failure due to environmental loads as well as other structural and operational related failures. These can be attributed to a much greater human-system interaction between the platform and operators. When modeling for mobile structures, these differences in failure probabilities should be taken into account.



* CTIM: Construction, Transportation, Installation & Mobilization

Figure 2: Severe offshore accidents 1970 - 1984

3.2 A Decision Tree Model

Figure 3 shows an event tree for the operation of a semi-submersible MODU under various averse weather and operating conditions. The event tree distinguishes decisions and events at various states of the system.

The tree is initially differentiated into the state of the weather conditions in the vicinity of the platform. If storm conditions exist, further distinctions are made between high and low severity storms. In the event of an oncoming storm, decisions are made regarding the evacuation of the rig and if to be made by surface vessel or helicopter.

If no evacuations are initiated, it is assumed the rig will operate with standard operational hazards such as blowouts, fires, and other potential dangers. However, the probability operational accidents are dependent upon the conditions in which the platform is operating. As shown in Table II, it is assumed the probability of operational accidents under averse weather conditions increase with storm severity. As mentioned in the previous section, approximations for the probabilities of these accidents can be assessed through experience and data collection.

Table II
Probability of weather conditions and operational accidents under these weather conditions for decision tree

	Normal Conditions	Low Severity Storm	High Severity Storm
Probability	.91	.06	.03
Blowout	.015	.03	.045
Fire	.03	.06	.06
Other	.005	.01	.015

Similarly, probabilities can be determined for evacuation accidents dependent upon the storm severity and the type of operational accident. For example, the hazards of landing a helicopter on the platform during a fire would be greater than during other accidents due to increased exposure to flames and smoke. The probabilities of evacuation accidents are also observed to increase with the severity of the storm. A model for the probabilities of the events are evaluated and expected costs are determined as shown in Table IV.

Though expected returns on this operation are quite good, the probability of evaluation accidents is greater than that of no evacuation accidents. In this case, the decision criteria based upon evacuation procedures should be reevaluated. Sensitivity analysis can be performed for the weather conditions to determine the expected returns during various times of year and its affects on the overall failure probabilities. However, the decision tree modeling leaves much to be desired regarding the interactions of various states and stages in the system. In the next section, a similar evacuation procedure is examined using influence diagramming, a more flexible decision modeling procedure.

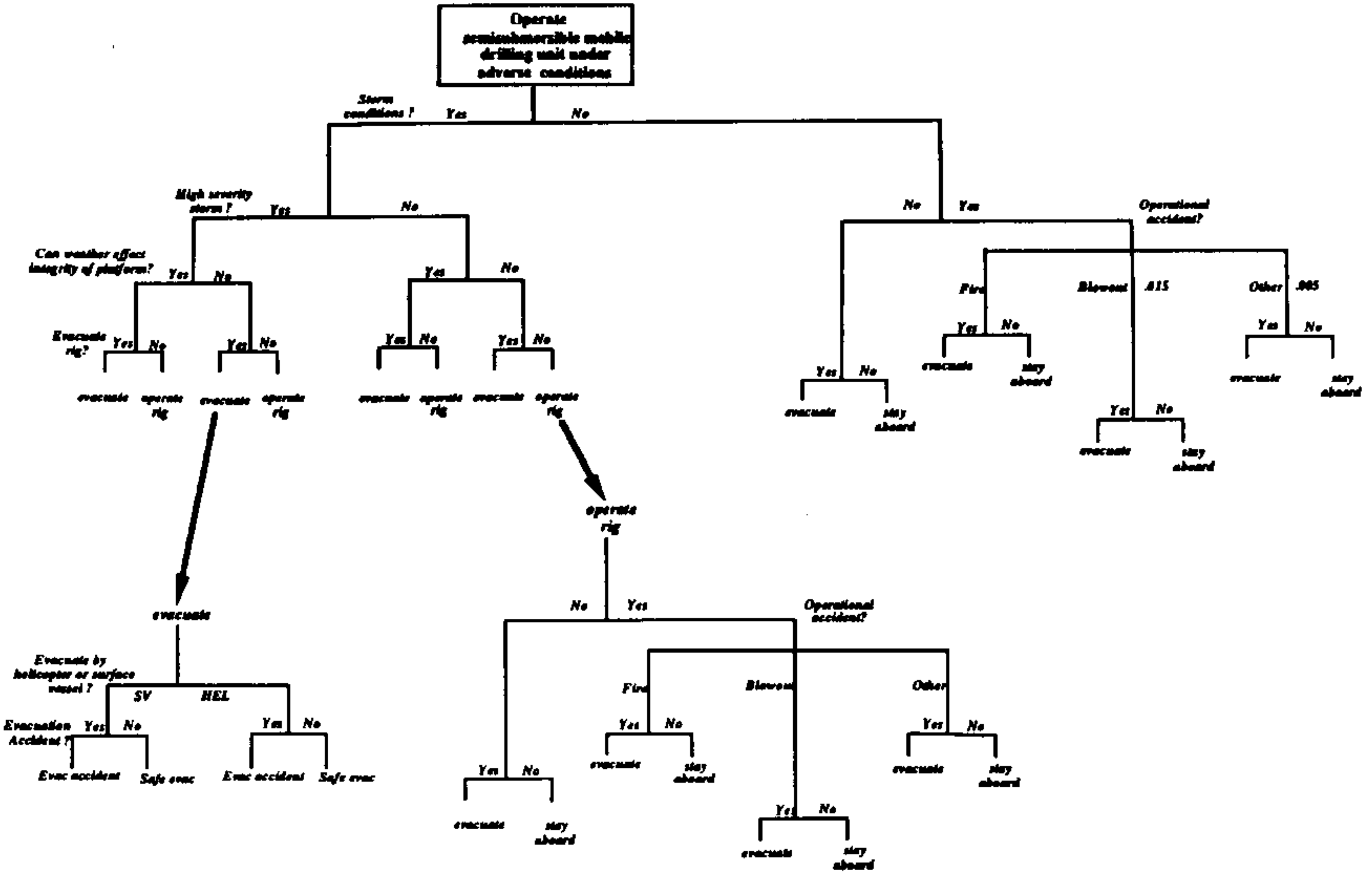


Figure 3: Decision tree for operating semisubmersible MODU under various weather conditions

Table III
Probabilities of evacuation accidents during averse storm conditions and operational accidents

	Evacuation method	Normal Conditions	Low Severity Storm	High Severity Storm
Blowout	surface vessel	.005 (.05)	.05 (.10)	.10 (.20)
	helicopter	.01 (.30)	.075 (.40)	.15 (.50)
Fire	surface vessel	.02 (.05)	.05 (.10)	.10 (.20)
	helicopter	.075 (.35)	.10 (.45)	.125 (.60)
Other	surface vessel	.005 (.05)	.05 (.10)	.10 (.20)
	helicopter	.01 (.50)	.075 (.40)	.15 (.50)
None	surface vessel	.005 (.05)	.05 (.10)	.10 (.20)
	helicopter	.01 (.30)	.075 (.40)	.15 (.50)

** The probabilities in parentheses represent the accident probabilities should the platform integrity not be intact.*

Table IV
Costs of evacuations and accidents

Event	Probability	Cost or revenue	Expected cost or revenues
Evacuation No accident	.02797	- $100,000	- $2,797
Accident during evacuation	.03337	- $1,500,000	- $50,055
Normal operations	.93866	+ $200,000	+ $187,732
		Total expected profits	+ $134,880

3.3 An Influence Diagram Model

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 <u>all</u> preceding aleatory and decision variables [8]. However, 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 [8].

With the influence diagramming program *DAVID*©, the following is another example examining 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 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 weather information to perform effective evacuation decisions.

Figure 3 is graphical representation of such a model. The model represents the evacuation of a fixed production platform where a storm is observed to be heading in its direction. The storm is of a severity where it can deteriorate from storm to hurricane force. Oval nodes with single borders represent probability distributions, double-border oval nodes represent deterministic costs and revenues and the square node represents a decision node for operation or evacuation. The profit 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 their reliability by using *Bayes' Rule*:

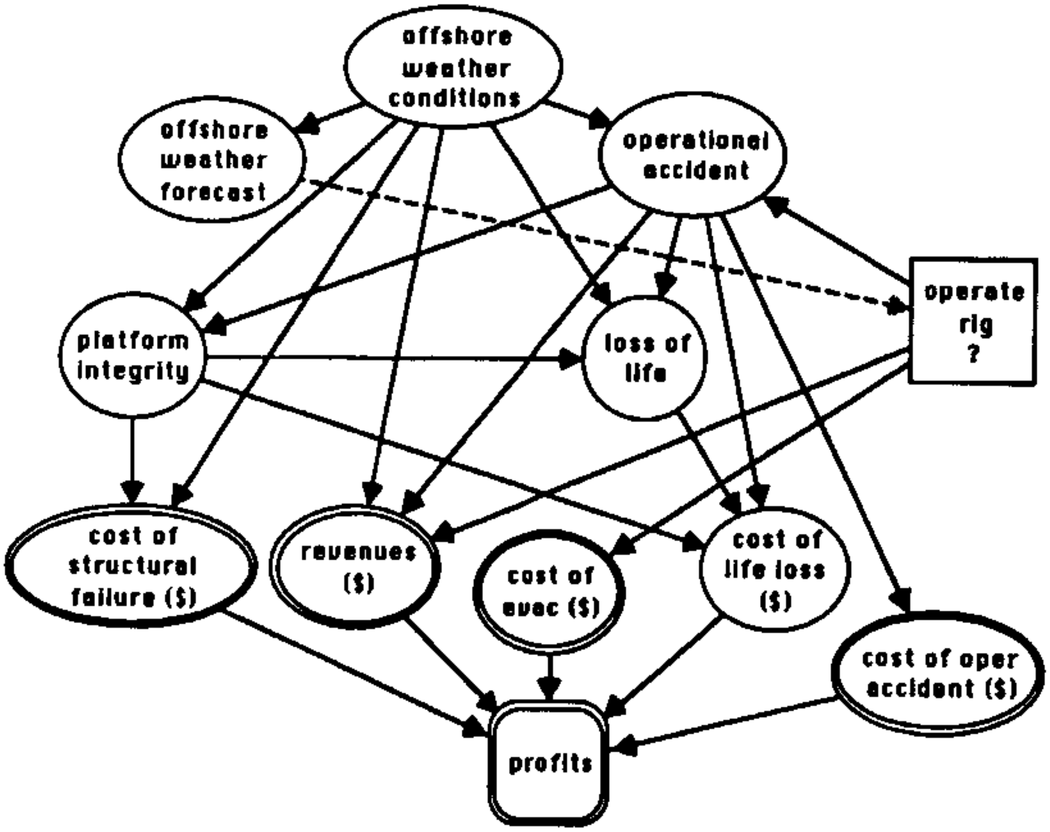


Figure 4: Influence diagram of rig operations during various weather conditions

$$P[W|WF] = \frac{P[W]\ \ P[WF|W]}{P[WF]} \tag{1}$$

where, *W* is the observed weather, *WF* is the weather forecast. The probabilities of each type of weather and forecasts are 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*. Using Baye's Rule, the probabilities would be based on forecasts of storms at a specific time periods and locations. This would allow for a better indication of forecasting reliability by standardizing these variables.[1] As discussed in

---

[1] As shown in Table I, the probabilities of correct forecasts would increase as forecasting periods decrease. Probability distributions can be established to indicate the reliability of forecasts at different time periods and locations.

Chapter 2, the forecast errors reduce as the forecasts become shorter in time. Table V represents weather patterns and reliability of forecasts in a hypothetical offshore region.

Second, the cost of an accident is dependent upon offshore weather conditions, while the cost of a platform failure is dependent upon the severity of the weather conditions in which it failed. Failures due to severe storms are likely to have a greater loss in both manpower and equipment. Evacuation accidents involve loss of life and helicopter or vessel.

Table VI describes the failure costs representative of the events which can be observed for an imaginary platform. Each of the failure and evacuation events have a cost associated with it. Therefore, each failure and evacuation node leads into a cost node. In addition, a revenue node for the operation included to determine the positive capital flow of the operation. Each of the revenue and cost nodes lead into the profit node which determine the difference between revenues and costs for expected returns for each operating and failure state.

Third, operational accidents are affected by weather patterns (e.g. mobile offshore drilling units which rely on humans to ensure platform stability). For this example, operational accidents are separated into three major categories: *blowouts*, *fires*, *evacuation accidents*, and *other*.

In addition, the operation of the rigs are dependent upon the weather forecasts. The choices at this decision node are to *operate* or *evacuate* the rig. The probability of an operational accident, the cost of evacuation, and the revenues gained 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", "revenue" and "evacuation cost" nodes.

The evacuation procedure is further differentiated into evacuation by helicopter or surface vessel. The reliability of each is expressed in the probabilities of failure under the weather conditions (Table III).

Table V: 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

Operational accidents affect platform integrity, severity of loss of life, cost of loss of life[2], revenues and the cost of the operational accident. If the accident is severe, it can cause structural damage and affect platform integrity thus resulting in a total platform failure. Platform integrity is distinguished between *operational* and *failure*. The weather conditions affect the loss of life resulting from the difficulty in performing rescue operations under the averse conditions and has a substantial affect on the cost of lives lost. A probabilistic node has been established for the cost of loss of life. The accident severities have a distribution shown in Table VII. Cost figures for the losses are

---

[2] Ongoing controversy exists regarding the "cost" of a loss of life. PRA modeling has been accused of using monetary values for the loss of life as a measure in making management decisions [9]. I am not attempting to fuel this controversy however, the cost of a life in this example is used strictly as a measure for <u>economically</u> based decisions.

dependent upon whether the platform was operational or failed. Further distinctions were established for the different accident events.

The weather conditions have a similar affect on the cost of operational accidents as to the cost of loss of life. Operational accidents during bad weather can be compounded due to the inability to effectively reduce the consequences of such accidents while attempting to bring them under control (e.g. high winds fueling a fire, controlling a blowout affecting the integrity of a riser while it is being hit by high waves). Table VIII shows the influences of both weather conditions and operational accidents on platform integrity.

Table VI: Cost of failure events

Event		Cost ($)
Evacuation (EV)		**$100,000**
Total loss of rig (TL)		**$150,000,000**
Blowout (BO)		**$2,000,000**
Fire (FR)		**$2,000,000**
Other (OTH)		**$2,000,000**
Evacuation Accident (EA)		
Helicopter (EVH)		**$ 1,000,000**
Surface Vessel (EVS)		**$ 1,000,000**
Additional damage due to high severity storm		**$ 2,000,000**
Operating failure free (annual basis)	**Revenues:**	**$ 3,000,000**

that less drilling, exploration, or production can be performed during bad conditions. The weather conditions have a similar affect on the cost of operational accidents as to the cost of loss of life. Operational accidents during bad weather can be compounded due to the inability to effectively reduce the consequences of such accidents while attempting to bring them under control (e.g. high winds fueling a fire, controlling a blowout affecting the integrity of a riser while it is being hit by extreme waves).

Table IX shows the probabilities of the types of operational accidents dependent upon a conditional variable, the weather, and the decision to operate the rig. The cost of the accident is dependent upon the accident magnitude.

Table VII: Probability distributions for operational accident events

	OPERATIONAL				FAILURE			
Cost ($M)	BO	FR	OTH	EA	BO	FR	OTH	EA
2.5	.4	.3	.4	.6	.25	.2	.4	.6
5.0	.3	.3	.3	.3	.35	.2	.3	.3
10.0	.2	.2	.2	.097	.25	.2	.2	.085
20.0	.075	.1	.075	.002	.1	.2	.075	.01
40.0	.025	.1	.025	.001	.05	.2	.025	.005

Table VIII: 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)=.05
OP given NC and EA	P(OP|NC,EA)=.99
FA given NC and EA	P(FA|NC,EA)=.01
OP given NC and NONE	P(OP|NC,NONE)=1.0
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 EA	P(OP|LSS,EA)=.97
FA given LSS and EA	P(FA|LSS,EA)=.03
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)= .90
FA given HSS and OTH	P(FA|HSS,OTH)=.10
OP given HSS and EA	P(OP|NC,EA)=.95
FA given HSS and EA	P(FA|NC,EA)=.05
OP given HSS and NONE	P(OP|HSS,NONE)=.905
OP given HSS and NONE	P(OP|HSS,NONE)=.005

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)=.90
BO given OR and HSS	P(BO|OR,HSS)=.045
FR given OR and HSS	P(FR|OR,HSS)=.06
OTH given OR and HSS	P(OTH|OR,HSS)=.015
NONE given OR and HSS	P(NONE|OR,HSS)=.88
EA given NC and EVS	P(EA|NC,EVS)=.001
EA given NC and EVH	P(EA|NC,EVH)=.01
NONE given EV and NC	P(NONE|EV,NC)=.999
EA given LSS and EVS	P(EA|LSS,EVS)=.03
EA given LSS and EVH	P(EA|LSS,EVH)=.05
EA given HSS and EVS	P(EA|HSS,EVS)=.07
EA given HSS and EVH	P(EA|HSS,EVH)=.10
NONE given EV and LSS	P(NONE|EV,LSS)=.97
NONE given EV and HSS	P(NONE|EV,HSS)=.93

4. EVALUATION OF INFLUENCE DIAGRAMMING MODEL

Table X shows the operational decisions based upon expected cost evaluations. The decisions to stay aboard the rig were based upon weighing the chance of evacuation accidents versus staying aboard. Though the model suggests no evacuation of the platform, the chances of catastrophic accidents could be substantially reduced if normal operations were not conducted during severe weather states. For evacuations to be conducted, it would be beneficial to obtain a more reliable evacuation system. The failure probabilities of the platform can be determined by summing the probability of operational, structural, and evacuation accidents:

$$P_{ftotal} = P_{foper} + P_{fstruc} + P_{fevac} \qquad (2)$$

If a total failure probability has been established for the platform, reducing the consequences of operational and evacuation accidents allows for greater flexibility in designing the structure with respect to failure.

Table X: Decision to operate rig based upon weather conditions

Normal conditions:	**Stay aboard rig**
Low severity storm:	**Stay aboard rig**
High severity storm:	**Stay aboard rig**

The consequences of evacuation accidents in this model outweigh the consequences of keeping the crew aboard. The following section discusses the effects of varying the probabilities of storm conditions as observed during seasonal variations in areas such as the Gulf of Mexico, North Sea, or the South China Sea.

4.1 Sensitivity Analysis

Probabilistic sensitivity on weather conditions was performed to adjust for seasonal variations. The analysis was performed to determine expected values for different weather probabilities and related evacuation decisions. Sensitivity analysis for weather conditions allow examination of operational decisions based upon seasonal variations in weather. As seen in Figure 5, if normal weather conditions are observed more than 63% it is economical to operate. On the other hand, if high severity storms are observed more than 8% of the time it would not be worth operating.

Operating during low severity storms has little effect economically with expected returns greater than zero for storm observations less than 73%. However, the expected returns would be dominated by the normal conditions and high severity storms where returns are less than zero.

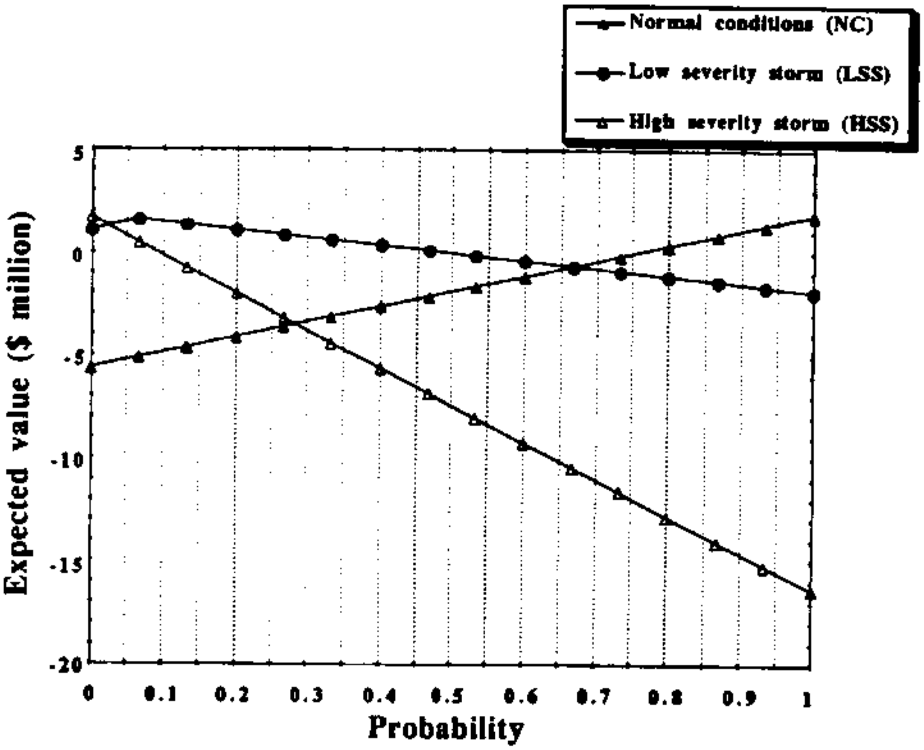


Figure 5: Sensitivity analysis - probability of weather conditions vs. expected profits

Table XI shows the evacuation decisions based on the model for normal, low severity storm, and high severity storms probabilities ranging between 0 and 1. If normal conditions are observed at the time of the evacuation, with the probability of normal conditions less than 73.3%, evacuations should be made by surface vessels. If normal conditions are observed more than 73.3% of the time, then crews stay aboard regardless of the weather forecast (the chances of HSS's would be quite negligible, therefore the crews stay aboard).

If LLS's are observed at the time of evacuation, it is most feasible to leave the crews aboard for all probabilities since evacuations by surface vessel would be dangerous yet the chances of a LSS threatening the integrity of the platform are negligible so evacuation by helicopter would not be necessary.

If the probability of HSS's are less than 40%, then evacuations by helicopter are warranted for HSS forecasts. For HSS storm probabilities between 40% and 93.3%, evacuations by helicopter are made for both LSS and HSS forecasts. Evacuations are made by helicopter regardless of storm forecasts for HSS storm probabilities equal to one.

Table XI: Evacuation decisions for weather conditions and forecasts

Weather Probability	Weather forecast	Evac decision for NC's	Evac decision for LSS's	Evac decision for HSS's
0.0	NC	SA	SA	SA
	LSS	SA	SA	SA
	HSS	EVS	SA	SA
.067	NC	SA	SA	SA
	LSS	SA	SA	SA
	HSS	EVS	SA	EVH
.133	NC	SA	SA	SA
	LSS	SA	SA	SA
	HSS	EVS	SA	EVH
.2	NC	SA	SA	SA
	LSS	SA	SA	SA
	HSS	EVS	SA	EVH
.267	NC	SA	SA	SA
	LSS	SA	SA	SA
	HSS	EVS	SA	EVH
.333	NC	SA	SA	SA
	LSS	SA	SA	SA
	HSS	EVS	SA	EVH
.4	NC	SA	SA	SA
	LSS	SA	SA	EVH
	HSS	EVS	SA	EVH
.467	NC	SA	SA	SA
	LSS	SA	SA	EVH
	HSS	EVS	SA	EVH
.533	NC	SA	SA	SA
	LSS	SA	SA	EVH
	HSS	EVS	SA	EVH
.6	NC	SA	SA	SA
	LSS	SA	SA	EVH
	HSS	EVS	SA	EVH
.667	NC	SA	SA	SA
	LSS	SA	SA	EVH
	HSS	EVS	SA	EVH
.733	NC	SA	SA	SA
	LSS	SA	SA	EVH
	HSS	EVS	SA	EVH
.8	NC	SA	SA	SA
	LSS	SA	SA	EVH
	HSS	SA	SA	EVH
.867	NC	SA	SA	SA
	LSS	SA	SA	EVH
	HSS	SA	SA	EVH
.933	NC	SA	SA	SA
	LSS	SA	SA	EVH
	HSS	SA	SA	EVH
1.0	NC	SA	SA	EVH
	LSS	SA	SA	EVH
	HSS	SA	SA	EVH

5. CONCLUSIONS

As shown above, PRA modeling can be used as a tool to assess the reliability and decision criteria of evacuation procedures for offshore platforms. Event tree analysis allows for the simple modeling of an evacuation procedure while influence diagramming gives a flexible modeling technique to analyze these decisions. Nevertheless, it should be kept in mind that PRA modeling should be used only as a tool to assist in making effective evacuation decisions and should not override sound and intelligent management decisions. Qualitative and quantitative analyses should be integrated to establish effective evacuation decisions.

REFERENCES

[1] Report of the Royal Commission on the Odeco Ocean Ranger Marine Disaster. Ottawa, Ontario, Canada. 1985.

[2] National Transportation Safety Board. *Capsizing and Sinking of the U.S. Mobile Offshore Drilling Unit Ocean Ranger Off the East Coast of Canada 166 Nautical Miles East of St. John's, Newfoundland February 15, 1982.* NTSB/MAR-83/2.

[3] National Transportation Safety Board. *Capsizing and Sinking of the United States Drillship Glomar Java Sea in the South China Sea 65 Nautical Miles South-Southwest of Hainan Island, Peoples Republic of China, October 25, 1983.* NTSB/MAR-87/02.

[4] Lynagh, N., The impact of weather forecasting on offshore safety. *Proceedings, Offshore Operations Post Piper Alpha Conference.* London, February 1991.

[5] Lynagh, N., Morgan, S. K., "Environmental Design Criteria for Transporting Offshore Oil Platforms Through Areas Affected by Tropical Cyclones", *Proceedings, Society of Naval Architects & Marine Engineers 2nd Offshore Symposium: Design and Codes*, Houston TX, April, 1991.

[6] Paté-Cornell, M. E., Warning Systems in Risk Management. *Risk Analysis*, Vol. 6, No.2, 1986.

[7] Veritec, The Worldwide Offshore Accident Data Bank (WOAD). Annual Reports through 1988. Oslo, Norway.

[8] Howard, R. A., Matheson, J. E., *Influence Diagrams*. Copyright © 1981.

[9] Perrow, C., *Normal Accidents: Living with High Risk Technologies.* Basic Books Inc., New York. 1984.