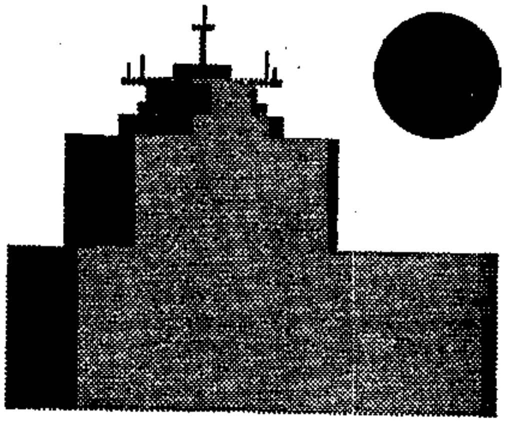
Human and Organizational Errors in Loading and Discharge Operations at Marine Terminals

Reduction of Tanker Oil and Chemical Spills: Engineering to Minimize Human and Organizational Errors

SEA GRANT PROJECT R / OE 28



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Preface

Approximately one billion barrels of crude oil and products are transported in California waters each year. Based on statistics provided by the California State Lands Commission, tanker discharge and loading operations are the predominate source of industrial oil and chemical spills into California waters. These operations account for a spill frequency that is a factor of 10 higher than that associated with offshore platforms, pipelines, and storage tanks.

Spill reports indicate that a significant number of the spills are the result of Human and Organization Factors (HOF) such as poor communications, inadequate training, improper monitoring, inadequate maintenance, improper emergency provisions, and under-staffing resulting in fatigue and excessive stress.

The objective of this project has been to further develop engineering procedures to assist in the definition and evaluation of alternatives to minimize the occurrence and effects of HOF in tanker Loading and Discharge Operations (LDO). As part of a Sea Grant - joint industry sponsored project conducted during the period 1990-93 titled "Reliability Based Management of Human and Organization Errors in Operations of Marine Systems" a general approach was developed to assist in evaluation of the roles of HOE in operations of marine systems (Bea, Moore 1992). This project has addressed reliability based HOF management technology as applied specifically to tanker LDO.

Two major needs were identified in the initial Sea Grant project on HOF in operations of marine systems. The first concerned the further development and field testing of a classification and evaluation system for HOF. The second concerned the further development of an HOF management system to interface with the marine operations analytical models developed during the first project.

This project has addressed these two needs in the framework of a "hands on" field operations oriented project involving tanker LDO. Testing of the HOF classification and evaluation system has been coordinated with a similar efforts conducted by the United States Coast Guard, the California State Lands Commission, and the Washington State Office of Marine Safety. The field studies have been concentrated on two 'high reliability' LDOs conducted by Chevron Shipping Co. and by Arco Marine Inc.

The results of this project are documented in three reports:

- "Reduction of Tanker Oil and Chemical Spills: Engineering to Minimize Human and Organization Errors," by Susan Stoutenberg, Robert Bea, and Karlene Roberts,
- "Reduction of Tanker Oil and Chemical Spills: Organizing to Minimize Human and Organizational Errors," by Thomas Mannarelli, Karlene Roberts, and Robert Bea, and
- "Reduction of Tanker Oil and Chemical Spills: Development of Accident and Near-Miss Databases," by Eliot Mason, Karlene Roberts, and Robert Bea.

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1. Introduction

Since the introduction of super tankers in the 1960s, there has been an increased awareness of oil spills and the potential dangers they present to the marine environment. It is estimated that 80 percent of all accidents in marine systems are attributable to human error, of which 80 percent occur during operations (Bea, 1994, 1993). It is the purpose of this project to study the consequences of human error in loading and discharge operations (LDO) of oil tankers at terminals.

This transfer of cargo oil, either crude or refined, is a very common practice on the west coast of the United States. Crude oil is carried from the oil fields in northern Alaska, through a pipeline to Valdez, where it is loaded into large tankers and transported to refineries in California. This refined oil is then loaded onto different tankers to be carried to distribution points to be delivered to the consumer.

This project is concerned with the transfer of oil between the ship and cargo terminals. The two operations studied are the Chevron Long Wharf Terminal in Richmond, California, and the *Arco California*, a VLCC in the TAPS trade between Valdez, Alaska and the Pacific West Coast. During transfer, the vessel's cargo system is connected to the shoreside cargo system by means of large loading arms or hoses. In a loading operation, oil is transferred from tanks on shore to the ship's cargo manifold in the arms or hoses, and then is distributed to the appropriate cargo tanks on board. In a discharge operation, oil is transferred from the ship's tanks out through the arms and to the storage facility on shore. Figure 1 is a photograph of the *Arco Alaska* discharging oil at the Richmond Long Wharf. (All photos in this report were taken on board the *Arco Alaska*, a sister to the *California*.)

The primary differences between the two modes of transfer occur when the operation is nearing completion. In loading, this process is called topping off. As tanks are filled it is critical that the shore valves are closed at the appropriate time to avoid spillage. In discharge, stripping -- the emptying of tanks-- is not as critical a process. Because there is essentially unlimited space for oil on shore, precise control is not required to prevent an oil spill. This is a complicated process on board the ship but in terms of transfer it is not as hazardous as topping off.

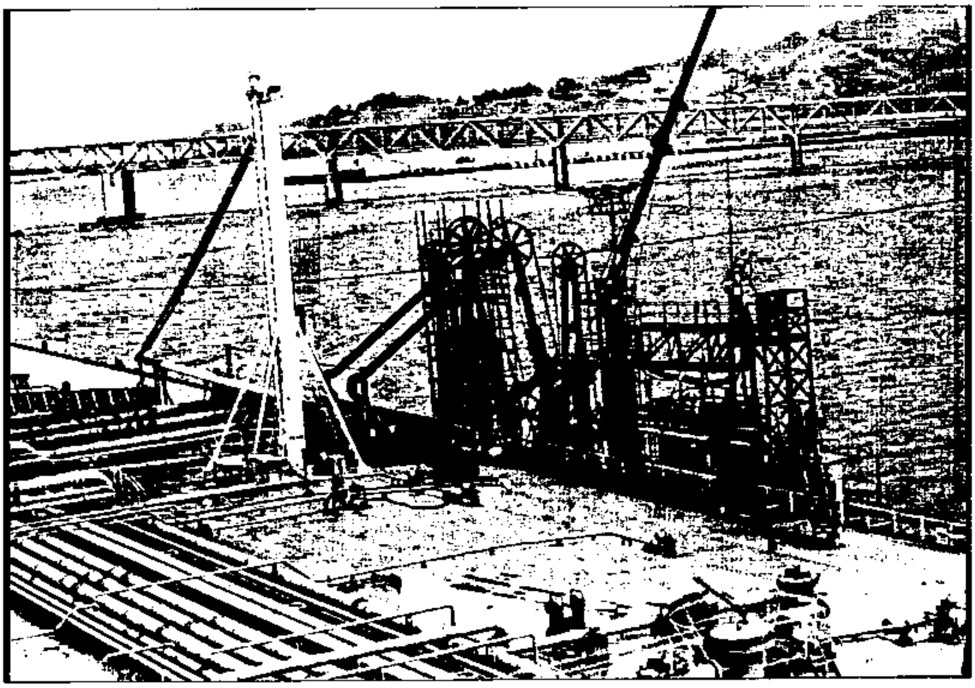


Figure 1. Arco Alaska at Richmond Long Wharf

Human error in marine operations has been a topic of research at the University of California since 1989. Dr. William Moore and Professor Robert Bea began to study human and organizational error in the marine industry with a concentration on tanker and platform operations. Dr. Moore's dissertation is a presentation of a method of classifying and studying human and organizational factors (HOF) to aid in the improvement and "idiot proofing" of marine systems (Moore, 1993). The HOF system is used in this project for the evaluation of loading and discharge operations at oil terminals. This evaluation also provides information for the creation of a database for archiving the causes and consequences of accidents (Mason, 1995).

In Moore (1993) the method of classifying human and organizational errors is used in the post-mortem analysis of well documented accidents. It is the objective of the project to test and evaluate the use of this method for proactive analysis of existing marine systems. This research is a group effort combining the work of researchers from the Haas School of Business and the College of Engineering (Hart, 1994; Mannarelli, 1994, 1995; Mason 1994, 1995).

The structure of this report is as follows. Chapter 2 is a description of background in the field of human and organizational error in the marine industry, including a historical perspective as well as present methods of reducing incidents and their effects. Chapter 3 discusses the approach that was followed in this project. Chapter 4 describes the method used to analyze the cargo transfer operations which were studied. Chapter 5 and 6 contain detailed evaluations of the Chevron Long Wharf and the *Arco California*, respectively. Chapter 7 presents a summary of two methods which can be used for a combined quantitative analysis. Chapter 8 briefly outlines the organizational factors which can affect the loading and discharge operation at marine terminals. Chapter 9 provides conclusions regarding applications of this method as well as observations of critical portions of the transfer process. Chapter 10 summarizes suggestions for future work in this field.

2. Background

Each year, thousands of barrels of oil are spilled in the vulnerable marine environment. While this is but a small portion of the total volume of oil carried, its effects can be disastrous to the areas where spills occur. Although some spills can be attributed to unpredictable equipment failure or adverse environmental conditions, most are the result of human or organizational factors. It is estimated that 80 percent of all marine accidents are caused by human factors of some kind. Although, some of these accidents can be attributed to design and construction processes, 80 percent are attributable to errors that occur during operations (Bea, 1993).

2.1 Human & Organizational Error

Human errors are defined as "actions taken (or not taken) by individuals that can lead an activity to realize a lower quality than intended." Human errors can be influenced by several factors, and these factors make a good start for the classification. These most basic of human error types are depicted in Figure 2. The four influences on human error can be defined as systems (hardware), procedures (software), environment (internal and external), and the organizations which influence the operator (Bea, 1993).

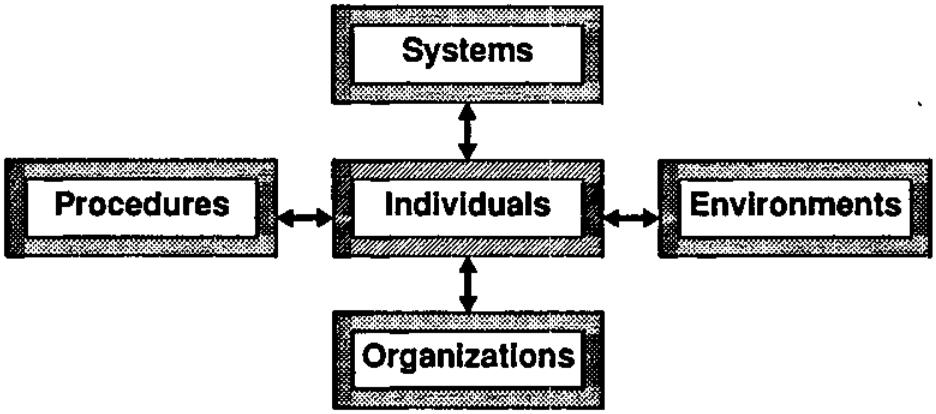


Figure 2. Components of Human Error

In addition to being classified by their origin, human errors can be classified by the form that they take. These can include acts of commission or acts of omission. An act of commission is one in which the person actively does something that is to the detriment of operational quality. An act of omission is, conversely, an error that occurs when the person does not do something necessary, directly or indirectly, for the quality of the operation. An example of an act of commission is a mistake, where the person consciously intends the action but this intention is incorrect. Another example is violation or circumvention, where an action intentionally deviates from normal procedures to expedite or facilitate the operation. Examples of acts of omission are slips and lapses, where the action is performed incorrectly or omitted inadvertently. Slips are not typically a large problem because they are easily detected and rectified. Figure 3 depicts a more complete classification of types of human error.

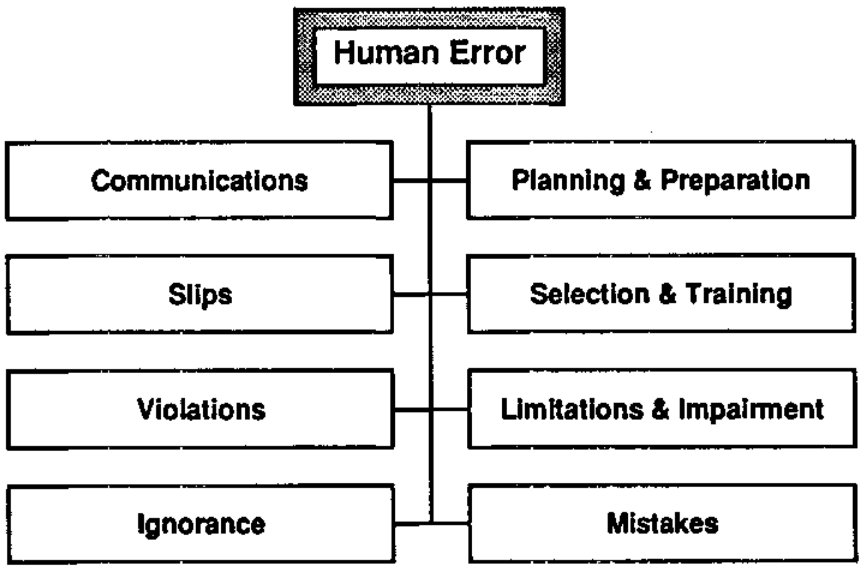


Figure 3. Types of Human Error

Mistakes are the most significant type of human error because the person who commits the error is convinced that he is doing the right thing. Mistakes can also be divided into several categories. Figure 4 depicts the classification of types of mistakes. Although each type of mistake is independent, they can be pictured in a chain of logic. Perception is general knowledge and awareness. Discrimination is the ability to perceive the distinguishing characteristics of the situation. Interpretation is the capacity to evaluate and assign meaning to these characteristics. Diagnosis is the clarification of causes and effects. Decision is the choice between alternatives. Finally, action is the execution of the procedure.

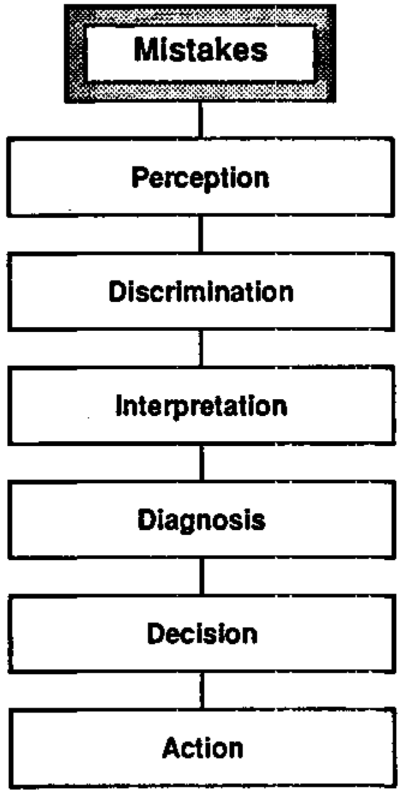


Figure 4. Types of Mistakes

Organizational error is defined as "a departure from acceptable or desirable practice on the part of a group of individuals that results in unacceptable or undesirable results." Organizational pressures can influence people to take calculated risks. These are usually due to conflicting goals and incentives of different parts of the organization. Typically such conflicts take the form of compromising safety for perceived benefits. This can lead to hasty execution of procedures in response to time pressures. It can also be manifested in system errors because of poorly prioritized maintenance schemes (Bea, 1993).

2.2 Historical Perspective

Recently, increasing attention has been paid to safety in the marine industry. This is perhaps in response to public outcry or perhaps independent on the part of the industry itself. Even as the industry improves its safety record, the public perception of complacency in the environmental arena has not improved. The marine industry is often compared unfavorably to the commercial airline and nuclear power industries on the basis of their larger body of research in the area of safety. To understand these differences it is important to look at the genesis of the various activities.

Both the nuclear power and commercial air travel industries have evolved in the last fifty years. Both involve clear dangers and these dangers have been taken into account since the birth of the industries. In contrast, the marine industry has been evolving for several thousand years. Not until this century were significant inroads made in the field of safety. Only after the advent of the super tanker in the 1960s, were oil spills of serious concern. At the same time, both the oil industry and the marine industry have historically attracted adventurers and risk-takers who did not always have an eye towards safety. In addition, both of these industries have traditionally had profit, above all else, as a driving compulsion. When finances are prioritized above safety, a dangerous situation results. Although this characterization does not describe all elements of the marine oil industry, negative public opinion other extends through the entire industry.

Since the 1960s, however, there has been slow but marked improvement in the safety strategy of marine oil transportation. Most changes in the marine industry are very slow because of the significant capital investment involved in any dramatic change. This can be seen in the implementation of new regulations. Very often rules are phased in and all vessels will not have to comply for more than a decade. Often, however, capital is not the solution. As organizational and human factors are identified as main drivers, energy can be focuses on reorganization and training versus capital investment.

Beginning in the 1980s, and spurred on by the Oil Pollution Act of 1990, the momentum of change has quickened. This is due internally to pressures from both operators and upper management alike. Operators are inclined to strive for safety because it makes their jobs easier as well as less hazardous. Managers see safety as a strategy for increasing the volume of oil sold versus spilled as well as a route to good employee relations and interaction with the community.

2.3 Present Context

This increased emphasis on safety has taken the form of root cause analysis in most cases. Many companies are strongly versed in contemporary quality management strategies and recognize the importance of the human component. While in the past failures were usually attributed to equipment failures, today's understanding of systematic problems extends to include human and organizational factors. Companies encourage the reporting of near misses and the investigation of root causes. It is advantageous for this to be done in such in a way that the placement of "blame" on individuals is minimized This is done so that even though the human error root is sought, the people responsible will not feel as though they need to be defensive or dishonest.

On an industry level, human error is handled in a bottom up approach. Each incident is analyzed and its causes rectified but there is little integration of these individual investigations. This is also a very reactive approach. It is the intent of this research to offer a top down systems approach, where the operation as a whole is studied to look at the far reaching effects of human and organizational factors. This is intended to be a proactive tool. Realistically, however, because the research is of a historical nature most items which have not caused problems in the past are not considered likely to be hazardous by those industry experts who are the source of our judgment.

For the past six years, researchers at the University of California led by professors Robert Bea and Karlene Roberts have investigated various aspects of human and organizational factors in the safety and reliability of marine systems. The product of this work -- most notably the doctoral dissertation of William Moore -- is a classification system and evaluation method for marine accidents and oil spills. This project is the application of this classification and evaluation to loading and discharge operations at marine oil terminals.

3. Approach

This project uses the method and classification defined by Moore and Bea to evaluate human error in loading and discharge operations. This method is a systematic way to organize the daunting task of investigating human error. Modes and types of errors are defined in a mutually exclusive and exhaustive, yet generic, way so that possible events can be easily sorted without the researcher becoming bogged down in detail. This method has been previously tested with accidents as a postmortem analysis for both the *Exxon Valdez* super tanker and the Piper Alpha platform (Moore, 1993). It is the purpose of this project to apply this method in foresight to marine terminals.

Specifically, this project seeks to define the possibility of high consequence accidents precipitated from normal operations. Although the term "high consequence" can be interpreted in several ways, in this context it can encompass all accidents. While most people agree that hundreds or thousands of barrels of oil lost is of high consequence, to people working on a terminal or a ship anything which reaches the water is considered to be of high consequence.

The major source of data and information for this project consists of visits to marine terminals, as well as shipping companies. The participating organizations are Chevron USA Products Company, Chevron Shipping Company, and Arco Marine Inc.

During these visits people at all levels of the organizations were consulted. This provides a diverse insight as well as an interesting contrast. Operators have provided the details depicted in the technical and procedural aspects of this project. Managers in some cases have the operating experience to comment on the details of the process and execution, but in all cases provide a perspective of the organizational complexity. The contrast between the two can be very important for evaluating the potential for organizational errors.

4. Evaluations

There are four parts to the analysis of human and organizational errors. These are the system, procedure, qualitative, and quantitative analyses. The system analysis examines the physical plant to determine which equipment or systems are the most vulnerable and also the most critical. The procedural analysis defines the steps involved in the process as well as possible influences on the performance of these steps. Qualitative analysis combines the results of these first two evaluations to define which steps or sub-steps are the most hazardous or vulnerable. Quantitative analysis uses numerical values determined from field research and expert opinion to assign probabilities of failure to the operation.

4.1 Systems

The system evaluation is the most easily defined portion of the human and organizational error analysis. In addition to accounting for all major components of the system -- pumps, piping, valves -- it is also important to include all seemingly minor equipment such as gaskets and o-rings. This analysis would begin with a schematic drawing of the transfer system and then a more detailed examination of the key connections. People often blame system failures for problems that are actually due to the mistakes of humans. Many system problems have their root in poor design, construction, or maintenance. These problems only become critical when a less than precise operation causes a failure.

System failures can be categorized into four groups (Bea, 1993). See Figure 5. System problems are typically related to a human error in the design process. In the context of operations they are often considered to be external to human factors. System variables are very important for the improvement of error tolerance. This is of particular concern in the marine area where all systems are designed with severe spatial constraints. This leads to very significant correlation in the failure modes of systems and components.

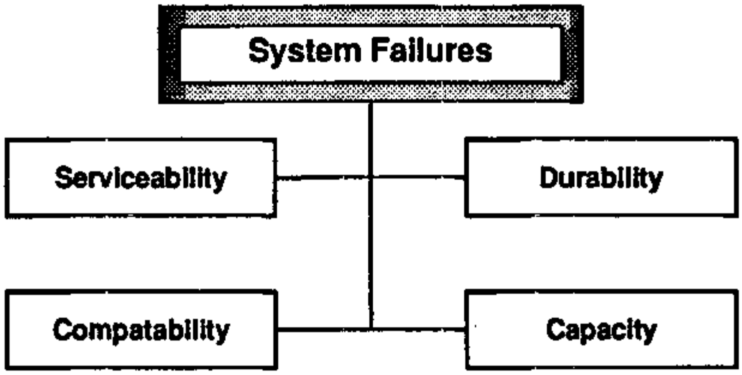


Figure 5. Classification of System Errors

4.2 Procedures

Similar to the system analysis, the procedural evaluation defines the process in a systematic way, using a differentiation of steps. The entire operation is broken into its key events and each of these is subsequently divided into its sub-steps. The correlation between steps and the importance of each with respect to oil spillage is determined to establish a "map" of the process and any possible spill mechanisms using an event tree structure. It is very important to consider every possible chain of events so that no unexpected routes can cause a large accident.

Procedural errors can be thought of as a poor definition of the correct actions to be taken (Bea, 1993). This can lead to the improvisation of problematic steps to achieve a goal. Errors in procedures can be categorized as depicted in Figure 6. These categories include both the existence of a systematic approach and the documentation of this approach.

Errors in procedures, both written and followed, greatly increase the chances for mistakes and other errors to occur. If the operation is performed in the same way every time, there will be less possibility of creative thinking providing a poor solution or disorganization leading to the omission of a key step.

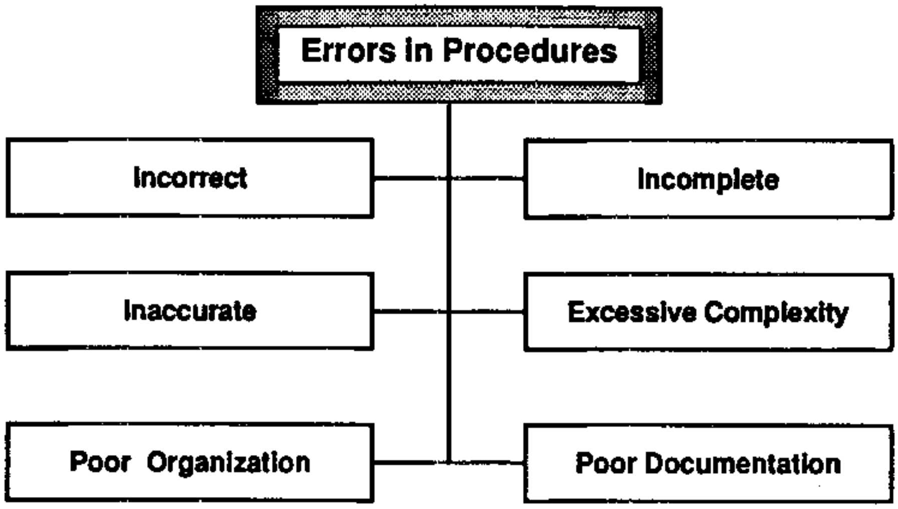


Figure 6. Classification of Procedural Errors

4.3 Qualitative

Qualitative analysis is the first level of evaluation. Even in the quantitative evaluation, numerical values are not precise predictors. For many problems, qualitative evaluations are all that are necessary. Quantification simply adds another degree of precision.

Qualitative analysis uses subjective judgment to describe the operation. This is generally expressed in terms of value variables. Hazards are thought of as posing "high" or "low" risk.

The goal of qualitative analysis is screening to identify potential problem areas which require closer attention. A further analysis of these areas will provide important influences and factors. These factors can provide a starting point for improvement of the system.

4.4 Quantitative

Quantitative analysis is often used in the study of operations that have the potential to experience very high consequence, low probability accidents. This approach uses numerical analysis to assess the probability of failure of the system. Quantitative analysis is most descriptive and useful when two or more alternatives are being compared.

Because these numbers are very imprecise it is difficult to use the results in anything but a qualitative way. In general, the probability of failure is not meant to be considered as a prediction of behavior, but as an indicator of relative safety.

Quantitative analysis has been very effective in fields that have highly developed databases from which statistics can be estimated. Commercial air transportation and nuclear power industries have been successful in the development and maintenance of such databases. These industries have also invested in behavioral research to assess the effects of different stressors on human operators. Unfortunately, the marine industry has not been as successful in implementing a collection system for accident information. In addition, human error was not of primary concern until recently. Because of this, most data which exists does not address human factors. This means that the estimation of numerical values is highly subjective. Data from the nuclear power industry are used here to extrapolate values for quantitative analysis (Gertman and Blackman, 1994). Mason (1995) presents an approach to the development of a database for specific implementation with marine accidents

4.5 Mixed Qualitative and Quantitative

Mixed qualitative and quantitative analysis is a way of avoiding the problems of assigning probabilities without adequate historical data. The soft linguistic variables derived from qualitative analysis can be translated to numerical variables to provide inputs into the quantitative approach.

To accurately portray the LDO process for the study of human and organizational factors, it is necessary to do as much research in the field as possible. In order to obtain quantitative data and to streamline the gathering of information, a questionnaire and interview process was used.

Questions in the interview instrument were based on a step-by-step definition of the process and were formulated to elicit numerically valued responses. Respondents were asked to gauge the "risk" of various steps based on two parameters, importance and grade.

The importance is a gauge of how critical the perfect performance of a step is to the prevention of an oil spill, measured on a seven point scale. A score of seven means that the improper completion of the step is very likely to cause a spill. A score of one means that even if the step is performed incorrectly or not at all it would be close to impossible for an oil spill to result.

Respondents were asked to grade how well each step is performed by the operators at their terminal (or crew of their ship), usually their peers. The grade is based on a typical grading scale as is used in school. For the purpose of data manipulation, a grade of "A" is given a weight of one, a "B," two, and so on. The product of the importance and the grade is the overall risk. Figure 7 shows the first level of the questionnaire, the basic seven step model.

Importance	Grade	Step	Definition
		Approach & Berthing	*The vessel approaches the terminal, with tug escorts. The vessel is secured to the wharf.*
		Connection	*Pre-transfer conference is completed. Hoses or loading arms are connected.*
		Start Up	*Product begins to be pumped, at increasing rate.*
		Steady Rate	*Product is transferred at steady agreed upon rate.*
		Topping Off	*Product flow is slowed and then ceased.*
		Disconnection	*Hoses or loading arms are disconnected.*
		Departure	*Vessel leaves the terminal.*

Figure 7. Example of Questionnaire Format

Every respondent was asked to answer the questions associated with this first level of the model. Each person was then asked to assess the risk in the performance of the two steps that he defined as the most risky.

The problem with this type of questioning is that the responses are highly subjective. This subjectivity causes the range in answers to be very high. The relative risks, however, were fairly consistent from person to person. For this reason the data are normalized or "anchored" to obtain an average risk value for each step (and sub-step) in the process. The absolute responses are subtracted from the individual's mean risk. These normalized risk values are averaged and the mean of all of the responses is added back to this average for each step to obtain the overall risk factor. These overall risk factors are used to establish the relative influence of each step in the operation.

5. Chevron Long Wharf, Richmond, California

5.1 System

The Richmond Long Wharf is owned and operated by the refining department of Chevron USA Products Company. The wharf is located on the northeast side of San Francisco Bay. It is 4200 feet from shore, accessible by a causeway. The long wharf has four ship and two barge berths.

All ship berths except Berth 2 have dual counter weight marine loading arms. Berth 2 has a large hose riser system for the transfer of refined products. Table 1 is a list of all of the major components of the various systems.

Table 1. System Components of LDO at Chevron, Richmond

Mooring System	*Pump System*	*Communication Systems*
Quick Release Pelican Hooks	Vacuum Pumps	Ship to Shore Main Communication
Bollards	Sumps	Ship to Shore Alternate Communication
Cleats	Back-flow Valves	Ship to Shore Portable Communication
Mooring Bumpers	Pressure Gages	
Tug Support		*Wharf Operations System*
Mooring Dolphins	*Hose or Pipeline System*	Wharf Control System
Breasting Dolphins	Causeway Pipelines	Wharf Labs
	Hose Risers	Wharf Offices
Containment System	Chickstands	Wharf Pump House
Ship Boom	Straight-away Valves	Wharf Personnel Shelters
Riser Containment Wells	Hose Gaskets	
Manifold Containment Wells	Sumps	*Monitoring System*
Valve Pit Containment Wells	Connection Manifolds	Wharf Control Room
Drains and Scuppers	Pipeline End Manifolds	Computer Terminals
Containment Wells	Manifold Bolts and Tightening Devices	Reporting Files
	Valve Pits	Checklists
	Safety System	
	Flame Arresters/Fire Fighting Gear	
	Emergency Escape Signs and Routes	
	"No Smoking" Signs	
	Gangways and Nets	
	Emergency Shutdown Devices	

Figure 8 is a photograph of the loading arms at Berth 4 connected to the cargo headers of the *Arco Alaska*. Figure 9 shows the typical wharf berthing arrangement. The wharf offices, including the control room, labs, pumping, and safety equipment are all centrally located at the wharf end of the causeway. A & B Berths house the spill booming and the boats used to deploy it.

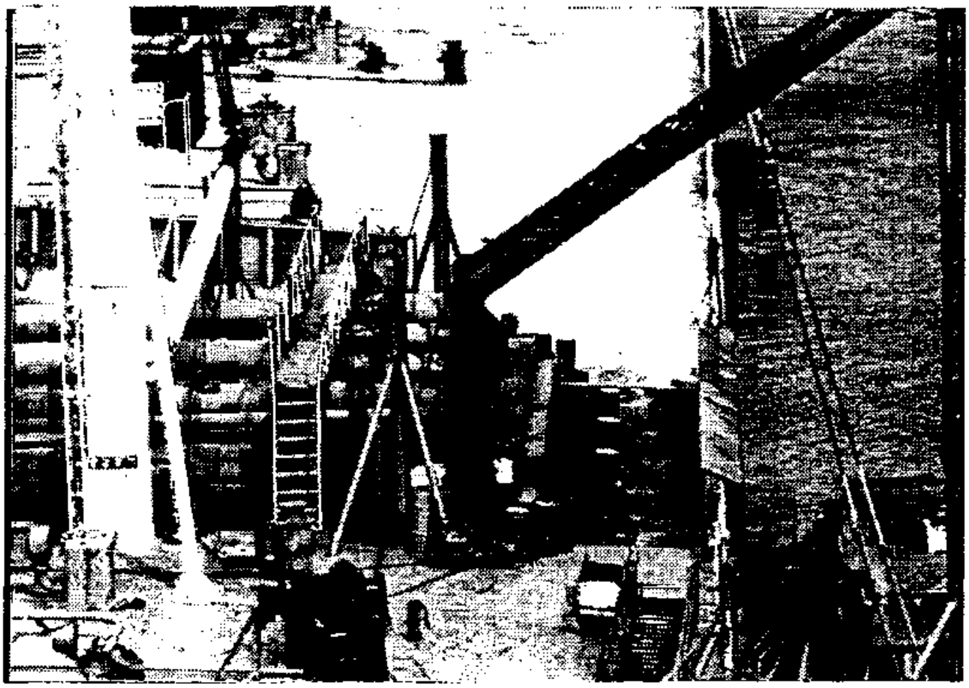
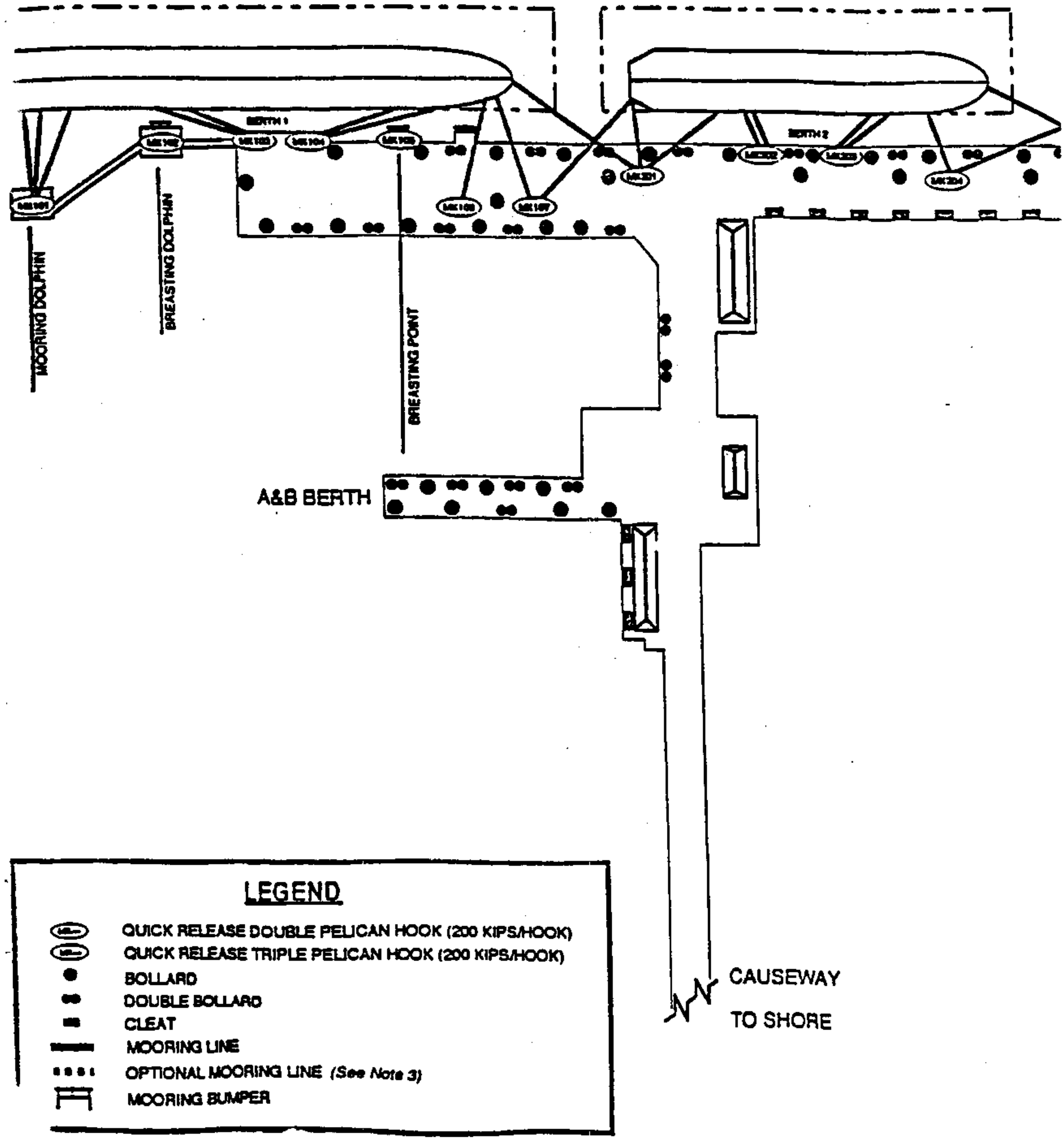


Figure 8. Berth 4 Loading Arms on Arco Alaska

TYPICAL LDO WHA



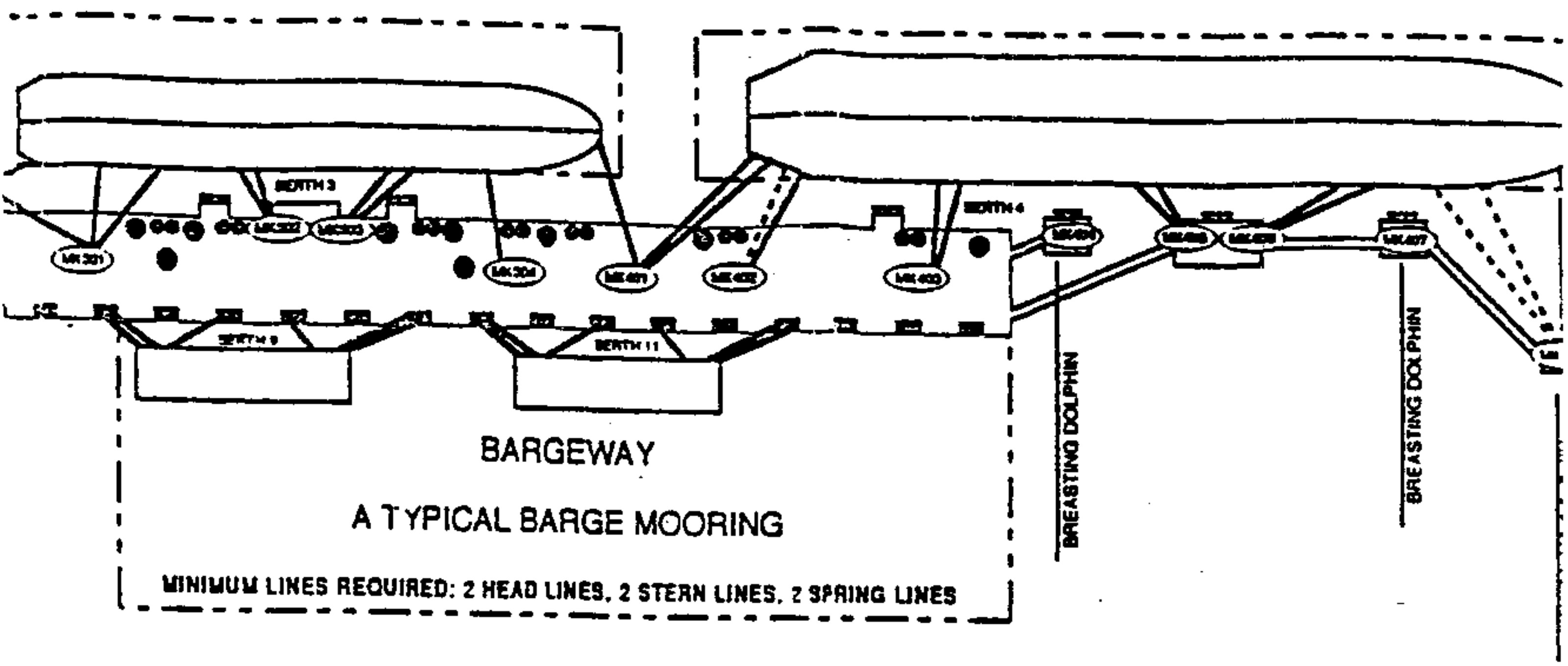


Figure 9. Typical Wharf Berthing Arrangement

NOTE:

1. AN ALL WIRE MOORING ARRANGEMENT IS THE SAFEST AND MOST DESIRABLE. THE MINIMUM AMOUNT OF MOORING LINES LEADING IN THE SAME DIRECTION WILL NOT BE MIXED. THIS IS AN UNSAFE PRACTICE AND CREATES A FALSE SENSE OF SECURITY OWING TO THE DIFFERENCE IN ELASTICITY. THE ONLY EXCEPTION WOULD BE WHEN ADDITIONAL LINES ARE UTILIZED ABOVE THE MINIMUM REQUIREMENTS.

   FOR BARGES LESS THAN 100.000 BARRELS AN ALL SYNTHETIC MOORING ARRANGEMENT CAN BE USED SUBJECT TO THE APPROVAL OF TERMINAL MANAGEMENT.

2. DIAGRAMS INDICATE TYPICAL VESSELS BERTHING PORT-SIDE-TO UTILIZING ALL WIRE ROPES FOR MOORING. IF SYNTHETIC MOORING LINES ARE USED THEN ADDITIONAL LINES WILL BE REQUIRED.

3. SOLID LINES REPRESENT MINIMUM NUMBER OF LINES REQUIRED. DASHED LINES ARE DEPENDENT UPON WIND AND/OR TIDAL CURRENT CONDITIONS AND MAY BE SYNTHETIC OR WIRE ROPE TYPE.

4. MOORING WIRES OR WIRE ROPES <u>ARE NOT</u> TO BE PLACED ON WHARF BOLLARDS WITHOUT THE WHARFMASTER'S PERMISSION IN EACH AND EVERY CASE. USE PELICAN HOOKS <u>ONLY</u>.

5.2 Procedure

The loading and discharge operations follow a basic seven step process. These steps are similar for both loading and discharge, independent of whether loading arms or hoses are used. Specific differences are noted in subsequent sections of this chapter. The steps are as follows:

1. **Approach & Berthing**
2. **Connection**
3. **Start Up**
4. **Steady Rate**
5. **Topping Off or Stripping**
6. **Disconnection**
7. **Departure**

The Approach is the movement of the vessel from the maneuvering basin to the pier. Berthing is the securing of the vessel to the pier. The Connection process is the part of the operation associated with the attachment of the ship and shore cargo manifolds. The pre-transfer conference is also considered as part of Connection. Start up is the gradual increase in flow rate up to the steady rate agreed upon at the pre-transfer conference. If the ship is being loaded, it will alert the shore when its tanks are nearly full and topping off should commence. Flow is gradually decreased until it is stopped completely. Products are allowed to drain by gravity, aided by pressure in the lines, out of the connecting hoses or loading arms. The vessel can then be disconnected and depart. Figure 10 shows the results of the improper performance of each step in the process. Each of the steps is described in more detail in later sections.

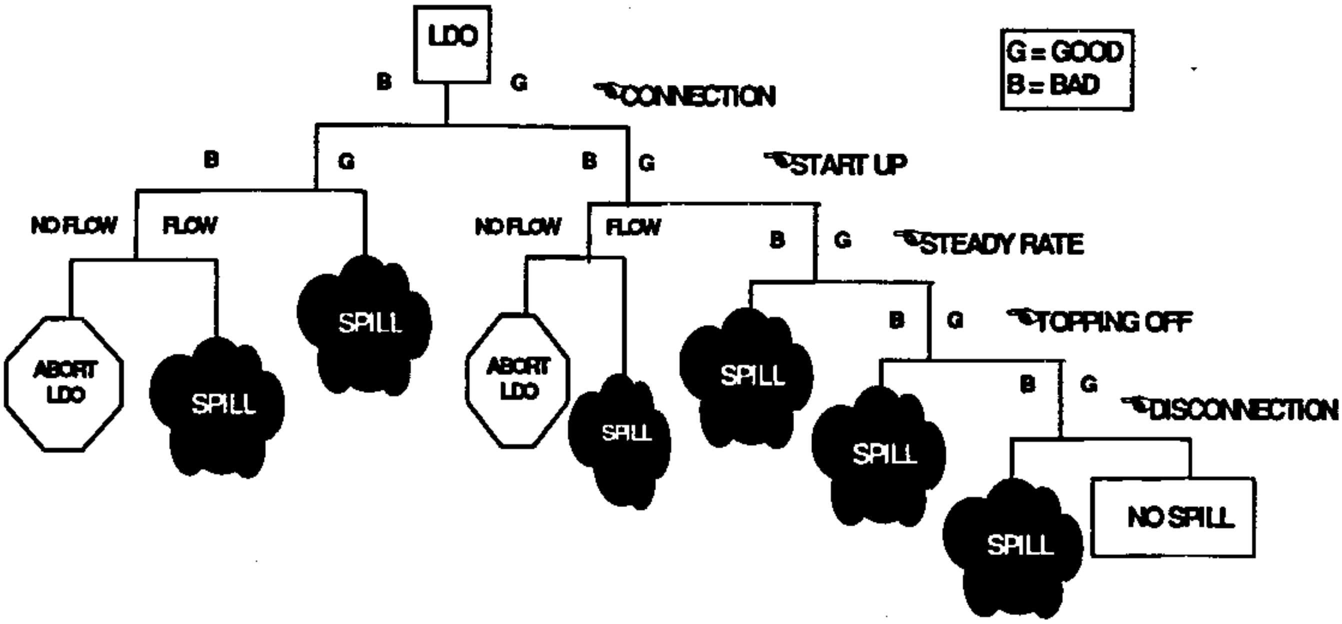


Figure 10. Event Tree Diagram of LDO

5.2.1 Approach & Berthing

There has been some discussion of the scope that this step should include. Because vessel navigation is outside the scope of this project we define the Approach, in this context, to only include the final docking of the ship. Approach and Berthing are described in more detail in Chapter 6. Six steps are associated with Approach and Berthing:

0. **Berth Selection**
1. **Approach with Escort Tug**
2. **Ship Positioning**
3. **Berth Approach**
4. **Line Handling**
5. **Final Positioning**

For vessels which have come to the long wharf before, there is a berth that is typically used based on the size of the vessel and the product(s) that she carries. If a vessel has never been to the wharf before, the berth to be used is planned in advance and the vessel is made aware of this plan so that there are no "surprises" when the ship arrives.

5.2.2 Connection

Connection is the process of attaching the shore piping system to the vessel piping system so that the flow of oil may commence in the appropriate direction. There are four primary steps in the process of Connection:

1. **Pre-Transfer Conference**
2. **Flange Preparation**
3. **Hose or Loading Arm Connection**
4. **Alignment Check**

During the pre-transfer conference, all details of the transfer of oil are agreed upon. Table 2 lists the items that are required by the United States Coast Guard and the California State Lands Commission. The Declaration of Inspection is a document that is completed and signed by all parties involved to verify the proper execution of the pre-transfer conference.

Table 2. Pre-Transfer Conference

- *Product Identity, Quantity and Type*
- *Sequence of Transfer Operations*
- *Amount of Notice Needed Before Stopping or Changing Flow Rate*
- *Arrangement of Transfer Systems*
- *Special Precautions at Critical Stages*
- *Initial, Maximum, and Topping Off Rates*
- *Federal and State Regulations*
- *Signals for Stand-By, Slowdown, and Stop Transfer*
- *Emergency Procedures*
- *Spill Reporting Procedures*
- *Watch and Shift Change Schedules*
- *Shut Down Procedures*
- *Anticipated Cargo Stoppages and Delays*
- *Declaration of Inspection is completed*

The Connection is made after the pre-transfer conference. The loading arms or hoses are moved to the vessel. If loading arms are used, the drains are opened and any product remaining in the arms is emptied. The face plate can then be removed. The face plates are removed by loosening the bottom connections first so that any remaining oil will be drained. The o-rings are examined before attachment to the ship flanges and are replaced if they are worn or damaged. The arm or hose flanges are then secured to the ship flanges, ensuring that all connectors are tight or that there are bolts in every hole, respectively. If the vessel is a Chevron ship that uses the port often, this process is performed by the vessel personnel without supervision. If the vessel is not from Chevron Shipping, an observer from the terminal is present on deck to witness the proper execution of this step. Figure 11 shows the consequences of poor performance of each of the steps of Connection.

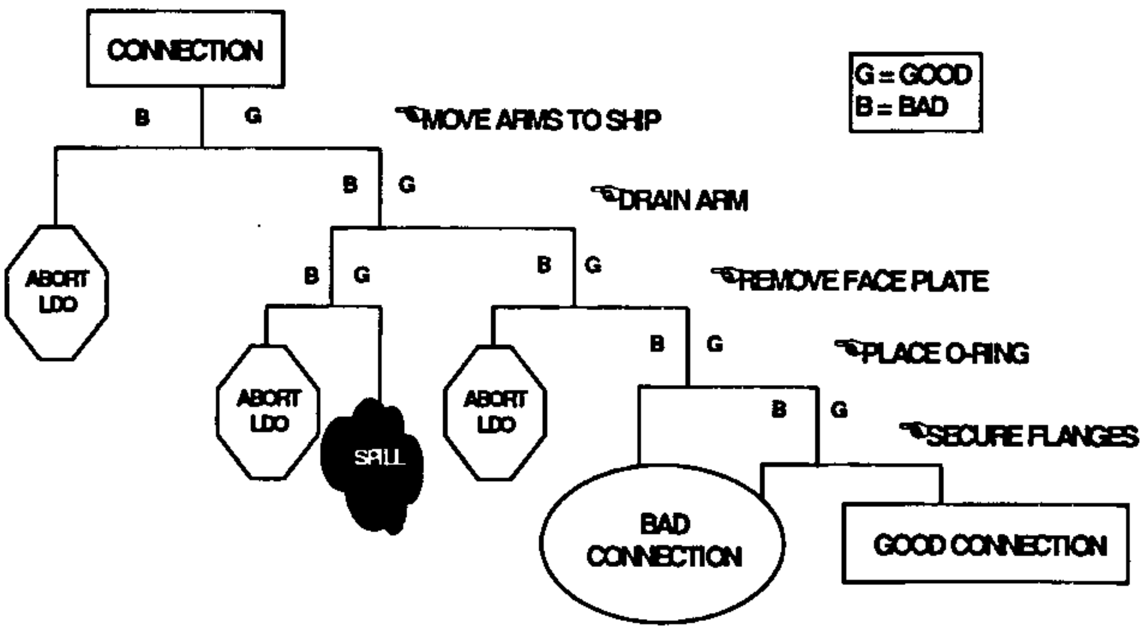


Figure 11. Event Tree Diagram of Connection Process

5.2.3 Start Up

During Start Up, the most critical components are communication and monitoring. As a part of the pre-transfer conference, the LDO plan is communicated among the vessel person in charge, the berth operator, and the pump operator. The receiving party opens its valves first. This is the ship in a loading operation and the shore in discharge. After the receiver's valves are opened and verified, the initiating party opens its valves. After the path of the product is verified, the initiating party requests permission to commence pumping. Flow is started at a slow rate and all connections are checked for leaks or other problems. Loading arms and hoses are observed to verify the absence of excessive cyclic loading due to fluctuating rates on line hammer. After both parties are certain that their side of the system is functioning properly, flow is increased gradually to the agreed upon steady rate. During this process, communication is constant between the vessel and the berth to verify the steps in rate on both sides. Figures 12 and 13 depict the effects of each of these steps on the successful completion of the Start Up process.

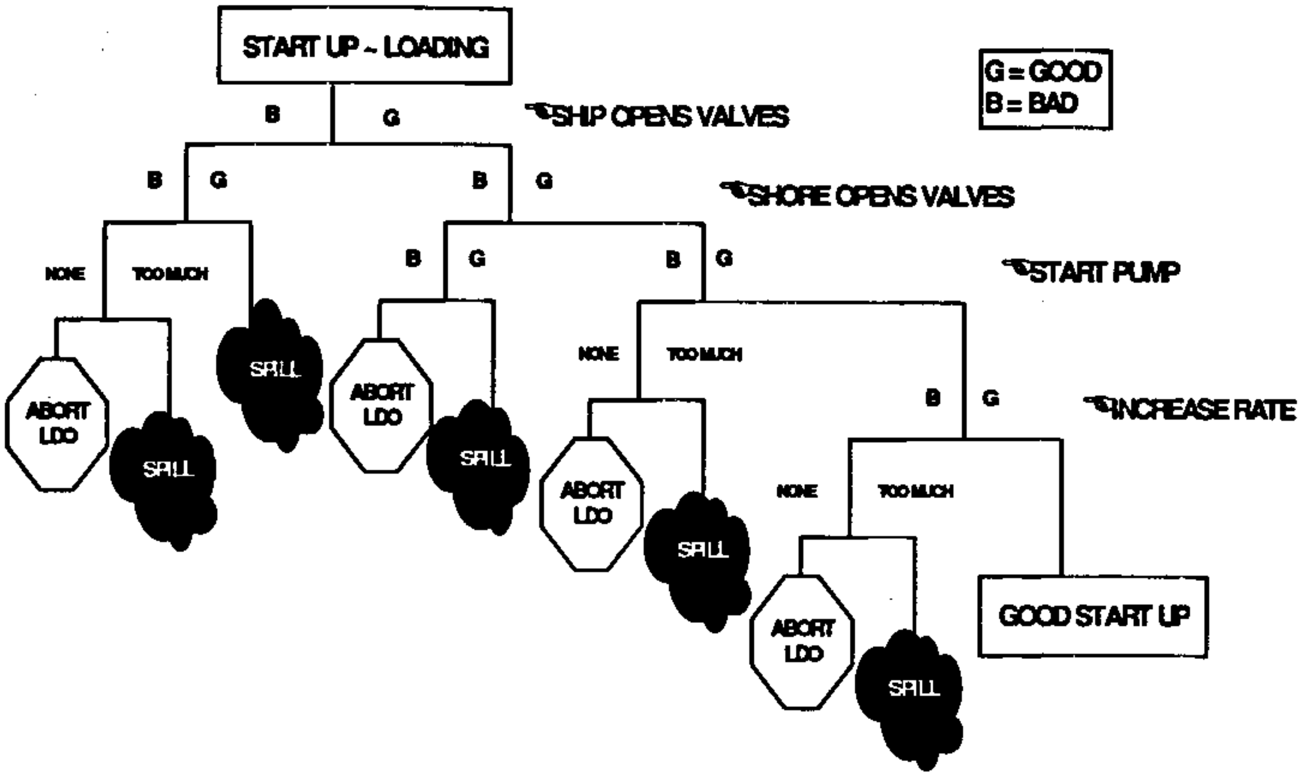


Figure 12. Event Tree Diagram of Start Up Process (Loading Operation)

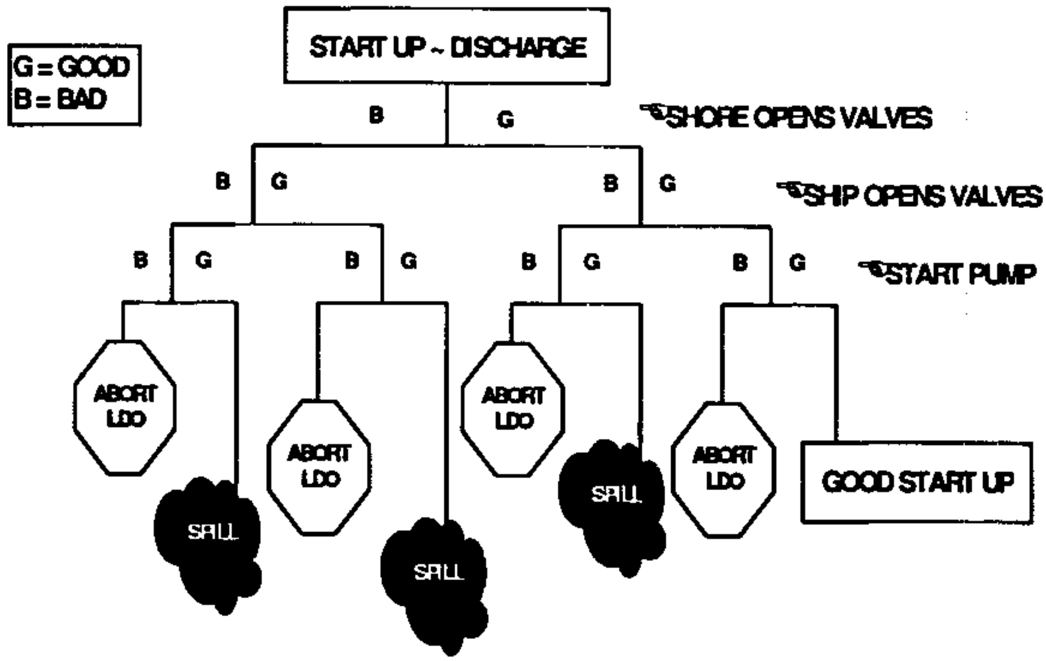


Figure 13. Event Tree Diagram of Start Up Process (Discharge Operation)

5.2.4 Steady Rate

There are no subsequent steps during the steady transfer of petroleum. Monitoring and communication are crucial during this time so that both the ship and the terminal keep track of the operation. This is important so that neither party will be surprised by the topping off of tanks as well as for the detection of spills. Flow rates and tank levels are monitored. The volume of transfer is calculated continuously and verified periodically to make sure that the ship and the berth agree and that all oil is accounted for. Some deviation is to be expected, but if it is unusually high it is possible that the "missing" oil is spilling somewhere.

5.2.5 Topping Off

Topping off is the most complex and difficult step in the loading process. It requires precisely timed communication and perfect control of critical equipment. The timing of the notification of topping off is crucial. Because the large motor operated valves at the berth move very slowly, it is very important that the operators be warned in advance. The recommended time of notification is thirty minutes before the transfer is to be completed. At this time the vessel will alert the berth to the topping of tanks and the berth operator will stand by the valves for further notification. Beginning fifteen minutes before the end of the transfer the valve is slowly closed incrementally. The careful and slow manipulation of these valves ensures that no hydraulic shock will result in line rupturing if the valves are slammed shut when the shoreside pumps are still operating. The pumps are slowed and then stopped in response to back pressure on the line as the valve is closed. When the final notification to stop the flow is received, the valve is closed completely and flow is ceased. The ships valves are left open so that lines can be allowed to drain in preparation for Disconnection. Figure 14 shows the relationship between the different steps in the Topping Off procedure.

Stripping is a much more simple process from the standpoint of the terminal. Because the terminal has an effectively unlimited capacity for oil, flow does not have to be stopped at a precise point. The same guidelines for notification are usually followed. The vessel will inform the berth when it is nearing the bottom of the tanks

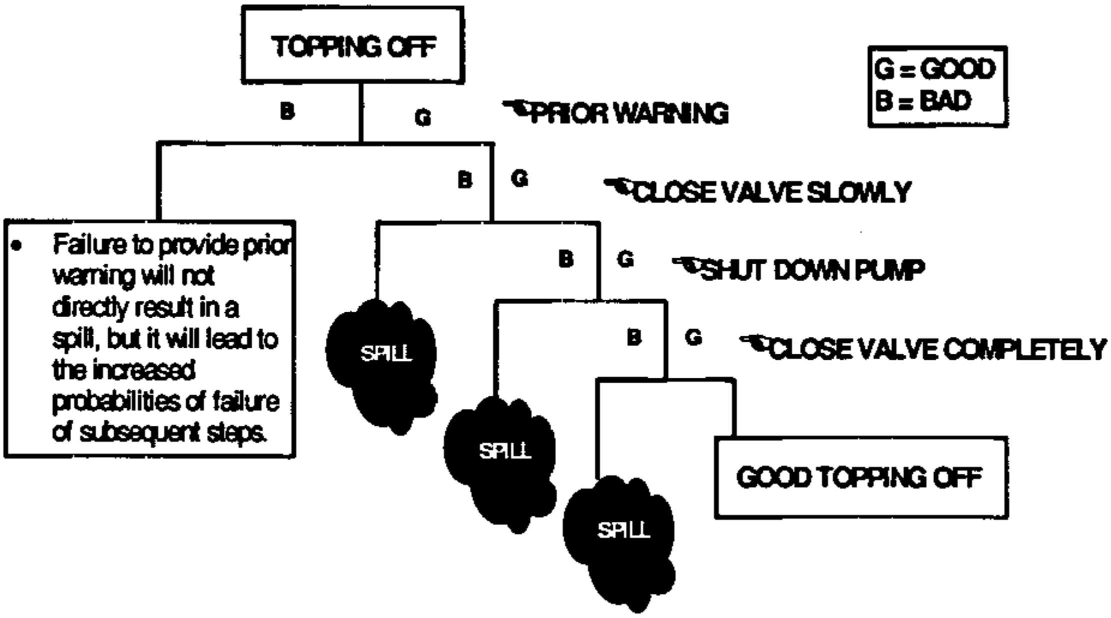


Figure 14. Event Tree Diagram of Topping Off Process (Loading Operation)

5.2.6 Disconnection

Disconnection procedures vary based on whether hoses or loading arms are used or whether crude oil or refined products are transferred. If the ship is being loaded, at this point in the operation she will be quite low in the water and most of the product will simply drain by gravity. To facilitate this process, some suction is provided in the tanks to draw oil out of the lines. The bolts in the connecting flanges are removed beginning from the bottom. If there is any product left in the line, it will drip into the containment and drip pans under the vessel's cargo manifold. If the hose was used to transfer refined product, face plates will not be replaced so that any remaining vapor will evaporate. If black oils are transferred, face plates will be secured so that any product adhering to the inside of the hose will not ooze out later.

If loading arms are used, the lines are drained using drain taps in both the headers and arms. Flanges are disconnected from the bottom around to the top connectors to allow any remainder to drain into the containment. After the arm is disconnected from the ship, the o-ring is carefully examined and replaced if there are any signs of wear before the faceplate is secured. After everything is resecured, the blanked off arms are covered with a plastic bag to catch any possible drips and the loading arms are returned to their "rest" position at the berth. Figure 15 shows the possible effects of problems in the performance of the steps in the Disconnection process.

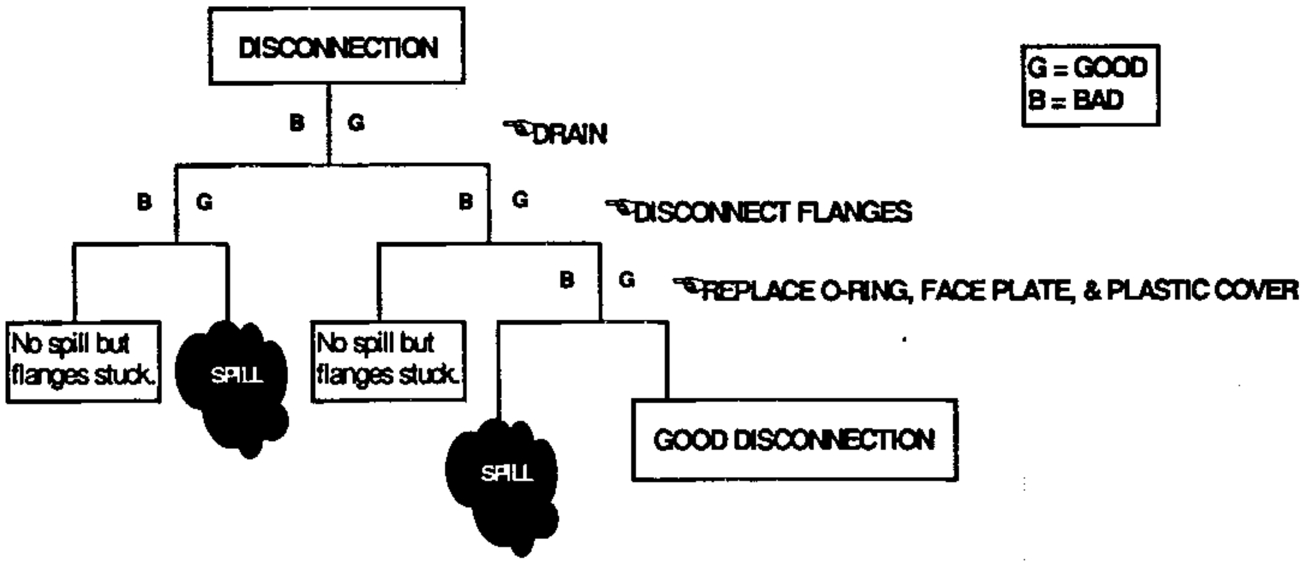


Figure 15. Event Tree Diagram of Disconnection

5.2.7 Departure

Departure is not strictly part of the loading and discharge process, but is included here for completeness. Departure is similar to Approach, but in reverse. The ships lines are let go and it is pulled away from the wharf by the assisting tugs. The only danger for oil spill in Departure is due to navigation. The hazard most closely related to Departure is the possibility of grounding a loaded tanker. This is not likely to happen close to the wharf because draft is very closely regulated with a significant margin between the allowable draft and the true depth of water. Departure is considered to be outside the scope of this project, although there is a more complete discussion in Chapter 6.

5.3 Qualitative

The qualitative analysis defines the problem areas of the process. These are then used in a more detailed analysis including quantitative evaluation.

5.3.1 Interview & Questionnaires

In order to examine the risk and quality of each step in the loading process a questionnaire was used to interview terminal operators. This questionnaire asked operators to evaluate the importance and grade of each step and substep in the process. The importance of a step is a value of how critical it is from the standpoint of spill prevention, ordered on a seven point scale. An importance of one corresponds to a step which can be virtually eliminated or grossly misperformed without the threat of a spill. An importance of seven corresponds to a step which must be performed perfectly in order to prevent any oil spill. The grade is similar to a letter grade in school. It is a value of how well each step is completed. To facilitate numerical analysis, each letter is assigned a number, "A" being one, "B" being two, an so on. The product of the importance and the grade is the risk of each step. A step which is not important and is performed well would have a very low risk value. A step which is crucial and performed poorly would have a very high risk value. See Figure 16.

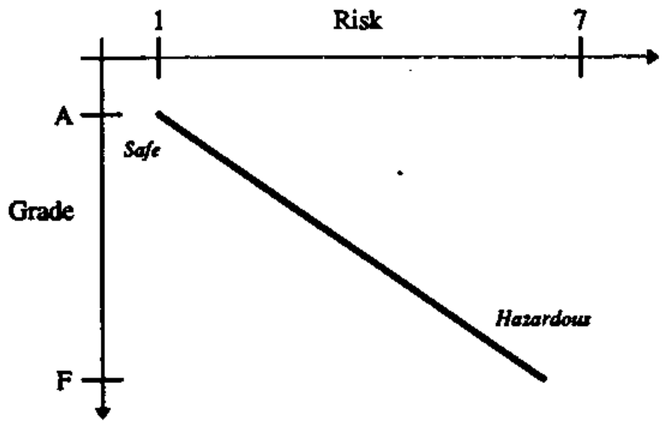


Figure 16. Risk x Grade = Hazard

Eighteen wharf operators responded to this questionnaire. Because of the subjective nature of the questions, the range in answers is very high. For this reason, the answers have been normalized to reflect the individual operator's average risk response as well as the average response of the whole group. This does not bias the qualitative results because although the range in answers is very high, most people ranked the steps in a similar order and gave a similar logic for their responses as reflected in their comments. Tables 4-11 show the risk values for each of the steps in the loading and discharge process and their substeps. All operators were asked to respond to questions regarding the overall process. They were then asked to evaluate the risk of each of the substeps of the steps which they chose as the most risky. For this reason, the number of respondents to each section of questions are included.

Table 3. Risk Factors for Steps of LDO

Rank	*Step*	*Risk*
1	Topping Off	6.89
2	Start Up	4.72
3	Approach	4.67
4	Disconnection	4.28
5	Connection	3.78
6	Steady Rate	3.00
7	Departure	3.00

No. of Responses – 18

As shown in Table 3, respondents felt that Topping Off and Start Up were the two most risky steps in the loading and discharge process. Topping off is the most risky step because it involves very careful manipulation of tank levels by the ships crew and consequently the precise manipulation of valve positions on shore. In addition, the communication between the ship and shore is very critical so that the manipulation of valves can be done at the proper time. The risk factors for the substeps of Topping Off are presented in Table 4.

Table 4. Risk Factors for Steps of Topping Off

Rank	*Step*	*Risk*
1	Request to Slow	5.94
2	Request to Stop	5.13
3	Flow Slowed	4.31
4	Valve Closed	4.13

No. of Responses – 16

Although there is no direct action involved in the communication of the request to slow the flow and then the request to stop, because the motor driven valves on the shore side move slowly it is important for these commands to be given early enough that the operator and the valve can respond in time. The communications during the Topping Off phase of the loading and discharge operation are given high risk values because there is sometimes a difficulty with communication between the ship and the shore. This is particularly true of foreign flagged vessels which may not be comfortable communicating in English. The manipulation of valves are given high risk marks for two reasons. The first reason is that these are the actual "action" steps in this process. In addition, these large motor operated valves are large and slow moving. It requires a certain degree of finesse to slow the flow precisely as desired. Stopping the flow is somewhat easier to accomplish, but if something goes wrong in this step there will certainly be a spill.

Start up is the second most risky step in the loading and discharge process. This is not because it is inherently difficult or problematic but because if there are any mistakes previously, it is when the flow is commenced that a spill will occur. Table 5 shows the risk factors associated with each of the steps of Start Up. The increase of flow is nominally twice as risky as any of the other steps. This is because when the flow is first started at a slow rate, it can be stopped quickly and easily in response to any leaks which are detected. At this stage any leak will be small and probably trickle or drip out. If these small leaks are not detected during the slow rate they could rupture further, spilling much more oil when the flow rate is increased.

Table 5. Risk Factors for Steps of Start Up

Rank	*Step*	*Risk*
1	Increase Flow	5.20
2	Communication	2.60
3	Clearance	2.60
4	Slow Rate	2.00
5	Sampling	2.00
6	Checking	1.80

No. of Responses ~ 5

Although Connection was not observed to be a particularly risky step in the process, it is directly correlated to Start Up and can therefore be considered to be subsidiary. Connection was not considered to be very risky because there is no flow at this time. Any spill would be the result of the draining of residual oil in the line. In contrast, any problem or mistake that occurs during Connection will be directly felt during the Start Up operation. Table 6 depicts the risk factors for Connection.

Table 6. Risk Factors for Steps of Connection

Rank	*Step*	*Risk*
1	Connection	1.67
2	Pre-Transfer Conference	1.33
3	Checking	1.33
4	Preparation	1.00

No. of Responses ~ 3

These responses are deceptively low. Proper connection is crucial to the continuation of the loading or discharge procedure. A possible reason for the low risk values is the routine nature of the task. This can have both positive and negative effects. The procedure is very simple and performed often which can lead to perfection of technique. Conversely, the routine nature of this procedure can lead to complacency.

An interesting aspect of Connection is that it is performed by the ship's crew and not by terminal personnel. In the case of vessels which are owned and operated by Chevron Shipping Company, the crew is solely responsible for the proper connection. In the case of other vessels, a witness is provided by the terminal to ensure that everything is done properly. The presence of this individual should mitigate complacency.

Approach is observed to be the third most risky step of loading and discharge. This is because of the navigation of the ship in the channel. Navigation is outside the scope of this evaluation because it is not within the strict confines of "transfer." Navigation is more risky than cargo transfer because when there is a possibility for vessel grounding there is limited control over the amount of oil lost. If a spill occurs during transfer, systems are in place to stop the flow of oil and limit the amount spilled. Table 7 shows the risk factors which were calculated from operator responses.

One reason for such high values may be the tendency for people to be more concerned with things that are outside of their control. It was noticed that any step which was performed by the ship or required communication with the ship was regarded as more risky than those which the terminal personnel have complete control over.

Table 7. Risk Factors for Steps of Approach & Berthing

Rank	*Step*	*Risk*
1	Final Approach	6.33
2	Initial Approach	5.83
3	Rough Positioning	4.50
4	Final Positioning	3.50
5	Line Handling	3.17
6	Berth Selection	1.50

No. of Responses – 6

The remaining steps were chosen by very few people and their risk factors are therefore very difficult to evaluate reliably. These results are presented in Tables 8-10. Steady rate involves no active procedures. It is important for the berth operator as well as the head operator in the control room and the vessel person in charge to double check values of pressure and flow rate and remain in contact. Although Disconnection requires many mechanical procedures, any spill will be limited to residual products in the lines. In Departure there is some risk similar to that in Approach, but because it is the result of navigation it is not considered in depth here. This risk is somewhat less than in Approach because the ship is moving away from shore. As the ship moves away the risk of collision with other vessels and with the pier decreases and the hazards to the very fragile beach environment are lessened.

Table 8. Risk Factors for Steps of Steady Rate

Rank	*Step*	*Risk*
1	Monitoring of Flow	10.00
2	Verification of Flow	10.00
6	Sampling	3.00

No. of Responses – 1

Table 9. Risk Factors for Steps of Disconnection

Rank	*Step*	*Risk*
1	Disconnection	4.67
2	Draining	3.33
3	Depressurizing	1.33
4	Sampling	1.00
5	Paperwork	1.00

No. of Responses ~ 3

Table 10. Risk Factors for Steps of Departure

Rank	*Step*	*Risk*
1	Request for Tug and Pilot	1.00
2	Positioning of Tug	1.00
3	Cast Off Lines	1.00
4	Departure	1.00

No. of Responses ~ 1

5.3.2 Influence Diagrams

Influence diagrams can be used to understand the correlation between different human factors in the steps of the process. This analysis is concentrated on the most risky steps in the loading and discharge process, Start Up and Topping Off. A detailed discussion of Connection is left for Chapter 6 because the steps of Connection are performed mainly by the ship's crew. Influence diagrams for each step show the substeps connected by dotted lines. Overlapping dotted lines indicate an iterative process. Solid lines connect human and organizational factors to the appropriate substep.

Figure 17 is an influence diagram of the process of Start Up. The most important component of Start Up is communication. It is essential that constant contact be maintained between the berth and the ship. If there is a problem with noise in the area, this can interfere with communication. Oil transfer operations are not typically loud enough to cause a problem. The problem most often complained of by the wharf personnel is the language barrier between the wharf and foreign flagged vessels. Although all vessels are required to have someone on board who speaks proficient English and can communicate with the wharf, often the most proficient person is not as fluent as desired.

A problem with communication which is cited by vessel personnel but not by wharf operators, is the communication between all berths and vessels on the same channel. Terminal personnel maintain that this is not a problem because the radio is only used for essential business so there is little chatter and everyone can reach the berth when they need to. This is not as much of a problem during Start Up as it can be in other phases of the operation. If one of the berths is going through a critical portion of their process and monopolizing the air, the berth waiting to start up can delay a few minutes until they are able to communicate more easily. During other steps, especially Topping Off, it is important to be able to communicate at the exact time that is necessary.

Once positive communication has been established, the valves can be opened. When the ship is being loaded, the terminal valves are opened and the cargo moves by gravity. When flow is increased, pumps are added. In discharge, the ship's pumps are warmed up before Start Up begins and are brought on line when needed to move product. When the valves and pumps are maneuvered, the most likely error factor would be due to the system itself: durability. Durability is the ability of the system to continue to perform its job without excessive need for maintenance or tuning. Although the valves and pumps are well suited to their purposes, over time, without proper inspection and maintenance, they may degrade in serviceability.

After flow begins at a very slow rate, the volume is checked on both sides. In addition the path is verified on both sides. Operators and watchstanders walk along the piping watching and listening for leaks. These steps are the mostly likely to find human errors. It is easy in this stage of the operation to simply forget to check one of the components or miscalculate the flow. In addition, because the verification of the path does not require a specific action, it is susceptible to environmental difficulties as well as fatigue. If an operator is tired and not very alert it would be possible to miss a problem which may be more subtle to the observer. If it is dark out or if it is raining visibility may be limited. If it is cold or raining, the operator may be in a hurry to get back in doors.

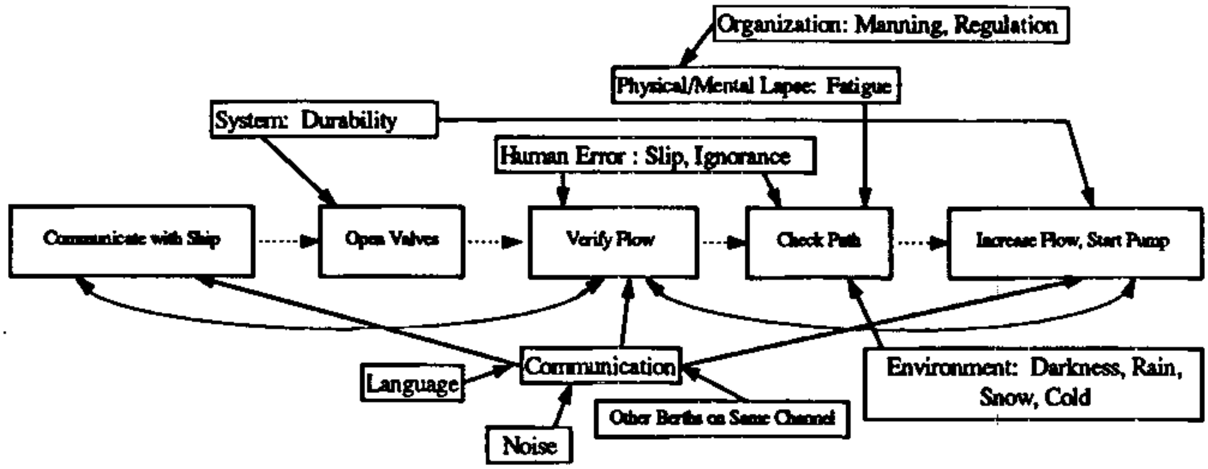


Figure 17. Influence Diagram -- Start Up

Figure 18 is an influence diagram of Topping Off. Communication is again very important during Topping Off. The ship must notify the berth one half hour before they anticipate stopping. At this time the operator will stand by the valve for further instructions. Fifteen minutes before shutting down, the ship will again signal the berth at which time the operator will close the valve half way. The valve is then closed incrementally with the ship giving proper warning and the operator manipulating the valve. It is important that the operator receive ample warning for each step because the valves are slow-moving and do not react immediately. This is where a particular problem lies with non-English speaking crews and berths all communicating on the same channel. Some crews with particularly poor English skills may be reluctant to call the berth. This can result in the berth operator not standing by the valve a full thirty minutes prior to shut down. If more than one berth is talking on the same channel there may be difficulty in getting through when necessary. Communication can be impaired after the beginning of Topping Off because once the operator begins to pinch off the flow, the noise in the lines becomes much louder than usual. Because this is always true, the communication system is designed so that it will always be heard.

Planning and preparation is also very important. If the operator is surprised, the valves may not be manipulated at the correct time or as quickly as need be. It is essential that the operator be standing by the valve and be prepared to act as soon as the ship gives the word. This is also where fatigue and environmental conditions are felt. If he is tired or it is cold or raining outside, the operator may not be eager to stand by the valve for a full thirty minutes. Also, if he is tired he may have some difficulty acting as quickly as necessary if the Topping Off occurs sooner than expected.

System error can cause trouble in Topping Off as well. Because the valves are slow moving, it is very important to have prior warning and to anticipate the precise moment when flow needs to be stopped. In addition, in order to pinch down on the line slowly, finesse is required to get the flow to be at just the precise rate. This can be difficult because as the flow is slowed, back pressure will cause the pump to kick off slowing the flow much more than intended.

This need for finesse in slowing the flow can be impacted by procedural problems. Because the variation in flow must be heard or felt, it is very difficult to teach and to document. The only way that it can be learned is through tutoring and practice. This can lead to each operator improvising his own way of doing things.

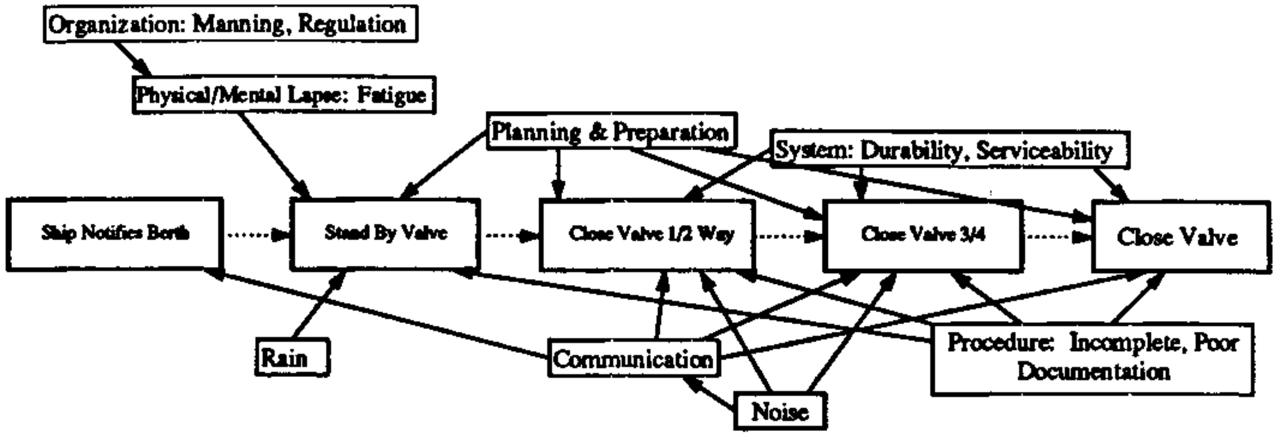


Figure 18. Influence Diagram -- Topping Off

5.4 Assessment of Chevron, Richmond Operation

The steps which have been determined to present the most hazard are Topping Off and Start Up, and, therefore, Connection. Topping off and Start Up are rooted in communication. Because Connection is performed by vessel personnel, if there is a problem on the terminal side, it would be due to system problems.

Communication is extremely important in Topping Off. While it is also important to Start Up, there is not as significant of a hazard when the transfer is beginning at a very slow rate. It would seem that if communication was managed to be optimal to the Topping Off procedure, problems that would be presented during Start Up would also be solved.

There are two problems with communication that are identified at Richmond Long Wharf. One was identified by terminal operators and the other by vessel crews. Terminal operators are primarily concerned with problems communicating with foreign crews. While all vessels are required to have at least one person who is proficient in English on board to communicate with the wharf, often the most proficient person is not as fluent as would be desired. In addition, this language barrier may cause foreign vessels to be more "shy" when communicating with the wharf. This can be a problem where ample notification is concerned in Topping Off.

The other problem with communication is the use of the same radio channel at all berths. Although this has never caused an accident or even a near miss, it is possible that communications at one berth could be impaired while another berth is talking. Transfer operations are coordinated, loosely, so that two berths will not be reaching critical points in their operations at the same time. This is not, however, a key planning step. It is possible that communication at one berth could be delayed, hazardously, while the radio is being monopolized by another.

Other human and organizational factors which influence the Topping Off process at Richmond Long Wharf are procedures and planning, environmental conditions, and personnel problems. Although operational procedures are well documented and continued training is an important part of an employee's career on the wharf, Topping Off involves the use of skills and techniques which cannot be easily mastered using a checklist type of procedure. For the flow to be slowed precisely, some finesse is required. This involves careful attention to the sound of the flow in the lines and the delicate manipulation of the large motor operated valves. This type of precision can only come from years of practice and not through exact completion of easily defined steps.

Topping off also involves careful planning and preparation. It is important for the berth operator to keep track of the rate of transfer so that he is not surprised by the vessel's warning. The thirty minute warning is meant to alert the operator before he needs to pinch down on the lines. At this time the operator should stand by the valve and await further instruction. Even though he can anticipate that no valve closure will need to be done for a few minutes, it is essential that the operator be prepared, and ready to act in case there has been a miscalculation and flow must be shut down in a hurry.

This is also the time when environmental conditions and the operator's attitude can adversely affect the operation. If it is raining or cold, or if he is fatigued or simply lazy, the operator may not be inclined to stand by the valve outside of the berth shack.

Because Connection is chiefly performed by ship personnel, problems in this phase due to a terminal problem are more likely to be system oriented. The loading arms are only hydraulically positioned but not hydraulically clamped as they are in some newer facilities. This can cause a problem for some crews. A witness is provided by the terminal to avoid any error that could be precipitated if the crew is not familiar with the system. The berth operator can locate the arms roughly near the ship's headers but they must be manually positioned more precisely and connected by hand. This means that any connection is subject to the physical limitations of the person tightening connectors or bolts. This can be difficult if the crew is fatigued or if it is raining and slippery.

6. Arco California, Arco Marine Inc., Long Beach, CA

6.1 System

The *Arco California* is a very large crude carrier (VLCC) operated by Arco Marine Inc. Arco Marine is a subsidiary of the Arco Transportation Company which is primarily responsible for the movement of crude oil from the Alyeska Oil Terminal in Valdez, Alaska to the US West Coast and Panama. AMI's product ships also service West Coast and Gulf Coast ports.

The usual route for the *Arco California* is from Valdez to Long Beach, California where half of the oil is discharged, then continuing to the Chevron Long Wharf in Richmond, California to discharge the remaining cargo. Table 11 lists the ship's particulars.

Table 11. Vessel Particulars -- *Arco California*

Displacement	217,070 long tons
Deadweight	188,436 long tons
Length Overall	952 feet 8 inches
Length Between Perpendiculars	915 feet
Beam, Molded	166 feet
Draft, Summer	59 feet 3 inches

The vessel is divided into 31 tanks: 17 cargo tanks (including port and starboard slop tanks), 10 ballast tanks (five double bottom tanks), and three bunker tanks. The hull is subdivided by six main transverse bulkheads. Similar to most modern tankers, the machinery and deck house are located aft and all cargo is between the pumproom and the forepeak. Figure 19 is an illustration of the tank arrangement. Table 12 shows the volume of each of these tanks in barrels.

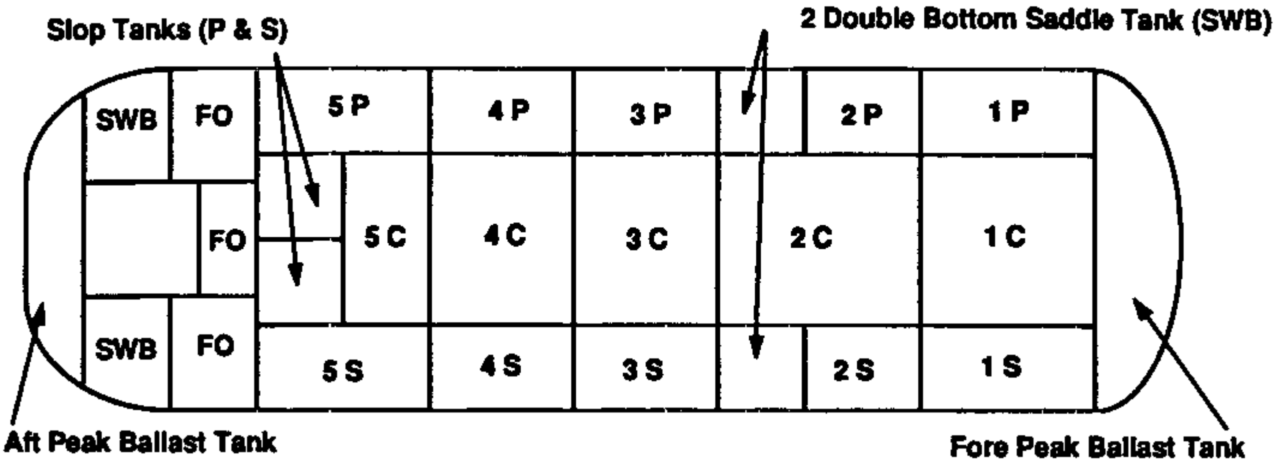


Figure 19. Tank Diagram -- Arco California

Table 12. Tank Volumes

Cargo Tanks	
1 Center	128,715 barrels
1 Port/Starboard	60,616 barrels, each
2 Center	157,306 barrels
2 Port/Starboard	55,109 barrels, each
3 Center	143,010 barrels
3 Port	78,846 barrels
3 Starboard	78,755 barrels
4 Center	128,715 barrels
4 Port/Starboard	70,783 barrels, each
5 Center	85,824 barrels
5 Port	65,615 barrels
5 Starboard	65,707 barrels
Slop Port/Starboard	21,470 barrels, each
Total Capacity	1,348,449 barrels
Fuel Oil	
Total Capacity	51,713 barrels
Salt Water Ballast	
Fore Peak	5,415 long tons
1 Double Bottom	6,250 long tons
2 Double Bottom/Saddle	19,220 long tons
3 Double Bottom	8,293 long tons
4 Double Bottom	7,459 long tons
5 Double Bottom	6,335 long tons
Engine Room Double Bottom	1,094 long tons
Engine Room Wing Port/Starboard	1,252 long tons, each
Aft Peak	3,544 long tons

The cargo piping is divided into three systems which are serviced by the three main cargo pumps. Crossover connections allow all three systems to operate by any of the pumps, or from either of two eductors or the steam stripping pump. Table 13 lists the tanks served by each of the cargo systems.

Table 13. Cargo Systems

Cargo System	Tanks Served
#1	1 Wings 2 Wings 4 Wings 5 Center
#2	1 Center 3 Center 4 Center Slop P/S
#3	2 Center 3 Wings 5 Wings

When cargo is loaded it is pumped from shore using the terminal's pumps and distributed from the headers at the cargo manifold to the tanks through deck piping to the loading drops. When cargo is discharged it is sucked from the tanks via main and stripping suction lines in each tank, through cargo tank mains, back to the pumproom. Figure 20 is a schematic diagram of the piping in the cargo tanks. Longitudinal cargo tank mains are 36 inches in diameter, branching into 20 inch lines to each of the center and wing tanks. Main suction spurs are 20 inches in diameter. Stripping suctions are 10 inches. Suction can be drawn from both slop tanks via 12 inch lines. The eductor discharge back to the slop tanks is 20 inches in diameter. The main discharge is connected through a 10 inch crossover to the port slop tank.

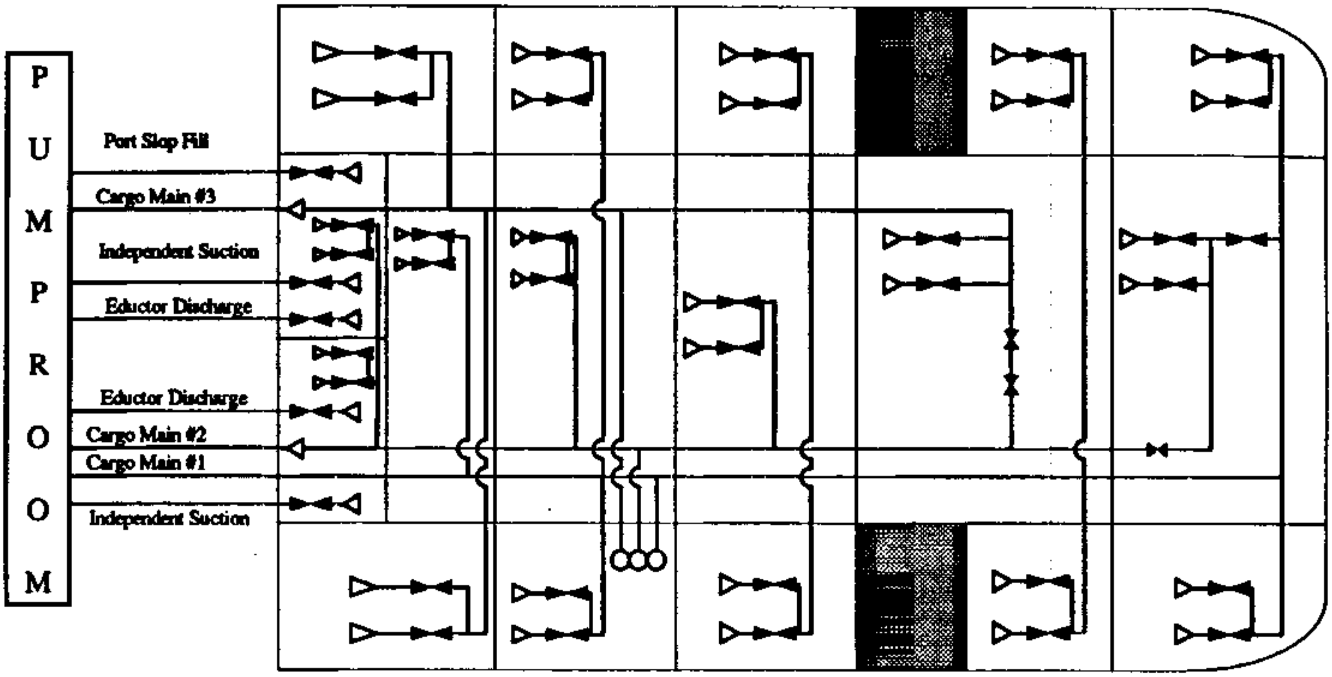


Figure 20. Cargo Tank Piping

In the pumproom the cargo is pulled through the main cargo pumps and pushed out through deck piping to the manifold and headers and over the side to shore. In the pumproom the cargo tank mains are 36 inches while the main cargo pump discharge lines and risers are 24 inches. There are three crossovers in the pumproom. The 24 inch main suction crossover connects all main cargo pumps and all tank mains. The discharge crossover is also 24 inches in diameter and allows all of the cargo pumps to discharge through all of the risers. The 20 inch ballast suction crossover connects all of the cargo pumps to the sea chest as well as the 12 inch independent suction line from the slop tanks. Also in the pump room is the 14 inch crude oil wash riser, as well as 4 inch suction and discharge lines for the steam stripping pump. The eductor system is driven by a 16 inch line from the main discharge crossover. Suction is drawn from the main discharge crossover. The 18 inch discharge line branches to 20 inches to the port slop tank and 12 inches to the starboard slop tank. Table 14 lists some of the particulars of the pumps and eductors.

Table 14. Pumps and Eductors

Main Cargo Pumps - 3	
Type	Centrifugal, Horizontal, Single Stage
Drive	Steam Turbine
Rated Capacity	24,857 barrels/hour
Rated Speed	1,250 rpm
Rated Discharge Pressure	440 feet head
Relief Valves	210 psig
Stripping Pump - 1	
Type	Horizontal, Reciprocating, Duplex, Double Acting
Drive	Steam, 180 psig
Rated Capacity	250 barrels/hour
Rated Speed	26 strokes/min.
Rated Discharge Pressure	174 psig
Relief Valve	210 psig
Eductors - 2	
Rated Drive Pressure	175 psig
Rated Suction Lift	16 feet
Rated Suction Capacity	5,714 barrels/hour

Figure 21 is a schematic diagram of the piping on deck. Deck piping consists of three 24 inch longitudinal deck mains and three 24 inch branches (athwartships) to the cargo headers. The loading drops are 20 inches in diameter. The stripping discharge and crude oil wash main maintain their diameters from the pumproom of 4 inches and 14 inches, respectively. Figure 22 is a photograph of the deck piping on the *Arco Alaska*.

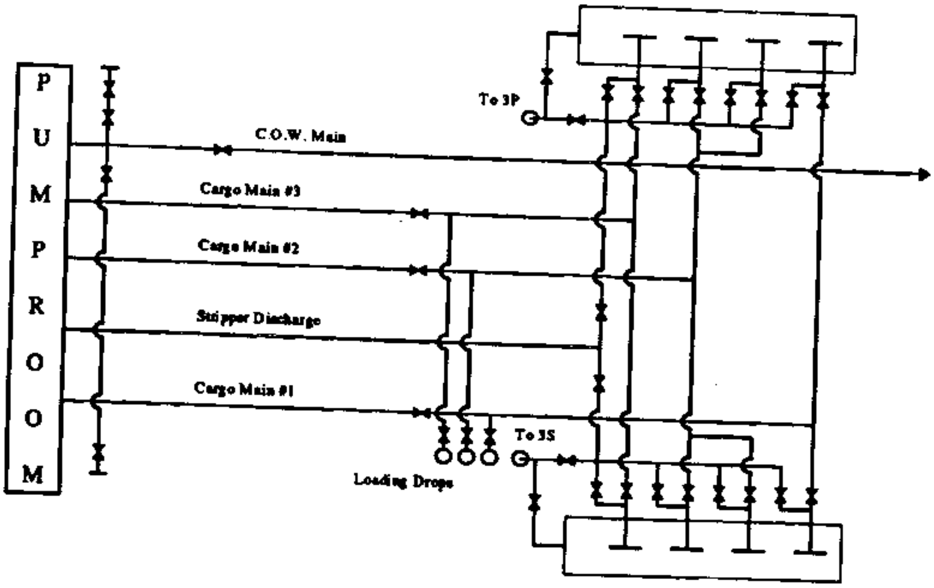


Figure 21. Deck Piping

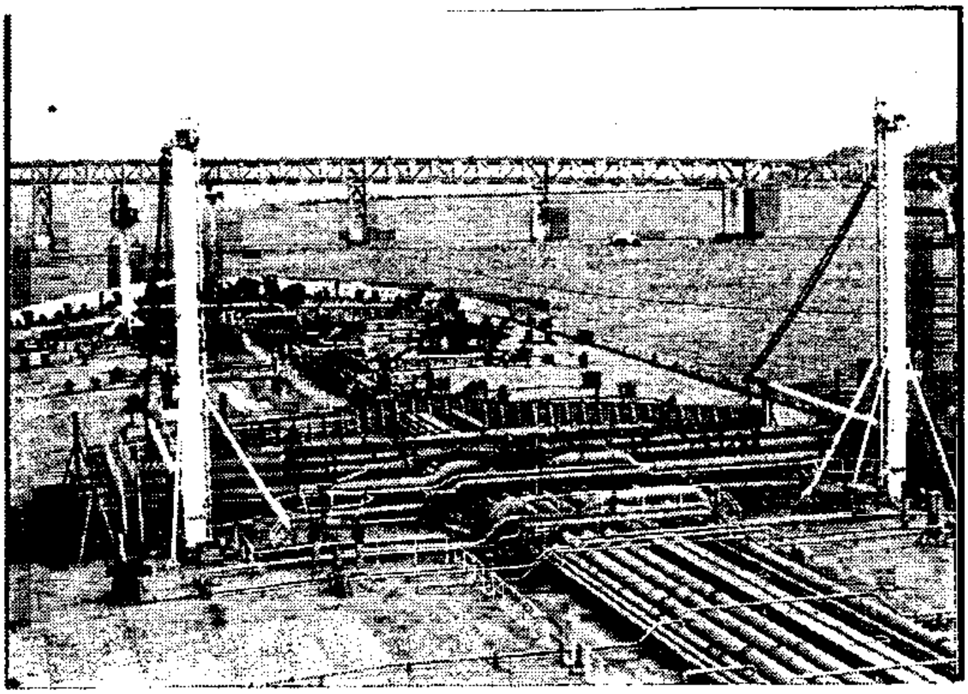


Figure 22. Arco Alaska Deck Piping

Troughs are in place under the headers to form a containment system. Portable drip pans are also used to catch small drips and drains from the loading arms. There is a two inch drain line from the troughs which ties into the 4 inch drain line from the headers into No. 3 Wing tanks. Figure 23 is a photograph of the cargo headers on the Arco Alaska. The containment is the large pan under the headers.

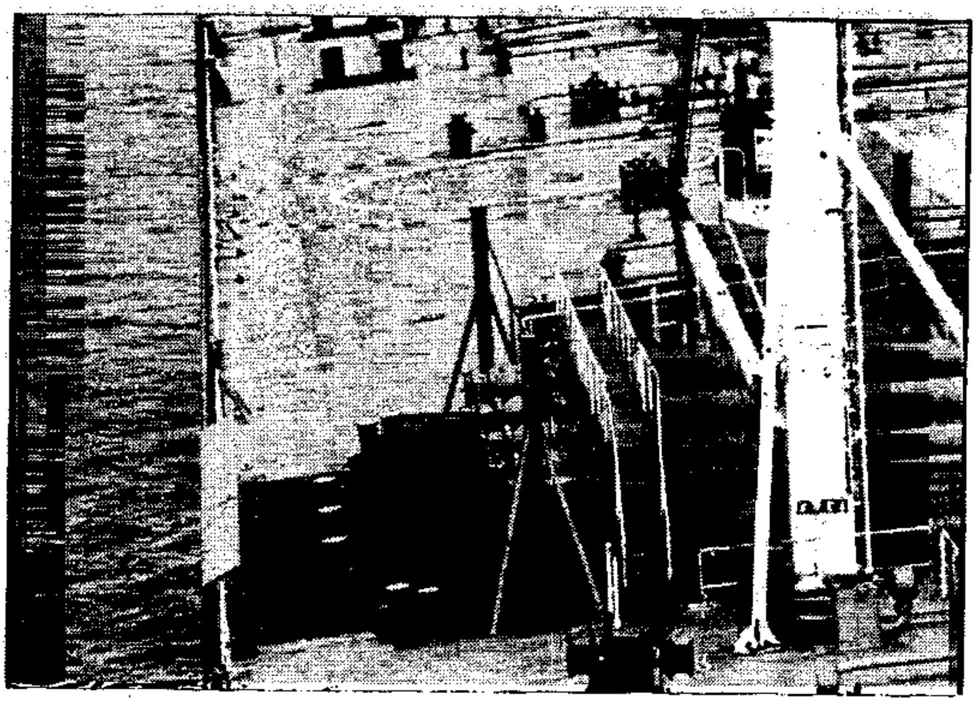


Figure 23. Cargo Headers and Containment System (Arco Alaska)

Valves are operated hydraulically. The hydraulic system has two pumps which operate from one 145 gallon reservoir. The working pressure of the system is 1250 psig. Deck supply and return valves have taps to deck boxes which contain solenoids for each valve. A circulation valve is provided to recirculate hydraulic fluid in cold weather. Valves are remotely controlled from the cargo control room using lighted push buttons. Valve movement must be verified at the deck boxes. Valves can also be opened or closed using solenoid levers at the boxes or by a hand operated pump.

Tank levels can be remotely checked in the control room using the Saab radar system. Soundings are also verified on deck using MMC portable sonic tapes. The high level alarm in all tanks will sound at an ullage of 6 feet. A high high alarm will sound at an ullage of 4 feet.

The inert gas system uses stack gases to control the oxygen content of the air in the cargo tanks. As cargo is loaded, gases are vented through the mast riser. When discharging, more gas is introduced into the tanks to maintain the low oxygen content. It is especially important to maintain a low oxygen level in the tanks when crude oil washing. Crude oil wash machines create a very volatile environment in the tanks that requires that the level of oxygen be kept below 8 percent throughout the tank to prevent ignition and explosion.

The design of the control room registered the most complaint on both the *California* and *Alaska*. Because valve actuators have only colored lights -- red or green -- to show the position of a valve, it is often difficult to tell what the valve position truly is. The control room is located on the main deck and has only one small porthole which affords almost no visibility of the deck.

6.2 Procedure

The steps involved in loading and discharge operations from a shipboard point of view are very similar to those of the terminal operation outlined in Chapter 5. This is especially true because Richmond is one of the *Arco California*'s ports of call. This section will concentrate on those portions of the operation which are significantly different. The primary steps are as follows.

1. **Approach & Berthing**
2. **Connection**
3. **Start Up**
4. **Steady Rate & Crude Oil Washing**
5. **Topping Off & Stripping**
6. **Disconnection**
7. **Departure**

Steps 1 and 7 are navigational steps which are not strictly part of the transfer operation. They are included with these primary steps so as to include docking as part of the process of cargo-handling in port. In addition, when a large loaded tanker is maneuvering there is much more danger of a catastrophic spill than at any point during the transfer operation itself. Navigation is discussed, but not evaluated in detail, in the following sections. Connection is virtually identical to that presented in Chapter 5. Some discussion is given to the differences of various terminals in the connection procedures. Start Up and Steady Rate are very similar to that outlined in Chapter 5. On board the ship these steps are somewhat more complicated than on shore because of the use of multiple tanks. The conclusion of the transfer operation, be it Topping Off or Stripping, is much more complicated than from the standpoint of the terminal. While the terminal operator is dependent on the ship's crew to alert him to the end of cargo transfer, and the precise timing of valve closure is very important, on board the ship many people must function as a team to manipulate and double check many valves as well as closely monitor and verify tank levels. Before Stripping can occur, several tanks per voyage are crude oil washed. This requires careful monitoring of tank oxygen levels, as well as attention to the operation of tank washing machines, in addition to the responsibilities of tank stripping. Similar to Connection, Disconnection varies from terminal to terminal but relies heavily on the labor of the ship's crew. Figure 24 shows the results of the improper performance of each step in the process. Each of the steps is described in more detail in later sections.

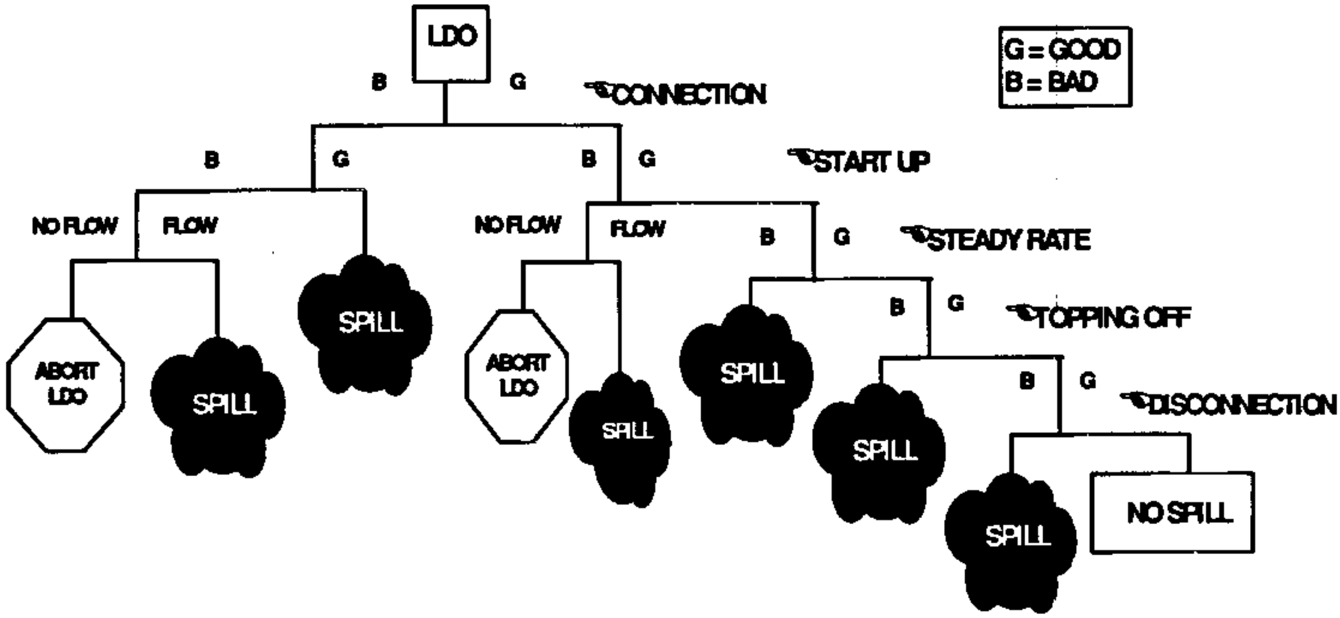


Figure 24. Event Tree Diagram of LDO

6.2.1 Approach & Berthing

There has been some discussion of the scope that this step should include. Because vessel navigation is generally outside the scope of this project, we assume that the Approach in this context is only to include the final docking of the ship. Basically, this will include movement from the maneuvering basin to the dock. Also included is the securing of the vessel to the pier. Six steps are associated with Approach and Berthing:

0. Arrival Planning

1. Approach with Escort Tug

2. Ship Positioning

3. Berth Approach

4. Line Handling

5. Final Positioning

Berth selection and arrival planning is done by three separate entities communicating together. AMI shoreside personnel determine which terminal the vessel will discharge at on each voyage and project arrival dates. The master will plan the arrival in more detail based on the tides and vessel's speed along the way. Throughout the course of the trip, the vessel will communicate with shoreside support, who will then communicate with the terminal. As the vessel gets closer to the port, the ship will communicate with the terminal directly. This is usually done close to arrival and picking up the pilot. After the ship "arrives" in the port -- sometimes several hours travel time to the dock -- the captain, a watch officer, and a helmsman must be on the bridge. A lookout should also be posted. After the pilot is onboard, he will give the commands to the helmsman and to the watch officer who is manning the throttle. Close to the dock the pilot will also give orders to the assisting tugs. After the ship enters the port, she will be met by escort tugs at some point during her transit to the wharf. The ship is roughly positioned well away from the pier and then slowly maneuvered into the dock using the tugs. Once close to the dock, the ship is spotted precisely to ensure its alignment with the shoreside cargo manifold. When the ship is positioned precisely she is secured to the pier. Because there is no transfer of oil at this stage in the operation, the probabilistic evaluation of risk is not within the scope of the project. An accident is, however, more likely to result in a larger spill at this point because with navigation in the channel there is always the possibility of grounding or collision that could lead to the loss of the ship.

6.2.2 Connection

Connection is the process of attaching the shore piping system to the vessel piping system so that the flow of oil may commence in the appropriate direction. There are four primary steps in the processes of Connection:

1. **Pre-Transfer Conference**
2. **Flange Preparation**
3. **Hose or Loading Arm Connection**
4. **Alignment Check**

During the pre-transfer conference, all details of the transfer of oil are agreed upon. Table 2 (in Chapter 5) lists the items that are required by the United States Coast Guard. If the vessel is at a terminal that she visits often, the pre-transfer conference will be more of a formality since everyone will already understand the typical operation. The Declaration of Inspection is completed to ensure that all pertinent information is exchanged and verified even if it seems routine.

The Connection is made after the pre-transfer conference. The loading arms are moved to the vessel. This is done by remote control by terminal personnel. In Richmond once the arms are near the manifold they are manually manipulated and attached by vessel personnel. In other ports which have newer hydraulic loading arms, they are manipulated and attached by remote control. In this case the only manual operation is the removal of the faceplates from the vessel's headers. Once the arms are over the containment, drains are opened and any product remaining in the arms is emptied. The face plate can then be removed. The o-rings are examined before attachment to the ship flanges and are replaced if they are worn or damaged. The arms are then secured to the headers, ensuring that all connectors are tight. Figure 25 shows the consequences of poor performance of each of the steps of Connection.

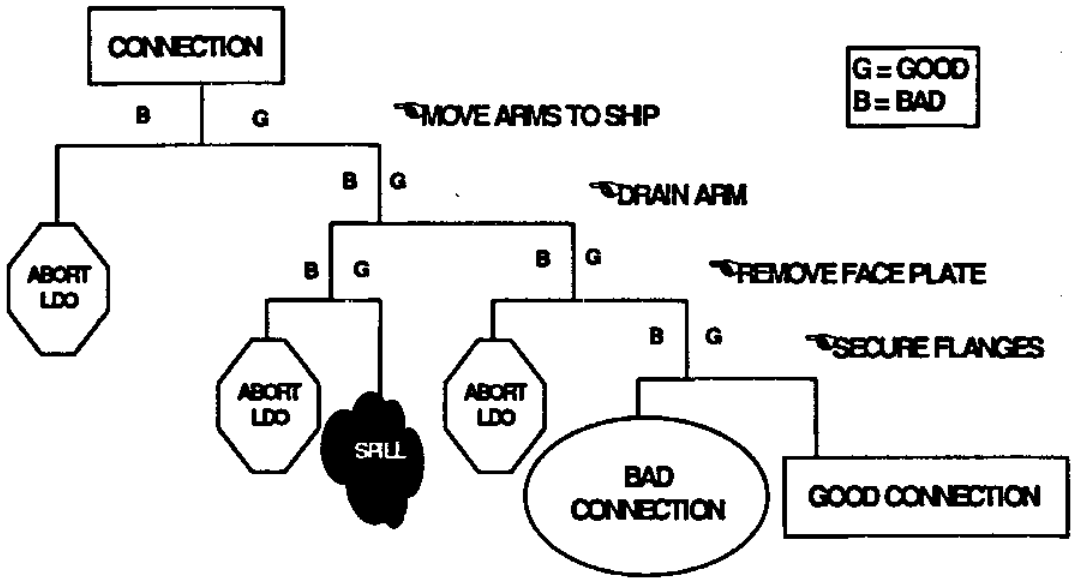


Figure 25. Event Tree Diagram of Connection Process

6.2.3 Start Up

During Start Up, the most critical components are communication and monitoring. As a part of the pre-transfer conference, the LDO plan is communicated among the vessel person in charge, the berth operator, and the pump operator. The receiving party opens its valves first. This is the ship in a loading operation and the shore in discharge. After the receiver's valves are opened and verified, the initiating party opens its valves. After the path of the product is verified, the initiating party requests permission to commence pumping. Flow is started at a slow rate and all connections are checked for leaks or other problems. When the ship is being loaded, cargo is initially loaded only by gravity. Shore pumps are added to increase the rate. When discharging, pumps must be used. The pumps are warmed while the pre-transfer conference and connection are taking place so that they will be ready when transfer can begin. The transfer is started slowly with one pump drawing from one tank. As the rate is increased, the other pumps and more tanks will be brought on line. After both parties are certain that their side of the system is functioning properly, flow is increased gradually to the agreed upon steady rate. During this process, communication is constant between the vessel and the berth to verify the steps in rate on both sides. Figures 26 and 27 depict the effects of each of these steps on the successful completion of the Start Up process.

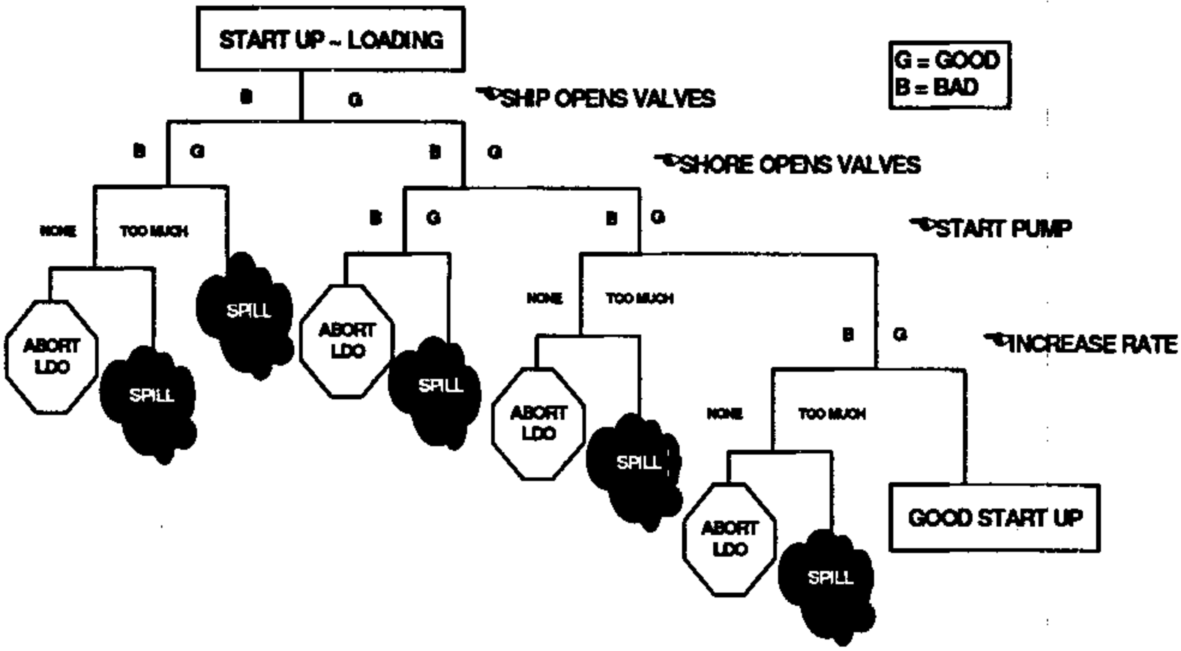


Figure 26. Event Tree Diagram of Start Up Process (Loading Operation)

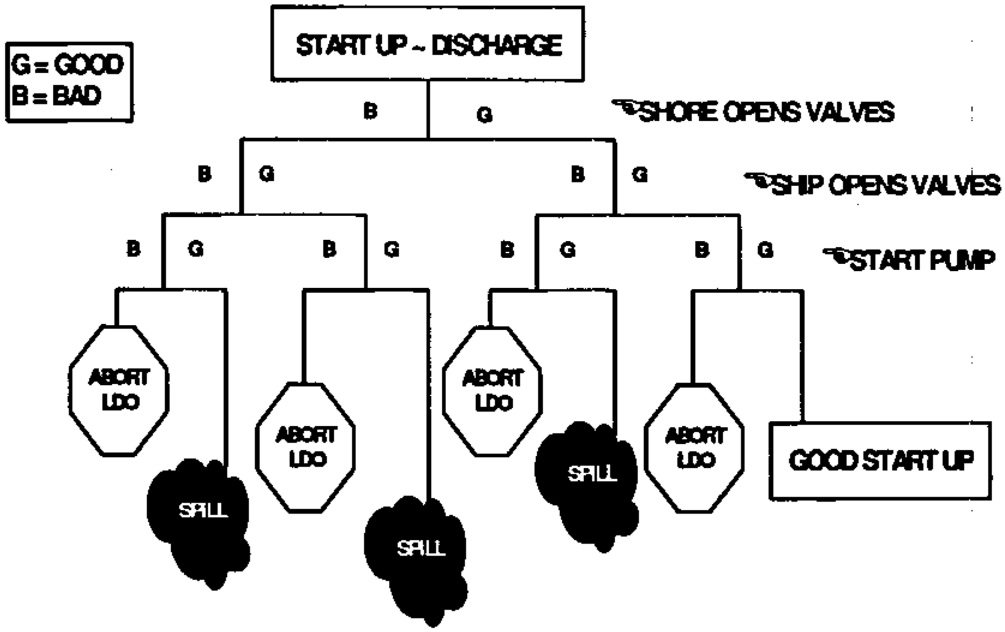


Figure 27. Event Tree Diagram of Start Up Process (Discharge Operation)

6.2.4 Steady Rate and Crude Oil Washing

Because the ship has many different tanks which are loaded or unloaded at the same time, it is necessary during the course of steady transfer to change the path of cargo so that tanks are stripped or filled according to plan. Tank levels are constantly monitored, both in the control room and on deck. Watchstanders are constantly observing activity on deck to make sure that there are no leaks or other problems. The pumproom is routinely checked to be sure that the pumps are operating properly. All crew members are keenly aware of how everything should function. Any deviation in sight, sound, or even smell out of the ordinary is noticeable.

When cargo is being discharged, crude oil washing (COW) occurs during the steady transfer of cargo. First, the COW machines in the tanks to be cleaned are programmed and the system is lined up. The next step is the most critical in the COW process: checking the oxygen level. The oxygen level in both the tank and the inert gas supply are checked. It is imperative that the oxygen level in the tank be less than eight percent. To achieve this, the level in the supply is kept to less than five percent. The oxygen content of the supply is monitored continuously in the control room. Tank oxygen levels are checked by the watch officer using a hand-held sensor. After the oxygen content is verified, the machines can be started. While the COW machines are running, cargo level in each tank is monitored from the control room and machinery operation is observed on the deck. When the machines have completed their full cycle, they are shut down and the system is secured. Figure 28 depicts the effect of the steps of crude oil washing on the possibility of oil spillage.

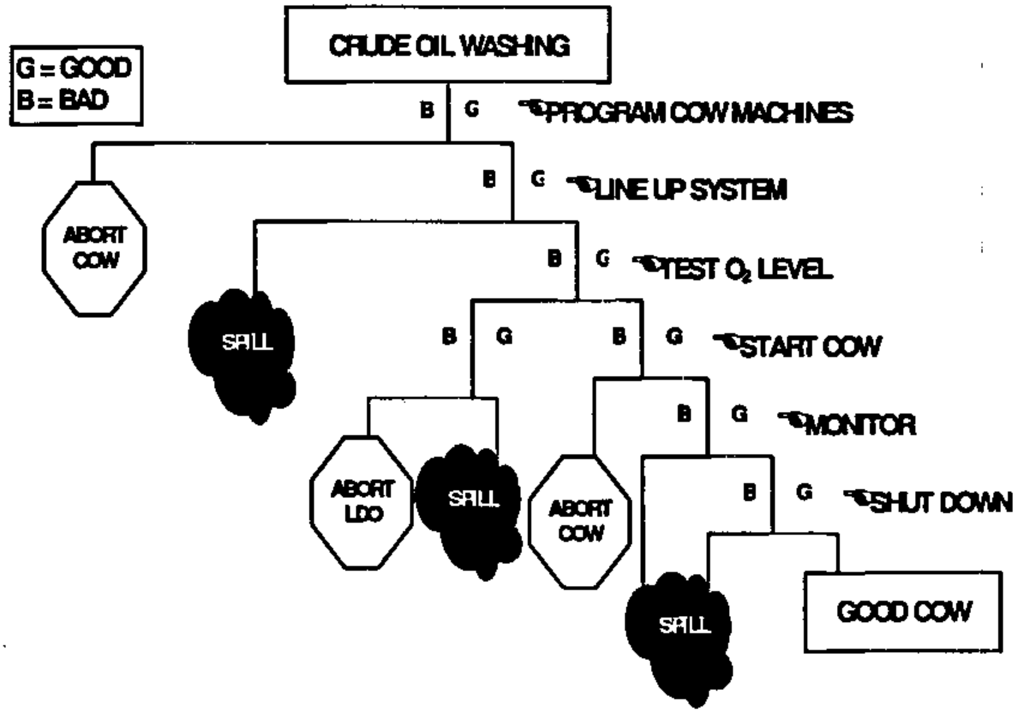


Figure 28. Event Tree Diagram of Crude Oil Washing Process

6.2.5 Topping Off or Stripping

The completion of the transfer operation is the most complex and difficult step in the process. From the point of view of spill prevention Topping Off is more critical than Stripping because there is the opportunity for overflowing tanks leading to spilled oil. It requires precisely timed communication and perfect control of critical equipment. The timing of Topping Off is crucial. It is very important to monitor the levels in tanks very closely, both remotely and directly. Precision is required to load exactly what is desired but not any more. The final Topping Off is very sensitive because it involves careful communication with the terminal to make sure that the shore valves are closed at the perfect time. Figure 29 shows the relationship between the different steps in the Topping Off procedure.

Stripping is not as critical a step from a spill standpoint, but is just as complicated to perform. Tank levels are monitored in the control room and when the innage in the tank becomes small -- less than three feet-- portable sounding tapes are used to determine when the tank is totally dry. This is verified by gauging the pump pressure. It is important to be precise about stripping tanks as all cargo should be emptied without sucking air through the pump.

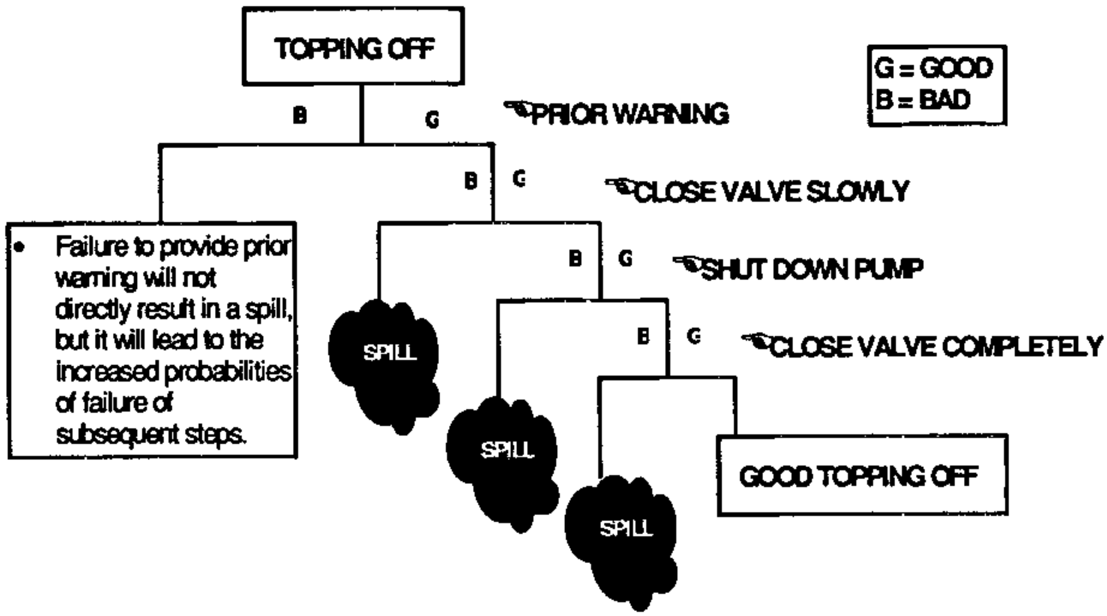


Figure 29. Event Tree Diagram of Topping Off Process (Loading Operation)

6.2.6 Disconnection

Disconnection procedures vary from terminal to terminal. Any remaining product in the arms is allowed to drain by gravity. Header drains allow the excess to drain back into the No. 3 Wings tanks. The drain tap at the bottom of the arm is opened over the containment and a portable drip pan. After the arm is completely drained it can be disconnected. This is done in the reverse sequence of Connection. If manual arms are used, flanges are disconnected from the bottom around to the top connectors to allow any remainder to drain into the containment. If hydraulic arms are used, the connectors are let go and the faceplates replaced. Figure 30 shows the possible effects of problems in the performance of the steps in the Disconnection process.

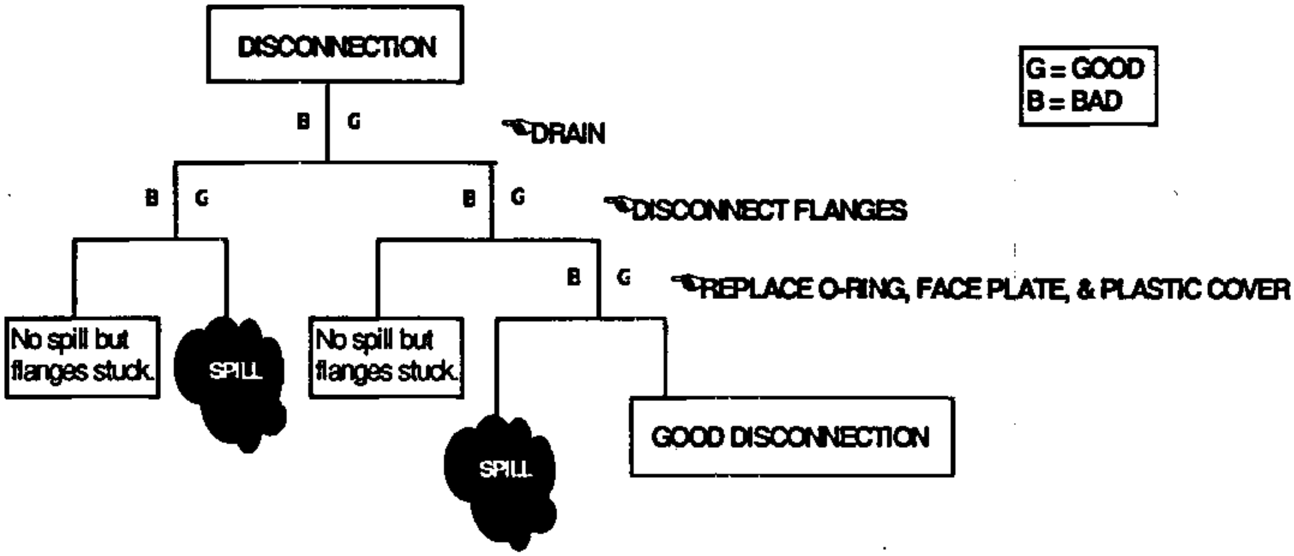


Figure 30. Event Tree Diagram of Disconnection

6.2.7 Departure

Departure is not strictly part of the loading and discharge process, but is included here for completeness. Departure is similar to Approach, but in reverse. The ship's lines are let go and it is pulled away from the wharf by the assisting tugs. The only danger for oil spill in Departure is due to navigation. The hazard most closely related to Departure is the possibility of grounding a loaded tanker. Departure is considered to be outside the scope of this project.

6.3 Qualitative

The qualitative analysis defines the problem areas of the process. These are then used in a more detailed analysis including quantitative evaluation.

6.3.1 Interviews & Questionnaires

A questionnaire similar to that used with terminal personnel was used with members of the crew of the *Arco California*. It was not used as extensively as at the Richmond Long Wharf. This is because more information was attainable from observation of the procedure and conversations with officers and crew. The results of questionnaires were helpful for the ranking of various steps. Three deck officers and one able-bodied seaman supplied the responses presented here.

Table 15. Risk Factors for Steps of LDO

Rank	*Step*	*Risk*
1	Topping Off	7.00
2	Start Up	5.75
3	Disconnection	5.75
4	Departure	5.38
5	Stripping	4.63
6	Approach	4.00
7	Connection	4.00
8	Steady Rate	3.75

No. of Responses ~ 4

As shown in Table 15, respondents felt that Topping Off and Start Up where the two most risky steps in the loading and discharge process. This is similar to terminal personnel. Topping off is the most risky step because it involves very careful manipulation of tank levels and careful communication between the ship and shore so that the manipulation of valves can be done at the proper time. The risk factors for the substeps of Topping Off are presented in Table 16.

Table 16. Risk Factors for Steps of Topping Off

Rank	*Step*	*Risk*
1	Flow Slowed	6.00
2	Request to Slow	5.50
3	Request to Stop	5.00
4	Valve Closed	5.00

No. of Responses ~ 2

These answers are somewhat different from those given at the terminal. It should be noted that all of the steps in Topping Off are given similar risk values. Each of the steps is equally critical and has similar potential for causing harm. On board the ship, many people are completing complementary tasks at this time and coordination is very important. Communication must be given to the terminal sufficiently ahead of time for the berth operator to react. The Topping Off process can be seen as a direct chain of events. No step can occur properly without the successful completion of the prior steps. While the ship's crew and shoreside personnel usually operate as separate teams, it is very important for the Topping Off phase of the transfer operation for both sides to work together. This cooperation makes Topping Off more susceptible to human errors.

Start up is the second most risky step in the loading and discharge process. This is not because it is inherently difficult or problematic but because if there are any mistakes previously, it is when the flow is commenced that a spill will occur. Table 17 shows the risk factors associated with each of the steps of Start Up. Similar to Topping Off Start Up is a strongly correlated chain. Communication between the ship and the dock is crucial to make sure that all of the connections have been made properly and that the path of cargo is lined up. Verification and checking are very important here to make absolutely sure that cargo is reaching its intended destination and that all connections are sound before the maximum rate is reached.

Table 17. Risk Factors for Steps of Start Up

Rank	*Step*	*Risk*
1	Communication	6.00
2	Slow Rate	6.00
3	Checking	6.00
5	Increase Flow	5.67
6	Clearance	5.57

No. of Responses ~ 3

Communication is risky not because of any spill that would result at the time but because of its strong correlation to Start Up. (Any oil flow at this time would be draining into the containment.) Table 18 depicts the risk factors for Connection. All of the steps are considered to be of similar risk except for the pre-transfer conference. This is because the active steps of making the physical connection have more direct consequences than the pre-transfer conference. Although the pre-transfer conference is important to ensure that all parties are in complete understanding of the operation, most of the information is routine. In addition, many people are involved and any deviation which is extreme would be caught before it could cause an accident through the checking and verification of orders.

Table 18. Risk Factors for Steps of Connection

Rank	*Step*	*Risk*
1	Connection	6.00
2	Checking	6.00
3	Preparation	6.00
4	Pre-Transfer Conference	5.50

No. of Responses ~ 2

Approach is seen as risky because of the navigation of the ship in the channel. Navigation is outside the scope of this evaluation because it is not within the strict confines of "transfer." Navigation is more risky than cargo transfer because when there is a possibility for vessel grounding there is no control over the amount of oil lost. If a spill occurs during transfer, systems are in place to stop the flow of oil and limit the amount spilled. Table 19 shows the risk factors which were calculated from responses to the questionnaire.

Table 19. Risk Factors for Steps of Approach & Berthing

Rank	*Step*	*Risk*
1	Arrival Planning	10.25
2	Initial Approach	5.75
3	Final Approach	5.50
4	Rough Positioning	5.50
5	Final Positioning	4.00
6	Line Handling	4.00

No. of Responses ~ 2

Arrival planning received the highest score of any step throughout the process. This was because it was graded at a "C" level by both respondents. This is because much of the planning is performed by shoreside personnel. Ports of call and scheduling are outside of the control of the vessel's crew for the most part. Maneuvering portions of Approach were given high risk values because of the movement of the vessel. Final positioning and line handling are not as risky because the vessel is no longer moving or is moving very slowly.

Although Steady Rate seems tedious, careful monitoring of the volume transferred and constant observation of the system are critical to ensure that the process is completed as planned. Throughout the steady transfer of oil it is important to keep track of tank levels so that tanks are topped off or stripped at the proper time. The volume transferred is calculated regularly and verified with shoreside personnel to account for all cargo. Although some difference can by attributed to the volume in the lines, a substantial deviation can mean a spill somewhere along the path. Table 20 shows the high risk factors given to monitoring of Steady Rate.

Table 20. Risk Factors for Steps of Steady Rate

Rank	*Step*	*Risk*
1	Monitoring of Flow	6.00
2	Verification of Flow	6.00

No. of Responses ~ 2

Although considered to be a part of Stripping, crude oil washing occurs during the Steady Rate phase of a discharge operation. Although all of the steps are simple and routine, several received high risk factors because of their supreme importance. Lining up the system is critical because it ensures that the path of oil to the washing machines is as expected and complete. It is important to make sure that crude oil is not directed to tanks that were not intended or out onto the deck. Testing the oxygen content of the air in the tanks is very important to the successful completion of tank washing. Due to the violent flow of crude oil being sprayed into tanks, it is possible to have ignition and explosion occur if the environment inside the tank is not controlled. The oxygen content in the tanks is kept below eight percent. To ensure this the oxygen content in the inert gas supply is kept less than five percent.

Table 21. Risk Factors for Steps of Crude Oil Washing

Rank	*Step*	*Risk*
1	Programming COW Machines	1.00
	Lining Up System	5.00
	Test O_2 Level in Tank	6.00
	Test O_2 Level in Supply	5.00
2	Start Machines	2.00
3	Monitor	3.00
	Shut Down	2.00
4	Secure System	5.00

No. of Responses ~ 1

Although the flow of product has stopped, there is still the possibility for a spill during Disconnection because of the volume still remaining in the loading arms. This residual cargo will drain back through the containment and header drains into the wing tank. It is important to make sure that all product is drained -- arm will sound hollow -- before arms are disconnected.

Table 22. Risk Factors for Steps of Disconnection

Rank	*Step*	*Risk*
1	Disconnection	5.50
2	Draining	4.00
3	Depressurizing	4.00
4	Paperwork	4.00

No. of Responses ~ 2

Departure is considered to be risky because of the navigation of the loaded ship in the channel. Navigation is outside the scope of this evaluation because it is not with in the strict confines of "transfer." Maneuvering the loaded vessel can be very dangerous because it is very heavy and responds very slowly. In addition, when leaving port the depth is more shallow and there are more obstacles than at sea.

Table 23. Risk Factors for Steps of Departure

Rank	*Step*	*Risk*
1	Request for Tug and Pilot	4.00
2	Positioning of Tug	4.00
3	Cast Off Lines	4.00
4	Departure	4.00

No. of Responses ~ 2

6.3.2 Influence Diagrams

Influence diagrams can be used to understand the correlation between different human factors in the steps of the process. This analysis is concentrated on the most risky steps in the loading and discharge process, Start Up and Topping Off. While both Start Up and Topping Off are included in the evaluation of the terminal operation in Chapter 5, Connection is included here as well, because it is accomplished primarily by the ship's crew. Influence diagrams for each step show the substeps connected by dotted lines. Overlapping doted lines indicate an iterative process. Solid lines connect human and organizational factors, to the appropriate substep.

Although Connection involves the direct physical connection between the berth and the ship, it does not require the communication and cooperation that Start Up and Topping Off do. The berth operator is present to maneuver the loading arms but may or may not board the ship. When the ship is at the Richmond Long Wharf, a terminal representative is on board but does not physically participate himself, he is merely present as a witness to ensure that everything is connected properly.

Human error could occur during any of the steps of Connection due to slips or ignorance. If a crew member does not remember how to do something properly or if he is unfamiliar with the terminal's system it could cause the connection to not be made perfectly. This unlikely however because there are several people present including wharf personnel. This supplies significant checking and verification. Fatigue can also cause the Connection to be a problem, because it will increase the probability of other slips and mistakes from occurring. In addition, when Connection is made manually, without hydraulic loading arms, physical strength is important to ensure that the connection is as tight as possible.

Environmental factors can influence the quality of Connection. If it is dark or raining or snowing, visibility can be impaired. If it is cold or raining or snowing the comfort level of the crew is degraded and the process may become rushed. If it is cold or snow the system may not respond it the optimal way. Faceplate may have become frozen during winter transit.

System factors also impact Connection. This is especially true of the terminal's system. Hydraulic remotely operated loading arms are very easy to manipulate and connect. The berth operator directs the arm to precisely where it needs to be and can disconnect the faceplate and reconnect to the headers by pushing a button. When manual loading arms are used, they are moved over the rail and in the vicinity of the headers remotely but must by positioned precisely by the ships crew. Faceplates must be removed and the arms connected to the header by hand using a large pipe wrench and the aid of several people. Figure 31 is an influence diagram showing all of the factors which impact Connection.

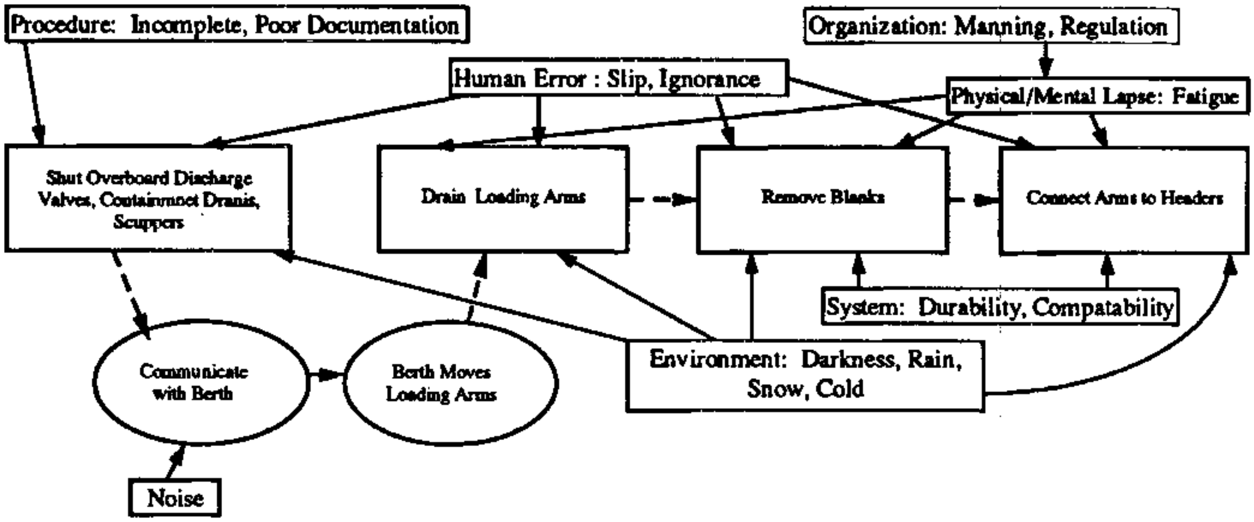


Figure 31: Influence Diagram -- Connection

Figure 32 is an influence diagram of the process of Start Up. The most important component of Start Up is communication. It is essential that constant contact be maintained between the berth and the ship. If there is a problem with noise in the area, this can interfere with communication. Oil transfer operations are not typically loud enough to cause a problem. A problem with communication is the communication between all berths and vessels on the same channel on some wharves, such as Chevron, Richmond. Terminal personnel maintain that this is not a problem because the radio is only used for essential business so there is little chatter and everyone can reach the berth when they need to. This is not as much of a problem during Start Up as it can be in other phases of the operation. If one of the berths is going through a critical portion of their process and monopolizing the air, the berth waiting to start up can delay a few minutes until they are able to communicate more easily. During other steps, especially Topping Off, it is important to be able to communicate at the exact time that is necessary.

Once positive communication has been established, the valves can be opened. When the ship is being loaded, the terminal valves are opened and the cargo moves by gravity. When flow is increased, pumps are added. In discharge, the ships pumps are warmed up before Start Up begins and are brought on line when needed to move product. When the valves and pumps are maneuvered, the most likely error factor would be due to the system itself: durability. Durability is the ability of the system to continue to perform its job without excessive need for maintenance or tuning. Although the valves and pumps are well suited to their purposes, over time, without proper inspection and maintenance they may degrade in serviceability. Serviceability can be an issue when considering the control board in the cargo control room. Because there are simply lights with push buttons, there is no sure way of knowing what the position of the valve is. Valve positions must all be verified at the boxes on deck and in the pumproom. Because these valves are hydraulic, there is no way to tell for certain whether the valve is opened or closed or whether the actuator is experiencing a problem.

After flow begins at a very slow rate, the flow is verified on both sides. In addition the path of the flow in verified on both sides. Operators and watchstanders walk along the piping watching and listening for leaks. These steps are the mostly likely to find human errors. It is easy in this stage of the operation to simply forget to check one of the components or miscalculate the flow. In addition, because the verification of the path does not require a specific action, it is susceptible to environmental difficulties as well as fatigue. If a crew member is tired and not very alert it would be possible to miss a problem which may be more subtle to the observer. If it is dark out or if it is raining visibility may be limited.

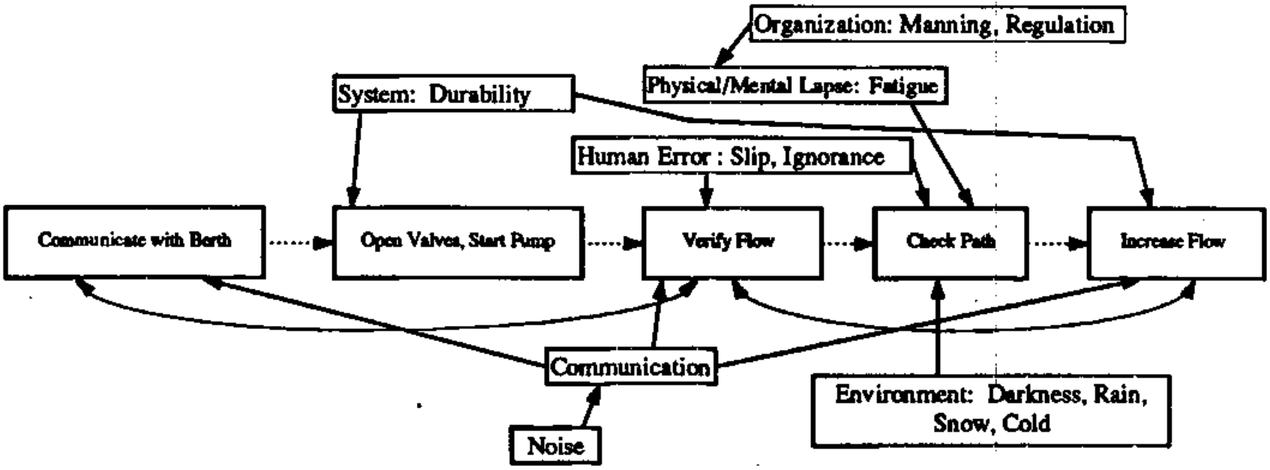


Figure 32. Influence Diagram -- Start Up

Although Topping Off is more hazardous than Stripping from the standpoint of oil spills, Stripping is just as complex. Figure 33 is an influence diagram which represents the factors in both Topping Off and Stripping.

Communication is critical to Topping Off. Ship crew members on the deck and in the control room must communicate with each other as well as communicating with the operator at the berth.

Tank levels are monitored continuously in the control room using the Saab radar gauging system and on deck using portable MMC sonic tapes. Neither of these systems are one hundred percent reliable. Redundancy is supplied be the presence of more than one sounding tape. If the Saab system is not functioning it is possible to simply gauge the tanks on deck. This is done when the reading from one particular tank is not being received properly. If the system were not working at all it is likely that the transfer would be shut down until the problem is solved.

Because the use of MMC tapes requires the user to be on deck, environmental factors are present. If it is raining or snowing or dark, visibility can be impaired. If severe weather is making the sailor uncomfortable, he maybe more inclined to make hasty and erroneous readings. Because the MMC tapes measure ullage, a quick arithmetic calculation is required to read innage as when stripping the tank.

As valves are closed cooperation is still required between the deck and the control room. Because valves are operated manually using the lighted push buttons in the control room, the position of the valve must be verified at the deck box. Although the position is not difficult to sense visually, it may be difficult to identify the particular valve in question when it is dark. The closing of valves may be influenced by the durability of the system. Because valves are located in the tanks, it is difficult to inspect or service them.

Manning and procedures are important to the Topping Off or Stripping process. There are many tasks to be completed at once and it is important that there are enough people present to accomplish everything. The dynamic of teamwork is important here also so that if there are enough people, or even more importantly if there are not, all tasks are covered and everyone is carrying his appropriate load. Procedures may be important because each officer may have a different way of doing things. It is important that everyone be aware of the procedure to be followed and be flexible to orders from different people. Cooperation is important so that new crew members may be able to acclimate themselves quickly without causing a disruption of shipboard operations.

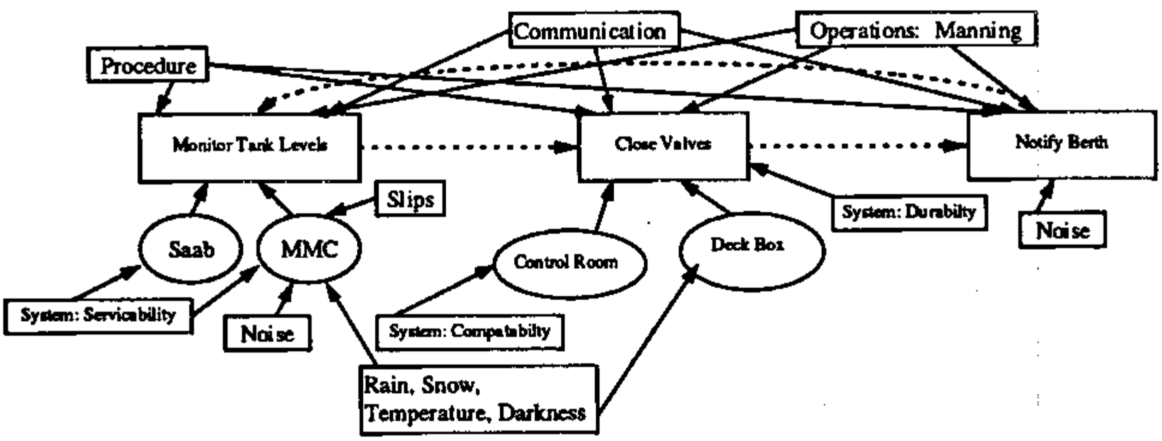


Figure 33: Influence Diagram -- Topping Off/Stripping

6.4 Assessment of Arco California Vessel Operation

The most prominent potential source of human error in transfer operations on board the *Arco California* is fatigue. Although the Oil Pollution Act of 1990 contains regulations that limit the number of hours a crew member can work in one day, there is still the possibility for people to have problems with sleep deprivation. Several parts of the operation require the close cooperation of many people. In order for everything to run smoothly, everyone must be doing his part. The two steps that require the most manpower and close coordination are Approach and Berthing and Topping Off (or Stripping.)

During Approach and Berthing, crew responsibilities are not restricted to their watch schedule. In many ports the ship will take arrival and pick up the pilot several hours before reaching the dock. While the ship is navigating in protected waters, all watchstanders as well as the captain and the pilot are present on the bridge (or on deck as lookouts.) As the vessel gets closer to the dock, all hands are needed for line handling. Once the ship is all fast, some of the crew can be dismissed, but there are still many things that need to be done before cargo can start. Because this happens over a long period of time, some of this work will be done during watch hours. If the arrival is scheduled for late at night or early in the morning, it is likely that some crew members will lose a significant amount of sleep. Although most people will get a chance to have a short nap at some point throughout the day, this will not replace an entire night's rest.

This sleep deprivation can cause trouble later during the transfer, when it is essential that everyone be attentive and able to cooperate effectively. When tanks are being topped off or cleaned and stripped, the effort of all watchstanders is necessary. If one person is not able to do his part, the others must take up the slack. When tanks are nearly full or nearly empty, the levels are verified both on deck and in the control room. Because when valves are remotely operated from the control room, there are only lights to tell their position, valve positions must be verified on deck, as well. In addition, watchstanders complete rounds of the pumproom, routinely, and calculate the flow transferred to be verified with the berth. When tanks are being cleaned, the mate on watch must check the O_2 levels in tanks, and the deck watch must keep an eye on the machines to make sure that they are operating properly. There will be one mate and two ABs on watch during a four hour period. In addition, the pumpman assists during cargo operations. All of the above tasks must be completed by these four people. Because of this everyone must cooperate and carry their share. If one person is not working up to his capacity, because of fatigue, sickness, or simply a bad attitude, the operation cannot be completed smoothly as intended.

7. Quantitative Analysis

This chapter is presented as a review of the two of the various techniques available for quantifying human error and a comparison of the resulting probabilities depending on the inputs of the analysis. The first method reviewed is that performed during the first phase of this research by Hart (1994). This method uses influence diagrams to identify contributing, initiating, and compounding events. Heuristic judgment is used with conditional probabilities to define the probability of failure of the system. The second method is a tree approach using values from the nuclear power industry. Errors are classified by their source and the probability of each type of error is evaluated.

Existing spill statistics regarding the number of occurrences can be used to verify the results of the quantitative analysis. This is more useful when viewed in an objective manner in terms of the number of spills per year versus the number of operations. While significant spill reporting is in place in both organizations, virtually no high consequence accidents have occurred in recent years. A reportable spill is enough to create a sheen on the water which means that the database is dominated by spills of a cup or less of oil. In addition most of these spills do not occur during transfer operations. Most of the spills at Richmond Long Wharf are due to pinhole leaks in hydraulic lines of loading arms or to grease from other apparatus. Several of the hydraulic leaks occurred during a construction project and are therefore not a consistent indicator. Nonetheless, spills on the wharf have been quite small.

Quantitative analysis can be used when evaluating the effects of implementing a proposed improvement. In this case, the example used is improved monitoring which will reduce the probability of mistakes due to carelessness.

7.1 Influence Diagram Method

This method uses influence diagrams to define contributing, initiating, and compounding events. These definitions are used to formulate the calculation of the probability of failure of the system by combining conditional probabilities. In algebraic form this calculation is:

$$P(loss_k) = \sum\sum P(in_i)P(finst_m|in_i)P(loss_k|finst_m)$$

Where, the probability of a spill is the product of the probability of an initiating event occurring, the probability of the final state occurring conditional on the initiating event, and the probability of a spill conditional on the final. These products are summed over all possible initiating events and final states. The calculation can be expanded to included actions and organizational factors. The initiating event is conditional on the action which is in turn conditional on the organizational policy.

This method was used to calculate the probability of an oil spill during the Start Up phase of the operation. Five categories of errors were included in the analysis: individual, organization, environment, procedures, and system. Figure 34 is a flow chart of the factors in the calculation.

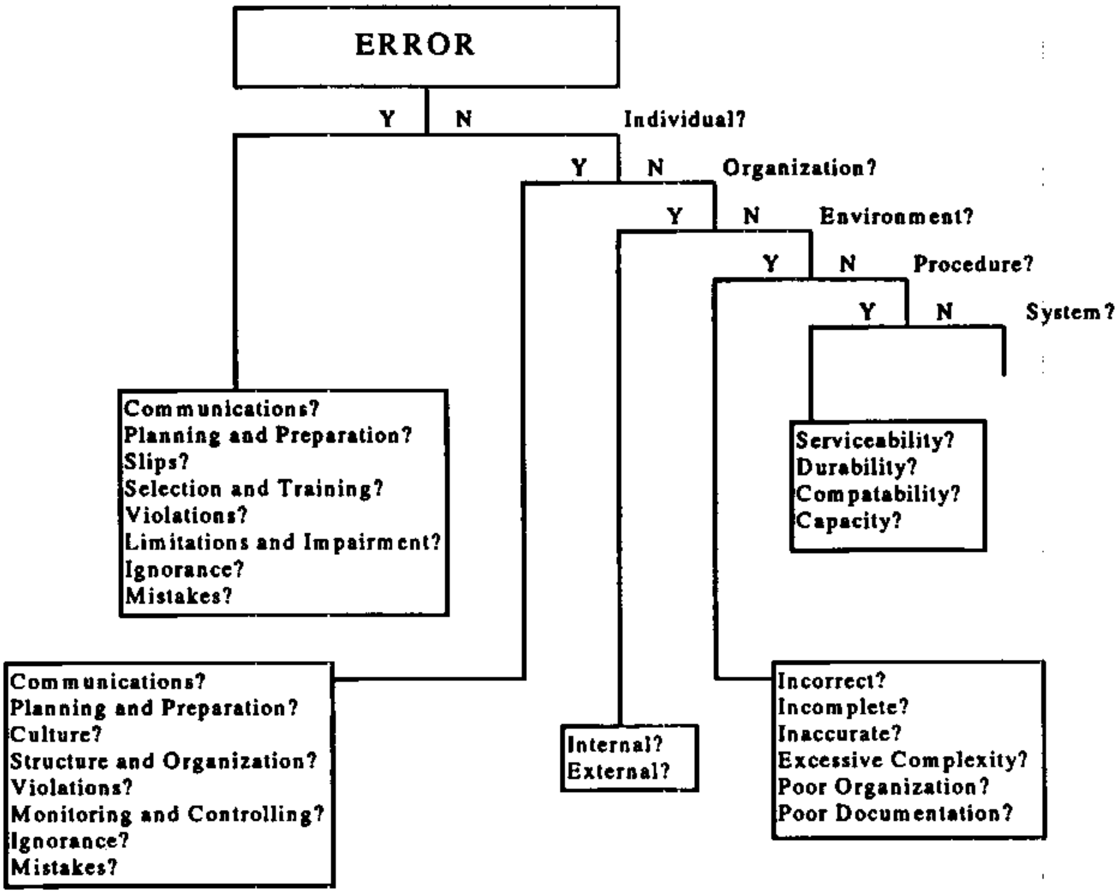


Figure 34. Error Flow Chart, Influence Diagram Method

There are also variables relating to the state of the system. Is the pump on or off? Is the hose attached properly? Are the valves aligned properly? Does a leak occur? Appendix C shows the probabilities associated with each of the accident scenarios. There are 322 scenarios included. The combined probability of failure is 0.1239. The highest probability of failure for a single scenario is $7x10^{-4}$. The lowest probability of failure for a single scenario is $2x10^{-4}$. When an improved monitoring program is implemented the probability of failure is reduced to .0778. The highest probability of failure of a single scenario is $5x10^{-4}$. The lowest probability of failure for a single scenario is $1x10^{-4}$.

7.2 Fault Tree Analysis

The second method of quantitative analysis uses fault trees as a tool to calculate probabilities of failure. The probabilities were derived from nuclear power data (Gertman,

1994) and corrected based on expert judgment. The fault tree structure is based on the classifications defined in the early chapters of this paper. Critical limbs are identified from the qualitative analysis of the Topping Off and Connection phases of transfer. This includes factors from both the terminal and vessel. (Although the *Arco California* is not loaded in Richmond, the factors from the vessel and terminal can be combined as generic.) Figure 35 shows the "unpruned" fault tree.

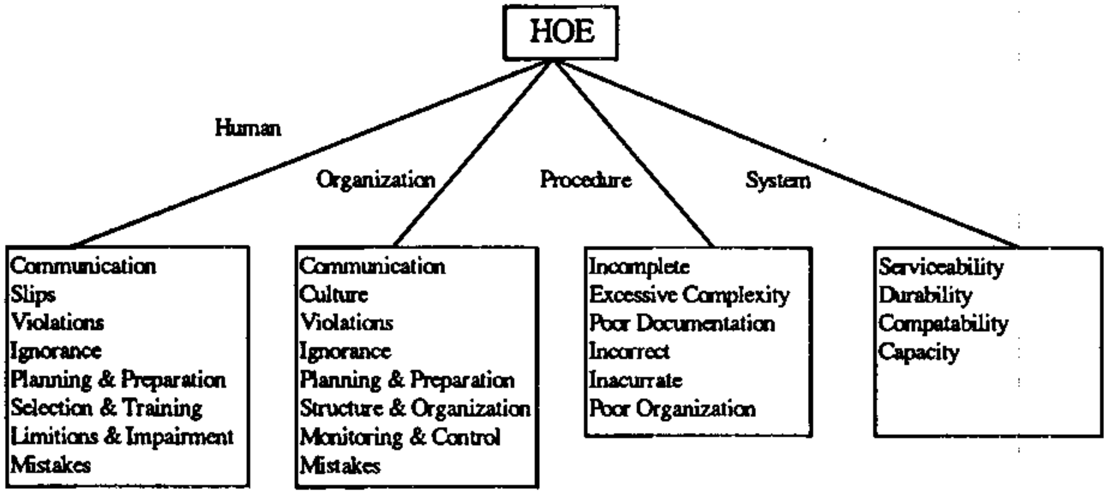


Figure 35. Base Fault Tree

This base tree is pruned to isolate those errors which were identified in the qualitative analyses of Chapters 5 and 6. The probabilities from each of the error are summed to give the probability for each category of error. These values are again summed to yield the total probability for the operation. Tables 24 and 25 show the calculation of the probability of failure for Topping Off and Connection phases of the transfer operation.

Table 24. Calculation of P_f in Topping Off

Human	Organization	Procedure	System
Communication: $1x10^{-1}$ Impairment: $1x10^{-1}$	Communication: $1x10^{-1}$	Incomplete: $3x10^{-3}$ Poor Documentation: $3x10^{-3}$	Serviceability: $7x10^{-2}$ Durability: $4x10^{-4}$ Compatibility: $5x10^{-4}$
Total: $2x10^{-1}$	Total: $1x10^{-1}$	Total: $6x10^{-3}$	Total: $7.09x10^{-2}$
			Total: 0.3769

Table 25. Calculation of P_f in Connection

Human	Procedure	System
Slips: 1×10^{-3} Impairment: 1×10^{-1} Ignorance: 1×10^{-3}	Incomplete: 3×10^{-3} Poor Documentation: 3×10^{-3}	Durability: 2×10^{-3} Compatibility: 4×10^{-3}
Total: 1.02×10^{-1}	Total: 6×10^{-3}	Total: 6.0×10^{-3}
		Total: 0.114

Although these values are in the same range as that calculated from the previous method (0.1239 in the Start Up phase), these values seem somewhat high. These results would correlated to between one and four failures in every ten transfers.

Improved monitoring will result in the reduction of human errors. If it is assumed that the probability will be reduced by half the results will be as follows in Tables 26 and 27.

Table 26. Calculation of P_f in Topping Off

Human	Organization	Procedure	System
Communication: 5×10^{-2} Impairment: 5×10^{-2}	Communication: 1×10^{-1}	Incomplete: 3×10^{-3} Poor Documentation: 3×10^{-3}	Serviceability: 7×10^{-2} Durability: 4×10^{-4} Compatibility: 5×10^{-4}
Total: 1×10^{-1}	Total: 1×10^{-1}	Total: 6×10^{-3}	Total: 7.09×10^{-2}
			Total: 0.2769

Table 27. Calculation of P_f in Connection

Human	Procedure	System
Slips: 5×10^{-4} Impairment: 5×10^{-2} Ignorance: 5×10^{-2}	Incomplete: 3×10^{-3} Poor Documentation: 3×10^{-3}	Durability: 2×10^{-3} Compatibility: 4×10^{-3}
Total: 1.005×10^{-1}	Total: 6×10^{-3}	Total: 6.0×10^{-3}
		Total: 0.1125

These results correlate to between one and three failures per ten operations which is somewhat better yet still severe.

8. Organizational Considerations

Although both oil terminals and ships seemed to operate in their own microcosms, they are subject to the policy, budget, and management of larger corporations. While a ship is at sea it would seem the she would be outside of the immediate control of the shoreside management. This is far from true. Especially as satellite communications become more and more advanced, the ship is constantly tied to her land based parent. Ships are becoming less and less independent, relying on shoreside support for scheduling, manning, budgeting, and safety support. On the terminal this is even more the case, because the upper levels of management are only a short drive away. Although operators may not interact with managers on a day to day basis, they are very close by.

The most interesting observation over the course of this project has been the contrasting opinions between management and front-line operators. This is most apparent in the "near-miss" reporting in both operations. While upper level managers claim that there is an extensive reporting system, operators and crew have a less formal approach. This informal approach can range from local review without formal reporting to "if nobody saw it, I didn't do it" secrecy. Although both corporations have tried to create a "no blame" culture, in which crew members will voluntarily come forward, it seems that people prefer to learn from their own mistakes rather than broadcast them to the rest of the fleet or wharf. It should be noted that the reporting of spills or accidents is very strong but it is the gray area of near misses that can cause communication to be blurred.

At Chevron, there is an extensive incident reporting system that includes oil spills as well as personal injury and other accidents. Management has recognized the deficiency in the system of near-miss reporting and redefined reportable incidents to include near-misses. This new system is taking hold but there are still problems as fear and mistrust of management hampers openness, candor, and accountability.

An example of the contrast between ship and shore personnel is AMI's personal injury policy. The safety department keeps careful track of attendance and lost time injuries on board the ships. The ship and the master are offered bonuses for perfect attendance or no injuries. This is meant to create a safety culture which encourages the crew to emphasize safety over production. Unfortunately, not all accidents are preventable. As masters come to rely on the bonus program, they can see themselves as being punished when accidents happen on their ships. While a good safety culture can prevent some accidents that are due to carelessness and rushing, the captain is held responsible for all minor slips and falls. While this does not pertain to oil spills, it can be seen where the difference of opinion between ship and shore can prevent the corporation from being a cohesive team.

Arco has attempted to ease the rift between ship and shore. One way that this is being accomplished is by allowing shoreside personnel to ride on the ships and rotating officers into the office. This allows both ship and shore personnel to appreciate how each is operating. By giving all personnel an understanding of the bigger picture, the lines of communication are opened and people can better see how the cooperation between the ship and shore can be improved.

9. Conclusions

There were two primary objectives of this research project. The first was the testing of the methodology previously used by Bea and Moore for the post-mortem study of accidents for use in analyzing existing or proposed oil transfer operations. The second was the development of an informational database for the classification of human and organizational error in marine oil transportation. The secondary objective of this project was to evaluate the operations at the Chevron Richmond Long Wharf and on board the *Arco California* to study the occurrence or possibility of occurance of human and organizational error.

This report concentrates on the testing of the proposed methodology and the evaluation of the specific operations. The database development portion of this project is presented in "Reduction of Oil and Chemical Spills: Development of Accident and Near-Miss Databases," by Elliot Mason, Karlene Roberts, and Robert Bea. More detail in the organization aspects of managing human error is presented in "Reduction of Oil and Chemical Spills: Organizing to Minimize Human and Organizational Errors," by Thomas Mannarelli, Karlene Roberts, and Robert Bea.

9.1 Testing of Methodology

The testing of methodology was threefold. The classification of human error was used to establish priorities for further study and to organize the research. Qualitative analysis was used to define which areas in the specific operations posed the most risk of human error and would require more detailed evaluations. Quantitative analysis was used to approximate the probability of failure associated with the transfer operation.

The difference between this research and previous applications of the Bea-Moore methodology is the proactive evaluation of existing operations versus the post-mortem analysis of well documented accidents. The classification system is still very useful. Categories are mutually exclusive and exhaustive to the extent that is possible. The primary difficulty is the desire to define every possible failure instead of analyzing the causes of one failure. This is further compounded by the desire to study high consequence accidents in a quantitative manner. In transfer operations, most spills are less than a cup of oil, and result from small leaks as opposed to gross negligence which causes thousands of barrels to be lost. In postmortem analysis, models become very complex to account for all of the contributing factors. In proactive analysis, these scenarios must be created through imagination instead of through recreation. In addition, when analyzing the entire operation, one must include all of the possible different combinations of failure modes. In order to establish a total probability of failure it is important to find the probability of occurrence of every permutation of contributing factors. In order to be exhaustive this would require the creation of literally millions of accident scenarios. This report has been narrowed to concentrate on the most hazardous phases of the transfer operation. Because high consequence accidents involve unusual modes of failure it is likely, however, that these freak accidents would occur at a time when they were least expected.

Quantitative analysis is the most difficult part of this analysis. Because of the lack of human error data from marine systems, values must be borrowed from the nuclear power industry or created using informed judgment. Because of this filtering, the results of the analysis can be manipulated completely by the analyst. This becomes further blurred when the goal is the study of low probability, high consequence accidents. Because the probabilities are so small, the variance on the values can be several hundred percent.

9.2 Evaluation of Chevron Long Wharf and Arco California

The most important human factors in the loading and discharge of oil are communication and manpower. The steps which have been defined as having the most potential for oil spills -- Start Up, and therefore Connection, and Topping Off -- are, not coincidientally, those which demand the most coordination and communication between all participants.

On the wharf, communication is the most critical factor. It is essential that communication between the ship and the berth be perfect. This means that warnings of Topping Off or problems during Start Up be made at the appropriate time. It is essential that both the ship and the berth be aware of each other's activities during all phases of the transfer. Wharf operators are most concerned with the difficulty of communicating with foreign crews. Although ships are required to have someone on board who can speak English, often there is some difficulty. Heavy accents are not easily understood over the radio. Of chief concern for ship crews when transferig cargos in Richmond is the use of one radio channel by all berths. When all of the berths are communicating on the same channel, it can create unnecessary clutter. This could be potentially hazardous if two berths are reaching a critical point in their operations at the same time.

On the ship, adequate manpower and fatigue are the primary factors. Although recent legislation has required the limitation of work hoursbefore entering port, some portion of the crew is likely to lose sleep during the manuevering and docking of the vessel. While this is a constant problem and steps are taken by individuals to mitigate the effects, fatigue is always of concern. Where this is of particular concern is during the critical portions of the operation that require the complete attention of all watchstanders. If one person is not alert or not feeling productive, the rest of the watch will have to carry his weight, often at the expense of their own duties.

10. Recommendations

The ultimate goal of this body of research is to provide a tool that can be used in the industry as a method for analyzing human and organizational error. The classification of errors is very useful to organize ideas in this area. Currently in most operations, human error is a minor consideration and not addressed in an organized and consistent fashion. This method provides some structure. The need for improvement is in the design of a protocol for qualitative and quantitative analysis. Qualitative analysis is potentially the most useful tool for the study of human error. Quantitative analysis is interesting but the potential variability of "answers" is so great that the time invested is not well spent.

The most important detail of the protocol will be the "interface" with frontline operators. During the course of this project several different questionnaires were used to elicit expert opinions. These questionnaires met with varying degrees of success when used in the field. The basic conclusion from this experience is that questionnaires are useful when the interviewer has limited knowledge of the system or operation being analyzed. When the interviewer is himself an expert in the field a less formal approach is more useful.

A possibility of further research in this area would be the development of a questionnaire framework that is sufficiently structured to ensure that all desired data is gathered but not so structured that it is confusing or frustrating either for the interviewer or the operator. In order for this methodology to be transferable into the field for any industry, the protocol must be generic and adaptable without blurring the classification or the basic method.

Mason (1995) suggests a taxonomy for the improved development of a database for the recording of marine accidents. An improved database would aid in this analysis particularly where it is currently necessary to look to other industry for quantitative values. Most of the existing data, however, do not adequately depict the underlying human factors in an accident except in the case of gross negligence. Recently there has been more emphasis placed on root cause analysis both by individual companies and the US Coast Guard. This should translate into improved data on human factors in accident reporting in the future.

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12. Appendices

Appendix A is the questionnaire which was used at the Chevron Long Wharf, in Richmond California. This is followed by the spreadsheet calculation for the risk factors which are presented in Section 5.3.1.

Appendix B is the questionnaire which was used on board the *Arco California*. This is followed by the spreadsheet calculation for the risk factors which are presented in Section 6.3.1.

Appendix C is a tabulation of the individual accident scenarios from Hart (1994).

Appendix A. Terminal Questionnaire and Data

Job Title__________
Terminal__________

To study LDO risks, we have broken the transfer process into a seven step model. Many of the following questions will refer to this model:

7 Stages of LDO -- Grading Matrix and Definitions

Risk	Grade	Step	Definition
		Approach/ Berthing	The vessel approaches the terminal, under own power or with tug escorts.
		Connection	The vessel is secured to the wharf. Lines/hoses are connected.
		Start Up	Product begins to be pumped, at increasing rate but not yet to agreed full rate.
		Steady Rate	Product is transferred at steady, agreed upon rate.
		Topping Off/ Stripping	Slow down from steady rate.. Tanks are topped off or stripped. Crude oil washing takes place.
		Disconnection	Lines/Hoses are disconnected.
		Departure	Vessel leaves terminal.

1. Does this model make sense to you? Are there any additional Stages that you think are important to consider?

2. On a seven point scale, how risky is each stage?

3. Now how would you grade your ship operations on each stage? Please give a grade, A to F, showing how well you think your ship conducts each stage.

4. The next questions ask about two LDO stages in greater depth. Each stage is composed of smaller steps.

(Use the two "riskiest" stages.)

Approach/Berthing:

Risk	Grade	Step	Definition
		Berth Selection	Selection and communication of berth.
		Approach with Escort Tug	Vessel enters the port and proceeds toward the terminal with tug escorts.
		Tanker Positioning	Vessel's position is aligned for approach to the berth.
		Berth Approach	Vessel enters berth, with assist tugs.
		Line Handling	First line ashore. Vessel is secured to dock.
		Final Positioning	Position is adjusted using tugs and line tension.

Do these steps make sense?

Are there any additional steps of the Approach/Berthing stage that are missing?

Please rate the risk of each step within Approach/Berthing.
Please grade how well your ship conducts each step within Approach/Berthing.

In the two riskiest steps of the Approach/Berthing stage what errors can or do occur?

Connection/Sampling:

Risk	Grade	Step	Definition
		Pre-Transfer Conference	Completion of DOI and other LDO planning activities.
		Flange Preparation	Flanges are checked and opened.
		Hose Connection	Flanges are bolted/connected together.
		Alignment Check	Alignment of all valves and hoses/arms is verified.

Do these steps make sense?

Are there any additional steps of the Connection stage that are missing?

Please rate the risk of each step within Connection.
Please grade how well your ship conducts each step within Connection.

In the two riskiest steps of the Connection stage what errors can or do occur?

Start Up:

Risk	Grade	Step	Definition
		LDO Plan Communication	Communication between VPIC, berth operator, and pump operator.
		Clearance	Initiating party requests clearance to commence pumping.
		Slow Rate	Flow commences at slow rate.
		System Check	Path of product is verified.
		Sampling	Quality is verified.
		Ramp Up	Transfer rate is increased to agreed steady rate.

Do these steps make sense?

Are there any additional steps of the Start Up stage that are missing?

Please rate the risk of each step within Start Up.
Please grade how well your ship conducts each step within Start Up.

In the two riskiest steps of the Start Up stage what errors can or do occur?

Steady Rate:

Risk	Grade	Step	Definition
		Monitoring	Flow rates and tank levels are monitored; Flow path is verified.
		Flow Calculation	Volume transferred is calculated hourly to match expected and actual flow.

Do these steps make sense?

Are there any additional steps of the Steady Rate stage that are missing?

Please rate the risk of each step within Steady Rate.
Please grade how well your ship conducts each step within Steady Rate.

In the two riskiest steps of the Steady Rate stage what errors can or do occur?

Topping Off:

Weight	Grade	"Risk"	Step	Definition
			Flow Reduction Notification	The receiving party notifies the initiating party to reduce flow rate.
			Reduction of Flow	Flow Rate is reduced.
			Cease Flow Notification	The receiving party requests pumps be stopped.
			Valve Closure	The product path is sealed at the vessel and terminal.
			Vessel Attitude Maneuvering	The stripping vessel adjusts its trim to maintain gravity feed to pumps.
			Tank Cleaning	Crude Oil Washing occurs.

Do these steps make sense?

Are there any additional steps of the Topping Off stage that are missing?

Please rate the risk of each step within Topping Off.
Please grade how well your ship conducts each step within Topping Off.

In the two riskiest steps of the Topping Off stage what errors can or do occur?

Disconnection

Risk	Grade	Step	Definition
		Line Depressurization	Lines are cleared of pumping pressure.
		Line Draining	Connecting lines are drained of residual product.
		Hose/Arm Disconnection	Flanges are unbolted and sealed.
		Sampling	More sampling occurs.
		Paperwork	Bill of Lading is completed..

Do these steps make sense?

Are there any additional steps of the Disconnection stage that are missing?

Please rate the risk of each step within Disconnection.
Please grade how well your ship conducts each step within Disconnection.

In the two riskiest steps of the Disconnection stage what errors can or do occur?

Departure:

Risk	Grade	Step	Definition
		Tug and Pilot Request	Vessel Master determines pilot and tug requirements.
		Tug Positioning	Tugs are positioned.
		Line Disconnection	Lines are slacked, then cast off and retrieved by the vessel.
		Cast Off	Ship moves away from berth.

Do these steps make sense?

Are there any additional steps of the Departure stage that are missing?

Please rate the risk of each step within Departure.
Please grade how well your ship conducts each step within Departure.

In the two riskiest steps of the Departure stage what errors can or do occur?

4. In preliminary research we noted that the stages of Start Up and Topping Off are often said to pose the greatest spill risk. Do you think that these two stages pose the greatest spill risk? Why or why not?

5. How does your company classify operations accidents? For instance, what is that minimum spill quantity that has to be reported?

6. Do you ever consider or discuss near incidents (incidents that almost happened)? What is considered to be a near miss?

Richmond Long Wharf

LDO Operations

Respondents = 18

Approach	Connection	Start Up	Steady Rate	Topping Off	Disconnect	Departure	Mean
8	6	5	4	2	6	4	5.00
3	1	2	1	4	2	1	2.00
2	2	4	2	4	2	2	2.57
5	8	10	4	6	4	4	5.86
12	7	2	6	20	3	2	7.43
	5	4	3	6	4	4	4.33
10	6	8	6	10	8	10	8.29
2	4	8	2	8	4	2	4.29
4	5	5	8	7	5	4	5.43
3	2	4	2	4	2	1	2.57
2	2	1	2	2	2	1	1.71
1	1	8	3	4	3	1	3.00
5	4	8	3	6	3	2	4.43
8	2	6	2	10	15	2	6.43
8	6	3	2	10	5	6	5.71
2	2	2	1	5	1	1	2.00
3	1	2	1	8	4	4	3.29
6	4	3	2	8	4	3	4.29
4.67	3.78	4.72	3.00	6.89	4.28	3.00	4.37

Richmond Long Wharf

Approach

Respondents = 6

Berth Selection	Tug Approach	Positioning	Berth Approach	Line Handling	Final Positioning	Mean
1	10	3	4	2	2	3.67
1		1	6	2	1	2.20
2	6	8	10	8	8	7.00
1	8	8	8	2	2	4.83
2	10	4	8	3	6	5.50
2	1	3	2	2	2	2.00
1.50	5.83	4.50	6.33	3.17	3.50	4.20

Richmond Long Wharf

Connection

Respondents = 3

Pre-Transfer Conference	Preparation	Connection	Checking	Mean
2	1	2	2	1.75
1	1	3	1	1.25
1	1	1	1	1.00
1.33	1.00	1.67	1.33	1.33

Richmond Long Wharf
Start Up
Respondents = 5

Communication	Clearance	Slow Rate	Check	Increase Flow	Sampling	Mean
1	6	2	4	4	2	3.17
8	2	2		4	2	3.33
1	1	2	2	4	1	1.67
1	2	2	1	8	1	2.80
2	2	2	2	6	4	3.00
2.60	2.60	2.00	1.80	5.20	2.00	2.79

Richmond Long Wharf
Steady Rate
Respondents = 1

Monitoring	Verification	Sampling	Mean
10	10	3	7.67
10.00	10.00	3.00	7.67

Richmond Long Wharf
Topping Off
Respondents = 16

Request to Slow	Flow Slowed	Request to Stop	Valve Closed	Mean
10	5	5	5	6.25
6	6	3	3	4.50
6	4	5	5	5.00
10	2	4	1	4.25
3	3	7	7	5.00
8	10	12	14	11.00
8	3	4	4	4.75
6	6	7	7	6.50
2	2	1	2	1.75
5	6	6	1	4.50
2	5	10	2	4.75
5	3	6	6	5.00
6	2	2	3	3.25
8	4	4	2	4.50
6	6	4	2	4.50
4	2	2	2	2.50
5.94	4.31	5.13	4.13	4.88

Richmond Long Wharf

Disconnection

Respondents = 3

Berth Selection	Tug Approach	Positioning	Berth Approach	Line Handling	Mean
1	1	1	1	1	1.00
2	8	12	1	1	4.80
1	1	1	1	1	1.00
1.33	3.33	4.67	1.00	1.00	2.27

Richmond Long Wharf

Departure

Respondents = 1

Call Tug/Pilot	Position Tug	Cast Off Lines	Depart	Mean
1	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00

Appendix B. Vessel Questionnaire and Data

Job Title____________

Ship_______________

To study LDO risks, we have broken the transfer process into a seven step model. Many of the following questions will refer to this model:

7 Stages of LDO -- Grading Matrix and Definitions

Risk	Grade	Step	Definition
		Approach/ Berthing	The vessel approaches the terminal, under own power or with tug escorts.
		Connection	The vessel is secured to the wharf. Lines/hoses are connected.
		Start Up	Product begins to be pumped, at increasing rate but not yet to agreed full rate.
		Steady Rate	Product is transferred at steady, agreed upon rate.
		Topping Off/ Stripping	Slow down from steady rate.. Tanks are topped off or stripped. Crude oil washing takes place.
		Disconnection	Lines/Hoses are disconnected.
		Departure	Vessel leaves terminal.

1. Does this model make sense to you? Are there any additional Stages that you think are important to consider?

2. On a seven point scale, how risky is each stage?

3. Now how would you grade your ship operations on each stage? Please give a grade, A to F, showing how well you think your ship conducts each stage.

4. The next questions ask about two LDO stages in greater depth. Each stage is composed of smaller steps.

(Use the two "riskiest" stages.)

Approach/Berthing:

Risk	Grade	Step	Definition
		Arrival Planning	Selection and communication of berth.
		Approach with Escort Tug	Vessel enters the port and proceeds toward the terminal with tug escorts.
		Tanker Positioning	Vessel's position is aligned for approach to the berth.
		Berth Approach	Vessel enters berth, with assist tugs.
		Line Handling	First line ashore. Vessel is secured to dock.
		Final Positioning	Position is adjusted using tugs and line tension.

Do these steps make sense?

Are there any additional steps of the Approach/Berthing stage that are missing?

Please rate the risk of each step within Approach/Berthing.
Please grade how well your ship conducts each step within Approach/Berthing.

In the two riskiest steps of the Approach/Berthing stage what errors can or do occur?

Connection/Sampling:

Risk	Grade	Step	Definition
		Pre-Transfer Conference	Completion of DOI and other LDO planning activities.
		Manifold Preparation	Blanks are removed. Flange Faces are checked.
		Hose Connection	Flanges are bolted/connected together.
		Line-Up Check	Line-up of all valves and hoses/arms is verified.

Do these steps make sense?

Are there any additional steps of the Connection stage that are missing?

Please rate the risk of each step within Connection.
Please grade how well your ship conducts each step within Connection.

In the two riskiest steps of the Connection stage what errors can or do occur?

Start Up:

Risk	Grade	Step	Definition
		LDO Plan Communication	Communication between VPIC, berth operator, and pump operator.
		Clearance	Initiating party requests clearance to commence pumping or loading.
		Reduced Rate	Flow commences at reduced rate.
		System Check	Path of product is verified.
		Sampling	Quality is verified.
		Max Rate	Transfer rate is increased to agreed steady rate.

Do these steps make sense?

Are there any additional steps of the Start Up stage that are missing?

Please rate the risk of each step within Start Up.
Please grade how well your ship conducts each step within Start Up.

In the two riskiest steps of the Start Up stage what errors can or do occur?

Steady Rate:

Risk	Grade	Step	Definition
		Monitoring	Flow rates and tank levels are monitored; Flow path is checked continuously.
		Calculation of Quantity	Volume transferred is calculated regularly to match expected and actual quantity.

Do these steps make sense?

Are there any additional steps of the Steady Rate stage that are missing?

Please rate the risk of each step within Steady Rate.
Please grade how well your ship conducts each step within Steady Rate.

In the two riskiest steps of the Steady Rate stage what errors can or do occur?

Topping Off:

Weight	Grade	"Risk"	Step	Definition
			Flow Reduction Notification	The receiving party notifies the initiating party to reduce flow rate.
			Reduction of Flow	Flow Rate is reduced.
			Shut Down Notification	The receiving party requests pumps be stopped.
			Valve Closure	The product path is sealed at the vessel and terminal.

Do these steps make sense?

Are there any additional steps of the Topping Off stage that are missing?

Please rate the risk of each step within Topping Off.
Please grade how well your ship conducts each step within Topping Off.

In the two riskiest steps of the Topping Off stage what errors can or do occur?

Stripping:

Risk	Grade	Step	Definition
		Tank Cleaning	Tanks are cleaned using crude oil wash or Butterworth machines.
		Stripping	Tanks are emptied of remaining product.

Do these steps make sense?

Are there any additional steps of the Stripping stage that are missing?

Please rate the risk of each step within Stripping.
Please grade how well your ship conducts each step within Stripping.

In the two riskiest steps of the Stripping stage what errors can or do occur?

Disconnection

Risk	Grade	Step	Definition
		Line Depressurization	Lines are cleared of excess pressure.
		Line Draining	Lines are drained of residual product.
		Hose/Arm Disconnection	Hoses or arms are disconnected. Blanks are replaced.
		Sampling	Final sampling occurs.
		Paperwork	Tanks are gauged. Transfer quantity is verified. Bill of Lading is completed..

Do these steps make sense?

Are there any additional steps of the Disconnection stage that are missing?

Please rate the risk of each step within Disconnection.
Please grade how well your ship conducts each step within Disconnection.

In the two riskiest steps of the Disconnection stage what errors can or do occur?

Departure:

Risk	Grade	Step	Definition
		Tug and Pilot Request	Vessel Master determines pilot and tug requirements.
		Tug Positioning	Tugs are positioned.
		Line Disconnection	Lines are slacked, then cast off and retrieved by the vessel.
		Cast Off	Ship moves away from berth.

Do these steps make sense?

Are there any additional steps of the Departure stage that are missing?

Please rate the risk of each step within Departure.
Please grade how well your ship conducts each step within Departure.

In the two riskiest steps of the Departure stage what errors can or do occur?

4. In preliminary research we noted that the stages of Start Up and Topping Off are often said to pose the greatest spill risk. Do you think that these two stages pose the greatest spill risk? Why or why not?

5. How does your company classify operations accidents? For instance, what is that minimum spill quantity that has to be reported?

6. Do you ever consider or discuss near incidents (incidents that almost happened)? What is considered to be a near miss?

Arco California
LDO Operations
Respondents = 4

Approach	Connection	Start Up	Steady Rate	Topping Off	Stripping	Disconnect	Departure	Mean
4	4	5	5	7	3.5	5	3	4.56
2	2	7	7	7	7	7	7	5.75
3	3	4	2	7	1	4	4.5	3.56
7	7	7	1	7	7	7	7	6.25
4.00	4.00	5.75	3.75	7.00	4.63	5.75	5.38	5.03

Richmond Long Wharf
Approach
Respondents = 2

Berth Selection	Tug Approach	Positioning	Berth Approach	Line Handling	Final Positioning	Mean
8.5	4.5	4	4	1	1	3.83
12	7	7	7	7	7	7.83
10.25	5.75	5.50	5.50	4.00	4.00	5.83

Richmond Long Wharf
Connection
Respondents = 2

Pre-Transfer Conference	Preparation	Connection	Checking	Mean
4	5	5	5	4.75
7	7	7	7	7.00
5.50	6.00	6.00	6.00	5.88

Richmond Long Wharf
Start Up
Respondents = 3

Communication	Clearance	Slow Rate	Check	Increase Flow	Mean
7		7	7	7	7.00
7	7	7	7	7	7.00
4	3	4	4	3	3.60
6.00	5.57	6.00	6.00	5.67	5.87

Richmond Long Wharf
Steady Rate
Respondents = 2

Monitoring	Verification	Mean
5	5	5.00
7	7	7.00
6.00	6.00	7.67

Richmond Long Wharf

Topping Off

Respondents = 2

Request to Slow	Flow Slowed	Request to Stop	Valve Closed	Mean
7	7	7	7	7.00
4	5	3	3	3.75
5.50	6.00	5.00	5.00	5.38

Richmond Long Wharf

Disconnection

Respondents = 2

Depressurizing	Draining	Disconnection	Paperwork	Mean
1	1	4	1	1.75
7	7	7	7	7.00
4.00	4.00	5.50	4.00	4.38

Richmond Long Wharf

Departure

Respondents = 1

Call Tug/Pilot	Position Tug	Cast Off Lines	Depart	Mean
7.00	7.00	7.00	7.00	7.00
1.00	1.00	1.00	1.00	1.00
4.00	4.00	4.00	4.00	4.00

Appendix C. Accident Scenarios (Hart, 1994)

Organization	Individual	Hose	Valves	Pspill
Communication	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0007
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0002
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0003
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0003
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
Planning	Communication	Not OK	OK	0.0005
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0004
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0005
"	"	OK	Not OK	0.0004
Culture	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004

“	Limitation	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Ignorance	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Mistake	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
Structure	Communication	Not OK	OK	0.0004
“	“	OK	Not OK	0.0002
“	Planning	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Slips	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Selection	Not OK	OK	0.0004
“	“	OK	Not OK	0.0005
“	Violation	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Limitation	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Ignorance	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Mistake	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
Violations	Communication	Not OK	OK	0.0004
“	“	OK	Not OK	0.0002
“	Planning	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Slips	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Selection	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Violation	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Limitation	Not OK	OK	0.0004
“	“	OK	Not OK	0.0004
“	Ignorance	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Mistake	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
Monitoring	Communication	Not OK	OK	0.0004
“	“	OK	Not OK	0.0002
“	Planning	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Slips	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Selection	Not OK	OK	0.0004

"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
Ignorance	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
Mistakes	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0003
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004

System	Individual	Hose	Valves	Pspill
Serviceability	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
Durability	Communication	Not OK	OK	0.0005
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
Compatibility	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002

"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
Capacity	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004

Procedures	Individual	Hose	Valves	Pspill
Incorrect	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
Incomplete	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004

"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
Inaccurate	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0005
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0005
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0003
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0003
"	"	OK	Not OK	0.0004
Too Complex	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0004
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0004
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0005
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0003
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0005
"	"	OK	Not OK	0.0004
Poor Organization	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0004
"	Planning	Not OK	OK	0.0004

“	“	OK	Not OK	0.0006
“	Slips	Not OK	OK	0.0003
“	“	OK	Not OK	0.0004
“	Selection	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Violation	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Limitation	Not OK	OK	0.0003
“	“	OK	Not OK	0.0004
“	Ignorance	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Mistake	Not OK	OK	0.0006
“	“	OK	Not OK	0.0002
Poor Documentation	Communication	Not OK	OK	0.0004
“	“	OK	Not OK	0.0003
“	Planning	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Slips	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Selection	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Violation	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Limitation	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004
“	Ignorance	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Mistake	Not OK	OK	0.0002
“	“	OK	Not OK	0.0004

Environment	**Individual**	**Hose**	**Valves**	**Pspill**
Internal	Communication	Not OK	OK	0.0004
“	“	OK	Not OK	0.0003
“	Planning	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Slips	Not OK	OK	0.0003
“	“	OK	Not OK	0.0004
“	Selection	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006
“	Violation	Not OK	OK	0.0003
“	“	OK	Not OK	0.0004
“	Limitation	Not OK	OK	0.0003
“	“	OK	Not OK	0.0004
“	Ignorance	Not OK	OK	0.0004
“	“	OK	Not OK	0.0006

"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
External	Communication	Not OK	OK	0.0004
"	"	OK	Not OK	0.0002
"	Planning	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Slips	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Selection	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Violation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Limitation	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004
"	Ignorance	Not OK	OK	0.0004
"	"	OK	Not OK	0.0006
"	Mistake	Not OK	OK	0.0002
"	"	OK	Not OK	0.0004