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Liquefied Natural Gas (LNG) Safe Loading and Unloading Model in Port Operation

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ABSTRACT

This project presents the study of the safe procedures of LNG loading and unloading operation in port. The purpose of this study is to maintain the safety record of LNG operation for this roughly forty years. The study is carried out by performing 'one to one interview' with the port's safety officer. Then, the collected data from the personal interview is analyzed using Hazard Identification (HAZID) approach. The detail procedures, technical data, and explanation from port's safety as an expertise in LNG handling field could be needed to determine the potential improvement that could trigger the idea to develop a generic safety model which is refined and improved of the existent holistic model that being reviewed in this study. The model developed in this study is to be applied onto either loading or unloading LNG terminal all over the world. This model is expected to meet the aim of minimizing the unsafe act and near miss which is always be the initiation point of harmful incident and accident. Model which has been developed is an improved and refined version of a generic safety model. The model developed describes the integration of technologies within the system of working competency which also reconsidering the individual performance. In the same time, it aimed to reduce the probabilities of the crews or operators to engage with unsafe act which always introduce the consequence of near miss, which is to be minimized in this research. The model developed in this study is called 'H-T-D' safety model, which stand for human factor, technical handling, and design element.

KEY WORDS: *LNG Loading and Unloading Operation; Safety Socio-Technical Model; Human; Technical Operation; Facilities Design*.

1.0 INTRODUCTION

LNG is liquefied natural gas (predominantly methane, CH4), produced from liquefaction of natural gas. It is sharply clear, odorless, colorless, nontoxic, non-corrosive, and hazardous.

1.1 Background of study

LNG is liquefied natural gas (predominantly methane, CH4), produced from liquefaction of natural gas. It is sharply clear, odorless, colorless, nontoxic, non-corrosive, and hazardous. It is comprises mainly methane, but has a percentage of constituents such as ethane, butane, and propane together with nitrogen. It is produced from either gas wells or oil wells that have been converted temporarily to liquid form for ease of storage and transport.

Natural gas is cooled and liquefied at cryogenic temperatures at approximately -162˚C and at close to atmospheric pressure, 25kPa. In this form, the LNG is ready for storage and shipping. In liquefied form, the volume of LNG is 600 times less than the same amount of natural gas at room temperatures.

Thus, LNG shipping is an economical way of transporting large quantities of natural gas over long distances. The LNG can be transported by specially designed cryogenic sea vessels called LNG carriers, cryogenic road tankers. The flammability range denotes the range of concentrations of LNG vapor in air that forms a flammable mixture that can be ignited and burn. For methane, the dominant component of LNG vapor, the flammability range is approximately between 5 and 15 percent by volume. When the vapor concentration exceeds this upper flammability limit, it cannot burn because too little oxygen is present and when concentration is below the lower flammability limit, it cannot burn because too little methane is present. Its dangers include combustibility, the freezing of its lower temperatures, and asphyxia from its vapors.

Purposes of this study is to study the major parameters of LNG ship safe loading and unloading in port operation as follow;-

i. Technical handling and operation of loading, transferring, exporting, and unloading operation of LNG
ii. Chronology of accidents that included in LNG operation
iii. Safety rules and regulations in LNG terminal, LNG tanker, and its facilities
iv. Review the failures experienced by LNG industries (import and export terminal, and LNG carrier)
v. Factors that contribute to LNG accidents
vi. General consequences or impacts of LNG accidents

1.2 Problem Statement

The LNG's industry highest priority has always been safety and security, which is reflected in the industry's enviable safety record. LNG transport and operation of LNG facilities have had over 60 years of development. During these times almost all accidents involving LNG resulting in explosion, confinement and leakage of LNG vapors have had a large impact towards environment, human life, and LNG facility.

The possibility of an incident leading to the total loss of containment involving an LNG tanker or a large LNG terminal must be considered in coexistence with the potential hazards such event pose and their impact on human's health, fatality, greenhouse gas effect, land and sea effect, and LNG facilities of industry.

From an overview, we can figure out roughly many factors that leading to failures of LNG loading and unloading in port operation, on top of them such as LNG facilities design selection, lacking in technical operation of LNG, human errors, and crew competency.

1.3 Objectives of Study

The objectives of this is to generate a generic model (general) of LNG ship safe loading and unloading in port operation and to identify high risk areas in LNG facilities (LNG ship and LNG terminal) during loading and unloading operation.

1.4 Scopes of Study

Scope of this study will be focused on proposing a general model of LNG loading and unloading operation for minimizing the risks and act as an alarming steps. For that, researcher will study deeply about the main parameters that need to be highly considered during LNG loading and unloading in port operation that consists;

i. Technical handling during LNG operation
ii. Safety guide and regulation of LNG industry
iii. Specially and well-trained of LNG terminal staffs and LNG crews

Investigation of factors of LNG accidents will become one of main scopes in this study.

Hence, researcher will identify high risk areas LNG during and unloading operation. Resulting from LNG incidents, researcher will estimate the high probability consequences towards environment, human life, and LNG industry.

At the end of that, as a result of study, researcher will propose solving method (generic model) to overcome and minimizing the risks during LNG loading and unloading operation conducted.

2.0 LITERATURE REVIEW

The production of Liquefied Natural Gas (LNG) has increased due to the increasing worldwide demand for that fuel (Dennis Wilfredo et al,July 2012).

2.1 Introduction

The production of Liquified Natural Gas (LNG) has increased due to the increasing worldwide demand for that fuel (Dennis Wilfredo et al,July 2012). That demand implies in the necessity of transportation of large amount of the product between the production areas and the consumer countries, implying in the increase in the operations with LNG carriers.

Although the safety standards for design, construction and operation of this kind of ship are very stringent, there are registers about minor accidents with those ships. The probability of accidents is greater during cargo loading and unloading operations due to the great number of systems and pieces of equipment involved in those operations.

2.1.1 Properties of Liquefied Natural Gas (LNG)

The LNG is a cryogenic fluid that is transported and stored at temperatures as low as -162°C. The main component of LNG is methane in a quantity between 85% and 95% but other light hydrocarbons are present in LNG such as ethane, propane, butane and nitrogen. The LNG is about 1/600th the volume of natural gas at standard temperature and pressure making feasible its transportation in LNG carriers (Sheila Goucher, 2013).

2.1.2 Type of LNG Carriers

There are two types of LNG tanker that mostly used in LNG industries, which is known as spherical type and membrane type. The difference between them is their shape of containment system.

a. Moss / Spherical type

Based on the "Risk Assessment Survey" by K.S.Wang in October 2010, almost 40 percent the LNG carriers in the world are of the spherical type.

Figure 1: Moss or spherical LNG carrier

Roughly, the life span of this type are about 40 years or more, and its range of tank sizes are about 125,000 m3 up to 145,000 m3 (Sheila Goucher, 2013). To construct this type of LNG carrier, its construction is about 2 years up to 2.5 years from signing of contractor.

b. Membrane type
Usually, standard sizes for this type are about 125,000 m3 up to 150,000 m3. Almost 60 percent the LNG carriers in the world are of this membrane type (K.S Wang, October 2010).


Figure 2: Membrane type LNG carrier

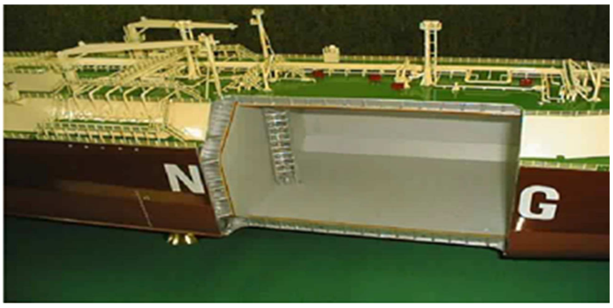
Figure 3: Membrane type LNG containment system

As for the membrane design, there are multiple barriers between the external environment and the LNG cargo. The dual membrane design consists of thin stainless steel or high nickel steel membranes 0.7 to 1.2mm thick which are capable of containing the hydrostatic load of 25,000m3 of LNG but rely on the vessel to provide the structural support (Pitblado et al, 2004). The tanks are maintained at very low positive pressure and the boil-off gas is collected and provides the ship's power. Internal pumps are used to export the LNG.

2.1.3 Comparison between Moss and Membrane containment system
Both of them have their own advantages and disadvantages, which is including aspects such as capacity, tank filling restriction, design of internal structure and construction cost.

Table 1: Comparison between Moss and Membrane containment system

Moss design	Membrane design
Long experience from LNG carrier	Long experience from LNG carrier
Not affected by sloshing	Affected by sloshing
No filling restriction	Have filling restriction
No internal stiffeners	Have internal stiffeners
Smaller loading capacity	Bigger loading capacity
Longer time in dry dock	Shorter time in dry dock
Higher construction cost	Primary membrane is to hold cargos and secondary membrane is to prevent leakage

2.2 LNG Loading and Unloading in Port Operation
LNG loading and unloading in port operation is very important in order to collect, transport and deliver, and store LNG before distributing it to end-use market.

2.2.1 LNG supply chain
In earliest stage, the LNGC will loading the gas from the supply well then deliver it to the processing LNG terminal. There, they will processes and liquefy the gas into LNG, then it will be stored in LNG storage tanks. After that, the LNG will be loaded into another LNGC to transport and unloading it at regasification LNG terminal for the purposes of end-use market.

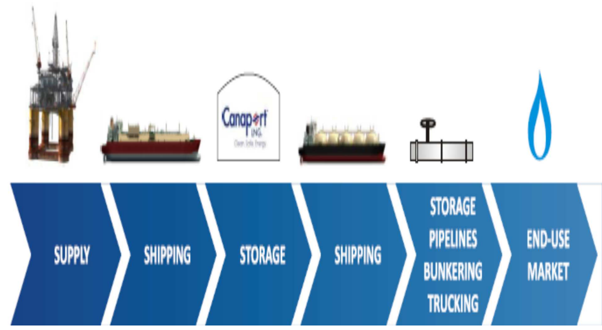

Figure 5: LNG supply chain from production until the end-user (Sheila Goucher, July 2013)

2.2.1.1 Processing and Liquefaction LNG Terminal
At this terminal, they will processes and liquefy supplied Gasified Natural Gas (GNG) to Liquefied Natural Gas (LNG). Then, LNG will be stored in LNG storage tanks for loading into LNG carriers. LNG is stored and will be transported by LNG carrier, which its temperature maintained at -162˚C.

Figure 6: Canaport Liquefaction LNG terminal, Canada (Sheila Goucher, 2013)

i.

2.2.2.2 Receiving and Regasification LNG terminal

Once the LNG carrier arrive its destination, the LNG will be unloaded and stored in insulated tanks built specially to hold their super cold temperatures. When there is demand, the LNG will be heated to turn it back into gas in ratio 1:600 (Will Horter, 2007). It is supplied to various need such as steel mills, industries, power stations, and homes.

Figure 7: Canaport Receiving / Import Terminal, Canada

2.2.3 LNG Loading and Unloading Process at LNG Terminal

The loading and unloading operations are developed when the LNG carrier is anchored at the liquefaction or regasification terminal and when there are environmental conditions such as calm water and low wind speed to have a low risk level. LNG loading and unloading process are as in figure below respectively.

2.3 Risks Study of LNG Loading and Unloading Operation

Based on “Risk-Based Analysis of LNG Loading and Unloading Operation” by Gilberto Francisco’s study in July 2012, the implication of LNG incidents will be resulting on three main areas as follow;

Environmental concerns
- a) Greenhouse gas effect
- b) Land and sea effect

Human life
- a) Health status of community
- b) Fatality

LNG industry
- a) LNG carrier and its facilities
- b) LNG terminal and its its facilities

2.3.1 Consequences of LNG leakage or exposure

Immediately following an LNG release, there is the potential for a range of different outcomes and types of consequences, depending on the direct receiving environment and the behaviour of the LNG.

Cryogenic damage
- a) If there is direct contact with cryogenic liquid (LNG), it may cause sores on the skin
- b) Steam inhalation of LNG for prolonged periods can cause lung damage as mentioned by Natacci et al (2010)

Pool fires
- a) If LNG spills occur near ignition source, a mix of the evaporating gas and air will burn above the LNG pool (Luketa-Hanlin,2006)
- b) As the pool of liquid begins to evaporate, the mixture of LNG vapour and air above the pool will burn when ignited, when the concentration of natural gas vapour is within the flammable range. The evaporating pool of LNG continues to provide fuel to the fire.
- c) Such pool fires are intense and burn far more rapidly than oil and gasoline fires. Due to high temperatures, thermal radiation from pool fire may injure unprotected people and damage property (IMO: Annex 1,Risk Analysis of LNG tankers, July 2007)

Asphyxiation
- a) Released LNG could be an asphyxiant for ship’s crew, nearby passengers, bunker boat crew, emergency response crew, and others in the vicinity if the gas reaches concentrations where it replaces enough air that there is a deficiency of oxygen
- b) Hightower et al (2004), in their study of large LNG spills, note that this is considered to be less of a concern than potential fire.

Vapor cloud fire
- a) This occurs if there is delayed ignition of the vapour cloud after release. A vapour cloud within the flammable range (5% to 15% natural gas) comes into contact with an ignition source away from the initial source of release, resulting in a fire.
- b) An ignited vapour cloud can burn back to the source of release, either as a “fire ball” if the vapour is mixed with air in a way that the fuel can rapidly be consumed, or as a slower burn, referred to as a “flash fire” (Luketa-Hanlin, 2006)
- c) These fires generate relatively low pressures and thus there is a low potential for pressure damages.

Explosion
- a) LNG in its liquid state is not explosive (IMO : Hightower et al. 2004)
- b) Certain conditions may, however, result in damaging overpressure from a vapour cloud fire. These include having a confined fuel-air cloud in spaces such as a ship’s hull or tank, which may occur in some scenarios (Hightower et al., 2004).

c) Detonation is noted to be possible where there is a high degree of confinement, strong mixing with air, and large ignition sources (Luketa-Hanlin, 2006).
d) Confinement can be provided by buildings in terminal area, areas congested with equipment and structures, including ship's deck**,** ABS (2004)

Rapid Phase Transition (RPT)
a) This phenomenon can occur when the very cold LNG comes into contact with water, which is much warmer. Explosive boiling results as the liquid transitions quickly into a gas, and shock waves and overpressure can result, similar to an explosion.
b) RPT is considered a physical or mechanical expansion with a high pressure energy release (Luketa-Hanlin, 2006).
c) Experimental studies described in a review by Luketa-Hanlin (2006), found that when RPTs were produced during the spills, most occurred early and were generally located near the spill point.

Pollution
a) LNG spills will cause minimal pollution or damage to the marine environment due to contact with cold liquid or possible damages from a possible fire (Will Horter,2009)
b) LNG produces 140% more greenhouse gases than regular natural gases (Paulina Jaramillo, 2007)

2.3.2 Causes of LNG incidents

From review of previous major LNG accidents, we can categorize the factors into three main areas which need to be considered to minimize the risks during LNG loading and unloading operation as below;

Design selection
a) LNG carrier and their facilities
b) LNG terminal and their facilities

Human error
a) Overwork / fatigue
b) Poor skilled and experienced

Operational
a) Less maintenance
b) Poor technical handling

2.3.3 Chronology of LNG incidents

Based on Formal Safety Assessment (FSA) by IMO in 2007, the sequences of LNG incidents were recorded, associated with their consequences and main causes.

Table 2.2: Historical record of LNG accidents of LNG industry by IMO in 2007

Incident's year	Name of vessel or terminal place	Status	Consequence	Comment
1979	Mostafa ben Boulaid	Unloading	LNG released and causing fractures of deck plating	Check valve failed when unloading
1985	Isabella	Unloading	Severe cracking of steelwork	LNG spilled on deck due to a cargo tank overflow because cargo valve failure during unloading
2002	Mostafa Ben Boulaid	Unloading	Cracked deck due to spillage	Thought to be human error as the alarm that should alert the personnal had been isolated
1944	Cleveland,Ohio, US	Construction failure	128 killed and 225 injured	A LNG storage tank failed,releasing LNG. Damage from the pool fire itself around the storage tank
1989	Thurley,UK	Human error and technical malfunction	2 workers received burns of their hands and faces	One of the natural gas drain valve was left open. LNG was released into the air as a high pressure jet
2004	Skikda,Algeria	Explosion and fire	27 killed, 5 injured, and damage to facilities	At LNG liquefaction plant, the leaking LNG into a boiler fan, boiler exploded and causing a huge explosion

2.4 Steps to Overcome Incidents / Failures during LNG Operation

Safety is an important issue for LNG facility, and numerous safety regulations exist in order to ensure the LNG ships and LNG terminals are safe. LNG carriers need to comply with a number of different rules that are common to all ship types, as well as a set of regulations particularly developed for ships carrying liquefied gas. In the following, a brief overview of the most important safety regulations applicable to LNG vessels, LNG terminal and their crew will be given.

2.4.1 General LNG safeguards

Safety and security features for LNG relate to the following elements (IMO code 2007).

i. Primary containment
ii. Secondary containment
iii. Safeguard system
iv. Training requirement of LNG crews

3.0 METHODOLOGY

3.1 Research Process

The process of this study is created to make the study easy to understand by explaining the flow of this study from beginning to the end. Saunders *et al* (2000) stated that, to ensure that the necessary preliminary work for later stages has been undertaken, there is a need to plan from the beginning of the process. The design of this study is important to examine the factors that influence auditor independence. For the purpose of this study, survey via interview and direct observation act as factual data and analysis is made up based on the data collected.

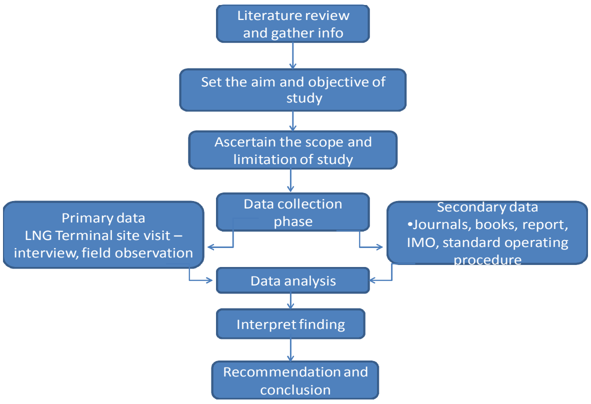

Figure 3.1: Research Process

3.2 Location of Study

As stated in the previous chapter, the purpose of this study was to determine the high risk areas during LNG loading and unloading in port operation. This study only focused on the respondents from Malaysia but some of them have experience with others foreign ship, that has been selected to conduct the study. The place was chosen is LNG terminal in Bintulu Port for researcher doing a personal interview as the main medium to collect the data. The location port selected because it was the most nearer and famous LNG import terminal in Peninsular of Malaysia.

3.3 Respondent of study

Engineering department of this LNG terminal are in priority first because these respondents have more experience and knowledge on ship operation and some of ship crew are not able to understand English. Interview will be conducted with several engineer of safety department as primary data, for purpose of identify the high risk areas, and safety enhancement and precaution step to minimize the failures during LNG loading and unloading operation.

4.0 MODEL DEVELOPMENT

The safety and reliability of LNG loading and unloading is a major concern for LNG operating companies. LNG hazards have a high potential financial impact in addition to shut down and failure of delivery.

4.1 Introduction

As Tarek Elsayed (2009) stated that the LNG industry has developed and refined its practices gradually over past 30 years, achieving very good results. Nowadays, the demand of LNG cargo is increased from the LNG industries all over the world, respecting with them, the LNG transfer operation also will be increase, these will elevate the probability or increment of failures in LNG operation.

4.2 Personal Interview

As stated in earlier section, the main goals of this study are to generate a generic safe model for LNG loading and unloading in terminal operation. Thus, as mentioned in the chapter of methodology, on determining the parameters to be assessed in development of model, a personal interview had been done.

4.2.1 Preliminary Parameters of the Interview Questions

As the earliest stage of model development, an interview questions constructed as in Appendix A, by using Hazard Identification (HAZID) as approaching medium, the parameter to be determined and become the points in the model development are;

i. Communication system
ii. Trained and competent crews
iii. Occupational fatigue (working rate)
iv. Maintenance program (watch-keeping)
v. Installation of safety system
vi. Terminal rules and regulations

4.3 Existing models

The main goals of system safety are to prevent the occurrence of accidents in engineered systems and to reduce their consequences if they occur. As stated by in a study related to ‘human relations’ by E.L Trist (1951), socio-technical theory implies that human agents and social institutions are integral parts of the technical systems, and that the attainment of organizational objectives are not met by the optimization of the technical system, but by the joint optimization of the technical and social aspects.

4.4 Selection of hollistic model

In this section, some traditional and modern hollistic will be reviewed for the selection of suitable model that may reach the objective of this study. By revising traditional models, there are some patterns that relevant with the socio-technical model, but those criteria still not sufficient for developing the safety model, since they cannot relating the complex interrelation between all the elements of safety purpose.

4.4.1 “Domino Model” of accident causation

Among of the existing hollistic model reviewed, there is two types of model that able to trigger some ideas in creating the new model related to safety. The first one is known as “Domino Model” as in Figure 4.2, this sequential model explain accident causation as the result of a chain of discrete events that occur in a particular temporal order and this pattern proposed by Heinrich, 1988.

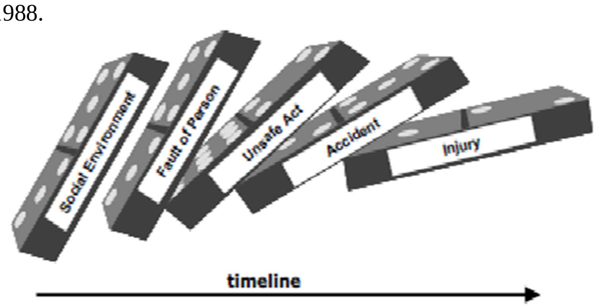

Figure 4.2: “Domino Model” of accident causation

The figure above simplifies that each factor leads to the next with the end result being the injury. There are five factors in the accident sequence;

i. Social environment (those conditions which make us take risks)
ii. Fault of a person
iii. Unsafe acts or conditions
iv. Accidents
v. Injury

4.4.2 The "Cartelli Model"

Ideally, instead of the traditional models like the "Domino Model" as explained above that not too relevant and not being able to cover up this scope of study due to its linearity features, there is a hollistic model known as "Cartelli Model" patterned by Cartelli in 2007.

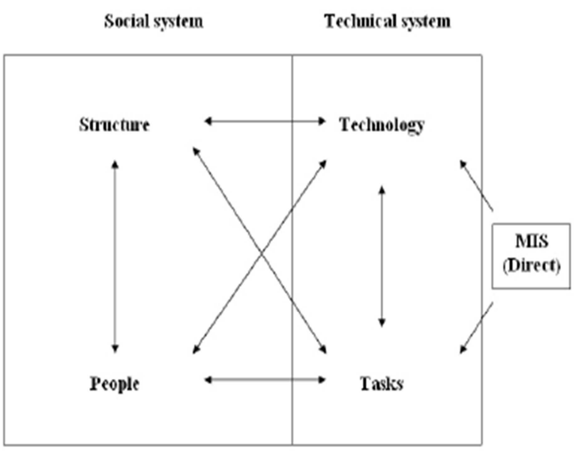

Figure 4.3: "The Cartelli Model"

4.5 Improvisation of existing model

The elements that to be improved in this Cartelli model is;
i. Terminal design
ii. Human factors
iii. Technical handling and operation

4.6 Conclusion

The model is developed after reconsidering the parameters determined which are;

i. Training received; relationship between safety of operation with human
ii. Education and usability of equipments; relationship between technology with human
iii. Communication and workload system; relationship between community structure with human
iv. Maintenance and operation manual; relationship between safety of operation with technology
v. Work planning; relationship between community structure with technical operation
vi. Maintenance program; relationship between facilities and associated equipment's with community structure

5.0 RESULT AND DISCUSSION

The purpose of this section is to discuss all the findings and the evaluation that has been collected and obtained from the study.

5.1 Introduction

It also discussed some observation made on creating the model developed in section 4.

5.2 Model Developed

To fulfill the target of safe operation, this led to the development of a new improved model which proposed known as qualitative type 'H-T-D social-technical model' as shown in Figure 5.1. This model shows the refined elements of socio-technical model, which always been missing in the implementation. The elements that form part of the model were transformed into a system to create a link between these three concepts; ***H***uman factors, ***T***echnical operation and ***D***esign of terminal.

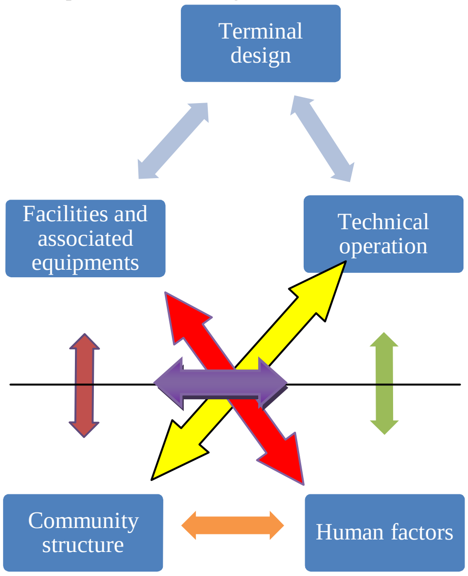

Figure 5.1: The H-T-D socio-technical model

- Maintenance and operation manuals
- Maintenance program / periodic inspection
- Work planning and handling
- Education and usability of equipment's
- Training received
- Communication and workload system

5.3 Discussion

As shown in Figure 5.1, a refined and improved socio-technical model had been developed. Using the HAZID as the safety management tool approaches, these elements that to be improved and refined in the Cartelli socio-technical model is;

i. Human factors
ii. Terminal design
iii. Technical operation

Other key elements are still in reliable and trusted condition in term of scope of this study.

5.3.1 Data Collection

The data collected in this study was obtained by personal interview (direct call medium) with the safety officer of LNG terminal. The general approaches of these data are:

i. Deep appraisal of LNG loading and unloading operation
ii. Understanding the related parameters that lead to a safe operation
iii. Develop the interview questions

Data collected from personal interview were by reviewing the safety checklist and procedures that given by the safety officer of Bintulu Port Sdn Bhd, refer Appendix A for reference. All the feedback of interview questions was tabulated and used as data collection, as shown in Table 5.1. The answer for the interview questions were covered these three (3) scopes;

i. Safe operation system
ii. Communication system conducted
iii. Personnel training and course
iv. Workload
v. Inpection or ‘rounding’ activity
vi. Alarming or standby system
vii. Terminal rules and regulations

5.3.2 Data analysis

The data collected were being analyzing using HAZID, which the approaches done were;

i. Describe the hazards from each activity
ii. Identify the threas that trigger hazardous event, identify the likely consequences
iii. Identify all possible solutions necessary to prevent the threat
iv. Identify all recovery measures to minimise the consequence
v. Using all the data collected and analysis made, then we have drawn some relevant and relationship between all of the elements that introduce these risk to be happening.

5.3.3 The relationship between elements

In order to complete in developing this new ‘H-T-D model’ as in Figure 5.1, the approach taken was gone through the each element that figure out how the technical aspects and social aspects may affect each other in LNG loading and unloading in terminal operation.

6.0 CONCLUSION AND RECOMMENDATION

The investigation upon the safety requirement and procedure of LNG loading and unloading operation in port had been done. This means, the objective of this research is achieved. From the investigation and other side studies narrowed according to the scope, an improved ‘H-T-D’ safety model consists of the following features had been developed.

i. Training received (human and technology evolvement interface)
ii. Occupational fatigueless
iii. Maintenance cycle
iv. Knowledge of technical handling and operation
v. Safety system installed at LNG terminal (design of terminal interface)

The results discussed in data verification concerning the relevance of the model conclude that the model valid and ready to be implemented.

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