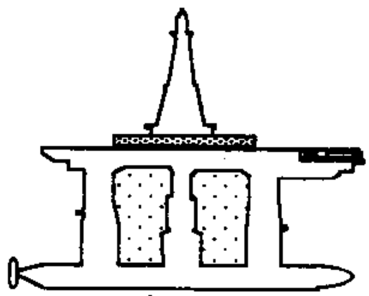
MANAGEMENT OF HUMAN ERROR IN OPERATIONS OF MARINE SYSTEMS



MODELING HUMAN ERRORS IN OPERATIONS OF MARINE SYSTEMS: CASE STUDY EXAMPLES

by

William H. Moore
&
Robert G. Bea

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Modeling Human Errors in Operations of Marine Systems: Case Study Examples

by

William H. Moore
Department of Naval Architecture & Offshore Engineering
University of California at Berkeley

&

Robert G. Bea
Professor, Department of Naval Architecture & Offshore Engineering
and Civil Engineering
University of California at Berkeley

1.0 INTRODUCTION

Approximately 65% of catastrophic marine related accidents (e.g. *Exxon Valdez* and *Piper Alpha*) are the result of compounded human and organizational errors (HOE) during operations. Yet to date there is no structured quantitative approach to assist engineers, operators, and regulators of marine systems to design human and organizational error (HOE) tolerant systems. No considerations have been established to include human and organizational errors as an integral part of the design, construction, and operation of tankers and offshore structures [Bea & Moore, 1991].

Analyses of current case study examples lead to a greater understanding of the effects of HOE in potential accident sequences. This report examines the development of human and organizational error models for two case study examples to identify and correlate the impacts of human factors on marine casualties. In addition, the model developments assist engineers, operators, and regulators in determining HOE management alternatives in developing future operating policy and procedures.

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The report examines the development of accident framework models for HOE analysis using the following operating case studies: loading and discharge of tankers and crane operations for offshore platforms. Through analysis of available accident data and expert opinion, influence diagram template models are developed for each operation. Both model templates are modified to incorporate various modes of operation. The loading and discharge (L&D) of tankers are modeled to account for dockside L&D, barge-tanker bunkering operations, and offshore spread mooring L&D. Offshore crane operations are modified to account for operators who are in the line of sight of the operation and those who require assistance from additional personnel. Preliminary quantitative analyses are conducted to acquire general magnitudes of failure and alternatives for managing HOE in these operations are considered.

2.0 BACKGROUND

Developing accident framework models is the third of five tasks proposed by the *Management of Human Error in Operations of Marine Systems* Joint Industry Project. The purpose of each task is to:

(1) Identify, obtain and analyze well documented case histories and databases of tanker and offshore platform accidents whose root causes are founded in HOE.

(2) Develop an organizational classification framework for systematically identifying and characterizing the various types of HOE.

(3) Develop general analytical frameworks based on real-life case histories to characterize how the HOE's interact to cause accidents. The case histories are post-mortem studies (*Exxon Valdez* and *Piper Alpha* disasters) and existing operations (tanker loading & discharge and offshore crane operations).

(4) Formulate quantitative analyses for the case histories based on probabilistic risk analysis (PRA) procedures using influence diagrams. Perform quantitative analyses to verify that the analyses can reproduce the results and implications from the case histories and general statistics of marine accidents.

(5) Investigate the effectiveness of various alternatives to reduce the incidence and effects of HOE. Evaluate the costs and benefits in terms of risk reduction (products of likelihood and consequences).

The *Management of Human Error In Operations of Marine Systems* project is examining the development of analytical framework models for examining the effects of HOE in two forms: post-mortem study analyses (*Exxon Valdez* and *Piper Alpha* disasters) and existing operation case study analyses. Examination of post-mortem studies give insight into factors particularly dependent upon specific human, organizational, and system actions and decisions unique to the accident scenario.

As established in Moore & Bea (1992a), post-mortem study models can be used to generate templates for particular classes of accidents. For example, models of particular accident classes have been developed through examination of the *Exxon Valdez* and *Piper Alpha* disasters: tanker groundings or collisions and offshore platform explosions and fires resulting from simultaneous production and maintenance.

The next stage in developing analytical frameworks for HOE analyses in marine operations, is to construct influence diagram models from existing tanker and offshore operations. Two marine system operations were identified by the project sponsors for HOE model development: loading & discharge of tankers and crane operations for offshore platforms. The following chapter discuss the factors involved in constructing influence diagram model frameworks to account for HOE's in tanker and offshore operations.

3.0 CONSTRUCTING HOE MODEL TEMPLATES

One of the keys to the development of an effective models is to determine the goals and preferences of the user. For example, tanker or offshore platform operators may wish to establish models that enable them to focus on specific areas to allocate limited resources. These goals and preferences may be established in the model to examine the effects of the operating alternatives weighing safety, economic, and production costs and benefits as the driving force. On the other hand, regulators and policy makers may wish to establish environmental, economic and social risks and costs of specific tanker and offshore operations. In short, the models would vary to project the preferences of the user in examining costs and benefits of these operations.

The complexity of the model must be weighed against the time, available resources, goals and preferences of the user. A primary issue in model development is striking a balance between a general models or highly detailed examinations of specific operations. The users must ask themselves if the marginal value of information gained as the model being constructed becomes more complex worth the addtional input of resources. For example, the user may wish to establish a general framework model with only limited detail and spend more time on analysis and examining the effects of sensitivity and uncertainty in the model. Yet another individual or group may wish to develop a detailed model at a substantial cost in time and resources. This preference allows the user to examine detailed aspects of human performance or limit the level of ambiguity and uncertainty in the model.

Regardless of the level of detail in which the user may wish to include, each model begins with a *template* diagram which forms a basis for a specific operation. The template is a diagram involving the most relevant factors affecting a class of accidents or specific operation. The development of a model diagram is cyclic process. Development of a model are an iterative process. The structure of the model should be shown to key players in the operation (managers, front line operators, regulators, consultants, etc.) to discuss whether the models are consistent with their judgments and experiences [Phillips, *et al.*, 1990]. If results are not consistent with case history examples, experience or available quantitative measures, further refinements are made.

3.1 Development of an Accident Framework

The intent of the project is to develop (and verify) PRA models for operations of tankers and offshore platforms to include the reliability effects of human and organizational factors. The general method is to integrate elements of process analysis and organizational analysis in assessing the probability of system failure [Patè-Cornell & Bea, 1989; Bea, 1989; Patè-Cornell & Seawell, 1988]. Figure 1 provides a schematic description of the structure of this integration model. The first phase (which does not appear in this diagram) is a preliminary *probabilistic risk analysis* (PRA) to identify the key sub-systems 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 sub-systems and their probabilities or base rates per time unit or per operation.

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 a system failure event).

The basis for developing HOE model frameworks has been established by Paté-Cornell (1992). The risk analysis model is extended to include relevant decisions, actions and organizational features in the risk assessment and risk management. Figure 2 is a hierarchical representation of the root causes behind systems failures. The primary level represents basic events affected by decisions and actions influenced by organizational policies and cultures. This procedure requires the modeler(s) to establish an exhaustive set of contributing events and determine relevant decisions and actions specific to the class of accident (or target event) of interest (explosions, fires, groundings, collisions, etc.).

A probabilistic model of the process includes determining the set of possible initiating accident events (in_i) and final states ($fist_m$) of the system. The probability of loss of components (platform, vessel, revenue, life, injury, etc.) to the system can then be represented by:

$$p(loss_k) = \sum_i \sum_m p(in_i)\, p(fist_m|in_i)\, p(loss_k|fist_m) \qquad \forall\, k. \qquad (1)$$

The model is expanded to include relevant decisions and actions (A_n) constituting an exhaustive and mutually exclusive set of decisions or actions affecting the marine system at different stages during the lifetime of the vessel or platform. These decisions and actions can be examined from the front-line operating crew level through to top-level management.

$$p(loss_k) = \sum_i \sum_m \sum_n p(A_n)\, p(in_i|A_n)\, p(fist_m|in_i, A_n)\, p(loss_k|fist_m, A_n) \quad \forall\, k. \qquad (2)$$

The effects of organizational procedures and policies on the risk are determined through examining the probabilities of the actions and decisions conditional on relevant organizational factors (O_h). The probabilities of various degrees of loss can be examined conditional upon different contributing organizational factors. Further developments into the quantitative aspects of HOE is the subject of a future report.

$$p(loss_k|O_h) = \sum_i \sum_m \sum_n p(A_n|O_h)\, p(in_i|A_n)\, p(fist_m|in_i, A_n)\, p(loss_k|fist_m, A_n) \qquad (3)$$

One of the keys to the development of an effective models is determining the goals and preferences of the model user. For example, tanker or offshore platform operators may wish to establish models that enable them to focus on specific areas to allocate limited resources in an efficient manner. These goals and preferences may be established in the model to examine the effects of the operating alternatives as the driving force by balancing safety, economic, and production costs and benefits. On the other hand, regulators and policy makers may wish to establish both economic and social costs of specific tanker and offshore operations. In short, the models would vary to project the preferences of the user in examining costs and benefits of these operations.

The complexity of the model must be weighed against the time, available resources, goals and preferences of the user. A primary problem in model development is striking a balance between a general models or highly detailed examinations of specific operations. The marginal value of information between simple and complex models should be addressed.

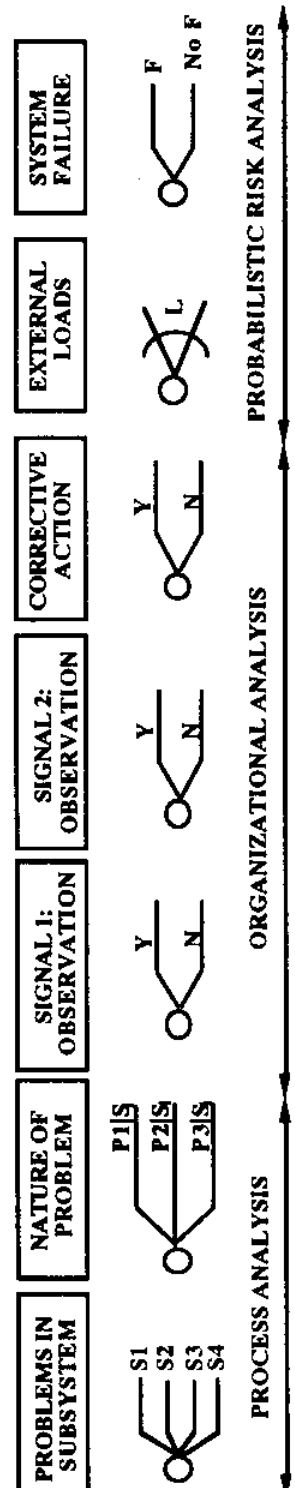

Figure 1: Structure of the generalized reliability model including organizational features and error detection [Paté-Cornell & Bea, 1989]

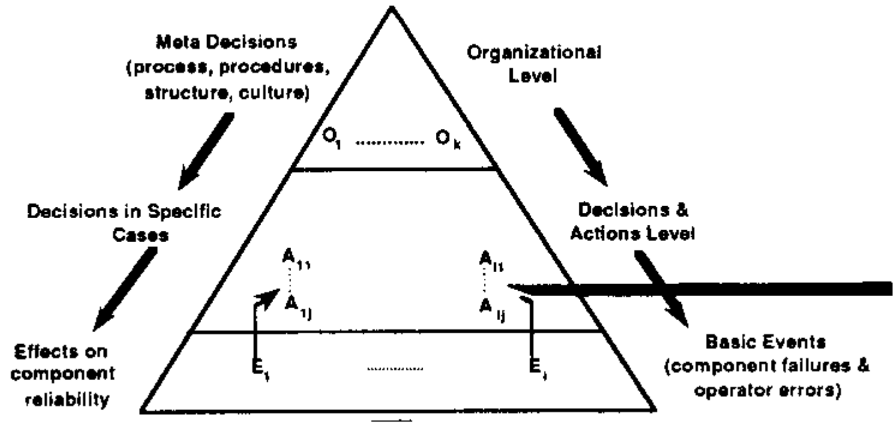

Figure 2: Hierarchy of root causes of system failures: Management decisions, human errors, and component failures [Paté-Cornell, 1992]

For example, the user may wish to establish a general framework model with only limited detail and spend more time on analysis and examining the effects of sensitivity and uncertainty in the model. Yet another individual or group may wish to develop a meticulously detailed model at a substantial cost in time and resources. This preference would allow the user to examine detailed aspects of human performance or limit the amount of ambiguity and uncertainty in the model.

Regardless of the level of detail in which the modeler may wish to include, each model begins with a *template* diagram which forms a basis for a specific operation. The template is a diagram involving the most relevant factors affecting a class of accidents or specific operation. The development of a model diagram is cyclic process.

Phillips, *et al.* (1990) discuss a method for framework modeling incorporating both decision theory and group processes. Decision theory provides a model framework for which to assess error rates and group interaction between knowledgeable parties provide information regarding influences between events and reasonable assessments of the rates of occurrence. Development of a model is an iterative process. The structure of the model is shown to key players in the operation (managers, front line operators, regulators, consultants, etc.) to discuss whether the models are consistent with their holistic judgment and experiences. If results are not consistent with case history examples and general quantitative measures, the discrepancies are explored further to gain greater insight. On the other hand, the model may be found to be inaccurate and adjustments are made to the current model or another model is formulated.

3.2 Influence Diagrams

One such method of developing accident framework models for PRA analysis is through the use of *influence diagrams*. Influence diagramming is a form of PRA model ing which allows greater flexibility in examining HOE and HOE management alternatives. There are distinct advantage for using influence diagramming as an alternative to standard event/fault tree analyses. Influence diagrams are used to organize conditional probability assessments required to determine unconditional probabilities of failures of specified target events [Phillips, *et al.*, 1990]. In standard decision tree analysis, decisions are based on all preceding aleotory and decision variables [Howard & Matheson, 1981]. However, not all information is necessarily available to a decision maker. In addition, information may come from indirect sources or not the specific order in which the decision tree is modeled. It is not necessary for all nodes be totally ordered in an influence diagram. This allows for decision makers who agree on common based states of information, but differ in ability to observe certain variables in the diagram modeling [Howard & Matheson, 1981].

3.3 Structuring Relevant Events, Decisions and Actions

The influence diagram models encompass the class of accidents in which the postmortem model is a representative. The development of influence diagram models (and preliminary model representations) should be the effort of a group of experts. Discussion of differences in opinion of relationships between events and their causes illicit the development of more realistic models [Phillips, *et al.*, 1990]. The models are developed through an iterative process discussed between experts to determine relevant influences and correlation between sub-systems and operations.

The modeling process follows the methodology discussed by Paté-Cornell (1992). This includes the structuring of a target event (e.g. loss of life or structural integrity due to loss of control of crane load, product spill resulting from loss of fuel containment during tanker loading or discharge, etc.) which is the final result of contributing events, decisions, and actions. The first step is to develop a model representing dependencies between relevant events. Events can be categorized into three states:

(1) *Contributing/underlying events*: The set of events which lead to an initiating accident event. Contributing/underlying events are those occurring prior to the initiating accident event contributing to the reduction of reliability or increase of risk for the system. For example, initiation of a tanker load or discharge at an improper rate or time, or conducting offshore crane operations without proper supervision.

(2) *Initiating/direct accident events*: The immediate accident event(s) resulting in the casualty. For example, loss of fuel containment while loading or discharging a tanker or loss of control of a crane load on an offshore platform.

(3) *Compounding events*: The progression of events which lead to compounding of accident consequences (e.g. oil spill, loss of life, or platform integrity).

Examples of the influence of events in accident sequences for tanker and offshore production platform are shown in Figure 3. For the tanker, the underlying/contributing event is the loading or discharge of cargo. The initiating/direct accident event is the loss of fuel containment during transfer, and the compounding event is a hydrocarbon spill in the body of water surrounding the vessel. Similarly, a diagram representation for crane accidents represents underlying/contributing event as initiation of crane operations, initiating/direct event is the loss of control of the crane load, and the compounding event is the loss of life, injury or structural damage. These examples are explored further in the following chapters.

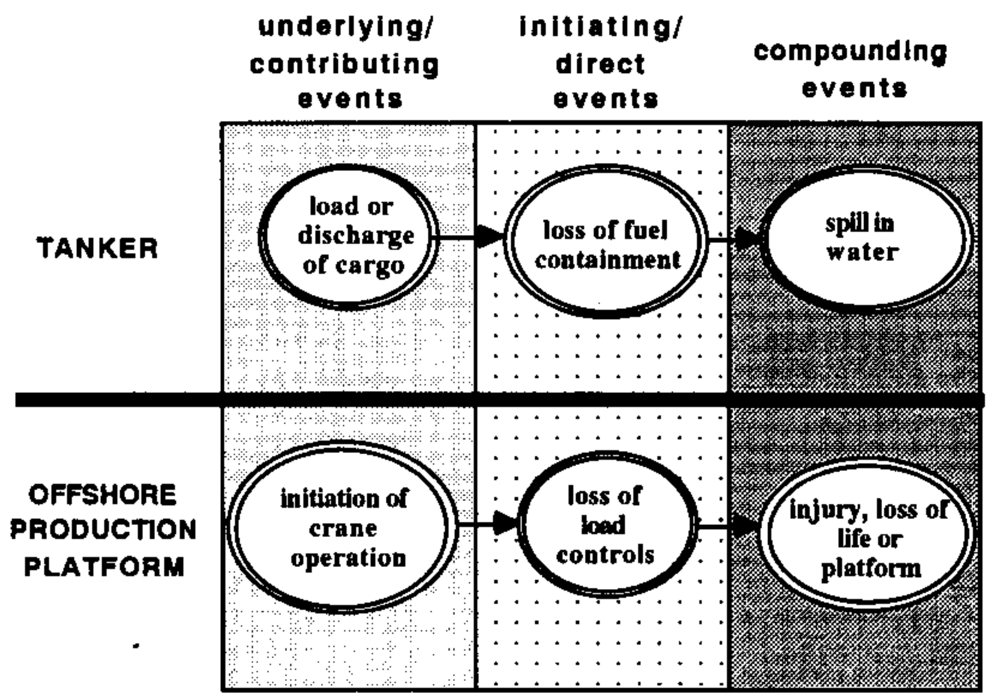

Figure 3: Examples representing progression of accident events

The next step is to establish contributing decisions and actions influencing the set of accident events. These events can be expressed in an influence diagram representation by a node representing the set of decisions or actions leading to the event node a s shown in Figure 4. The relationship between the nodes is a conditionality and can be represented as shown. For further study of influence diagramming modeling, refer to *Influence Diagrams, Belief Nets and Decision Analysis* (1990) edited by Robert M. Oliver and James Q Smith.

The final step in developing the model framework entails extending the model to include the influences of HOE and operating environment factors upon events, decisions and actions. HOE and conditions in the operating environment can affect on events, decisions and actions conducted by operating crews. Moore & Bea (1992b) have developed an HOE taxonomy for addressing contributing HOE factors and environmental operating conditions as represented in Figure 5. Environmental conditions (temperature, wind, waves, smoke, fire, etc.) can potentially influence events, decisions, actions and human and organizational errors. For example, crews operating in excessive noise environments (e.g. tanker engine room or platform production module) are subject to communication errors, or maintenance crews working in excessive temperatures without proper protection may result in fatigue or inattention to the job. Post-mortem models of the *Exxon Valdez* and *Piper Alpha* disasters were used as case study examples relating the influences of HOE and operating environment factors [Moore & Bea 1992a, 1992b].

Analysis of each of contributing events, causes, and decisions should be examined to determine the relevant HOE factors which can potentially lead to the accident factor. The contributing factors should be supported by available data and expert opinion of operators, engineers, managers, and regulators.

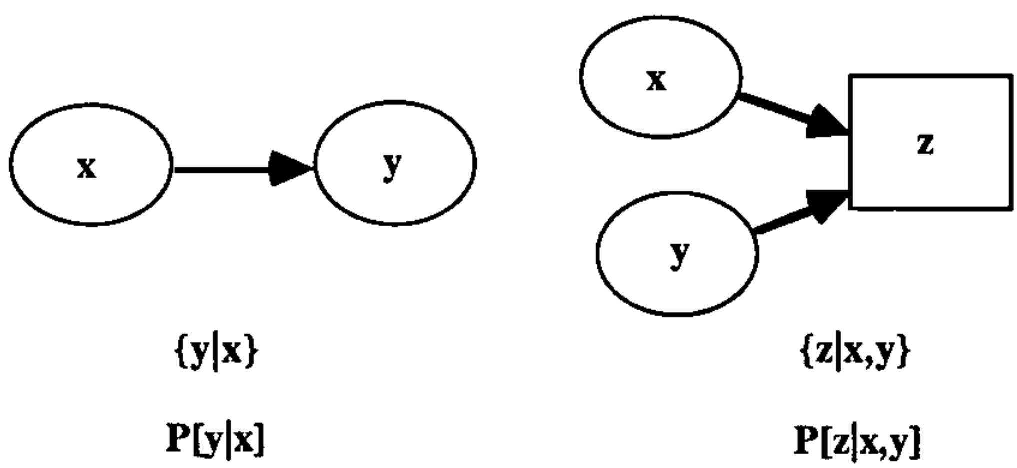

Figure 4: Examples of relationship of nodes in an influence diagram

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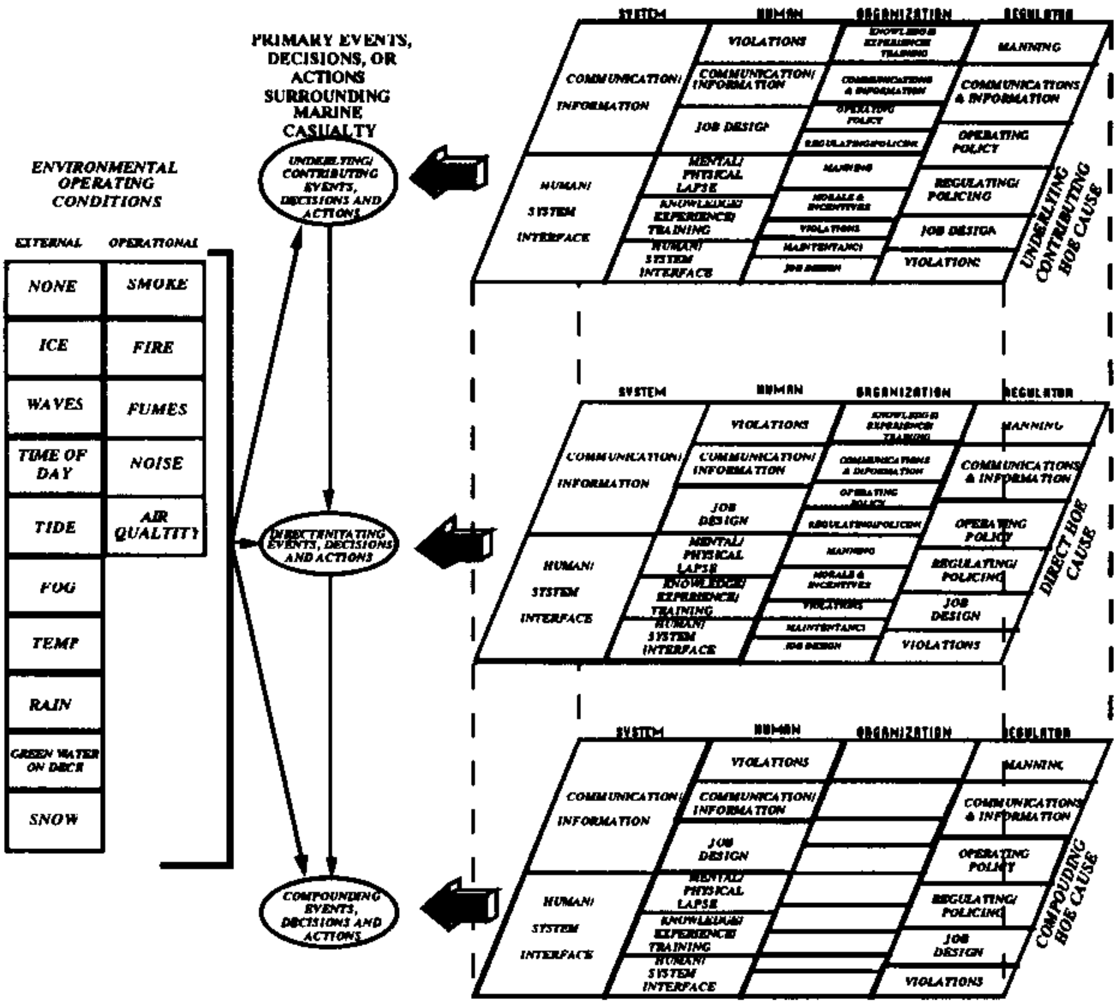

Figure 5: Influence of HOE's and operating environments on marine casualty events, decisions and actions

4.0 CASE STUDY EXAMPLES

The following chapter demonstrate case studies of analytical framework developments for HOE analyses. As mentioned previously, two operations were identified for analysis: load and discharge operations for tankers and crane operations for offshore platforms.

The tanker load and discharge influence diagram is developed and modified to account for three operations: (1) dockside load and discharge, (2) barge-tanker bunkering, and (3) offshore spread mooring facility load and discharge. The crane operation influence diagram is used to examine the differences in risk between operations where the operator is in the line of sight of the load and where assistance is required from additional personnel. Examples of alternatives for HOE management are evaluated for each operation.

4.1 TANKER LOAD AND DISCHARGE

4.1.1 Background

The load and discharge models focuses primarily upon proper interface between vessel and docking facility, proper monitoring of load or discharge, and potential of load or discharge system failure (hoses, pumps, etc.). The failure of the system includes both HOE and mechanical failure of the system.

Before an exchange of product between parties a Declaration of Inspection (DOI) is required in which a Pre-Transfer Conference (PTC) between ship and shore regarding details of the operation and cargo. The Pre-Transfer Conference includes [Chevron USA Inc., 1990]:

(1) *Quantity and type of stocks*

(2) *Cargo transfer sequence*

(3) *Cargo transfer rates*

(4) *Anticipated stoppages*

(5) *Maximum rail pressure*

(6) *Maximum rail temperature*

(7) *Number and speed of ship's pumps to be used*

(8) *Names of personnel involved*

(9) *Transfer details and critical stages*

(10) *Applicable rules*

(11) *Emergency, discharge containment and reporting, shutdown procedures*

(12) *Shift change procedures*

4.1.2 Structuring primary events, decisions, and actions

The first stage is to determine the target events for the model. The model template should include the most remedial of events which include the class of accidents. For the load and discharge model, the underlying or contributing event is the initiation of the loading or discharge. The direct event is the loss of fuel containment. Loss of fuel containment includes rupture or leakage of hose or loading arm, failure of vessel/dockside interface, overload of tanks, and failure of valves leading to spill. The compounding event is the spill of oil into the surrounding water. As shown in Figure 6, the model the contributing or underlying event is "Initiate Load & Discharge". The direct event is the "Loss of Fuel Containment" and final target event is the "Product Spill in Water".

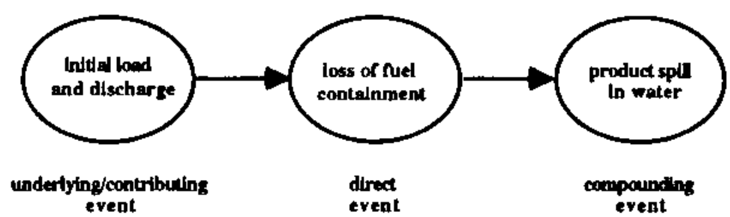

Figure 6: Load & discharge primary accident events

The primary associated decisions and actions which can influence the potential accident events are the monitoring of the load or discharge by both the vessel crew and the dockside personnel. Crew changes during loading or discharge operations affect the monitoring aspect of the operation. The influence of crew changes while monitoring are discussed below. The rate of load and discharge is a factor which can directly influence the failure of the system. It is assumed that higher rates of loading or discharge increase the chances of a system failure over time. The system failures are hoses, valves, pumps, power plant, and emergency shutdowns. The influences of these factors are shown in Figure 7.

4.1.3 Relating relevant HOE and environmental factors

Figure 8 is used as a guide to determine the relevant HOE and environmental factors influencing the accident events, decisions, and actions. The primary events shown in Figure 6 are each have contributing HOE and environmental factors. For the underlying/ contributing event "Initiation of Load or Discharge", there may be miscommunications (incomplete or inaccurate) of any one of the details of the Pre-Transfer Conference. System errors may present wrong information to the operator. Human errors are include miscommunication, lack of training, experience and knowledge of the system, mental/ physical lapses (fatigue, alcohol, drugs, etc.). Incentives or morale of the vessel or dockside operators may affect the transfer operation. Experiences of marine facility investigators have shown that loading and discharge problems are generally the result of miscommunication between parties involved (tanker crews, barge crews, and shore personnel), lack of training, experience, and knowledge of the system [State Lands Commission, 1992].

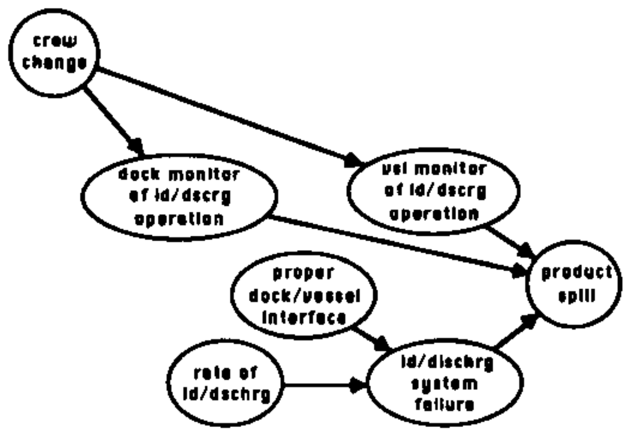

Figure 7: Influence of factors leading to a product spill during load and discharge operation

Organizational factors influencing the underlying/ contributing events are operating policy which affects the decisions made by front-line operators. Operator views toward safety, operating policy, and internal regulating and policing vary between crews and organizations. Operators with limited resources and low commitments to safety may be more willing to violate policies or regulations. Regulatory errors such as insufficient regulating or policing can contribute to an accident scenario.

The direct accident event, "Loss of Fuel Containment" may be the result of system errors (failure of operating console or inability to sufficiently read console). For human errors, the operators may lack the knowledge, training, experience, insufficient manning, or other duties may distract them (job design) from the load or discharge operation. Similar to the underlying and contributing causes, miscommunications between personnel lead to the loss of fuel containment by loading or discharging at an improper rate, time or duration. Lack of a commitment to maintenance from the operators potentially contribute to the failure of the system.

The compounding accident event "Product Spill in Water" can be the result of not being aware of the loss of fuel containment while monitoring. This may be due to system errors (no early warning), inattention or fatigue (mental/physical lapse), lack of contingency plans by the operator (emergency shutdown system or procedure), lack of proper maintenance.

Environmental factors (i.e. wind, waves, etc.) are observed to affect only the offshore spread mooring operations by influencing the mooring/vessel interface of the operation. The hoses or riggings may be affected by dynamic motions of the vessel during the operation.

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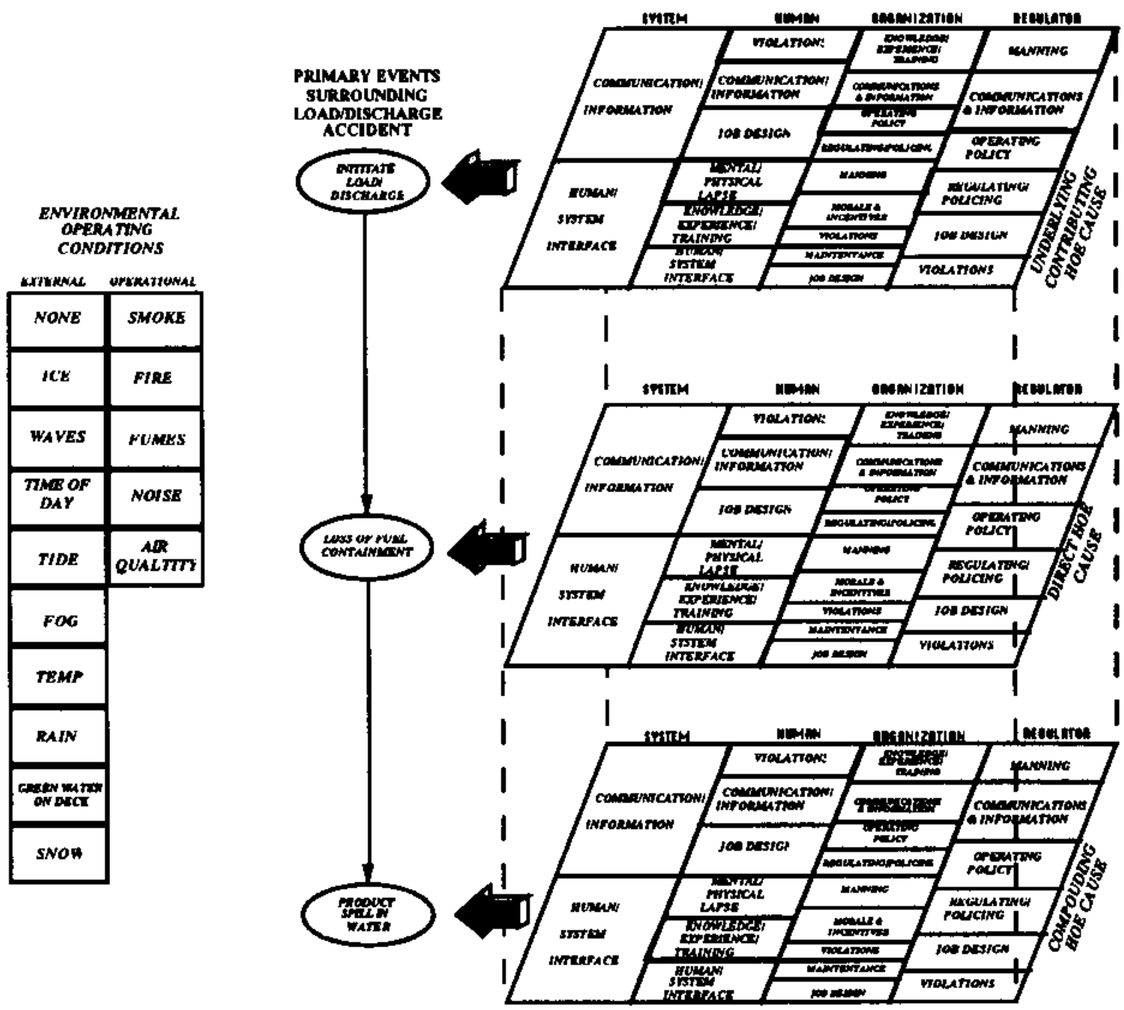

Figure 8: Influence of HOE and environmental factors upon primary events of a tanker load & discharge

Figure 9 shows the influence diagram representation for loading and discharge operations. Organizational errors affect the human errors on the front-line operator level. The human and system errors directly influence the dock and vessel monitoring of the load or discharge operation. Figure 10 is a modified diagram to account for load and discharge operations in the offshore spread moorings. Environmental conditions are observed to affect the mooring/vessel interface described above. Table I provides the outcomes for each factor described in the model.

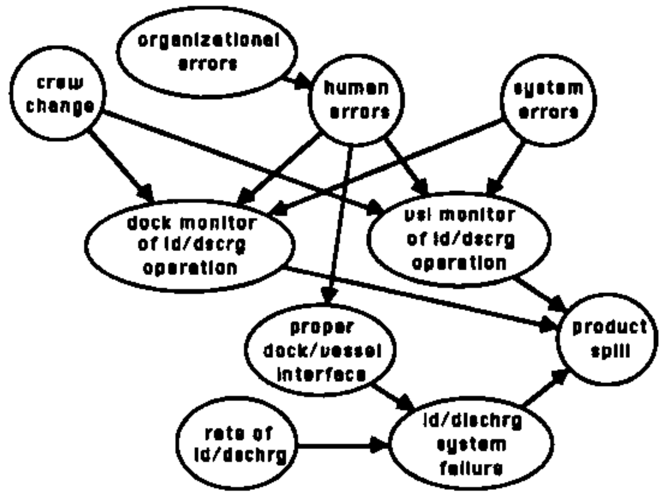

Figure 9: Tanker load and discharge influence diagram

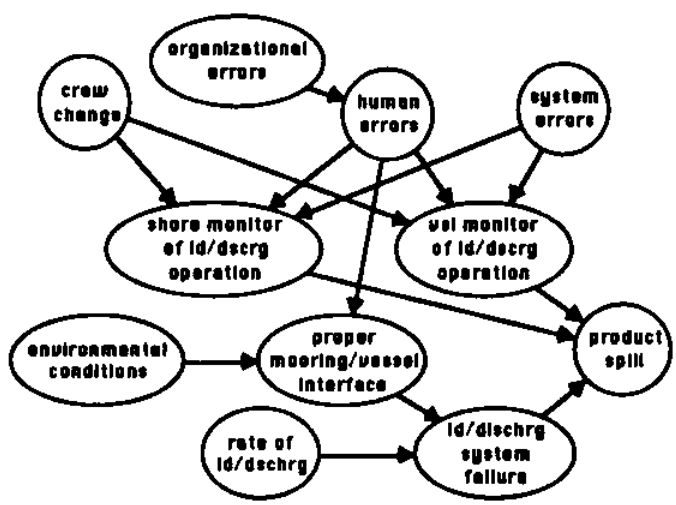

Figure 10: Tanker load and discharge influence diagram for offshore spread mooring

Table I: Outcomes within each node of load & discharge influence diagram

organizational errors	**system errors**	**envrionmental conditions**
none	*none*	*none*
manning	*comm/info*	*waves*
comm/info	*hmn syst intrface*	*wind*
oper policy		
regul/policing	**human errors**	**ld/dschrg system failure**
job design	*none*	*operational*
moral/incent	*violations*	*failure*
violations	*comm/info*	
maintenance	*job design*	**rate of ld/dschrg**
knwl/exp/trning	*mntl/phys lapse*	*none*
	knwl/expr/trng	*moderate*
	hum/syst intrfc	*high*
vsl monitor of ld/dscrg operation	**dock monitor of ld/dscrg operation**	**crew change**
monitor	*monitor*	*change*
no monitor	*no monitor*	*no change*
properdock(mooring)/ vessel interface	**product spill**	
proper interface	*spill*	
improper interface	*no spill*	

4.1.4 Example evaluation of models

The next step is to evaluate the model to determine base rates of loading or discharge spills per unit time dependent upon the factors presented. The probabilities (and conditional probabilities) of outcomes presented are those of "expert" opinion and are at input the discretion of the user. Developments of frameworks for probabilistic updating of HOE influences on accident factors are the subject of a following report. As an example, the three operations are compared to determine the probabilities of failure with specific conditions applied. The primary differences between the dockside, tanker/barge, and spread mooring operations lies in the load or discharge monitoring. An organization with the three operations within a specific region may wish to determine where limited resources should be directed if one operation is substantially more risky than another.

For dockside monitoring, it is assumed that both the terminal personnel and tanker crew are equally aware of the status of the operation. In tanker-barge bunkering operations, experience has shown that vessel crews tend to be less aware of the status of the loading operation [California State Lands Commission, 1992]. This has been attributed to the additional duties assigned to tanker crews not directly associated with bunkering and inexperience, lack of knowledge and training (particularly for non-tankship vessels). The offshore spread mooring is assumed to have better monitoring from the vessel than shoreside monitoring which is not in direct sight of the load or discharge.

In evaluating the models, the dockside loading and discharge model is assumed to have equivalent probabilities for dock and vessel monitoring. The tanker-barge bunkering operation is assumed to have 10% higher probability of effective monitoring than that of the vessel monitoring. Similarly, for the offshore mooring operation the vessel is assumed to have a 10% higher probability of effective monitoring than that of the shore crew.

Table II demonstrates shows the probabilities of product spills for the load and discharge operations. Dockside load and discharge has the lowest frequency of spills followed by the bunkering and spread mooring operation. A higher probability of product spill for spread mooring operations can be partially attributed to environmental conditions not associated with the other operations.

Table II: Comparison of probabilities of failures between 3 types of load and discharge operations

Operation	Probability of product spill
Dockside	**4.57×10^{-4}**
Tanker-barge bunkering	**5.11×10^{-4}**
Offshore spread mooring	**5.76×10^{-4}**

4.1.5 Examples of HOE management alternatives: Offshore spread mooring

The comparison between the operations has shown that the highest risk operation is the offshore spread mooring. An alternative to reduce risk of spills has been proposed by placing a mooring master and an additional deck master to aboard a vessel . The duties of the mooring master entails advising the vessel master on approaching and departing the berth, mooring and unmooring. All maneuvering within the mooring area is done only in accordance with the advice of the mooring master. The addition of a deck master to monitor and advise all placing of mooring lines and anchors, load and discharge interfacing between vessel and connecting hoses . All decisions and actions of the deck master are in accordance with the advice of the mooring master.

The addition of the deck master is assumed to increase the reliability of the loading or discharge operation through: (1) greater knowledge, training, and experience, (2) vessel/ mooring interface, (3) vessel monitoring of operation. The addition of the deck officer is assumed to reduce the probability of knowledge, training, and experience errors by 5%. An additional affect of increased knowledge and experience results in a 5% reduction in failure at the vessel/mooring facility interfaces and the monitoring of operation. The probability of product spill has now reduced to 4.13×10^{-4} which is comparable to the probability of dockside spills.

4.2 OFFSHORE CRANE OPERATIONS

4.2.1 Background

Crane accidents are of particular concern to operators and regulators alike. Between 1971 and 1983 there were reported 50 crane accidents of which 35 were results of human error resulting in 37 fatalities and 26 injuries [U.S. Department of Interior, 1984].

The offshore crane model focuses primarily upon crane operator and rigger errors and their influences upon the loss of load control and the loss of load. The loss of load control is defined as the inability to control the movement of the load by the operator or rigger. The loss of load is defined as the inadvertent, uncontrolled or accidental dropping of the crane load. Rigging and operational failures include both human and system (mechanical) errors.

4.2.2 Structuring primary events, decisions, and actions

The first stage is to determine the target events for the model. The model template include the remedial events which are specific to the class of offshore crane accidents. As shown in Figure 11, the model the contributing or underlying event is "Initiation of Crane Operation". The direct event is the "Loss of Load Control" and finally target event is the "Loss of Load". These events are defined as the accident events.

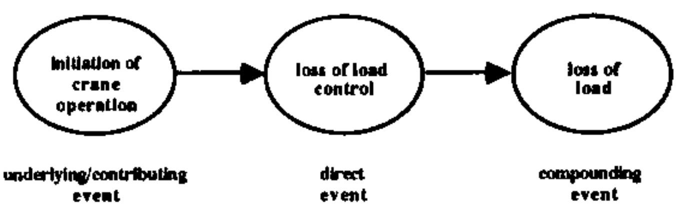

Figure 11: Crane operation primary accident events

The primary associated decisions and actions which can influence the potential accident events are rigging or operational failures. Riggings may be improperly arranged by the rigging crew or riggings may be improperly maintained. Operating failures can be breakdown of the crane during operation or failure of the crane operator. In addition, an important factor during operation is the ability of the crane operator to be in the line of sight (LOS) of the job which he/she is conducting. This is expressed by the lack of visual cues to the operator and potentially result in the loss of load control. The influences between these factors are shown in Figure 12.

4.2.3 Relating relevant HOE and environmental factors

Figure 13 is used as a guide in determining the relevant HOE and environmental factors influencing the accident events, decisions, and actions. The primary events shown in Figure 11 each have contributing HOE and environmental factors. For the underlying/ contributing event "Initiation of Crane Operation", human errors such as violations by operators (unsafe procedure, willful overload of crane, etc.), miscommunications between operators and other installation personnel, lack of training, experience and knowledge of the system or other operations being conducted within the vicinity of the crane. Operating policies of the organization, lack of incentives, limited regulating and policing of offshore crane operations can contribute to violations and unsafe operations.

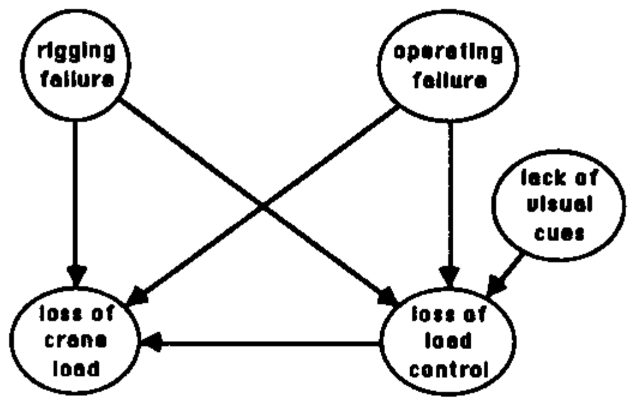

Figure 12: Offshore crane accident influence diagram

The direct accident event, "Loss of Load Control" may be the result of system errors (failure of operating console or inability to sufficiently read console). Human errors can be the operators may lack the knowledge, training, experience, insufficient manning, or other duties may distract them (job design) from the load or discharge operation. Similar to the underlying and contributing causes, miscommunications between personnel lead to the loss of fuel containment by loading or discharging at an improper rate, time or duration. Lack of a commitment to maintenance from the organization or operating crews can contribute to the failure of the system. Environmental factors such as wind and waves can illicit vessel motions while loading or off-loading can contribute to both rigging and operating problems. Waves pose a particular problem while loading or off-loading when vessels are heaving and wind may cause the operator to loose control of the load during transfer.

The compounding accident event "Loss of Load" can be the result of loss of load control or operator errors. Trained and experienced operators are assumed to function better in crises involving the loss of load control. The crane control system or riggings may be inadequate to allow the operator to bring the load under control. Environmental factors affect the "Loss of Load" event in the same manner as the "Loss of Control".

Figure 14 shows the influence diagram template for offshore crane accidents. Organizational errors affect the human errors on the front-line operator level. The human and system errors directly influence the operating and rigging failures. The the operator not being within the LOS of the lift operations lack of visual cues to maintain load control. Operator and rigging failures directly influence the loss of load control and crane load. Table III provides the outcomes for each factor described in the model.

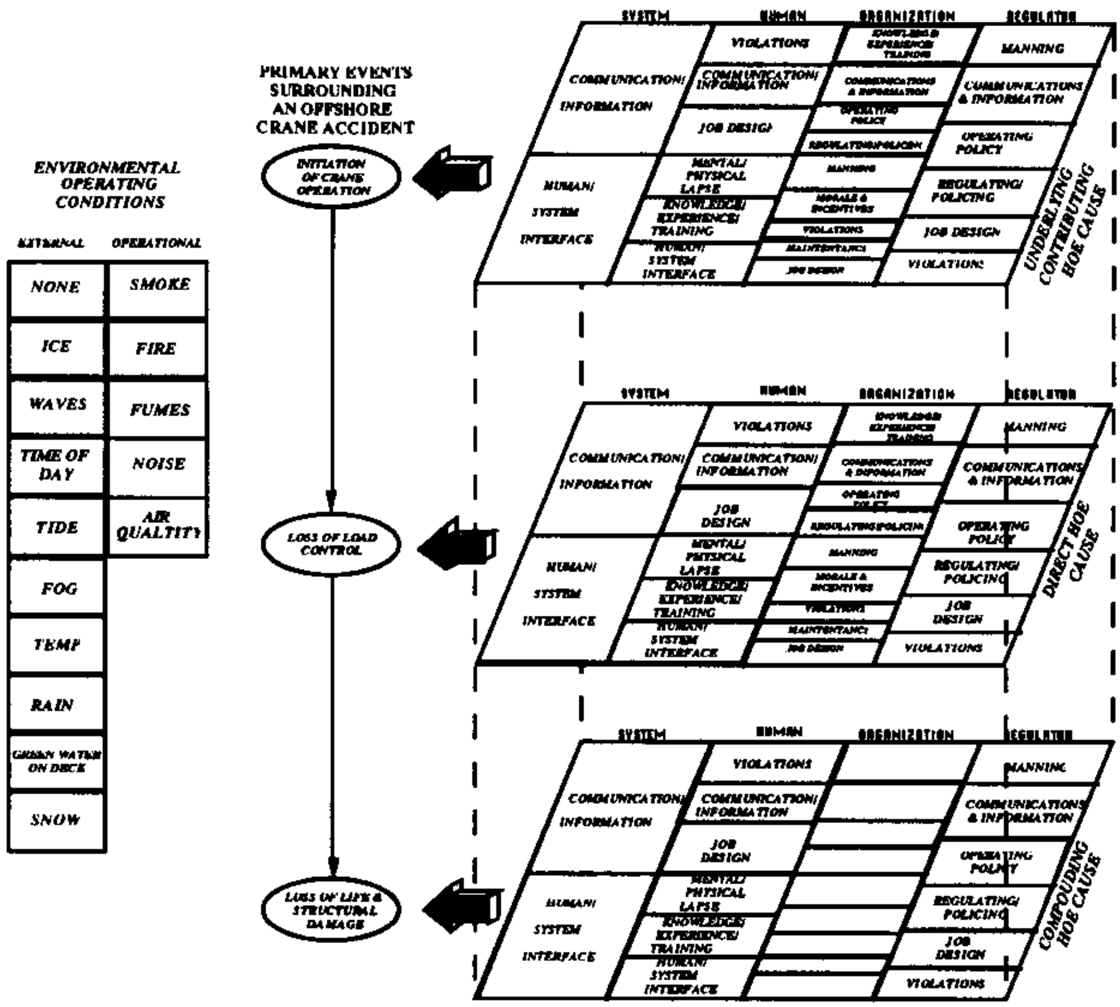

Figure 13: Influence of HOE and environmental factors upon primary events of an offshore crane operation

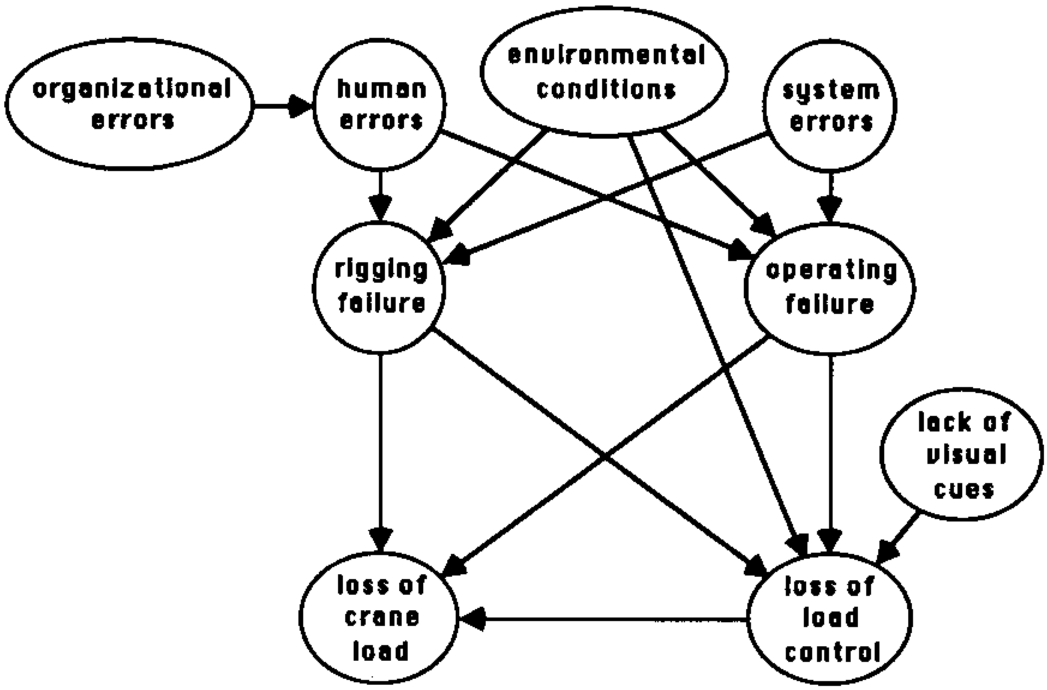

Figure 14: Offshore crane accident influence diagram with HOE factors

Table III: Outcomes within each node of crane accident influence diagram

organizational errors	system errors	envrionmental conditions
none	*none*	*none*
manning	*comm/info*	*waves*
comm/info	*hmn syst intrface*	*wind*
oper policy		
regul/policing	**human errors**	**rigging failure**
job design	*none*	*operational*
moral/incent	*violations*	*failure*
violations	*comm/info*	
maintenance	*job design*	**operating failure**
knwl/exp/trning	*mntl/phys lapse*	*none*
	knwl/expr/trng	*moderate*
	hum/syst intrfc	*high*

lack of visual cues	loss of load control	loss of crane load
within line of sight (LOS)	*load control*	*loss of load*
not in line of sight (LOS)	*no load control*	*no loss of load*

4.2.4 Example evaluations of model

The determination of loss of load control and loss of load are factors in which to address in the preliminary analysis of in the crane accident models. As an example, we wish to determine the direct influence of human errors on loss of load control and loss of load. Evaluation of the influence diagram shown in Figure 14, results in Table IV shows the probabilities of loss of load control and loss of load conditional upon human errors. As observed, the loss of load and load control have higher frequencies for lack of communication and information, mental and physical lapses, lack of knowledge, training and experience and human system interface problems.

Table IV: Probabilities of accident events conditional upon human errors for offshore crane accidents

human error	P[loss of load control| human error]	P[loss of load| human error]
none	**0.0644637**	**0.0165069**
violations	**0.1561176**	**0.0577316**
comm/info	**0.286762**	**0.1694268**
job design	**0.2273544**	**0.0985724**
mntl/phys lapse	**0.2907227**	**0.1309497**
knwl/expr/trng	**0.2824033**	**0.1370118**
hum/syst intrfc	**0.2997536**	**0.1495823**

4.1.5 Examples of HOE management alternatives: Crane operations within and outside of lines of sight (LOS)

After the initial observation that human errors in communication and information contribute to high probabilities of loss of load control and loss of loads, a further examination into potential contributing factors is warranted. Let us address the issue of crane operations within and outside the LOS of the operator. Crane operators working outside of their LOS require the assistance of additional personnel to direct the operation. It is assumed that the crane load is within the LOS of the operator 85% of the time. First we examine the influence of the lack of visual cues upon the loss of load control and loss of load. As demonstrated in Table V, loss of load control and loss of load have higher frequencies conditional upon being outside the LOS of the crane operator. Table VI shows higher frequencies of crane events for work outside of the LOS of the operator . The events are particularly affected by a lack of communication and information.

Table V: Probabilities of accident events conditional upon visual cues for offshore crane accidents

P[Loss of load control | LOS]	0.0653773
P[Loss of load control | no LOS]	0.126287
P[Loss of load | LOS]	0.0201432
P[Loss of load | no LOS]	0.0296052

Table VI: Probabilities of accident events conditional upon human errors and visual cues for offshore crane accidents

human error	P[loss of load control| human error & LOS]	P[loss of load| human error & LOS]
none	0.0555163	0.0152439
violations	0.1454179	0.0551900
comm/info	0.0761926	0.0977538
job design	0.2153635	0.0947782
mntl/phys lapse	0.2773971	0.1261383
knwl/expr/trng	0.2695173	0.1320464
hum/syst intrfc	0.2864021	0.1442394

Table VI Probabilities of accident events conditional upon human errors and visual cues for offshore crane accidents (cont.)

human error	P[loss of load control|human error & no LOS]	P[loss of load|human error & noLOS]
none	0.1151659	0.0236638
violations	0.2167488	0.0721338
comm/info	0.3733327	0.2177538
job design	0.2953031	0.1200731
mntl/phys lapse	0.3662344	0.1582143
knwl/expr/trng	0.3554244	0.1651494
hum/syst intrfc	0.375412	0.1798588

Analysis of the model has shown communication and information to have considerable impact upon the accident events. An alternative of establishing better communication systems and increased operator training are expected to reduce the probability of communication and information errors by 1/2. A residual affect of operator training is assumed to reduce the probability of knowledge, training and experience errors by 1/4. Table VII demonstrates reductions in accident events dependent upon these factors.

Table VII Probabilities of accident events conditional upon human errors and visual cues for offshore crane accidents with communication system and training

human error	P[loss of load control| human error & LOS]	P[loss of load| human error & LOS]
comm/info	0.0634091	0.0774316
knwl/expr/trng	0.2382977	0.0998348
	P[loss of load control|human error & no LOS]	**P[loss of load|human error & noLOS]**
comm/info	0.3510655	0.1840456
knwl/expr/trng	0.3287994	0.1256609

5.0 CONCLUSIONS

Examination of current tanker and offshore operations which to construct probabilistic models (influence diagrams) of general classes of accidents. The development of influence diagrams should rely upon group interaction between experts knowledgeable of the system being modeled. Effective modeling of these operations can lead to the development of templates in which to modify to address a wide range of tanker and offshore operational accidents influenced by human and organizational errors.

A lack of quantitative information limits assessment of conditional probabilities of accident related factors. Therefore, we must rely on expert opinion and limited data sources. Nevertheless, developments of influence diagram models assist users in determining and examining complex interactions of human, organizational, and systems.

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