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TITLE OF REPORT

IDENTIFICATION OF POSSIBLE HUMAN ERRORS
THAT CAN RESULT IN FIRES/EXPLOSIONS
DURING TANKERS' CARGO LOADING/UNLOADING OPERATIONS
AT THE XYZ MARINE PETROLEUM TERMINAL

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IDENTIFICATION OF POSSIBLE HUMAN ERRORS THAT CAN RESULT IN FIRES/EXPLOSIONS DURING TANKERS' CARGO LOADING/UNLOADING OPERATIONS AT THE XYZ MARINE PETROLEUM TERMINAL.

by

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A Research Paper

Submitted in Partial Fulfillment of the
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ABSTRACT

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(Name of Style Manual in this Study)

This study identifies possible human errors that can result in fires/explosions during tankers' cargo loading/unloading operations at the XYZ marine petroleum terminal. Risk control solutions are developed to minimize the human errors.

Between the oil fields of the world and the users of derivative products, independent terminals like XYZ perform vital connecting services. Independent storage terminals are those which are not owned by the clients they serve and do not own any of the products they handle.

XYZ's clients include private and state oil companies, refiners, petrochemical companies, and traders in petroleum products and chemicals. Located in Houston, Texas, the XYZ terminal handles more than 3.6 million tons of oil products annually (XYZ terminal, 2000).

Similarly, oil tankers play a vital role on the transportation of the major part of the world's huge production of crude oil. Supertankers carrying 300,000 tons or more of crude are in service, and oil accounts for half the annual tonnage of all sea cargoes. (International Labour Office Geneva, 1983).

In general, the bulk carriage of crude oil presents special problems, such as the surging and expansion of the liquid cargo. In addition, the hazardous nature of crude oil has to be taken into account; flammable vapors have to be dispersed safely, especially during fast loading/unloading of cargo at the marine terminals. To meet some of these requirements, tankers are equipped with inert gas systems and vapor control systems to minimize fire and explosion risks (Carlebur, 1995).

Despite the advances that have been made in tanker design, fire prevention systems, and firefighting technology, shipboard fires remain a very real threat (Mediola & Achutegui, 2000). The enormous amount of hazardous and flammable materials transported by water raises concerns not only for the safety of the vessel's crew, but also for the protection of the surrounding environment against catastrophic spills and pollution (Williams, 1999). Human errors have been determined as one of the biggest causes of these accidental losses. At least 80% of the 911 tanker accidents that occurred between 1974 and 1996 were caused by human error (Marcus & Brown, 1997).

Accident data gathered worldwide has verified that human errors were the cause of 64% of the accidents during loading/unloading operations (Hart, 1994). According to the International Tanker Owner Pollution Federation Ltd (2000), the highest likelihood of occurrence for fires/explosions happens during operational activities at the loading/unloading jetty.

The Objectives of this study is to (1) identify possible types of human errors that can result in fires/explosions during tankers' cargo loading/unloading operations and (2) provide risk control solutions to the identified problems at the XYZ petroleum marine terminal.

A literature review was conducted in order to compiles available information for the better understanding of possible human errors that result in fires/explosions during tankers' cargo loading/unloading operations. Twenty questionnaire-surveys were sent to the terminal and ten of them returned with answers. Consequently, a secondary study was needed in order to support and verify the results previously mentioned above. This section summarizes some of the most relevant worldwide human-error experiences that have resulted in fires/explosions during tankers´cargo loading/unloading operations within the petroleum industry. Finally, the research brings conclusions and recommendation to be used in future operations at the XYZ terminal.

ACKNOWLEDGEMENTS

I would like to thank the University of Wisconsin-Stout, Risk Control Staff including Dr. John Olson / Dr. Elbert Sorrel / Dr. Brian Finder / Craig Jameson / Dr. Gene Reunger / Steven Señor / and Mary Fandry for their assistance, and honest opinions. Special thanks however, goes to Mr. Ricardo Vera for his energetic enthusiasm and his expert advise during the development of this research paper

SPECIALLY DEDICATED TO

My family (Mi muchacho, Merce, and So ….), my grandparents (all you four!!), and my friends. Thank for your support.

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Purpose of the study

This study identifies possible human errors that can result in fires/explosions during tankers' cargo loading/unloading operations at the XYZ marine petroleum terminal. Risk control solutions are developed to minimize the human errors.

Research Goals

1) Identify possible types of human errors that can result in fires/explosions during tankers' cargo loading/unloading operations.
2) Provide risk control solutions to the identified problems.

Background

Every year lives are lost and millions of dollars' worth of damage is caused through fires in ships (see table 1). Human error is by far the most common cause of fires. It is often a single careless act that endangers the lives of all the crew. (The International Tanker Owners Pollution Federation Limited, 1999).

Despite the advances that have been made in tanker design, fire prevention systems, and firefighting technology, shipboard fires remain a very real threat. Accidents involving fires/explosions rank second in maritime casualties. A survey of total loss accidents in 1500 oil tankers over a period of 25 years, 1971 to 1996, showed that these can be arranged in the following order: stranding, fire, water-leaks, gales and collisions (Mediola & Achutegui, 2000). The enormous amount of hazardous and flammable materials transported by water raises concerns not only for the safety of the vessel's crew, but also for the protection of the surrounding environment against catastrophic spills and pollution (Williams, 1999).

Table 1, Fires/explosion some related costs

Losses & Damages	**Incurred Costs**
Tanker damages	Depends on the severity of the accident (equipment, vessel structure integrity and areas affects). Fires/explosions are well known as the largest vessel damage costs (Tobit estimation, 1988)
Environmental liability	As high as $1,200 per vessel ton or $10 Million for vessels over 3000 gross tons; whichever is greater (Oil Pollution Act (OPA-1990)).
Oil-spill: Environment clean-up	$1,500 – $38,000 per ton of spilled product (National Research Council, 1991)
Oil-spill: Crude oil cost	$30.48/ barrel (OPEC) $31.75/barrel (Brent) $33.97/barrel (West Texas) (Source: Oil World Market, Nov 10/2000)
Terminal: Service demurrage	$20,000/day Tanker capacity: 80,000 deadweight tons (Source: XYZ terminal)
Terminal: Business interruption	$80,000/tanker Tanker capacity: 80,000 deadweight tons (Source: XYZ terminal)

At least 80% of the 911 tanker accidents that occurred between 1974 and 1996 were caused by human error (Marcus & Brown, 1997).

Similarly, accident data gathered worldwide has verified that human errors were the cause of 64% of the accidents during loading/unloading operations (Hart, 1994). In addition, the International Tanker Owner Pollution Federation Ltd (2000) determined that the highest likelihood of occurrence for fires/explosions happens during operational activities at the loading/unloading jetty. Thus, 1) A source of ignition generated by friction in the flanged joint interface of the tanker manifold/terminal piping system when hook up operation, 2) a flammable vapor leakage because of poor sealing in the flanged joint interface of the tanker manifold/terminal piping system during loading/unloading operation, 3) a seaman careless using cigarette lighters in no smoking areas, 4) preparedness**,** and lack of experience to set adequately the inert gas system for vapor control and fire prevention, 5) and poor quality in maintenance work because of operators no following appropriated company procedures and fire safety precautions, are some of the typical cause of losses directly related to tanker-terminal operator errors (XYZ terminal, 2000)

The existing petroleum transportation industry operates in a very strongly regulated business environment. Companies are liable to pay for worker's compensation, property damages, and the clean up of the environment. In addition, indirect costs, such as terminal-tanker loading/unloading demurrage, terminal-refinery crude/product delivery demurrage, and accident investigation service by the U.S National

Coast Guard, among others, enlarge the total operational costs (see table 1).

Definitively, failures of this nature aren't acceptable in today's aggressive and competitive oil transportation market. To prevent these losses, risk control solutions developed in this research paper will contribute to minimizing these additional costs.

Limitations of the Study

1. This study is limited to one petroleum terminal operator located in Texas, The United States of America.
2. Interviews and questionnaire feedback are based on the performance and experience of the XYZ petroleum terminal operator located in Texas, U.S.A.

Definition of Terms

Behavior questions:

Questions that ask about behavior and/or actions. Examples are: characteristics of people, things people have done, or things that have happened to them that are, in principle, verifiable by an external observer. Knowledge questions are considered behavior questions.

Human error:

It is the failure of a planned sequence of mental or physical activities.

Mistakes:

A mistake is a planning failure, where actions go as planned but the plan was faulted. These are errors of judgment, inference, and the like, that result in an incorrect intention, incorrect choice of criterion, or incorrect value judgments.

Moral Hazard:

Hazard arising from personal, as distinguished from physical, characteristics, such as the habits, methods of management, financial standing, mental condition, or lack of integrity of an insured who may intentionally cause a loss (Anderson & Talley, 1995).

Safety:

The condition of being free from exposure to a hazardous situation, injury, illness, or loss. It is based on knowledge and skills of avoiding accidents (Tarrants, 1970).

Stranding:

Vessel tanker grounding or hitting the sea bottom

Risk:

Hazard/condition/behavior that may increase the likelihood of frequency and/or severity of accidental loss.

Risk Control:

All methods of reducing the frequency and/or severity of losses, including exposure avoidance, separation, combination, loss prevention, loss reduction, segregation of exposure units and noninsurance transfer of risk. The term focused on economic measures, broad areas of risk, and is management oriented yet employee inclusive.

Tanker:

A ship designed to carry liquid petroleum cargo in bulk, including a combination carrier when being used for this purpose.

Terminal:

A place where tankers are berthed or moored for the purpose of loading or discharging petroleum cargo.

Terminal service – demurrage:

A charge by a carrier for the detention of equipment and cargo beyond the free period which is allowed for loading and/or unloading.

Other Definitions

Anti-static additive:

A substance added to a petroleum product to raise its electrical conductivity to prevent accumulation of static electricity.

Flame screen:

A fitted device incorporating one or more corrosive resistant woven wire fabrics of very small mesh used for preventing sparks from entering a tank or vent opening or, for a short time, preventing the passage of flame.

Gas free:

A tank compartment or container is gas free when sufficient fresh air has been introduced into it to lower the level of any flammable, toxic, or inert gas; it is required for a specific purpose, e.g. hot work, entry, etc.

Hazardous area:

Areas on shore, which for the purpose of the installation and use of electrical equipment, are regarded as dangerous.

Hot work:

Work involving sources of ignition or temperatures sufficiently high to cause the ignition of a flammable vapor mixture. It is commonly referred to cutting and welding operations

Inert conditions:

A condition in which the oxygen content throughout the atmosphere of a tank has been reduced to 8% or less by volume by addition of the inert gas.

Insulating flange:

A flanged joint incorporating an insulating gasket, sleeves and washers, to prevent electrical continuity between pipelines, hose string or loading arms.

Purging:

The introduction of inert gas into a tank already in the inert condition with the object of further reducing the existing oxygen content, and/or reducing the existing hydrocarbon gas content to a level below which combustion cannot be supported if air is subsequently introduced into the tank.

Static electricity:

The electricity produced on dissimilar materials through physical contact and separation.

Topping up:

The introduction of inert gas into a tank that is already in the inert condition, with the object of raising the tank pressure to prevent any ingress of air.

CHAPTER II

REVIEW OF RELATED INFORMATION

Introduction

This chapter compiles available information for the better understanding of possible human errors that result in fires/explosions during tankers' cargo loading/unloading operations at the marine petroleum terminal. The review studies the variable human errors to better appreciate and understand possible direct/indirect relationships associated with fire/explosion losses within the interface: oil tanker-marine terminal.

Oil Transportation and Tankers

The major part of the world's huge production of crude oil has to be carried to overseas refineries by tankships. The prototype of the modern tanker was built in 1886 to carry 2300 tons of oil. Today, supertankers carrying 300,000 tons or more of crude are in service, and oil accounts for half the annual tonnage of all sea cargoes. The actual carrying capacity of world tankers exceeds 180 million tons (International Labour Office Geneva, 1983).

In general, crude oil is carried in large tankers, and smaller vessels are used to carry the refined petroleum products. The bulk carriage of crude oil presents special problems, such as the surging and expansion of the liquid cargo. Moreover, the hazardous nature of crude oil has to be taken into account; flammable vapors have to be dispersed safely, especially during fast loading of cargo. To meet some of these requirements, tankers are built with engines aft and the cargo space divided into a number of separate tanks. The cargo areas can be entered through small hatches, which are of limited sizes and quantities to preserve the vessel's structural integrity. Cargo pumps are housed in individual pumprooms, and forced ventilation is provided to purge compartments of hazardous gases and vapors. Some tanks are also equipped with inert gas systems to minimize fire and explosion risks in cargo spaces (Carlebur, 1995).

Loading/Unloading Operations

Based on description provided by Hart (1994), a transfer operation at the marine terminal can be described as a seven-step process (figure 1).

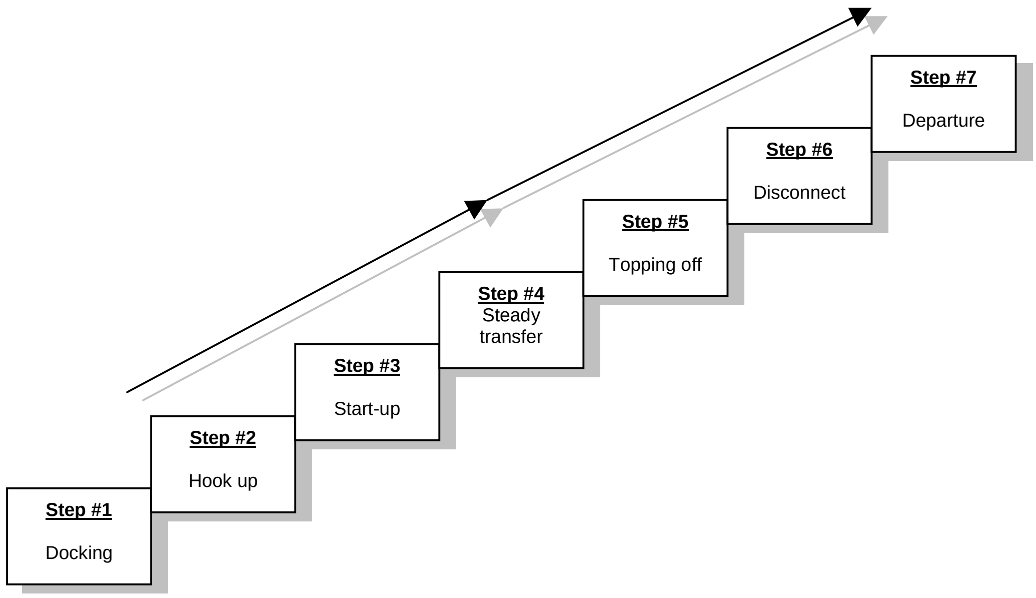


Figure 1.

Loading Operations

Here, oil products are pumped from the terminal storage area to the tanker being loaded. The steps are:

1. Docking: It is the process of approaching and securing a ship to a terminal in a safe fashion.
2. Hook up: It is the commencement of the transfer operation. Cargo types, flow rates, communication signals, stoppages, and emergency procedures are some of the activities covered in a conference conducted between authorized representatives of the ship and terminal personnel. In addition, a preliminary inspection is pursued in order to ensure safe conditions onboard of the tanker vessel. “It looks for specific conditions that have proved to be the most critical from the past experience” (International Safety Guide for Oil Tankers and Terminals, 1988). Once the understanding is reached and the accompanying declaration of inspection is signed, the transfer of the tanker's cargo may begin with the hook-up of hoses and loading arms.
3. Start up: It is the initial stage in the transfer process of fluid pumping. The initial flow rate should always be low. All valves in a dedicated pipeline must be opened during pumping. The valve closest to the source tank is the last one opened. When the pumps are turned on, the flow rate is set

to the minimum. At this point checks are conducted to ensure that the flow is indeed going to the correct place and no leaks are occurring in any of the pipes or connections. Once the flow has been proved to have no leaks, orders are given to increase the flow to the maximum agreed upon.

4. Steady transfer: It starts with a slow increase of the flow rate to the maximum flow, about 400 bbl/min, which is continued for the duration of the transfer. It takes about 10 hours and involves hourly checking for leaks, tank soundings, flow volume calculations, and general proper operation of the entire system. In addition, the inert gas system and vapor control system must be turned on in order to keep flammable vapors below 8% oxygen inside of the tank areas.
5. Topping off: It is the continuous decreasing of flow rate that starts before the tanks become full. Topping off occurs usually in the last 1.5 hours of the transfer and the operation is similar to that of start-up, except opposite. In general, the liquid level is at least 2 feet below the deck level at the expansion trunk-- that means 98% of the tank capacity.
6. Disconnect: It involves removing the bolts connecting the shore hoses and/or loading arms to the ship manifolds, purging the hoses with air or inert gas to clear it of excess product, and capping both the hoses and manifolds.

7. Departure: It's when the ship has completed all the legal and technical aspects of the business, so it is ready to leave the terminal.

Unloading Operations

Basically, unloading operations follow the same steps as loading operations. However, products are pumped from the tanker vessel to the terminal and the venting system must allow air to pass into the unloading tanks in order to preserve the structural integrity of the ship.

Oil Tanker's Existing Technologies and Risk Control Guidelines

Through the years, the oil transportation industry has developed effective technologies and applicable safety guides for the operation of oil tankers and terminals. The existing technologies are based on hazard control principles and exposure minimization.

These systems are:

1. The inert gas system;
2. The venting system and;
3. Anti-static additive for static electricity controls in cargo products

1. The Inert Gas System.

When flammable gases are present in areas where they can develop into a flammable or explosive hazard, the safest way to remove them is to purge the area with inert gases (Cote & Linville, 1990). One of the greatest advances in tanker operations over the last 20 years seems to be the introduction, on an increasing scale, of inert gas systems. The United States Coast Guard (USCG), in concert with the Chemical Transportation Advisory Committee (CTAC), have developed and implemented regulations, under title 46 CFR, part 39, governing the design and operation of these systems. Today, numerous tank vessels have been modified for vapor control operations as required, and are conducting closed operations at loading facilities.

It is known that petroleum gives off flammable vapors, and that the actual amount of these depends on the particular grade of petroleum being handled. However, petroleum vapors are only flammable when certain air/vapor mixtures are achieved (Rutherford, 1980). The limits of the flammable range of petroleum vapors have been determined to be from 1% to 10% per volume of the atmosphere at the cargo area (International Chamber of Shipping Oil Companies - International Marine Forum International Association of Ports and Harbors, 1988). Nevertheless, there are many times during operations, especially loading/unloading operations, when the tank atmosphere can fall within the flammable range; it is therefore necessary to take special precautions to avoid the possibility of fire/explosion.

It must be remembered that a fire/explosion situation can only occur if there is enough oxygen in the atmosphere to support the combustion. In general, ordinary air contains about 21% oxygen and is capable of supporting combustion. It is a fact that if the oxygen level were reduced to below 11%, there would be insufficient oxygen to start the flame, even when a possible sparking source exists (Compressed Gas Association, 1987). The object of the inert system is to reduce the oxygen level in the tank atmosphere by replacing it with some other gas such as carbon dioxide or nitrogen. This is usually achieved by using a fixed piping arrangement to blow the inert gas into the cargo tank (International Chamber of Shipping Oil Companies - International Marine Forum International Association of Ports and Harbors, 1988). Finally, this piping system is directly related to a venting system.

2. The Venting System.

Whenever a liquid is introduced into a closed tank, it is necessary to ensure that air is adequately vented in order to avoid a possible over-pressure that can distort the tank due to liquid entering it. Similarly, when liquid is taken from a closed tank by a pump, without air being allowed to enter, the tank will be distorted because the pressure outside will exceed the pressure inside (Mechanical Engineers' Handbook, 1998)**.** This phenomenon clearly applies to tanker operations. However, the issue is not under control just by ensuring a clear airway to and from the tank (Rutherford, 1980). By the nature of the cargo, flammable vapors may also be vented from the tanks. The venting arrangements are gas lines that lead from each tank to a common main line running the full length of the ship. The excess vapors from the common line are carried up a vertical structure, a 30-40ft riser, above the main deck level to ensure their effective dispersion before they can fall to the deck level. In addition, a special pressure vacuum valve installed at the foot of the riser retains vapors in the tank venting system until the pressure rises to approximately 0.01 kg/cm^2, in order to minimize the continuos vapor release. When this pressure is reached, the valve lifts and releases vapors to the atmosphere; when the pressure drops below this figure, the valve closes. Therefore, a vacuum effect will happen if oil cargo contracts because of temperature changes. When the valve of the vacuum side reaches 0.002 kg/cm^2, this will open and allow air to enter the tank, thus preventing any distortions of the cargo tank bulkheads. When cargo is being loaded, the vacuum valve would cause an undesired obstruction to the passage of the large volume of vapor pushed from the tank by the incoming cargo. In order to overcome this problem, it is usual to fit a “manually operated bypass” around the vacuum valve, allowing a clear passage for the gas to pass directly to the mast riser. Moreover, a flame arrestor is usually installed at the outlet in the riser (at the top end), or sometimes next to the vacuum valve (at the riser base). Thus, measures are taken in order to block a flame passing through into the common main vapor pipeline and possibly the cargo tanks. Finally, an independent tank vent system can also exist. The principles are basically the same (Compressed Gas Association, 1987).

3. Anti-static additives for static electricity control in cargo products.

Conductivity is another important concern when the cargo being handled is an accumulator of static electricity. Oils that have sufficient conductivity to prevent an accumulation of static electricity may be loaded without anti-static precautions, regardless of tank flammability. These are: crude oil, residual fuel oils, black diesel oils, and asphalt (bitumen). In contrast, gasolines, kerosenes, white spirits, jet fuels, naphthas, heating oils, heavy gas oils, diesel, and lubricating oils; they are accumulators of static electricity because of their low conductivity under certain conditions. Thus, they will require special precautions such as the usage of anti-static additive and the regulation of the flow rate during loading/unloading operations (Vinnem & Skjelldal, 1991).

Moreover, procedures enforce the aim of these existing technologies. The International Safety Guide for Oil Tankers and Terminal was the most valuable documentation found during this literature review since it is what every one applies in the field. “It is the integration of the vast storehouse of worldwide experience in many varied disciplines associated with the tanker/terminal functions” (Institute of Petroleum, 1981). Its information is frequently up-graded using recommendations generated during annual conferences and symposiums around the world.

Fires/Explosions during Tankers’ Cargo Loading/Unloading Operations in Marine Petroleum Terminals

Every year lives are lost and millions of dollars' worth of damage is caused through fires in ships (see table 1, p. 2). Human error is by far the most common cause of fires. It is often a single careless act that endangers the lives of the entire crew. (The International Tanker Owners Pollution Federation Limited, 1999). Is there any place where failure or malfunction could bring disaster onboard tankers? The danger spots are machinery rooms, accommodation, and cargo spaces (The Capt. Loannides’ Web Site, 2000). Every member of the ship’s crew and terminal operator has a part to play in preventing fires. For instance, take a look at oil tanker operations and some fire/explosion cases:

- An oil product vessel carrier was on fire in the North Sea Area. Although the access hatches to the holds were gas-tight, they were opened at intervals to check the temperature of the cargo. The mast houses above were also clearly marked as "NO SMOKING" areas because of the danger of vapors lingering after each opening of the access hatch. While loading petroleum products in port, a seaman lit a cigarette lighter to see more clearly under a shelf in the mast house. There was a flash fire and the seaman and his mate were badly burned. Both were taken off the ship by helicopter and rushed to hospital for treatment (The Capt. Loannides' Web Site, 2000).
- On a very cold day in December, 1981, a collision on the Ohio River touched off a fire aboard a ship-tanker carrying 1,250,000 gallons of gasoline. The vessel superstructure hit the dock fender when arriving to the terminal. Despite the significant increase in wind speed and the extensive current flow, the terminal leader and the tanker operator decided to continue with the arrival activities; these bad conditions, combined with the unfortunate decision of the terminal leader and the tanker operator, were the direct causes of the accident. After 25 minutes of foam application, the fire was extinguished. However, the fire was reignited by hot carbon buildup falling from the interior roof into the gasoline below. Human error was

determined as the cause of this accident. (The Capt. Loannides' Web Site, 2000).

- While unloading crude oil in the terminal, the engineer aboard the carrier was using oxy-acetylene equipment to carry out minor repairs in the Engine Room workshop when a fire broke out near the oxygen and acetylene bottles. Subsequent investigation revealed that it had started because of a leaking hose of the oxy-acetylene equipment (International Chamber of Shipping, 1986).
- A ball of fire erupted in the engine room of the Australian tanker Helix when a flanged joint on a hydraulic system failed under pressure. The fire was the result of the failure of bolts securing a flange on a hydraulic pump. Later, investigations proved that these bolts were improperly adjusted, being out of the specification. The hydraulic pumps shut down automatically on loss of pressure, causing the fireball to be short-lived. Nobody was hurt and no pollution resulted. Moreover, in another part of the ship, personnel heard and felt a thump as the spray of leaking hydraulic oil ignited on the exhaust of a diesel engine driving the hydraulic pump. The damage was limited to light fittings, melted indicator and warning lights, and smoke damage (Australia's Commonwealth Department of Transport and Regional Services, 1999).

- On December 19, 1998, the Australian flag tanker Tasman was alongside at No.28 wharf in the port of Melbourne, where it was undergoing some maintenance, modification work and being surveyed, while oil-products were being unloaded at the port. An accident was caused by a vibration on the pipes because one of the maintenance operators left two Allen screws loose, allowing fuel to be sprayed into a hot-box before igniting on the exhaust pipes. The fire caused some damage to the No.1 generator, but the most significant damage was that sustained by electric cables in the cable trays beneath the deckhead. Since tanker/terminal maintenance operators did not follow procedures, the human error was determined as the cause of this accident (Australia's Commonwealth Department of Transport and Regional Services, 1998).
- On January 19, 1996, the U.S. tug Scandia had an engine room fire while towing the unmanned U.S. tank barge into the Point Judith Petroleum Terminal in Rhode Island during the arrival operations. All six crewmembers abandoned the Scandia amid 10-foot waves and 25-knot winds. The crew was unsuccessful in its attempts to release the anchor of the barge, which ran aground and spilled 828,000 gallons of home heating oil, causing the largest pollution incident in Rhode Island's history. The National Transportation Safety Board determined that the

cause of fire damage aboard the tug Scandia, and the subsequent grounding of and pollution from the barge North Cape, was the inadequate maintenance and operations aboard the towing vessel, which permitted a fire of unknown origin to become catastrophic and eliminated any possibility of arresting the subsequent drift and grounding of the barge. Contributing to the accident were the lack of adequate U.S. Coast Guard and industry standards addressing towing vessel safety (U.S National Transportation Safety Board, 1996).

- In Veracruz, Mexico, a tanker ship was being unloaded of its cargo of highly lethal and flammable polar solvent. Then, a container holding the same solvent was accidentally dropped inside the ship, setting off a fire. The hatches were closed and the ship's own CO_2 firefighting system was used to extinguish the fire, as the ship was towed out of the harbor and anchored off the coast. Believing they had achieved successful extinguishments, the ship's officials ordered the hatches reopened, allowing oxygen into the hold. This created a tremendous explosion and reignited the fire (Tank Ship Fires and Study Cases, 1981).
- In September 1990, a tanker was unloading gasoline at an oil company dock in Bay City, Michigan when an explosion sent flames and black smoke hurling over the Saginaw River. The fire

aboard this tanker, which was carrying 1.5 million gallons of gasoline, is considered to be one of the largest tanker ship fires in marine history to be successfully extinguished. The causes of the explosion couldn’t be determined; however, U.S and Michigan authorities suspect that the lack of preparedness for the unloading operation led an operator to make an error while setting the inert gas system for vapor control and fire prevention (Tank Ship Fires and Study Cases, 1990).

In brief, all these losses were directly related to human errors while tanker-terminal operators were performing their job. Based on the provided data, five out of eight (62.5%) of fire/explosion accidental losses happened during tankers’ cargo loading/unloading operations in marine terminals. In addition, unloading operations seem to be the most critical in terms of accident frequency. They represent 50% of the accidents listed above, and are the result of non-compliance with existing risk control rules regarding “hot work permits” and “no smoking areas.

Since accidents described in this section aren’t acceptable in today’s aggressive and competitive oil transportation market, the existing petroleum transportation industry has been challenged to invest in large financial and time efforts to prevent losses and to control risk associated with fires/explosions in tanker/terminal operations.

For instance, some efforts and results have been focused on:

1. Process hazard analysis
2. Training
3. Fire/explosion risk control precautions
4. Behavior based safety
5. Tanker/barge inspection systems
6. Hot work permits

The following section describes these risk control practices

Risk control practices for human error reduction during loading/unloading operations in marine petroleum terminals.

A Positive Experience in Citgo Petroleum & Co.

According to Citgo Petroleum (1996),a “process hazard analysis” (P.H.A) for each activity that has the potential to generate fires/explosions is the core component of a process safety management procedure implemented in refineries, terminals and storage facilities belonging to the Energy Corporation. Its implementation has cut losses from 22% to 15%.

The process hazard analysis examines, but is not confined to:

1. Human factors analysis of working conditions that may adversely impact the safety performance of CITGO personnel and potentially produce accident event sequences, especially during startup, maintenance operations, and upset/emergency conditions.

2. The P.H.A is actually performed by a group of operators previously trained during the initial phase by individuals with expertise in engineering, process operations, and maintenance. Everyday activities are performed by teams, which at least have one person with experience and specific knowledge to the hazard or process under evaluation.

   Consequently, the program enforces:

   - A detailed and effective communication of procedures, activities and hazards related to the ongoing operations. It is possible by the usage of "preliminary job analysis form";

   - The training programs for unit operators and supervisors;

   - The training and certification programs for inspection personnel;

- The adequacy of training and equipment for emergency responders and firefighting personnel;
- Authority and responsibility of personnel to identify and correct hazardous conditions;
- Refresher and supplemental training sessions provided at least annually to ensure understanding and adherence to the current procedures for performing activities safely and reducing risk.

A productivity issue at Kurnell Refinery and Marine Terminal.

In Australia, the terminal company operator at Kurnell Refinery & Marine Terminal, included in its policy requirements the provision of improved signing systems on board clients' barges and tankers, since having vessels parked in the dock for long periods of time became a productivity issue. The decision not only provided better controls on the required activities for loading/unloading products, but also delayed a construction project for the expansion of the existing terminal. As result, vessels spend less time parked in the facility. Paper work and documentation were also reduced and the company manages a higher volume of products annually.

Actions also assure the existence of "NO SMOKING" signs posted on board vessel and dock-terminal surroundings, a monitoring program for perfect connections on combustible liquid and vapor control piping, and continuous operation inspections (CALTEX, 2000).

A behavior based safety program

It is a program focused almost entirely on modifying the behavior of workers in order to prevent accidental losses. The fundamental premise is that the overwhelming majority of losses are the result of human errors. Since 1991, Chevron & Co. has been implementing and reinforcing the program at its loading/unloading terminal facilities located in New Jersey and California. The first step in the behavior-based program is usually listing critical worker behaviors. Next, inspectors (observers), are selected to periodically monitor the work activities of operators. The company was able to reduce losses by 20% and improve the quality of internal services. They train their employees using the "Dupont Safety Training and Observation Program," improving operators' compliance with the existing standards operational procedures. Keeping the safety awareness level high positively affects operators' behavior (Chevron Marine Terminals, 2000). Some important aspects of the program are:

- Two times a week, terminal management (general supervisors, safety manager, and facility manager) attends a morning meeting to review the previous days' safety and productivity issues. General supervisors take the information back to their areas to share with their supervisors.
- All operators attend monthly safety meetings. The safety team chooses the monthly topic. Safety tips are generated and posted in the monthly company bulletin.

"Safety behavior at the facilities has progressed and is currently at the observation and empowerment levels. Workers use risk-free practices as a matter of habit" (Chevron Marine Terminals, 2000).

The results enforce the fire/explosion error free expectations. Operators call each other to attend in precaution of possible risky actions and to avoid dangerous situations. Important fire/explosion precaution practices are listed below, table 2.

Table 2, Important fire/explosion precautionary actions

Rule	**Remark**
No Smoking	• Strictly enforce NO SMOKING rules
No Matches or Cigarette Lighters	• Collect matches and cigarette lighters at the checkpoint before entering the facility.
No Smoking Signs	• Post NO SMOKING WITHIN 50 FEET signs where they can be seen.
Flame-and Spark-Producing Equipment	• Do not use open flames, heating stoves, electrical tools, or other such apparatus in petroleum storage areas, tankers, and dock areas.
Explosion-Proof Equipment	• Use only authorized tools, equipment, and clothing. • Use explosion proof lights and flashlights.
Tools	• Keep tools and equipment in safe and good working condition.
Equipment Bonding and Grounding	• Bond and ground pumps, tank vehicles, and storage tanks.
Spills	• Control spills with a proactive spill prevention system. Immediately clean up and report spills. • Treat the area as especially hazardous until vapors are gone. When vapors are gone, remove the spill.
Leaks	• Always inspect tank seams, joints, piping, valves, and pumps for leaks. • Repair leaks at once. • Replace defective hoses, gaskets, and faucets immediately.
Inspections	• Inspect equipment, safety devices, and work areas frequently to ensure risk-free expectations and to correct hazards.
Solvents	• Use only authorized solvents for cleaning.
Beware of unventilated spaces.	• Becareful around unventilated or confined spaces.
Consult with others when conducting ventilating and vapor-freeing operations.	• Consult other area operations that could be sources of ignition.
No handling of Products During Electrical Storms	• Place fire extinguishers and other fire fighting equipment within easy reach but where it will be safe from fire.
Hot work permits	• Gas free certificate must be issued. • Portable continuos gas detector must keep monitoring the atmosphere in the working area. • Work area must be clear of any combustible material. • Fire fighting equipment must be ready for immediate use.

Source: Chevron Marine Terminals, 2000.

Tankers/Barges Report Data Base for Inspection

As a consequence of a number of tanker fire accidents in the late 1970s, oil and chemical companies individually introduced ship-venting arrangements to assess vessels prior to chartering. Later, in the 1990s, the Oil Companies International Marine Forum (OCIMF) system called SIRE (Ship Inspection Report Programme), and the Chemical Distribution Institute (CDI) inspection report data-sharing scheme were developed. With these systems, which are worldwide, inspections are carried out and reports issued in a consistent format. The reports are held in a central database and can be accessed by system-scheme members who are considering chartering the vessel in question. The reports themselves do not pass or fail the vessels, but describe their physical condition and operational systems. It is then up to the individual charterer to decide whether the vessel conforms to the standards for the voyage and cargo in question. It represents a great advantage since the tanker world fleet is very heterogeneous in terms of size, design, age, instrumentation, and fire prevention/protection systems. Thus, terminal operator crews can get prepared prior to the loading/unloading operations on a specific vessel, reducing the probability of accidental losses because of human errors (Oil Companies International Marine Forum, 2000).

Tanker/Barge Inspection System

Moreover, in the early 1990s, concern also arose about the situation in the European petroleum industry following a series of incidents that had occurred with tankers and barges. These incidents coupled with an on-going catalogue of lesser events, which arose more through operator errors than mechanical deficiencies. In effect, oil and petrochemical companies employing tankers introduced a variety of tanker/barge inspection and assessment arrangements to minimize exposure to substandard operators. Recognizing the existing uncoordinated approach to tanker inspections and the advantages of adopting a scheme similar to the maritime SIRE and CDI systems; CONCAWE, the Oil Companies´ European organization for environment, health and safety, was approached at the beginning of 1995 by several of its member companies and their associated petrochemical companies to host a series of meetings to enable the development of a European tanker/barge inspection scheme (Vinnem & Skjelldal, 1991).

A Successful Hot Work Permit System

Hot work permit systems have been implemented in the petroleum industry for a long time. Basically, it is the completion of a series of requirements before operators start performing the job. The hot work can be a part of any activity but is especially related to maintenance work. It involves brazing, cutting, grinding, soldering, and thawing frozen pipes and equipment. The European Petroleum Loss Prevention Council (UK) found that 83 serious fires (those fires with damages exceeding $100,000 and/or resulting in fatality) were caused by hot work between 1992 and 1996. Estimated losses from these fires equaled ninety million-dollar. Liquid petroleum gas blowlamps and acetylene cutting equipment were the most common devices involved in all serious hot work fires. Today, guidelines concerning hot work emphasize the role of human intervention in making hot work safer. They require frequent training for all staff members who perform hot work. Additionally, a person not performing the actual hot work maintains a continuous fire watch during the procedure as well as 1 hour after the work has been finished. At the North Sea area petroleum and petrochemical companies have successfully controlled fire/explosion related accidents since they have implemented more accountability on the equipment and hot work permits. A checklist for effective hot work practices, a strict written permit system, and training outline the mandatory requirements for all hot work operations (International tanker owner pollution federation Ltd, 2000).

The following sections of this chapter compile valuable information about human errors, the close relationship between human performance levels and human errors, and methods of investigating human errors.

Human Errors

Definition

Kirwan (1994) writes that “human errors are a natural by-product of human behavior” (p. 87).

Another definition states that “human error is the failure of a planned sequence of mental or physical activities” (Reason, 1990. p. 9).

Just 60 years ago, scientists and psychologists hardly ever had considered human errors profoundly, or even systematically.

Today, the most obvious impetus for this interest has been a growing public concern over the terrible cost of human errors. Events such as the Tenerife Runway Collision in 1977, Bhopal Methyl Isocyanate in 1984, the Challenger and Chernobyl in 1986, the King’s Cross tube station fire in 1987, and the Piper Alpha Oil Platform explosion in 1988, are some of the most relevant tragic episodes in human history (Westurm, 1989). In the past, the injurious consequences were usually confined to the immediate vicinity of the disaster. Now the nature and the scale of certain potentially hazardous technologies mean that human errors can have adverse effects upon a whole continent and over several generations (Reason, 1990).

Types of Human Errors

Human error is a very large subject, quite as extensive as that covered by the term of human performance. However, the topic can be categorized by using the many well-documented error types.

Basically, errors can only be meaningfully applied to planned actions that fail during the process of achieving the desired outcome. Consequently, two basic human error types have been identified by Reason (1990):

- *Slips and/or lapses*, where the actions don't go according to the plan, and
- *Mistakes*, where the plan itself is inadequate to achieve its objectives.

Human Errors and Performance Levels

Human errors can be categorized according to the performance levels at which they occur (Rasmussen, 1983). Rasmussen classification wraps the two human error types into three possible basic levels of human performance: 1) skill, 2) rule, and 3) knowledge. (Levels shown in figure 2).

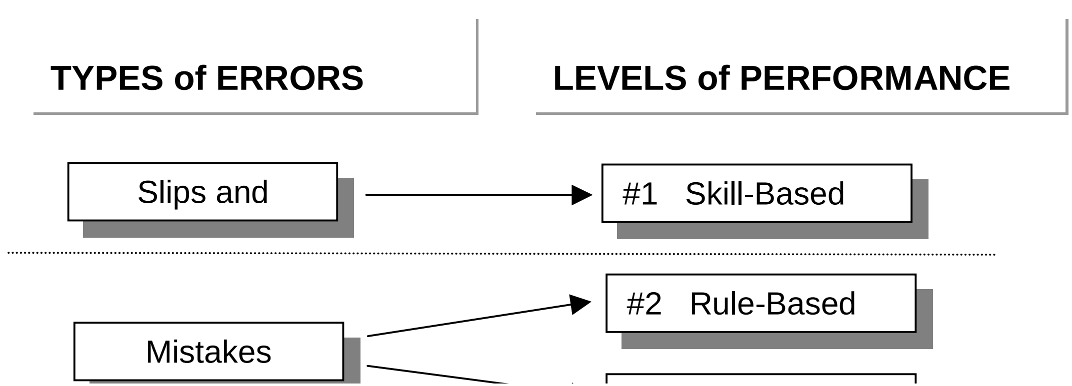


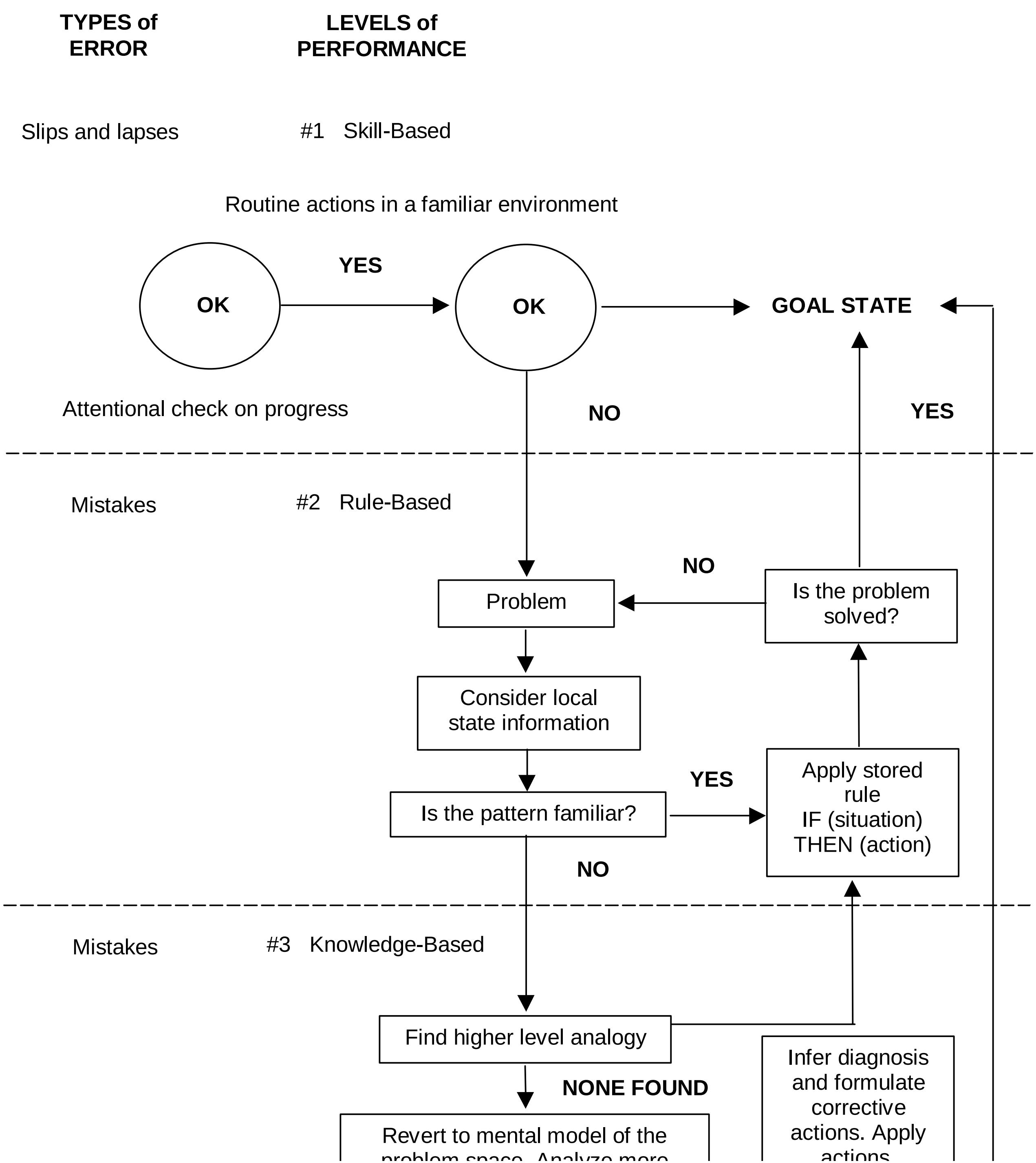
Figure 2.

In order to better relate the connection between human errors and human performance levels, it is important to understand that each level has its own characteristics. According to Rasmussen (1983), the descriptions are:

- *#1 Skill-Based* is the ability to carry out a task. It refers to actions that are automatic and easy due to an acquired skill. They usually happen quickly and without express effort on the part of the actor or person performing the actions. All actions may become automatic, unconscious actions that actors don't need to explicitly "think about" in order to accomplish. In this level, most training is concerned with skill development and its goal is the development of an automatic process. Typically, people need to understand how to execute a set of instructions, but they do not necessarily need to understand the reasons behind them. Through training, they will become proficient enough to perform the actions.

- *#2 Rule- Based* is when the actor needs to fall back upon a set of explicit instructions or rules at his disposal. Rule-based action plays when an automatic skill fails. It involves matching the procedure and the problem currently facing the actor. These rules are typically of the "if X then Y" variety, and based on past experience and explicit instructions. To pursue the training analogy mentioned above, the person examines and interprets the situation, and chooses a rule that can best solve the problem. It is the first step to becoming a conscious actor.
- *#3 Knowledge-Based* is when someone is faced with unfamiliar situations, or where low-level rules aren't appropriate. If rule-based processing doesn't solve the problem, the actor falls on knowledge-based processing. For example, in the situations of establishing an emergency diagnosis, making strategic decisions, and/or solving a problem. Knowledge-based processing is a conscious process. It refers to what we typically think of as ”analytic thought.”

A description of the interaction among the three human performance levels is known as the Generic Error Modeling System (GEMS). The system outlines the dynamic of these three levels. The description is based on information provided by Leape (1994). (figure 3).



Thus, committing an error can be not only related with the actor's level of performance, but also with the interaction among the levels, depending on the consciousness that he or she has during the operation (figure 4).

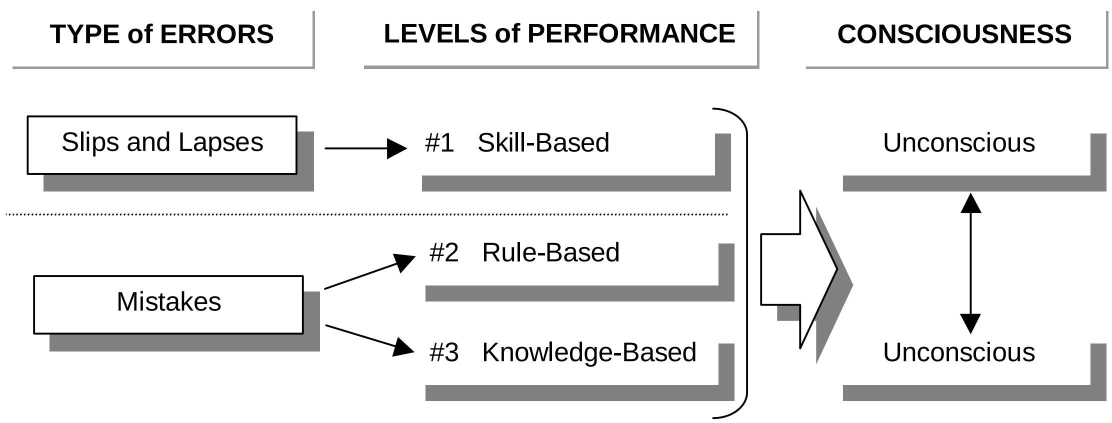


Figure 4.

Human Errors, Performance Levels and Failure Modes

Before beginning any analysis to relate human errors, performance levels, and failure modes, it is important to do some preliminary prep work defining what "failure" means.

It is possible to get 100 different definitions; however, it would make the analysis far too broad. Focusing not on everything, but on the things that are most important to the research, the definitions presented by Kenneth C. Latino at the National Petroleum Refineries Association (NPRA) Maintenance Conference in May 1996 are the most appropriate since this paper is absolutely related to the petroleum industry. Thus, failure is:

- Any loss that interrupts the continuity of production.
- A loss of asset availability.
- The unavailability of equipment.
- A deviation from the status quo.
- Not meeting target expectations.
- Any secondary defect.

Hence, the term "failure mode," for the purpose of this research, is defined as "any loss that interrupts the continuity of production" (Latino, 1996) since it focuses on the primary issues.

Consequently, the failure modes at each of the three performance levels have been studied to identify error types before and/or after incidents occur (Reason, 1990). These modes are described in the following sections:

Table 3. First, the skill-based performance:

Failure Modes		Description
Inattention	**Double-capture slips**	Internal preoccupation / external distractors limit the attention.
	Omissions following interruptions	External distractors limit the attention.
	Reduced intentionality	A delay between the formulation of the tasks to be performed and the execution of the activities; generates failure of prospective memory (lapses).
	Perceptual confusions	When the human recognition schema accepts as a match for the proper object something that looks like it.
	Interference errors	When two current activity plans become entangled, affecting each other.

Overattention	**Omissions**	Omission of some necessary steps.
	Repetitions	When the actor decides that he has not reached the goal where actually he is; then he repeats the actions already done.
	Reversals	An inappropriately timed check can cause an action sequence to double back on itself (reversal).

Table 4. Second, the rule-based performance:

Failure Modes		Description
Misapplication of good rules	**First exceptions**	Individual encounters a significant exception to a general rule after making a mistake.
	Countersigns and nonsigns	Individual establishes a wrong exception to an applicable general rule.
	Informational overload	Abundance of good information limits the adequate problem-solving process.
	Rule strength	Because of its great success in the past, a strong rule is used although its matching conditions (requirements) are less than perfect.

	General Rules	Because general rules are likely to be stronger and applicable to a high level of rule, here is a misapplication of a strong rule in a low-level of rule requiring it.
	Rigidity	The lack of flexibility becomes a barrier to application of a good rule never used before.
Application of bad rules	**Encoding deficiencies**	Matching conditions of a particular situation are misrepresented; an inappropriate rule is then applied.
	Action deficiencies (Wrong rules, Inelegant rules, Inadvisable rules)	The action generates unsuitable, inelegant or inadvisable responses.

Table 5. Third, the knowledge-based performance:

Failure Modes	Description
Selectivity	Mistakes will occur if attention is given to a wrong feature condition.
Workspace limitations	Improper space to perform a task.
Out of sight / Out of mind	Ignoring what is not presented.
Overconfidence	The problem solver is likely to be overconfident in evaluating the correctness of his/her knowledge.

Biased reviewing	The individual is likely to review his/her planned courses of actions at some time prior. Based on this, he/she assumes that all possible factors have been taken account.
Illusory correlation	The problem solver is poor at detecting many types of co-variation.
Problems with casualty	The problem solver tends to underestimate the irregularities of the future because they are guided primarily by the stored recurrences of the past. As consequence, they will plan for fewer contingencies than will actually occur.

Once human errors have been classified into workable categories, it is necessary to explore the most frequent techniques for their effective investigation. This is summarized in the following section.

Methods of Investigating Human Errors

Rizzo, Bagnara, & Visciola (1986) listed the following as the most useful methods of investigating human errors:

- The naturalistic study *identifies and describes naturally occurring phenomena based on its observation.*
- The questionnaire study *documents everyday human conditions and performance through self-reports and questionnaires.*
- The laboratory study *examines mechanisms through the deliberate elicitation of particular error types under controlled laboratory conditions.*
- The simulator study *uses computer-based software to create many of the dynamic features of real-life and complex decision-making tasks.*
- The case study *assesses a single case that can yield valuable information about the circumstances leading up to catastrophic errors.*

To properly identify possible human errors in the XYZ petroleum terminal, two techniques may be applicable. They are: 1) A case study and, 2) a questionnaire. However, a case study is not available; therefore, a questionnaire research tool documenting the combination of efforts presented by Reason, Rasmussen and Leape, previously described in this chapter, will be designed.

In summary, chapter II presents a very extensive literature review regarding aspects such as ship-tankers and oil transportation, tanker's cargo loading/unloading operations, worldwide oil tanker fire/explosion cases, and tanker-terminal operator errors; all of them related to fires and explosions. The above information is used as bases to identify possible operator errors in terminal XYZ. Chapter IV presents the questions and their results.

CHAPTER III

METHODOLOGY

METHODOLOGY: IDENTIFICATION OF HUMAN ERROR AT TERMINAL XYZ

(FIRES/EXPLOSIONS)

Introduction

The purpose of this chapter is to discuss the procedures used to conduct this research for the identification of possible human errors regarding fires/explosions during loading/unloading operations at the XYZ marine petroleum terminal.

Procedure

I. In general, research available information for the better understanding of operations within the tanker/terminal interface.

   1. Marine oil transportation
   2. Tankers' cargo loading/unloading operations
   3. Fires/explosions
   4. Fire protection existing technologies
   5. Fire prevention and risk control guidelines
   6. Major losses because of fires/explosions

II. Research available literature regarding the subject of human errors

   1. Definitions and types.
   2. Human errors and human performance levels

    3. Human performance levels and their failures modes
    4. Methods of investigation

III. Research worldwide experiences regarding back issues

    1. Human errors that have resulted in fires/explosions in the tanker-terminal interface during cargo loading/unloading operations.
    2. Identify possible human errors that can result in fires/explosions during tankers’ cargo loading/unloading operations at the XYZ marine petroleum terminal
    3. Outlines major observations from the field visit to the XYZ terminal

IV. Develop a questionnaire-survey (see appendix I) based on:

    1. Real operational conditions in the terminal
    2. Critical activities that in the past have resulted in fires/explosion because of human errors
    3. Identification of typical human errors focused on human performance levels and their modes of failures
    4. Existing fire prevention and risk control guidelines
    5. The company-operators fire/explosion loss prevention culture.

V. Interpret data-results

1. Survey: observations-questionnaire applied to the XYZ terminal operators
2. Risk control solutions

VI. Conclusions and recommendations

CHAPTER IV

THE STUDY: IDENTIFICATION OF POSSIBLE HUMAN ERRORS BASED

ON

THE SURVEY-QUESTIONNARIE RESULTS

THE STUDY

Introduction

Chapter four is the analysis of collected data gathered from a questionnaire-survey specifically designed to identify “possible human errors” directly related with fires/explosions” among operators at the XYZ petroleum terminal. Twenty questionnaire-surveys were sent to the terminal and ten of them returned with answers. Consequently, a secondary study was needed in order to support and verify the results previously mentioned above. This section summarizes some of the most relevant worldwide human-error experiences that have resulted in fires/explosions during tankers´cargo loading/unloading operations within the petroleum industry. Successful risk control solutions are also presented.

The Questionnaire

A survey-questionnaire was prepared for the qualitative part of this research paper. Its aim is the identification of possible human errors that result in fires/explosions during tankers’ cargo loading/unloading operations at the marine petroleum terminal XYZ. Since the collected information is expected to be confidential, none one was identified by name and/or other type of identification system. Appendix I lists the survey questions themselves.

Ten out of twenty tanker-terminal operators were the sample subjects of the survey conducted by the safety director at the terminal in December 2000.

Because the collected data was limited to 50% of the operator population; a secondary study complements and verifies the results and the analysis generated in this research.

Moreover, the survey-questions were designed based on relevant information collected in the literature review, chapter II. They describe real operational conditions in the terminal and test the most important aspects for the identification of typical human errors and their relation with the company-operators fire/explosion loss prevention culture. In general, three types of human performance levels were identified in chapter II, so their modes of failure are used as an identification tool to prove whether or not the existence of potential human errors that can result in fire/explosion accidents among the tanker-terminal operators subject matter of this study. In other words, questions were formulated following the descriptions that characterize the way every level of human performance fails (see table 6, next page). In addition, the survey focus in critical activities that in the past have resulted in fire/explosion losses because of human errors in marine petroleum terminal around the world.

The final collected results are discussed in the following section, and used in chapter V to outline risk control solutions and recommendations to minimize losses.

Table 6. Identification of possible human error: Questionnaire-Survey

Question	**Description**
1	General question: fires/explosions and errors factors
2	General question: human errors
3	General question: human errors in loading operations
4	General question: human errors in unloading operations
5	General question: past experience dealing with fires/explosions (1)
6	General question: past experience dealing with fires/explosions (2)
7	Skill based performance: failure mode: Inattention 1. Double-capture slips 2. Omissions following interruptions
8	Skill based performance: failure mode: Overattention 3. Omissions
9	Skill based performance: failure mode: Overattention

	4. Omissions
10	Skill based performance: failure mode: Inattention 5. Perceptual confusions
11	Skill based performance: failure mode: Inattention • Perceptual confusions
12	Knowledge based performance: Biased reviewed
13	Knowledge based performance: Biased reviewed
13.1	Knowledge based performance: Workplace limitation
14	Skill based performance: failure mode: Inattention 6. Reduced intentionality
15	Rule based performance: Application of bad rules • Action deficiencies
16	Knowledge based performance: Selectivity
17	Rule based performance: Application of bad rules • Encoding deficiencies
18	Rule based performance: Application of bad rules • Action deficiencies
19	Rule based performance: Misapplication of good information • Informational overload
20	Rule based performance: Misapplication of good information • Informational overload
21	General question: asking suggestions to decrease human errors
22	Knowledge based performance: Out of sight/out of mind
23	Knowledge based performance: Overconfidence
24	General question: asking about relevant training

Legend

- General questions
- Skill based questions
- Rule based questions
- Knowledge based questions

Questionnaire Results

The following questions were asked and the results are reported below:

XYZ Terminal Operators Information (participants)

Table 7, Operators' job position and age

Title	Quantity / percentage
Terminal operator (day shift)	5 / 50%
Terminal operator (night shift)	5 / 50%
Age	**Quantity / percentage**
25-30	6 / 60%
30-35	3 / 30%
35-40	1 / 10%

Note: terminal operators are in charge of loading/unloading operations and maintenance activities. They are set in-group of 5 operators, and one of them is the team leader. There are 4 groups working in two different shifts. Shift #1 is from 7am to 7pm, and shift #2 is from 7pm to 7am. The teams work continually during 4 days. Then, the teams that have worked in the day shift must switch to the night shift after 4 off days. Basically, It happens every 8 days.

Table 8, Operators' experience and educational background

Years of experience	Quantity / percentage
< 3 months	1 / 10%
< 1 yr	2 / 20%
< 3 yrs	5 / 50%
< 5 yrs	1 / 10%
< 10 yrs	1 / 10%
> 10 yrs	0 / 0%
Educational background	**Quantity / percentage**
Mechanics	4 / 40%
Marine	2 / 20%
Certified professional welder	1 / 10%
Technical college (no completed)	3 / 30%

Note: data collected shows that 70% of the operators have a work experience longer than 3 years. In addition, seven out of ten operators, have an educational background related to typical operations at the terminal. Only three operators have not completed studies in the technical college.

Table 9, Terminal-working conditions (noise, temperature, illumination):

Noisy	
Yes	20%

No	80%
Temperature	
Hot	100%
Cold	0%
Illumination	
Poor	66.6%
Good	33.3%

Note: Terminal-working conditions such as temperature and illumination seem to be the mayor areas for improvement

1).- Based on your experience dealing with fires or explosions in the terminal, what is the probability that a fire or explosion can be attributed to the following factors?: (Check all the possible answers)

Answers:

1.- Human errors

	Low (1)	(2)	(3)	(4)	High (5)
Answer	0%	0%	10%	70%	20%

2.- Company organizational factors

	Low (1)	(2)	(3)	(4)	High (5)
Answer	90%	10%	0%	0%	0%

3.- Environmental factors (weather conditions)

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

4.- Hardware system

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

5.- Pipeline system

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

6.- Pump system

	Low (1)	(2)	(3)	(4)	High (5)
Answer	70%	30%	0%	0%	0%

7.- Operational procedures

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

8.- Inert gas system

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

9.- Venting system

	Low (1)	(2)	(3)	(4)	High (5)
Answer	90%	10%	0%	0%	0%

10.- Valve failure

	Low (1)	(2)	(3)	(4)	High (5)
Answer	90%	10%	0%	0%	0%

11.- Static electricity as source of ignition

	Low (1)	(2)	(3)	(4)	High (5)
Answer	10%	70%	20%	0%	0%

Results collected in question #1 prove that human error is the number one reason of fire/explosion accidental losses in the terminal followed by the presence of static electricity as source of ignition.

2).- If human error is one of your answers in the previous question, what is the probability that it is due to:

Answers

1.- Ignorance

	Low (1)	(2)	(3)	(4)	High (5)

Answer	10%	10%	80%	0%	0%

2.- Communication

	Low (1)	(2)	(3)	(4)	High (5)
Answer	10%	0%	10%	80%	0%

3.- Preparation

	Low (1)	(2)	(3)	(4)	High (5)
Answer	80%	10%	10%	0%	0%

4.- Judgment

	Low (1)	(2)	(3)	(4)	High (5)
Answer	90%	10%	0%	0%	0%

5.- Training

	Low (1)	(2)	(3)	(4)	High (5)
Answer	50%	50%	0%	0%	0%

6.- Violations

	Low (1)	(2)	(3)	(4)	High (5)
Answer	0%	0%	0%	10%	90%

Violations of company rules and standards, lack of communication and operator's ignorance are the most relevant factors that put in risk the operations in the terminal-tanker interface.

3).- Based on your experience, assess in term of fire/explosion accident caused by human errors the level of risk for each of the steps in a typical loading operation? Answers

1.- Vessel arrival

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

2.- Hook up

	Low (1)	(2)	(3)	(4)	High (5)
Answer	0%	0%	90%	10%	0%

3.- Start up

	Low (1)	(2)	(3)	(4)	High (5)
Answer	0%	10%	90%	0%	0%

4.- Steady - rate

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

5.- Topping off

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

6.- Disconnect

	Low (1)	(2)	(3)	(4)	High (5)
Answer	0%	90%	10%	0%	0%

7.- Departure

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

Operations such as hook-up, start-up, and disconnect seem to be the most critical in term of fire/explosion prevention. Specific measures must be taken to minimize potential losses.

4).- Based on your experience, assess in term of fire/explosion accident caused by human errors the level of risk for each of the steps in a typical unloading operation? Answers

1.- Vessel arrival

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

2.- Hook up

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

3.- Start up

	Low (1)	(2)	(3)	(4)	High (5)
Answer	0%	0%	10%	90%	0%

4.- Steady - rate

	Low (1)	(2)	(3)	(4)	High (5)
Answer	0%	50%	50%	0%	0%

5.- Topping off

	Low (1)	(2)	(3)	(4)	High (5)
Answer	0%	0%	0%	0%	0%

6.- Disconnect

	Low (1)	(2)	(3)	(4)	High (5)
Answer	0%	0%	50%	50%	0%

7.- Departure

	Low (1)	(2)	(3)	(4)	High (5)
Answer	100%	0%	0%	0%	0%

Data collected shows similar trends between loading operations and unloading operations. Again, activities such as start-up, and disconnect, affect the risk-free conditions while tanker's cargoes is unloaded.

5).- Have you ever dealt with fires or explosions during loading or unloading operations in the terminal?

	Never (1)	(2)	(3)	(4)	Always (5)
Answers	60%	10%	20%	10%	0%

6).- If yes, mention one case that you remember because of its significance

No answers. The question was not used since the terminal supervisor did not give the approval for its application.

7).- The following is a hypothetic work situation at the terminal.

You just have a limited period of time to complete maintenance work on pump #1 before your shift ends in the afternoon. This pump handles an important flow volume from the tanker to the terminal storage area. Suddenly, your direct supervisor calls you by radio. He asks you to complete the remaining tasks before the next tanker hooks up to the terminal piping system. You just remember your doctor appointment scheduled after work. The following are some of the possible remaining tanks to complete:

TASKS	**Time**
1.- Pick up pump spare parts at the terminal warehouse	15 min
2.- welding work	15 min
3.- Get approval for hot work	20 min
4.- Assembling pump parts	30 min
5.- Pump post-testing	20 min
6.- Call your doctor to move the appointment 2 hours later	Unknown

What plan would you most likely follow to take care of your responsibilities and be on time with the operation' schedule? (Check one)

Answers ("C" is correct answer)

	Quantity	Percentage
(A) 1+2+3+4+5+6	4	40%
(B) 1+6+2+3+4+5	3	30%
(C) 1+6+3+2+4+5	2	30%

Question #7 was designed to measure external/internal distractors (ex. In this case a radio call, and a doctor appointment), limiting operator's attention while performing their job. The results prove that 70% mistook providing the correct answer.

8).- Do you remember any time that, while performing your job, you have omitted or forgotten a step or procedure knowing perfectly that it was one of the requirement of your task?

Answers

	Quantity	Percentage
Yes	3	30%
No	7	70%

9).- If yes, how often

	Never (1)	(2)	(3)	(4)	Always (5)
Answers	70%	20%	10%	0%	0%

Results from questions #8 and #9 indicate that operators rarely omit or forget required procedures. However, 30% admitted no to strictly follow rules.

10).- Do you consider that your job is highly routinized on the same set of actions every day?

Answers

	Quantity	Percentage
Yes	7	70%

No	3	30%

Data collected displays that 70% of the answers converge in the same opinions: “operator’s job is highly routinized.” Moreover, question 11 below indicates that only 57% of the answers assure that operators wouldn’t use wrongly a valve while performing the everyday work.

11).- If yes, how often have you wrongly opened or closed a valve that looks similar to the right one?

	Never (1)	(2)	(3)	(4)	Always (5)
Answers	57%	21.5%	21.5%	0%	0%

12).- An inspection using a safety checklist is designed to review safety conditions in general. Additional observations can enforce the effectiveness of the inspection. How often do you limit the inspection just to the items on the checklist? (Check one)

	Never (1)	(2)	(3)	(4)	Always (5)
Answers	0%	10%	20%	20%	50%

13).- In your opinion, does the checklist cover all the safety aspects involved in the operations?

Answer

	Quantity	Percentage
Yes	6	60%

No	3	30%
I don’t know	1	10%

Questions #12 and #13 attempt to evaluate how effective the existing checklist system covers safety aspects involved in the operations while loading/unloading tanker’s cargoes at the terminal. Results from question #12 indicate that all operators limit their inspections just to the items on the checklist. Nevertheless, question #13 indicates that only 30% believe that existing checklist doesn’t cover every possible hazardous condition.

“Whenever volatile petroleum products are being loaded, all doors, portholes and openings leading from the main deck to accommodation or machinery spaces are required to be kept shut; although modern tank vessels have been modified for vapor control operations”. The above statement is:

(True is the correct answer).

Answers (percentage)

☐ True (70%) ☐ False (30%)

The aim of question #13 is to evaluate whether or not operators know the rules. 70% correctly answered the question.

14).- A tanker is already hooked up to the loading arm, and you have been told to fill one of the cargo tanks on board with inert gas before the terminal oil-pumping system starts the transfer of product. Suddenly, at the middle of the inert gas setting process, someone calls you by radio regarding information about the status of the operation. How often does the below statement become true in your everyday job?

"A interruption, for example a radio call, will likely affect the continuous performance of the required tasks and their logical sequence".

Answers

	Never (1)	(2)	(3)	(4)	Always (5)
Answers	0%	70%	30%	0%	0%

This question measures the probability that an external agent, such as a radio call, can modify or affect the logical sequence of the operation. All answers converge upon the same opinion. External factors may affect performance's outputs.

15).- Are fire extinguishers required to be around the manifold area during loading/unloading operations? (The correct answer is "yes")

Answers

	Quantity	Percentage
Yes	7	70%
No	3	30%

The aim of question #15 is to evaluate whether or not operators know the rules. 70% correctly answered the question.

16).- What is the required oxygen concentration level in an inerted cargo tank?

Answers ("Below 8% is the correct answer")

	Above 21%		About 21%		Just 18%		Below 8%	
Answers	10%		10%		40%		40%	

The aim of question #16 is to evaluate whether or not operators know the rules. Only 40% correctly answered the question ("Below 8%").

17).- List 4 typical required conditions to carry out a hot work in hazardous areas

According to the International Safety Guide for Oil Tankers and Terminals (1988), a complete answer for this question would be:

- Fire fighting equipment must be ready for immediate use.
- Gas free certificate must be issued.
- Portable continuous gas detector must keep monitoring the atmosphere in the working area.
- Work area must be clear of any combustible material

The collected answers were:

- 100% answered "fire extinguisher"
- 100% answered "gas free certificate"
- 40% answered "gas detector for monitoring"
- No one mentioned that "work area must be clear of any combustible material"

Operators didn't prove to know the expectations and requirements to carry out hot work. The use of gas detector for monitoring the atmosphere while performing a hot work is critical among this group of operators.

18).- Did you know that gaskets and seals in good conditions at the flange face in the tanker manifold are important to prevent fires during loading/unloading operations?

Answers (percentage)

☐ Yes (70%) ☐ No (30%)

30% of the operator's answers didn't prove knowledge about the importance of gaskets and seals in good conditions at the flange face in the tanker manifold (tanker-terminal connections). Since results from question #3 tell that operations such as hook-up, start-up, and disconnect seem to be the most critical in term of fire/explosion precautionary actions, specific measures must be taken to minimize

leakage, spill, and/or the presence of explosive atmospheres in the tanker-terminal surroundings.

19).- In your opinion, do available information, standards, and company rules provide you with enough information to prevent fires/explosions during loading/unloading operations?

Answers (percentage)

☐ Yes (100%) ☐ No (0%)

20).- In your opinion, does the abundance of information, standards, and company rules limit you in the adequate solving problem process?

Answers (percentage)

☐ Yes (10%) ☐ No (90%)

90% says that abundance of information doesn't limit the effectiveness of solving problem process. Standards and rules seem to be simple and easy to use.

21).- If any, what changes would you suggest to decrease the chance of fire/explosion due to human errors during loading/unloading operations in the terminal?

The answers were:

- The company should provide more training sessions during the year (For example: one every three months).
- Have fire/explosion demonstrations.
- Review existing fire prevention procedures to make them easier for the daily usage.
- Fire prevention training to review the most critical operations at the terminal.
- Ensure perfect seal in pipes/hoses connections.
- Use the required tools (no spark producing source)
- Require better housekeeping onboard tankers.
- Plan ahead activities at the terminal. Get their approvals.

22).- List situations that require maintenance of cargo tanks in non flammable conditions

According to the International Safety Guide for Oil Tankers and Terminals (1988), a complete answer for this question would be:

- Empty cargo tanks
- Tanks while cargo is being unloaded
- Tanks while deballasting
- Tanks during crude oil washing and cleaning

The collected answers were:

- 40% answered “empty cargo tanks”
- 100% answered “Tanks while cargo is being unloaded”
- 30% answered “Tanks while deballasting”
- 40% answered “Tanks during crude oil washing and cleaning”

23).- How confident do you feel about the correctness of your answer in the previous question? (Check one below)

	Low (1)	(2)	(3)	(4)	High (5)
Answers	10%	60%	30%	0%	0%

From the collected data in questions # 22, and #23, operators should be trained more about requirements for maintenance of cargo tanks in non-flammable conditions. These results prove deficiencies in the operations and lack of knowledge.

24).- Could you list some relevant training sessions in which you have participated specifically focused on fire/explosion prevention?

Answers	
1	LP-gas fires/explosions
2	Pipes connection failed-fires
3	Hot work – welding and cutting operations (fire prevention)
4	Fire/explosion protection and emergency plan
5	Heat detectors
6	Competency is key to responders' performance (Fires in petroleum terminals)
7	Use of multigas detectors
8	Training programs' effectiveness questioned (Storage facility fire/ tank farm fire)
9	Fuel line leak vapors and fire/explosions onboard tankers
10	Spilled gasoline vapors ignited by pilot light
11	Natural gas fires
12	Fire/explosions in high pressure line leaks
13	LP-gas fires and explosions
14	Natural gas fires and explosions
15	Natural disaster emergency response
16	NFPA fire inspector certification program

Summary

The past pages have displayed the questionnaire data, of which is explained initially, during its presentation. The following section analyzes the results, grouping the questions in three categories: skill based, rule based, and knowledge based. Finally, results generated are also compared against world industry errors.

Questionnaire Analysis

Table 10. **Skill Based Questions** (Results)

Question 7

Fault	70%	No fault	30%

Question 8

Fault	30%	No fault	70%

Question 9 (frequency of failure for question 8)

	Never (1)	(2)	(3)	(4)	Always (5)
Answers	70%	20%	10%	0%	0%

Question 10
70% said that his work is highly routinized. 30% said : "NO"

Question 11

Fault	43%	No fault	57%

Note: Frequency of failure (question 11)

	Never (1)	(2)	(3)	(4)	Always (5)
Answers	57%	21.5%	21.5%	0%	0%

Question 14

Fault	100%	No fault	0%

Note: Frequency of failure (question 14)

	Never (1)	(2)	(3)	(4)	Always (5)
Answers	0%	70%	30%	0%	0%

(See appendix I to refer question listed in this table)

Data collected indicates that external distractors (ex. a radio call) and internal preoccupations (ex. a doctor appointment) can highly limit operators' attention (question 7). Only 30% of answers were right in question 7. Basically, operators mistook planning the sequence of tasks well; hot permit approval must happen before any welding operation takes place. In contrast, results from question 8 and 9 tell that operators would rarely omit or forget procedures. Moreover, 70% said that his work is highly routinized. Almost half of them, 43%, communicated that they might wrongly open or close a valve. Finally, question 14 supports results from question 7. Interruptions can affect the continuous logical sequence of operator's work. Overall, special attention should be paid to operators' highly routinized work. External/internal distractors may be root errors in the operations.

Table 11. **Rule Based Questions** (Results)

Question 15

Fault	30%	No fault	70%

Question 17

The collected answers were:

- 100% answered "fire extinguisher"
- 100% answered "gas free certificate"
- 40% answered "gas detector for monitoring"
- No one mentioned that "work area must be clear of any combustible material"

Question 18

Fault	30%	No fault	70%

Question 19

Rule based performance: Misapplication of good information.

- Informational overload

Answer: there is enough information such as standards and rules, to prevent fires/explosions during loading/unloading operations at the terminal.

Question 20

10% said that existing abundance of information limit the adequate solving problem process. 90% said: "NO

(See appendix I to refer question listed in this table)

Data collected indicates that 70% of operators recognized the requirement for having fire extinguishers around tankers' manifold areas during loading/unloading operations. However, they partially know the required conditions to carry out hot work. Results from question 17 show that around half of operators would use gas detectors to keep monitoring atmosphere quality at the work area. Nevertheless, none one mentioned the importance of having good housekeeping to free work areas from combustible materials before performing any hot work. In addition, operators expressed that the company provides enough information such as standards and rules, to prevent fires/explosions during loading/unloading operations at the terminal; however 10% said that existing abundance of information limit the adequate problem solving process. Overall, special attention should be paid to existing training for hot-work permit conformance since operator's answers didn't prove knowledge of the rule and its requirements.

Table 12. **Knowledge Based Questions**

Question 12

Fault	100%	No fault	0%

Note: Frequency of failure (question 12)

	Never (1)	(2)	(3)	(4)	Always (5)
Answers	0%	10%	20%	20%	50%

Question 13
60% said that checklists cover all the safety aspects involved in the operations. 40% did not agree.

Question 13.1

Fault	30%	No fault	70%

Question 16

Fault	60%	No fault	40%

Question 22
The collected answers were:

- 40% answered “empty cargo tanks”
- 100% answered “Tanks while cargo is being unloaded”
- 30% answered “Tanks while deballasting”
- 40% answered “Tanks during crude oil washing and cleaning”

Question 23
Complements question 22.
This measures correctness versus “confidence”

	Low (1)	(2)	(3)	(4)	High (5)
Answers	10%	60%	30%	0%	0%

(See appendix I to refer question listed in this table)

Data collected indicates that 100% of operators assume that all possible factors have been taken into account when limiting inspections just to the items on the checklists. Nevertheless, 30% said that checklists don’t cover all the safety aspects involved in the operations (question 13).

Feedback from question 16 is also very critical. Six out of 10 operators answered wrong. They didn't know the required oxygen concentration, 8%, to keep tankers and terminals safe against fires. Moreover, about 30% to 40% of operators answered correctly question 22 regarding groups of situations that require maintenance of cargo tanks in non-flammable conditions. Even though, everyone knew that unloading operations require assuring non-flammable atmosphere. Results from question 23, tell operators don't feel overconfident. They ranked their knowledge based on answers provided to question 22. All operators believed in their expertise, yet admitted no to provide a complete answer.

Worldwide Human-Error Experiences

The world industry experience among oil-terminal companies verifies the results gathered from the questionnaire-survey since potential issues detected among operators at the XYZ terminal seem to be the same and follow similar trends. Aspects such as inadequate safety inspections, jobs highly routinized, deficient hot work permit systems, and lack of knowledge about fire/explosion precautionary actions; still need to be considered as high priority by companies

Table 13, page 86, presents alternative solutions that have been developed and implemented world-wide by oil-terminal companies to effectively control frequent problems regarding operators performance issues. This summarizes valuable information gathered in the literature review.

Table 13. Worldwide Human-Errors and Fire/Explosion Experiences

<table>
<tr><th><u>Identified issues</u>
(Tanker-terminal operator errors)</th><th><u>Identified corrective actions</u>
(Some successful risk control solution)</th></tr>
<tr><td rowspan="6">1. Usage of cigarette lighters in no smoking areas.

2. Preparedness, and lack of experience to set adequately the inert gas system for flammable vapor control.

3. Operators no following appropriated company procedures and fire safety precautions

4. Operator lack of judgment on assessing good condition of gaskets and/or seals at the interface tanker manifold/terminal piping system. Consequently:

• Ignition generated by friction in the flanged joint interface of tanker manifold/terminal piping system when hook up operation.

• Fire fed by flammable vapors leakage.

5. Tanker/terminal operator lack of communication.

6. Terminal operators no familiar enough with tanker instrumentation, piping, and tanker layout.

7. Operators non-compliance with existing risk control rules regarding “hot work permits”

8. Fire set off by operators holding no-approved solvents onboard tankers.

9. Terminal inspectors lack assessing safety conditions onboard tankers (tanker inspections).</td><td><u>Process hazard analysis</u>: a core component of the process safety management procedure implemented in refineries, terminals and storage facilities belonging to Citgo Petroleum & Co. This includes a human factors analysis of working conditions that may adversely impact the safety performance of CITGO personnel and potentially produce accident event sequences, especially during startup, maintenance operations, and upset/emergency conditions</td></tr>
<tr><td><u>Training</u>: operators trained on: Process hazard analysis, effective communication of procedures, certification programs for tanker’s inspections, and fire/explosion precaution practices.</td></tr>
<tr><td><u>Communication</u>: a stronger terminal policy requirement for the provision of improved signing systems on board clients’ barges and tankers (Kurnell Marine Terminal, 2000).</td></tr>
<tr><td><u>Behavior based safety</u>: program focused almost entirely on modifying the behavior of terminal operators. Listing critical worker behavior, monitoring periodically operator’s work activities, training operators to perform correctly, and encouraging operators to care about each other safety, Chevron Co. has built safe work practices as a matter of habit at its L.A and N.J terminal facilities.</td></tr>
<tr><td><u>Tanker/barge inspection systems</u>: the Ship Inspection Report Programme (SIRE) and The Inspection Report Data-Sharing (IRDS) scheme were developed in the 1990s. With these systems, which are worldwide, tanker/barge inspections are carried out and reports issued in a consistent format. Thus, terminal operator’s crews can get prepared previous to the loading/unloading operations on a specific vessel.</td></tr>
<tr><td><u>Hot work permits</u>: the European Petroleum Loss Prevention Council (UK) requires frequent training for all North Sea company staff members who perform hot work. Additionally, a person not performing the actual hot work maintains a continuous fire watch during the procedure as well as 1 hour after the work has been finished. Companies have implemented more accountability on equipment and permits.</td></tr>
</table>

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Chapter V

Conclusions and Recommendations

Introduction

The purpose of the study was to identify possible human errors that can result in fires/explosions during tankers' cargo loading/unloading operations at the XYZ marine petroleum terminal. The objectives of this study were to: (1) Identify possible types of human errors that can result in fires/explosions during tankers' cargo loading/unloading operations; (2) Provide risk control solutions to the identified problems.

Conclusions

Human error types identified among operators at the XYZ terminal are:

- Skill based performance level (inattention):

  Operators defined their job as a highly routinized condition. This situation could be cause for root errors since human recognition schema can accept as a match for the proper object something that looks like it.

  External distractors/ internal preoccupations can limit operators' attention

- Rule based performance level (encoding deficiencies):

  Operators didn't completely know the rule's requirements to carry out hot-work and to compliance with the permit. This situation could cause root errors since matching conditions of a particular situation are misrepresented. Then an inappropriate rule is applied.

- Knowledge based performance level (Biased reviewing)

  100% of operators limited their inspections just to items on the checklist, although 30% said that these lists don't cover all the safety aspects involved in the operation. This situation could cause root errors since the operator is likely to assume that all possible factors have been taken into account.

- Knowledge based performance level (Selectivity)

  Mistakes will occur if attention is given to a wrong feature condition. When providing a list of possible values, 60% operators wrongly answered the oxygen concentration required to keep safe tankers and terminals against fires/explosions

- Knowledge based performance level (Out of sight/out of mind)

  Ignoring what is not present. 60% - 70% of operators incompletely answered group of situations that require maintenance of cargo tanks in non-flammable conditions. This could cause root errors since operators ignore part of the group of situations required.

The goal of introducing risk controls for the identified behavioral errors is presented in table 14

Table 14. Risk Control Solutions to identified problems:

Identified issue	**Risk control solution**
Operators' job as a highly routinized condition	• Plan ahead activities and follow them using a checklist system. • Rotate operators to different shift and job positions.
External distractors/ internal preoccupations limit operators' attention	• Limit the use of radios. • Operators should always follow the activities checklist.
Operators are lacking about requirements to carry out hot-work	• Provide more training to educate operators about standard operational procedures • Implement more accountability on equipment and permits.
Operators limit inspections just to items on the checklist. These lists don't always cover all the safety aspects involved in the operations	• XYZ terminal could become member of the OCIMF report data system for tankers/barges inspections. • Implementation of process hazard analysis (P.H.A) for activities that have the potential to generate fires/explosions

Table 14. Risk Control Solutions to identified problems (continue):

Identified issue	**Risk control solution**

Operators lacking knowledge about oxygen concentrations required to keep tankers and terminals safe against fires/explosions	• Provide more training to educate operators about standard operational procedures
Ignoring part of the group of situations required to maintain cargo tanks in non-flammable conditions	• Enforce operator's knowledge on fire/explosion safety rules

Recommendations

The following are recommendations for actions by terminal XYZ:

1.- Terminal XYZ should start implementation of risk controls presented above as soon as possible since conformance costs are much less than potential loss from fires/explosions.

2.- Terminal XYZ must focus training on specific issues listed in the conclusions.

3.- In order to be more appropriate, future study is recommended to involving a larger number of terminal operators.

APPENDIX I

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