COMPARISON OF RISK ASSESSMENT FOR DECISION MAKING BY USING ANALYTIC HIERARCHY PROCESS: CASE STUDY OF TANK FARM IN POWER PLANT

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Thematic paper
entitled

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COMPARISON OF RISK ASSESSMENT FOR DECISION MAKING BY USING ANALYTIC HIERARCHY PROCESS: CASE STUDY OF TANK FARM IN POWER PLANT

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ABSTRACT

The risk assessment for tank farm in power plant can be done by many techniques. However, there are no studies showing which one is the most suitable for this process. So, the main objective of this study was to compare the effectiveness of risk assessment techniques for the tank farm in power plant which including Checklist, What-If and HAZOP analysis. Risk assessment team was set up by ten workers who had different jobs in power plant. To compare between each technique, the 6 criteria (the number of identified risks, the cost of eliminating intolerable risks, the number of identified human errors, the identified high risk levels , the time and budget required) had been used to perform the assessment. Moreover, the Analytic Hierarchy Process (AHP) which is the method to analyze complex decision were used to determine which ones was the most suitable.

The results of this study showed that HAZOP could get the highest number of identified risks and high risk levels whereas, What-if analysis could encounter the greatest number of human errors, and Checklist spent lowest controlling cost, budget and time for hazard identification. The Analytic Hierarchy Process (AHP) which analyzed under the 6 criteria showed that HAZOP was more effective than What-if and Checklist analysis to perform risk assessment of tank farms in power plant with a consistency ratio less than 0.1, which is acceptable.

KEY WORDS: RISK ASSESSMENT / ANALYTIC HIERARCHY PROCESS / TANK FARM / DECISION CRITERIA

106 pages

การเปรียบเทียบวิธีการประเมินความเสี่ยงเพื่อใช้ในการตัดสินใจโดยใช้กระบวนการลำดับชั้นเชิงวิเคราะห์: กรณีศึกษาคลังน้ำมันเชื้อเพลิงโรงไฟฟ้า

COMPARISON OF RISK ASSESSMENT FOR DECISION MAKING BY USING ANALYTIC HIERARCHY PROCESS: CASE STUDY OF TANK FARM IN POWER PLANT

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บทคัดย่อ

การประเมินความเสี่ยงในคลังน้ำมันเชื้อเพลิงโรงไฟฟ้ามีหลายวิธี แต่ยังไม่มีการศึกษาใดที่แสดงให้เห็นว่าวิธีใดเป็นวิธีที่เหมาะสมที่สุดสำหรับกระบวนการนี้ ดังนั้นงานวิจัยชิ้นนี้จึงมีวัตถุประสงค์เพื่อเปรียบเทียบประสิทธิภาพของวิธีการประเมินความเสี่ยงในคลังน้ำมันเชื้อเพลิงโรงไฟฟ้า ซึ่งประกอบด้วยวิธี Checklist, What-if analysis และ HAZOP โดยมีทีมประเมินความเสี่ยงเป็นผู้ปฏิบัติงานที่มีหน้าที่แตกต่างกันในโรงไฟฟ้าจำนวน 10 คน การเปรียบเทียบแต่ละวิธี มีเกณฑ์การตัดสินใจที่ใช้ในการประเมินจำนวน 6 เกณฑ์ ได้แก่ จำนวนความเสี่ยงที่พบ, ต้นทุนในการลดความเสี่ยงสูง, จำนวนความผิดพลาดของมนุษย์ที่พบ, จำนวนความเสี่ยงสูงที่พบ, เวลาและงบประมาณที่ใช้ นอกจากนั้นยังมีการนำกระบวนการลำดับชั้นเชิงวิเคราะห์ (Analytic Hierarchy Process: AHP) ซึ่งเป็นวิธีที่ใช้ในการวิเคราะห์การตัดสินใจที่ซ้ำซ้อน มาใช้ในการเลือกวิธีที่เหมาะสมที่สุด

ผลการศึกษาพบว่าวิธี HAZOP มีจำนวนความเสี่ยงและจำนวนความเสี่ยงสูงที่พบมากที่สุด แต่วิธี What-if analysis พบจำนวนความผิดพลาดของมนุษย์มากที่สุด และวิธี Checklist ใช้ต้นทุนในการลดความเสี่ยงสูง เวลาและงบประมาณที่ใช้ในการชี้บ่งอันตรายน้อยที่สุด กระบวนการลำดับชั้นเชิงวิเคราะห์ (AHP) ภายใต้เกณฑ์การตัดสินใจทั้ง 6 เกณฑ์ แสดงให้เห็นว่าวิธี HAZOP มีประสิทธิภาพในการประเมินความเสี่ยงในคลังน้ำมันเชื้อเพลิงโรงไฟฟ้ามากกว่าวิธี What-if analysis และ Checklist และมีค่าอัตราส่วนความสอดคล้องของข้อมูลน้อยกว่า 0.1 ซึ่งเป็นค่าที่ยอมรับได้

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CHAPTER I
INTRODUCTION

1.1 Research Rationale

Tank farm is a high risk area and most of accidents in the tank farm caused very serious damage to lifes and properties. For example, in case of a huge fire broke out at petroleum oil refiner in Chonburi caused 7 people had been killed, 21 others were injured, 6 fire trucks were destroyed, fuel burned 24.5 million liters, many building were collapsed, and total damage was estimated more than 800 million baht. The oil tank fire at lime plant in Nakhon Ratchasima caused 3 deaths, 1 injury, and about 100,000 liters of fuel were burned. The oil storage warehouse in Chachoensao fire caused total damage was estimated more than 100 million baht. Also, in case of the oil tank fire at lube oil refinery company in Chonburi caused 5-10 million baht losses(1).

There were different causes in the each accident. The petroleum oil refiner in Chonburi case was from the negligence of worker that made mistake to open the oil pipeline valve caused to gasoline flowed into the wrong tank before overfilled and fired(2). The oil tank fire at lime plant in Nakhon Ratchasima happened when the sparkle from an electric welding on the fuel tank ignited with fuel and caused severe explosion(1).

Our studied Power Plant contained a diesel oil tank farm to use diesel oil as the reserve fuel in case of the failure to deliver natural gas to power plant. Tank farm consists of 2 storage tanks with diameter 34 meters, height 15 meters, and capacity 10 millions liters. And one unloading tank with diameter 15 meters, height 8 meters, and capacity 1 million liters. The tank farm might affect to safety of workers and communities in many ways such as oil spills, fire, or explosion around tank farm. The importance of this issue was realized by the manager and would like to seek out hazards , impact of hazards, and preventive measures to prevent the accidents and reduce the loss that can be occur, the implementation of risk assessment in tank farm is very important.

There are several methods to identify hazards and risk assessment. The ministry of Energy announced the 6 different methods of risk assessment in tank farm such as Checklist, What-If Analysis, Failure Modes and Effects Analysis, Event Tree Analysis, Hazard and Operability Study (HAZOP), and Fault Tree Analysis[(3)].

At present, this Power Plant still has no hazard identifications and risk assessment in tank farm as the legal procedures required. Instead, The Power Plant uses the Hazard Classification methods of the World Bank that showed in the documentation of Techniques for Assessing Industrial Hazards a Manual, 1990 and API 2000. Also, the plant uses the risk assessment techniques from The American Petroleum Institute (API), which evaluate hazards from oil leak and ignition, that is not cover all risks.

According to all information, researcher would like to do risk assessment in diesel tank farm by 3 techniques including the Checklist, What-If Analysis, and Hazard and Operability Study (HAZOP). These techniques were chosen because of non complicated and high efficiency.

1.2 Objective of the Research

1.2.1 General objective

To compare the results of risk assessment in the tank farm in power plant

1.2.2 Specific objectives

1.2.2.1 To compare the results of the risk assessment using the Checklist, What-If Analysis, and Hazard and Operability Study (HAZOP) by consideration the following factors : the number of identified risks, the cost of eliminating intolerable risks, the number of identified human errors, the identified high risk levels, the time and budget required to perform the assessment.

1.2.2.2 To apply the Analytic Hierarchy Process in order to choose the most effective risk assessment method.

1.3 Scope of the Research

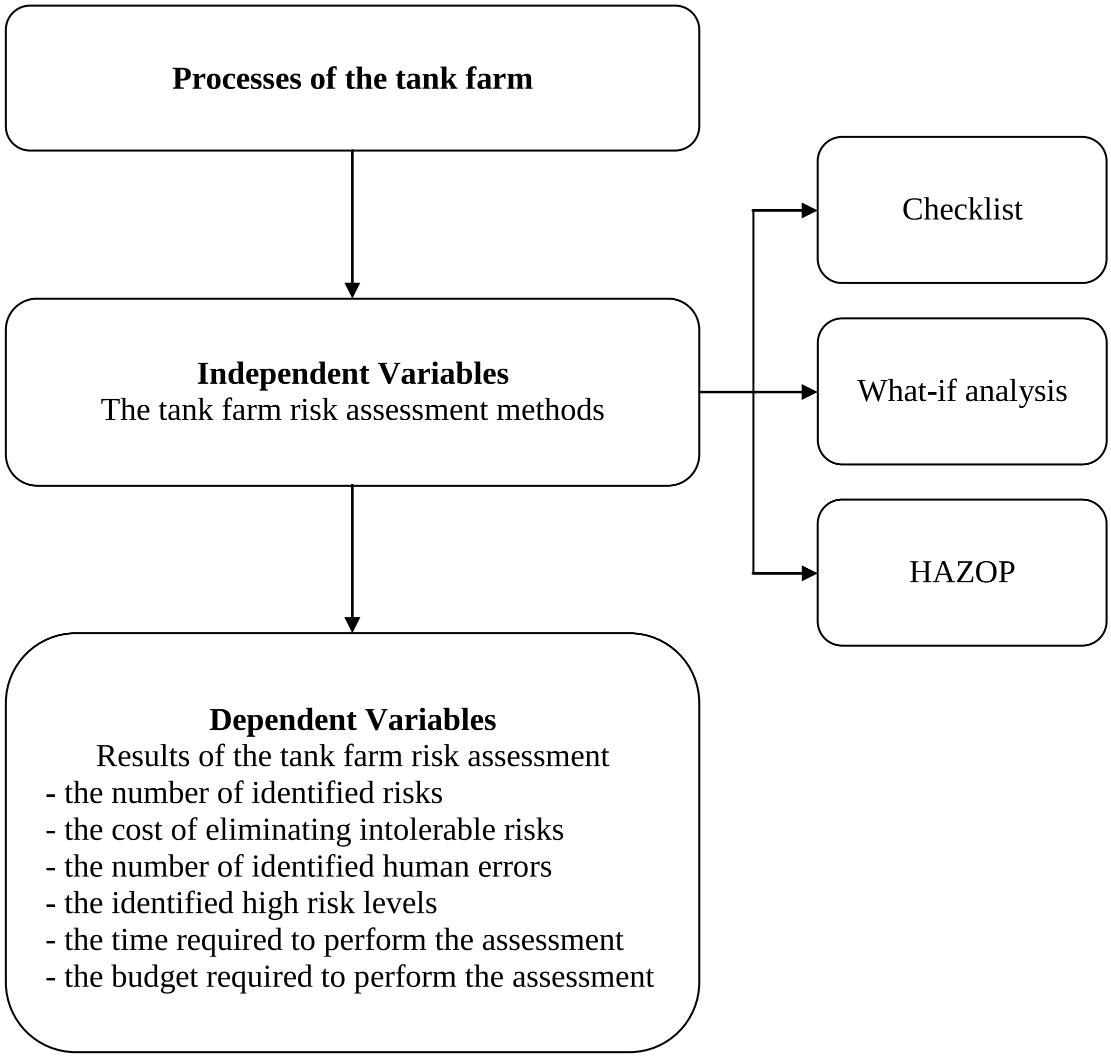
The diesel tank farm in this Power Plant

1.4 Benefits

1.4.1 Aware of the possible hazards of the tank farm

1.4.2 Know the most appropriate risk assessment method for the tank farm

1.5 Conceptual Framework



1.6 Glossary Terms and Definitions

1.6.1 Analytic Hierarchy Process: The effective tool for decision making, and may aid the decision maker to set priorities and make the best decision[(4)].

1.6.2 Tank Farm: The place for a fuel storage including area defined in the license to be a tank farm area; as well as all related buildings, tanks, pipes, tools, and equipment; either the place for a fuel storage that is used as raw materials in refinery processes or fuel production processes[(5)].

1.6.3 The number of identified risks: The number of risks that identified by each risk assessment method.

1.6.4 The cost of eliminating intolerable risks: The cost of taking control measures of intolerable risks.

1.6.5 The number of identified human errors: The percentage of the risks that attributed to human errors.

1.6.6 The identified high risk levels: The percentage of high risk levels.

1.6.7 The time required to perform the assessment: The number of man hours that a team spent for risk assessment.

1.6.8 The budget required to perform the assessment: The total of hourly wages that a team spent for risk assessment.

CHAPTER II
LITERERATURE REVIEW

2.1 Process of Tank Farm

When power plant needed to use reserve fuel oil, forwarding pumps will start working by pumping oil from storage tank through the piping system to the gas turbine in quantity and pressure needed. While the fuel oil is delivered to combustion chamber, the air will be drawn from outside into the compressor until reaches the high pressure before moves to the combustion chamber respectively. Inside the combustion chamber, fuel oil and air are burned together to become hot gas and drive to a gas turbine. Then the high temperature exhaust from the combustion chamber will transfer to Heat Recovery Steam Generator (HRSG) to generate the high pressure steam deliver to steam turbine.

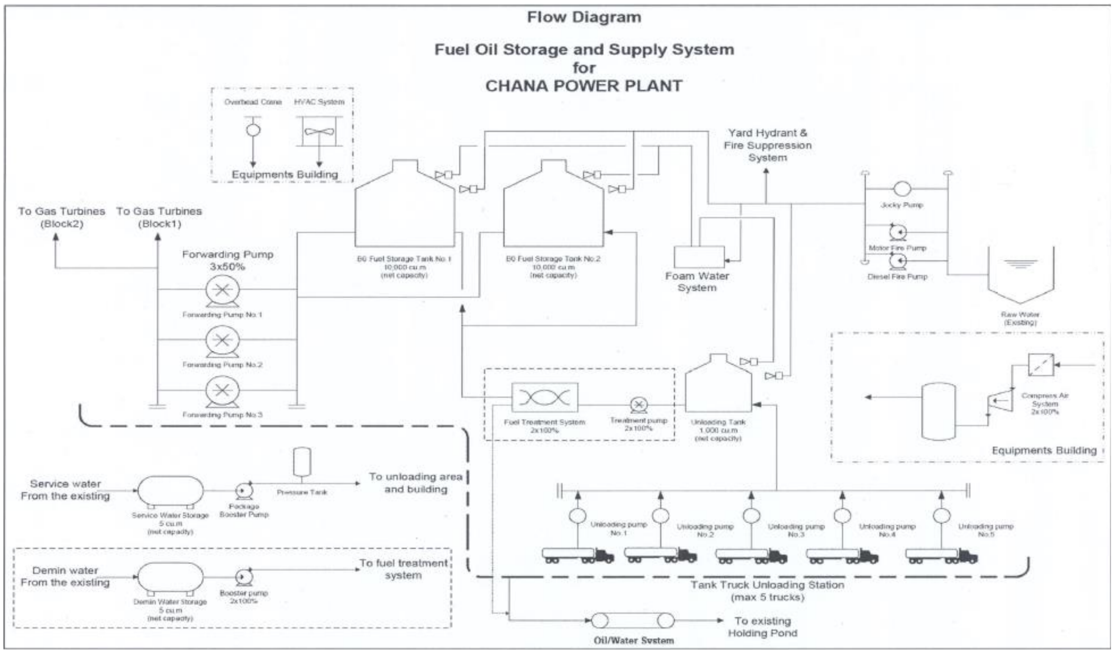


Figure 2.1 Flow Diagram Fuel Oil Storage and Supply System for Power Plant

2.2 Material Safety Data Sheet of Diesel Oil

2.2.1 Product Data

2.2.1.1 Trade Name: Marine Diesel Oil

2.2.1.2 Use: Use as fuel in ship

2.2.1.3 Manufacturer/Importer: PTT Public Company Limited Address: 555 Vipavadee-rangsit rd. , Jatujak , Bangkok 10900
Telephone Number : +66(0)2537-2000

2.2.2 Composition / Information on Ingredient

Table 2.1 Composition / Information on Ingredient

Substances	CAS No.	Labelling	Percent	Safety Standard	
				TLV (ACGIH)	PEL (OSHA)
Fuels, Diesel; Gasoil **Carc.Cat.3; R40 **Note; H N	68334-30-5	Xn R: 40 S: (2-)36/37	100	100 ppm (TWA)	-
Sulfur Compound	-	-	0 – 1.5	-	-

2.2.3 Hazard Identification

2.2.3.1 Product Specification: Product which cause concern for human owing to possible carcinogenic effect according to Directive 1999/45/EC but in respect of which the available information is not adequate for making a satisfactory assessment. There are some evidence form appropriate animal studies

2.2.3.2 Physical and Chemical Hazards / Fire and Explosion Hazards:

- Product is flammable liquid and can release vapors that can readily form flammable mixtures at below room temperatures

- Product can accumulate static charges which can cause an incendiary electrical discharge, should be bonded and grounded

2.2.4 First Aid Measures

2.2.4.1 Skin Contacting:

- Flush with large amounts of water, use soap is available
- Remove grossly contaminated clothing, including shoes, and launder before reuse
- If irritation or redness has develops, seek medical attention

2.2.4.2 Eye Contacting: Flush with fresh water for 15 minute. If irritation persists, get medical attention.

2.2.4.3 Inhalation: Remove to fresh air. Obtain medical attention in all case.

2.2.4.4 Ingestion: If swallow, DO NOT induce vomiting. Keep at rest. Get prompt medical attention.

2.2.5 Fire-Fighting Measures

2.2.5.1 Fire-fighting procedure:

- Water maybe ineffective on flames, but should be used to keep fire-exposed containers cool. Large fire such as tank fires, should be fought with caution. If possible, pump the content from the tank and keep adjoining structure cool and protect personnel. Avoid spreading burning liquid with water used for cooling purposes. Do not flush down public sewers. The use of self-contained breathing apparatus and protective clothing is recommended for fire-fighters. Avoid inhalation of vapors.
- Use foam or dry chemical to extinguish fire

2.2.5.2 Special fire precaution: Vapor may travel along the ground to a source of ignition (heat, electric motor) some distant away

2.2.6 Accidental Release Measures

2.2.6.1 Land spill:

- Eliminate sources of ignition. Prevent liquid from entering sewers.
- Contain spilled liquid with sand.

- Recover by pumping (use a suitable absorbent) If liquid is too viscous for pumping, scrape up with shovels or pails and place in suitable containers for recycle or disposal.

2.2.6.2 Water spill:

- Eliminate sources of ignition
- Notify port or relevant authority and keep public away
- Remove surface by skimming or with suitable absorbents
- If allowed by local authorities and environmental agencies sinking and/or suitable dispersants may be used in non-confined waters

2.2.7 Handling and Storage

2.2.7.1 Storage temperature: Ambient

2.2.7.2 Transport temperature: Ambient

2.2.7.3 Loading/unloading temperature: Ambient

2.2.7.4 Storage/transport pressure: Atmospheric

2.2.7.5 Electrostatic accumulation hazard: Use proper grounding procedure

2.2.7.6 Storage/Handling:

- Keep container closed. Handle container with care. Open slowly in order to control possible pressure release. Store in a cool, well-ventilated place away from incompatible materials.
- DO NOT handle, store or open near an open flame, source of heat or source of ignition. Protect material from direct sunlight.
- Material will accumulate static charges with may cause an electric spark (ignition source). Use proper bonding and/or grounding procedure
- DO NOT pressurize, cut, heat, or weld container
- Empty product container may contain product residue. DO NOT reuse empty containers.

2.2.8 Explosure Controls / Personal Protection

2.2.8.1 Engineering control measures / Ventilation: The use of local exhaust ventilation is recommended to control process emission near the source.

Laboratory samples should be handling in a lab hood. Use explosion-proof ventilation equipment.

2.2.8.2 General advise: The use and choice of personal protection equipment is related to the hazard of the product, the workplace, and the way the product is handled. In general, we recommend as a minimum safety precaution the safety glasses with side-shields and work clothes protection arms, legs and body be used. In addition, any person visiting an area where this product is handles or processed should at least wear safety glasses with side-shields.

2.2.8.3 Respiratory protection: Where concentrations in air may exceed the limits given in this section, it's recommended to use a half face filter mask to protect from overexposure inhalation. Suitable filter material depends on the amount and type of chemicals being handle in the workplace, but filter material of type "A" or similar may be considered for use and should be use appropriate NIOSH-approved respiratory protection

2.2.8.4 Hand protection: When handling this product, it's recommended to wear chemical resistant gloves. The choice of suitable protective gloves depends on work conditions and what chemicals are handled, but we have positive experience with gloved made of Nitrile. Gloves should be replace immediately if sign of degradation is observed.

2.2.8.5 Eyes protection: See general advice

2.2.8.6 Skin and body protection: See general advice

2.2.9 Physical and Chemical Data

2.2.9.1 Boiling point: Maximum 357^{o}C (90% vol. recovered)

2.2.9.2 Vapor pressure: <0.5 kPa (40 ^{o}C)

2.2.9.3 Solubility in water: Negligible

2.2.9.4 Density @ 15^{o}C kg/m^{3}: Maximum 900

2.2.9.5 Evaporating rate: Slower

2.2.9.6 Appearance color and odor: Yellow, Oily odor

2.2.10 Fire and Explosion Hazard Data

2.2.10.1 Flash point: minimum 60 ^{o}C

2.2.10.2 Flammable limits by % volumes:

- LEL = 0.6
- UEL = 7.5

2.2.10.3 Autoignition temperature: 250 ^{o}C (minimum)

2.2.10.4 Hazard rating: NFPA (Health-2, Fire-2, Reactivity-1)

2.2.10.5 Chemical reactivity: Stable under ordinary conditions of use and storage

2.2.10.6 Material to avoid: Strong oxidizing agents, chlorate, nitrates, peroxides

2.2.10.7 Hazardous decomposition products: Carbonmonoxide, Carbondioxide, Hydrocarbons

2.2.11 Toxicological Information

2.2.11.1 Acute:

- Inhalation: Vapor may be irritating to the respiratory tract, may cause headaches and dizziness, irritation of eyes, nose and throat, signs of intoxications, could be anesthetic and may have other central nervous system effects
- Skin contact: Causes severe skin irritation; cause redness, drying of skin
- Ingestion: Aspiration hazard if swallowed, can enter lung and cause damage
- Eyes contact: Will cause eyes discomforts, but will not injure eyes tissue

2.2.11.2 Chronic: prolong and repeated contact with skin can cause defatting and drying of the skin resulting in skin irritation and dermatitis. Prolong exposure to high vapor concentration can cause headache, dizziness, nausea, blurred vision and central nervous system depression

2.2.12 Ecological Information

2.2.12.1 Environmental degradablility: Not readily biodegradable

2.2.12.2 Ecotoxicity and bioaccumulation: Expected to be toxic to aquatic organisms

2.2.13 Disposal Considerations

2.2.13.1 Combination of other materials may well indicate another route of disposal. If in doubt, contact manufacturer / importer or local Authorities

2.2.13.2 This product is not suitable for disposal by either landfill or via municipal sewers, drains, natural steams or rivers

2.2.13.3 Empty packaging should be taken for recycling, recovery or disposal through a suitably qualified or licensed contractor

2.2.13.4 Care should in any case be taken to ensure compliance with national and local regulations

2.2.14 Transport Information

2.2.14.1 Land:

Class 3 PG III UN Number 1268

2.2.14.2 SEA-IMDG (Package Good and BLCs):

Class 3 PG III UN Number 1268

2.2.15 Regulatory Information

2.2.15.1 Governing directive: According to Dangerous Substance Directive 67/548/EC, as modified

2.2.15.2 Classification and labeling:

- Classification/Symbol: Carcinogens/Carc

2.2.15.3 Nature of special risk:

R40 Limited evidence of a carcinogenic effect

2.2.15.4 Safety advice:

S2 Keep out of the reach of children

S36/37 Wear suitable protective clothing and gloves

2.2.16 Other information

2.2.16.1 MSDS Usage: This information relates only to the specific material designated and recommendations contained herein are to the best of manufacturer's knowledge and may not be valid for such material used in combination with any other material or in any process, therefor, it's the user's responsibility to satisfy itself as to the suitability and completeness of such information for its own particular use

2.3 Hazard identification

Hazard identification[6] means the hidden hazard identification in the workplace at every activity from storage, transportation, raw materials, fuel, chemicals, products, machineries, equipment, production processes, and operation procedures. There are many methods to identify the hazard. This study will focus on the HAZOP, What If Analysis, and Checklist. The detail of 3 methods are discussed as below;

2.3.1 Checklist

Checklist is one of method to identify hazard by inspect the factory operations are complied with the standards of design, standards of practice, or Law. This tool consists of the question topics relate to the factory operation. Result from the inspection will be used to identify hazards.

2.3.1.1 Hazard Identification procedure by Checklist

1) Define the scope of checklist

2) Prepare information and relate documents such as law, standard, other regulations, working processes, working procedures etc.

3) Create question topics that relate to the subject of checklist Use the requirement from law, standard, other regulations, working processes, or working procedures to make questions. The questions need to be easy and practicle by start with the first step until the last step of process because the questions need to be covering all the key steps.

4) Checklist needs to be verified by an expert person.

5) Improve the checklist by following recommendation from the expert person before implementation.

6) Take the results, which did not follow the rule / or followed but uncorrect / or not completed / or delayed action, to identify the hazard by filling in non-compliant on the "Checklist result" of the table.

7) Consider detail that identify in "Checklist result", what is the hazard or what would happen when did not follow the assigned questions then take notes in "dangers or consequences" on the checklist table.

8) Consider the current prevention and control measures then fill information in "protective and control measure" on the checklist table.

9) Suggestion methods to prevent and control by considering the current protective measurement. If the current protective measurement is not appropriate, the factory needs to add more protective and control measure in order to be more safety in the operation by fill information in "Recommendation" on the checklist table.

10) Risk assessment and level ranking.

2.3.1.2 Inspection rules

- Select "Yes" if the plant has complied with the topic in the checklist / or have equipment/ or is appropriate according to the topic in the checklist.

- Select "No" if the plant has no complied with the topic in the Checklist / or complied with the topic but not completes / or have no equipment / or is not appropriate according to the topic in the checklist.

- Select "Not relate" if the plant did not operate in accordance with the topic specified in the checklist.

- Note : Provide a reason for not being able to follow the topics listed in the checklist / or do not complete the required.

2.3.1.3 Advantages of checklist[7]:

- Easy to apply.

- Inexperienced team can be performed.

2.3.1.4 Disdvantages of checklist(7):

- In order to complete the assessment, this method requires the checklist. In case, the questions are not comprehensive areas will result to failure of study because the researcher cannot identify the possible hazards.

- It seems to be hard to apply to new processes because the checklist created from past experience.

2.3.2 What-if Analysis

This technique study, analyze, and review the hazard identification in the factory by using the question start with "What if" and find the answers to identify dangers. This technique is suitable to be used in the design phase and improve the old system by considering situation with unsatisfied result. What-if analysis helps to improve system since the design phase.

2.3.2.1 Hazard identification procedure by what-if analysis

1) Scope:

Define the physical scope of hazard source and area that might be affected such as tools, production processes, or communities

Target area for what-if analysis divided into 3 groups such as:

- Incident that affect to workers
- Incident that affect to production processes and cause to losses
- Incident that affect to neighborhood communities

Criterias for the hazard severity rating

- Hazard severity such as none, low, medium, high
- Number of workers in the workplace
- The level of leakage that must be reported to a government agency
- Economic losses for the company

2) Define the team

Team will be selected from people in various department for example; operator, design engineer, safety officer, maintenance staff, and other staffs.

3) Study the related documents for creating "What-if" questions such as:

- Process Chemistry Description
- Operating Procedure
- Maintenance Procedure
- Operating Job Description
- Process Flow Diagram (PFDs)
- Piping and Instrumentation Diagram (P&IDs)
- Hazardous Material Inventories
- Other Documents

4) Create questions

Questions are created from scenario with the word "What would happen, if.........";

- Tools and equipment have problems or error
- Condition failed such as temperature, humidity, and ventilation
- Power outage
- Operation system failed
- Connection system failed
- Human error such as hasten, not follow the procedure, or not pay attention
- Working in different methods from the regular workflow or Stopping production lines for maintenance
- Accident while maintenance process
- Accident from delivery process in factory
- Problem from materials or other stuffs transfer, crane's impact, or machanical tools
- External impacts such as aircraft accident, robbery, hurricane, or multiple simultaneous incidents like machines breakdown in the same time while the process.

Then sort the questions by production processes or working procedure. Select only the rational and possible questions.

5) Evaluate quidelines for emergency response

Arrange the questions in these following topics:

- Question detail
- Event of question both the hazards and the consequences
- Severity levels
- Recommendation or corrective actions

Members discuss about the risk assessment in these following topics:

- Severity of event
- Decrease the likelihood of event
- Decrease the spread of leak to outside
- Decrease the amount of people to exposure the hazard

6) Summary the result in the table form by divided into columns as belows:

- Column 1 – What-if question
- Column 2 – Answers / Risks
- Column 3 – Crisis or severity
- Column 4 – Recommendation or corrective actions
- Risk Assessment

2.3.2.2 Advantages of what-if analysis[7]:

- Easy to apply

2.3.2.3 Disadvantages of what-if analysis[7]:

- Experience of team are required
- Time consuming for complex production process

2.3.3 Hazard and Operability Study: HAZOP

HAZOP is a technique for studying, analyzing, and reviewing the hazard identification as well as finding the potential operation problems in a plant. The hazard and problem analyzing which might occur by unintentionally mistake and imperfection in the design will be ask the questions that assume the situation in various production condition by using HAZOP GUIDE WORDS.

HAZOP studies details of processes in a systematic way in order to consider the possibility of hazards or problems in the workplace. Hazards and risks are hidden in the tools and machineries might cause both direct and indirect accidents. The study will select appropriate parameters (e.g. pressure, temperature, flow rate) and examine by the Guide word.

2.3.3.1 Principles of HAZOP

1) Study details of production processes then set the system frame and identify each point of the each position to find the hazard that probably occur

2) Record every detail that suspected to be cause of hazard then write a flow sheet

3) Set parameters and use guide words for examine

4) Develop and improve machines and equipment that were found the problems

2.3.3.2 Hazard Identification Procedure by HAZOP

1) Set objectives and scope of study

2) Choose a team to study HAZOP, which consists of:

- Team leader who has experience in HAZOP
- Engineers or people who have knowledge about machines and P&IDs (Piping and Instrumentation Drawings)
- Engineers and process controllers
- Electrical engineers / Computer engineers
- Safety specialists
- Toxicologists
- Maintenance technicians
- Secretary to take note

3) Collect the following information;

- Information about production processes and products
- Flow sheet of production processes
- Diagram of the piping system and equipment
- Diagram of the production process controlling
- Plant layout drawing, machines, and equipment

- Information about physical, chemical, and toxicological of raw materials

- Environmental monitoring data

- Maintenance procedures

- Emergency Procedures

- Safety Training Guideline

4) Study the detail of production processes then record all the detail that suspected to be dangerous and write a flow sheet by dividing the study system into NODE

5) Define Parameters by using guide words to examine, see table 2.2 and 2.3

6) Risk assessment by using Criticality Rating and Frequency, then compare with Hazard Classification Matrix

7) Summary the risk levels including prepare report then develop and correct the problematic process by considering the risk score

Table 2.2 HAZOP Guide word

HAZOP Guide word	Operating Deviation
None	- No flow - Reverse flow - No reaction
More	- Increased flow - Increased pressure - Increased temperature - Increased reaction time
Less	- Reduced flow - Reduced pressure - Reduced temperature - Reduced reaction time
Part of, as well as others	- Change of ratio of material balance - Different material present

Table 2.2 HAZOP Guide word (cont.)

HAZOP Guide word	Operating Deviation
Part of, as well as others (cont.)	- Different plant conditions from normal operation - Machine start up - Machine shutdown - Chemical, pressure, etc. (Relief) - Instrumentation - Sampling - Utility failure - Corrosion - Maintenance - Erosion - Grounding/Static

Table 2.3 HAZOP Guide words and design parameter

Design parameter / Guide word	More	Less	None	Reverse	Part of	As well as	Other than
Flow	High flow	Low flow	No flow	Back flow	Wrong percentage	Contaminant	Wrong material
Pressure	High pressure	Low pressure	Vacuum				
Temperature	High temperature	Low temperature					
Mixing	Excessive mixing	Poor mixing	No mixing			Foaming	
Level	High level	Low level	No level				
Reaction	High reaction rate	Low reaction rate	No reaction	Reverse reaction	Incomplete reaction	Side reaction	Wrong reaction
Time	Too long	Too short					Wrong time
Sequence	Step to late	Step to early	Step left out	Step backwards	Part of step left out	Extra action included	Wrong action taken

Other parameters : Vapor pressure , pH , Heat capacity , Number of phases , Flash point , Viscosity , Static charge , Specific concentration , etc.

2.3.3.3 Advantages of HAZOP[7]:

- Systematic and comprehensive technique. The Guide words and parameters can be apply to determine the consequences of the failure, which help to minimize or mitigate the hazard.

2.3.3.4 Disadvantages of HAZOP[7]:

- Time consuming and expensive.
- Requires detail of design drawing to perform the full study.
- Requires the additional guide words for unusual hazards.
- Requires experienced workers.
- Focuses on one-event causes of deviation only.

2.4 Risk Assessment

Risk assessment[6] means processes to analyze factors and situations that be a cause of potential hazard become to an accident by considering the probability and severity of those situations. The Risk assessment guidelines in accordance with the Department of Industrial Works regulations on hazard identification, risk assessment, and the Risk Management Plan year 2000[8] consist the following detail;

2.4.1 Considering the probability of events: by ranking in 4 levels as the table 2.4

Table 2.4 Probability level in various events

Level	Specification
1	Rare opportunity to occur such as never occur in more than 10 years
2	Less opportunity to occur such as occur once in 5-10 years
3	Moderate opportunity to occur such as occur once in 1-5 years
4	High opportunity to occur such as occur more than once a year

2.4.2 Considering the severity of events: that affect to people, community, environment, or assets. The severity divided as 4 levels as the table 2.5, 2.6, 2.7, 2.8

Table 2.5 Severity level in various events that affect to people

Level	Severity	Specification
1	Less	Minor injury in first aid level
2	Medium	Injury that require medical attention
3	High	Severe injury or illness
4	Very High	Disability or death

Table 2.6 Severity level in various events that affect to community

Level	Severity	Specification
1	Less	Not effect to the community around factory / or less effect
2	Medium	Effect to the community around factory and take short time to be solved
3	High	Effect to the community around factory and take more time to be solved
4	Very High	Severe effect to the community in wide area or must be solved by the government agency

Note: Community affect means nuisance in the community, injury, illness, and damage to community and people assets

Table 2.7 Severity level in various events that affect to environment

Level	Severity	Specification
1	Less	Less effect to the environment and can control or solve
2	Medium	Moderate effect to the environment and take short time to be solved
3	High	Severe effect to the environment and take more time to be solved
4	Very High	Very severe effect to the environment and need resources and more time to be solved

Note : Environment impact means degradation and damage environmental such as air, soil, water source, etc.

Table 2.8 Severity level in various events that affect to assets

Level	Severity	Specification
1	Less	Less or no asset damage
2	Medium	Moderate asset damage and the production can be continued
3	High	Severe asset damage and have to stop some production processes
4	Very High	Sever asset damage and have to stop all production processes

Note : The damage of asset in each level, the factory can be suitably assigned by consider the factory's capacity

2.4.3 Risk Level:

Risk levels consider the result of the probability level multiply by the severity level that affect to people, community, environment, and assets. If the severity level is different, select the highest level as risk assessment level of the each event. The risk level divided as 4 levels as the table 2.9

Table 2.9 Risk level

Level	Result	Meaning
1	1-2	Less risk
2	3-6	Acceptable risk but require to review the control measure
3	8-9	High risk but require the action to decrease risk
4	12-16	Non-acceptable risk, need to stop the production process and immediately solve to decrease risk

2.5 Analysis Hierarchy Process: AHP

Analysis Hierarchy Process (AHP)[4,9,10,11,12] is a structured multi-attribute decision method. AHP is the most efficient technique based on paired comparisons and provides a review of various scenarios. The advantage of AHP is

- The result is more credible than other methods because AHP use a Pairwise Comparison method before make a decision.
- Structure of AHP is a hierarchical chart likewise the human thought process that easy to use and understand.
- The result is quantitative, which easy for prioritization also can use the results for Benchmarking with other agencies.
- Biased elimination
- Available for both individual and group decisions
- Make compromises and build referendums
- No need the specialists to be controlled

Decision procedure by using Analysis Hierarchy Process:

AHP (Analysis Hierarchy Process) is very effective. The processes start by compare the importance of criteria used to make the decision, find the weight of each criterion, and evaluate all alternatives then rating for each decision alternative. The decision processes show as below:

2.5.1 Create a hierarchical chart or model of decision: Decompose the decision-making problem into a hierarchy of criteria and alternatives.

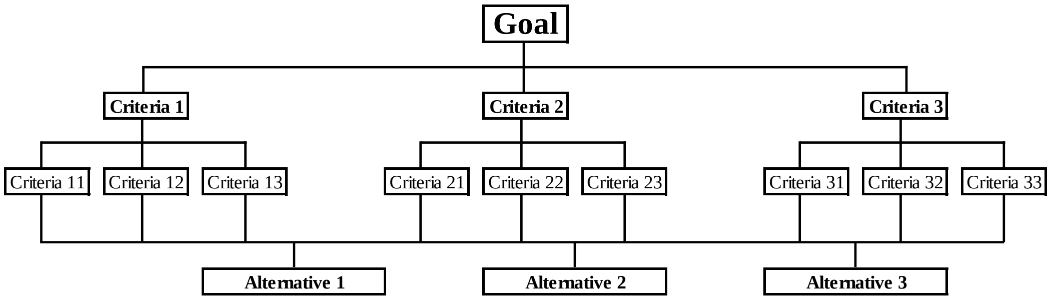


Figure 2.2 Example of hierarchical chart or model of decision

The structure of this chart consists of "elements" or factors that relate to make the decision. Features of this chart are kind of levels. The number of level is depending on the complex of decision.

- Level 1: This is a top level displays the goal of the decision.

- Level 2: The level represents the decision criteria that affect to target in the decision making.

- Level 3: This level and next to this level down show sub criteria. The amount of sub criteria depends on the clarity of the Level 2 (This level may not necessary, if the main criteria is clear enough.)

- The bottom level or the last level is the alternative choice that was consider by the decision criteria.

2.5.2 Develop the Weights for the criteria: Because each criteria have different influences for decision, so we need to weigh the importance of the criteria before evaluate alternatives. There is processes as below:

- Develop a pairwise comparison matrix for each criterion.

Table 2.10 The example of a pairwise comparison matrix

Criteria	C1	C2	C3
C1	c_{11}	c_{12}	c_{13}
C2	c_{21}	c_{22}	c_{23}
C3	c_{31}	c_{32}	c_{33}

By c_{ij} is a member of row i column j in the matrix, the comparison results between factors C_i and C_j

- Define scales for comparison

Pairwise Comparison must use a set of numbers to compare. The set of number is very important and there are 9 levels of AHP Measurement Scale.

Table 2.11 The example scale for comparison (Saaty, 1980)

Scale	Degree of preference
1	Equally Preferred
2	Equally to Moderately Preferred
3	Moderately Preferred
4	Moderately to Strongly Preferred
5	Strongly Preferred
6	Strongly to Very Strongly Preferred
7	Very Strongly Preferred
8	Very Strongly to Extremely Preferred
9	Extremely Preferred

The number of scale levels in this comparison depends on comparison detail that the analyst needs: for example; the analyst can add the scale level, if a_{ij} = 9 mean factor A_i is more important than A_j excessively or if the gap between factor A_i and A_j is very high. The add level will decrease the A_i and A_j gap: for example; a_{ij} = 2 mean factor A_i is more important than A_j lightly, a_{ij} = 3 mean factor A_i is more important than A_j moderately and so on.

2.5.3 Calculate the criteria weights:

Team will rate the criteria weights by using Pairwise Comparison start with the top level to the bottom down. After got the scores, team will calculate the weight or relative priority of that each level from the top to the bottom to do, so will know the total score from all level.

2.5.3.1 Create the Pairwise Comparison matrix by The criteria in the row will be compared to the criteria in the column

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}$$

2.5.3.2 Sum the value in each column of the pairwise matrix

$$C_{ij} = \sum_{i=1}^{n} C_{ij}$$

2.5.3.3 Divide each element in the matrix by its column total to generate a normalized pairwise matrix. The sum of each column is 1.

$$Xij = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}}$$

$$\begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix}$$

2.5.3.4 Divide the sum of the normalized column of matrix by the number of criteria used (n) to generate weighted matrix.

$$Wij = \frac{\sum_{j=1}^{n} X_{ij}}{n}$$

$$\begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix}$$

2.5.4 Calculating and checking the consistency ratio (C.R):

The purpose for doing this is to make sure that the original preference ratings were consistent. There are 3 steps to arrive at the consistency ratio:

2.5.4.1 Calculate the the maximum eigenvalue of matrix (λ_{max})

- Multiply the pair wise comparison matrix by the weights vector.

- Divide the weighted sum vector with criterion weight.

- Average the value of the consistency vector

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{21} \\ Cv_{31} \end{bmatrix}$$

$$Cv_{11} = \frac{1}{W_{11}} [C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31}]$$

$$Cv_{21} = \frac{1}{W_{21}} [C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31}]$$

$$Cv_{31} = \frac{1}{W_{11}} [C_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31}]$$

$$\lambda_{max} = \frac{(Cv11 + Cv21 + Cv31)}{n}$$

2.5.4.2 Calculate the consistency index (CI)

$$C.I. = \frac{(\lambda_{max} - n)}{(n-1)}$$

2.5.4.3 Calculate the consistency ratio (CR)

$$C.R. = \frac{C.I.}{R.I.}$$

where Random Consistency Index (RI) is the consistency index of a randomly-generated pair wise comparison matrix as shown in Table 2.12

Table 2.12 Random consistency index [n = size of the reciprocal matrix]

N	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Acceptable value of Consistency Ratio (C.R.) must lower than 0.1 (10%.) If the C.R equal or higher that 0.1, analyst needs to compare the value again or cut off this information. In order to confirm the importance weight, we have to calculate C.R. in all levels to the final level.

2.5.5 Develop the ratings for each decision alternative for each criterion: by the process as same as 2.5.2 – 2.5.4

2.5.6 Calculate the weighted average rating for each decision alternative and choose the one with the highest score:

Table 2.13 The example of the weight of criteria and alternative

Criteria	C1	C2	C3
The weight	W_{11}	W_{21}	W_{31}
Alternative 1	X_{11}	Y_{11}	Z_{11}
Alternative 2	X_{21}	Y_{21}	Z_{21}
Alternative 3	X_{31}	Y_{31}	Z_{31}

Alternative 1 = $(W_{11} * X_{11}) + (W_{21} * Y_{11}) + (W_{31} * Z_{11})$

Alternative 2 = $(W_{11} * X_{21}) + (W_{21} * Y_{21}) + (W_{31} * Z_{21})$

Alternative 3 = $(W_{11} * X_{31}) + (W_{21} * Y_{31}) + (W_{31} * Z_{31})$

2.6 Literature reviews

Habibi E. and team (2011)[(13)] studied the comparison of Hazard Identification in the chemical department of a power plant using Energy Trace and Barrier Analysis (ETBA) and Hazard Operability Study (HAZOP). According to the result of HAZOP, there were 126 deviations and 293 causes, most of which related to equipment 43.5%, operators 35.8%, control measures 9.2% and others 12%. 175 recommendations were developed, that related to equipment modification and improvement 42%, normal maintenance 35%, and correct operation method controlling 23%.

The ETBA found 113 hazards. The higher risk levels were about flange leaks, hose failures, and explosion from improper mixing of acid and alkaline. 47 recommendations were developed, that related to equipment modification and improvement 28%, normal maintenance 30%, and correct operation method controlling 42%. Even though HAZOP could identify more hazards than ETBA, there were some specific hazards must identify by ETBA. Using both HAZOP and ETBA together help to enhance the evaluation accuracy and can be more investigate than using one.

Mohammadfam I. and team (2012)[(14)] studied the comparison of safety assessment of Chlorination Unit in Tehran Treatment Plant by doing hazard identification and risk assessment under the method of Hazard and Operability Study (HAZOP) and Energy Trace and Barrier Analysis (ETBA) then selected the best method by using the technique of Analytical Hierarchy process (AHP). There are 6 factors which had to be determined including number of identified risks, the cost of eliminating intolerable risks, the number of identified human errors, the identified risk levels, the time and budget required to perform the assessment.

According to HAZOP study, there were 151 risks that divided to 16 intolerable risk levels, 33 moderate risk levels, and 102 low risk levels. According to ETBA study, there were 59 risks that divided to 20 intolerable risk levels, 14 moderate risk levels, and 25 low risk levels.

ETBA found the amount of human errors 5% of the all errors, while HAZOP found only 0.6% of the overall. HAZOP had cost of control measures the intolerable risk higher than ETBA . Time and cost required to perform the assessment by HAZOP are triple more when compared to ETBA.

When selected the best method by using the technique of Analytical Hierarchy process (AHP) with 6 factors as show above, ETBA had higher scores than HAZOP and the Consistency Ratio lower than 0.1 or 10%. This study can conclude that ETBA is more appropriate than HAZOP.

Abbasi S. and team (2014)[(15)] studied the risk assessment using HAZOP and ETBA in Gasoline Refinery Unit in Iran. According to the result of HAZOP, there were 44 deviations and 126 causes, consisted of unacceptable risks 11.37%, undesired risks 36.36%, acceptable risks but need to review the control measure 29.55%, and acceptable risks 22.72%. In accordance with the hazard causes analysis, it found equipment failure 46.03%, system functions and control systems failure 40.47%, human error 7.95%, and weather conditions and natural disasters 5.55%. According to the result of ETBA, there were 33 total defects divided to unacceptable risks 10.52%, undesired risks 27.27%, acceptable risks but need to review the control measure 22.72%, and acceptable risks 39.39%. The study concluded that HAZOP has more appropreate for hazard identification than ETBA, but some hazards can be found by ETBA,where HAZOP cannot identify. Hence, using both HAZOP and ETBA together for risk assessment is more agreeable.

CHAPTER III
MATERIALS AND METHODS

3.1 Research Pattern

The research is cross-sectional analytical study. The researcher will give the production information for risk assessment of tank farm in power plant by Checklist, What-if analysis, and HAZOP. Then compare the result of each method and choose the most effective method by using Analytic Hierarchy Process (AHP).

3.2 Research Tools

3.2.1 Risk and Hazard form (Figure A.1, Appendix A)

3.2.2 Checklist form (Figure A.2, Appendix A)

3.2.3 What-If Analysis form (Figure A.3, Appendix A)

3.2.4 Hazard and Operability Study (HAZOP) form (Figure A.4, Appendix A)

3.2.5 Analytic Hierarchy Process (AHP)

3.3 Research Procedures

3.3.1 Create lists of the risks and hazards: Using the risk and hazard form (Figure A.1, Appendix A)

3.3.2 Conduct the Hazard Identification and Risk Assessment by using Checklist:

3.3.2.1 Prepare all data needed and related documentaries such as law, standard, regulation relating to tank farm, and tank farm production processes

3.3.2.2 Create question topics related to the tank farm by start with the first production process until the last.

3.3.2.3 Correct the Checklist by specialist then adjust the Checklist according to expert advice

3.3.2.4 Begin study by using the revised Checklist

3.3.2.5 Identify hazard by bring the answer that did not follow the prescribed, follow the prescribed but not correct, not suitable, uncompleted, or delayed (Using the checklist form in Figure A.2, Appendix A)

3.3.2.6 Consider the hazards or consequences according to not follow the question topic

3.3.2.7 Consider the current control and prevention measures

3.3.2.8 Suggest more prevention and control methods

3.3.2.9 Do the Risk Assessment and Risk Ranking

3.3.3 Conduct the Hazard Identification and Risk Assessment by using What-If Analysis:

3.3.3.1 Study information and related documents: for example; information about tank farm production processes, working processes in both normal and emergency situations, safety equipment guidebook, maintenance documentations, and Piping and Instrumentation Diagrams (P&ID).

3.3.3.2 Create questions about hazards or causes of accidents that may occur sorting by production processes or working processes

3.3.3.3 Select questions that are useful for reducing accidents or health problems then identify the hazards and consequences (Using the what-if analysis form in Figure A.3, Appendix A)

3.3.3.4 Identify preventive or control measures and suggestion or improving guideline

3.3.3.5 Do the Risk Assessment and Risk Ranking

3.3.4 Conduct the Hazard Identification and Risk Assessment by using HAZOP:

3.3.4.1 Prepare all data needed such as Piping and Instrumentation Diagrams (P&ID) and the tank farm production processes.

3.3.4.2 Divided the diagram to NODE then select the NODE needed

3.3.4.3 Set the parameters

3.3.4.4 Use the Guide words to study about relate parameters that probably have problems or hazards (Using the hazard and operability study (HAZOP) form in Figure A.4, Appendix A)

3.3.4.5 Record possible causes, result, and solutions

3.3.4.6 Do the Risk Assessment and Risk Ranking

3.3.5 Compare the results from the 3 methods in the each activity: by considering the number of identified risks, the cost of eliminating intolerable risks, the number of identified human errors, the identified high risk levels, the time and budget required to perform the assessment

Table 3.1 The result of risk assessment by HAZOP, What-if analysis, Checklist

Criteria	Hazard identification and risk assessment method		
	Checklist	What-if analysis	HAZOP
The number of identified risks			
The cost of eliminating intolerable risks			
The number of identified human errors			
The identified high risk levels			
The time required to perform the assessment			
The budget required to perform the assessment			

3.3.6 Select the most effective risk assessment method using the Analytic Hierarchy Process:

3.3.6.1 Create hierarchical charts or decision models

3.3.6.2 Develop the Weight for the criteria

3.3.6.3 Calculate the criteria weight

3.3.6.4 Calculating and checking the consistency ratio (C.R)

3.3.6.5 Develop the rating for each decision alternative for each criterion

3.3.6.6 Calculate the weighted average rating for each decision alternative. Choose the one with the highest score

3.4 Data Analysis

3.4.1 Analyze the result of risk assessment of the 3 methods by descriptive statistics in terms of numbers and percentages.

3.4.2 Select the most effective method using the result from Analytic Hierarchy Process (AHP) with the highest score.

CHAPTER IV
RESULTS

This chapter presents the results of hazard identification and risk assessment in the power plant's tank farm by checklist, what-if analysis, and HAZOP techniques, then selects the most effective method by using Analytic Hierarchy Process (AHP). The risk assessment team consists of 10 workers, who associate with the tank farm such as 1 safety section manager, 2 plant operation engineers, 2 operators, 1 mechanical engineer, 1 electrical engineer, 1 civil engineer, 1 chemist, and 1 safety officer. All the team members are the people whose experience over 1 year in the tank farm, including expertise in the production processes.

The chapter covers the list of risk and hazard, results of hazard identification and risk assessment under the methods of Checklist, What-if analysis, and HAZOP, and outcomes of decision making under the Analytic Hierarchy Process: AHP.

4.1 The list of risk and hazard

There are 3 processes in the tank farm such as unloading diesel oil from oil truck, diesel oil storage, pumping diesel oil to gas turbine. In the each process contains risks and hazards as shown in table 4.1

Table 4.1 The list of risk and hazard

Plant Processes	Risks and Hazards	Potential Impact	Note
1. Unloading diesel oil from a oil truck			
1.1 Checking diesel oil level in the unloading tank before pumping	- Fall down from ladder or unloading tank	- Employee gets injured	

Table 4.1 The list of risk and hazard (cont.)

Plant Processes	Risks and Hazards	Potential Impact	Note
1.1 Checking diesel oil level in the unloading tank before pumping (cont.)	- The cover of gauge hatch hits the hand - Sounding tape cut the hand - Diesel oil vapor	- Employee gets injured - Employee gets injured - Inhalation of vapor can irritate to the respiratory system - Fire or explosion, if has ignition source	
1.2 Preparing for the diesel oil unloading			
- Drive a oil truck to truck loading area then prepare for the diesel oil unloading	- Truck crashes an operator - Truck hits a pole	- Operator gets injured or died - Damage to property	
- Connect the ground wire between the truck and the diesel oil unloading platform	- Ground wire cut the hand - Ground wire becomes worn out	- Operator gets injured - The electrostatic is occurred and cause to fire or explosion	
- Check water contamination in the oil truck	- Fall down from the truck - Diesel oil vapor	- Operator gets injured - Operator gets injured - Inhalation of vapor can irritate to the respiratory system - Fire or explosion, if has ignition source	

Table 4.1 The list of risk and hazard (cont.)

Plant Processes	Risks and Hazards	Potential Impact	Note
1.2 Preparing for the diesel oil unloading (cont.) - Collect the oil sample in a truck - Connect a flexible hose to the oil truck	 - Oil spill - Diesel oil vapor - The head of hose cut the hand - Stumble on the hose	 - Slipping - Inhalation of vapor can irritate to the respiratory system - Fire or explosion, if has ignition source - Operator gets injured - Operator gets injured	
1.3 Open the oil truck valve	- Valve cut the hand - Stumble on the flexible hose - Oil spill around the pump or joints - Diesel oil vapor	- Operator gets injured - Operator gets injured - Operator gets injured because of slip - Inhalation of vapor can irritate to the respiratory system - Fire or explosion, if has ignition source	
1.4 Take off the flexible hose and ground wire from the truck	- Get the hand cut by the head of flexible hose - Stumble on the flexible hose	- Operator gets injured - Operator gets injured	

Table 4.1 The list of risk and hazard (cont.)

Plant Processes	Risks and Hazards	Potential Impact	Note
1.4 Take off the flexible hose and ground wire from the truck (cont.)	- Oil spill - Diesel oil vapor - Get the hand cut by ground wire	- Operator gets injured because of slip - Inhalation of vapor can irritate to the respiratory system - Fire or explosion, if has ignition source - Operator gets injured	
1.5 Drive a oil truck out of the truck loading area	- Truck crashes an operator - Trucks collision	- Operator gets injured - Damage to property	
1.6 Checking diesel oil level in the unloading tank after pumping	- Fall down from ladder or unloading tank - The cover of gauge hatch hits the hand - Sounding tape cut the hand - Diesel oil vapor	- Operator gets injured - Operator gets injured - Operator gets injured - Inhalation of vapor can irritate to the respiratory system - Fire or explosion, if has ignition source	
2. Diesel oil Storage	- Storage tank or pipe leak is a cause of oil spill	- Fire or explosion, if has ignition source - Environmental damage by oil contaminate water and soil	

Table 4.1 The list of risk and hazard (cont.)

Plant Processes	Risks and Hazards	Potential Impact	Note
2. Diesel oil Storage (cont.)	- Thunderclap - Sabotage	- Fire or explosion cause to the property damage - Fire or explosion cause to the property damage	
3. Pumping diesel oil to gas turbine	- Pipe leak is a cause of oil spill - Diesel oil vapor - Noise - Electrical shock - Electrical equipment short circuit	- Fire or explosion, if has ignition source - Environmental damage by oil contaminate water and soil - Inhalation of vapor can irritate to the respiratory system - Fire or explosion, if has ignition source - Hearing loss - Operator gets injured - Fire or explosion cause to the property damage	

4.2 The result of hazard identification and risk assessment using Checklist, What-if analysis, and HAZOP techniques

Hazard identification and risk assessment by Checklist are starting from create the checklist for power plant's tank farm. The question topics were from Ministerial Regulations Tank Farm B.E. 2556, Ministerial Regulations Power Supply and Lightning Protection of the Oil Business B.E. 2556, Ministerial Regulations Oil Transportation by Oil Tank B.E. 2558, and Work Instruction of Unloading Fuel Oil in Power Plant. After the team verified actual works in power plant's tank farm, there are

7 non-compliances with requirements (Appendix B). The team did implement in all the non-compliances for hazard identification and risk assessment with the Checklist method. The result of assessment found 7 risks, which consisted of 3 less risks and 4 acceptable risks. Most of the risks were about lack of annual inspection of storage tanks, safety valves of firefighting and safety system, safety valves or hose of the oil pumps, fire pumps, and alarm system. Describing the detail in the Figure C.1, Appendix C.

Hazard identification and risks assessment by What-if analysis with 3 processes, included unloading diesel oil from oil truck, diesel oil storage, pumping diesel oil to gas turbine, displayed the assessment results in 25 risks. The risks consisted of 1 less risk, 20 acceptable risks, and 4 high risks. The high risks associated with having no ground wire while unloading fuel oil from a fuel oil truck, ground wire becomes worn out, or having heat or ignition in the tank farm, which were the potential cause of fire or explosion. Describing the detail in the Figure C.2 – C.7, Appendix C.

Hazard identification and risks assessment by HAZOP divided the systems of tank farm into 3 NODE. NODE 1 starts from unloading fuel oil from the fuel oil truck through to the unloading pump before transfer to the unloading tank. NODE 2, the fuel oil transfers from transfer pump into 2 storage tanks. The forwarding pump in NODE 3 will pump the fuel oil to gas turbine as details in figure 4.1.

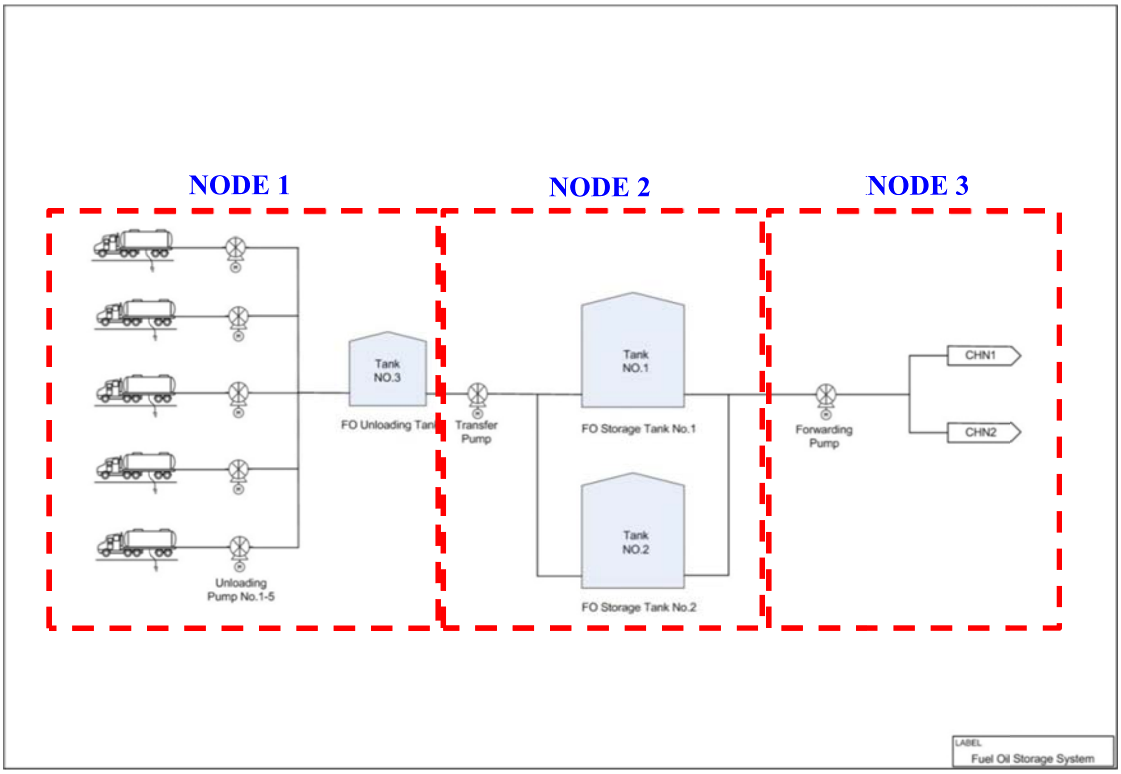


Figure 4.1 Study area on the method of HAZOP of Fuel Oil Storage System

The result of HAZOP, there were 54 risks consisted of 1 less risk, 34 acceptable risks, 17 high risks, and 2 non-acceptable risks. The non-acceptable risks were the decreasing of oil flow rate and there was no pressure within the forwarding pump, which created the system to malfunction, no ignite, or prevent the oil from entering to the system, impact for the process of generating electric power. Describing the detail in the Figure C.8 – C.22, Appendix C.

According to the evaluations conducted, 56% of the errors identified by the What-if analysis and 20.4% of the errors by the HAZOP were attributed to human errors, while Checklist had no human error. Considering about cost of higher risk control, the cost of taking control measures in HAZOP is more than What-if analysis and Checklist. In accordance with economic analysis, hazard identification under the method of HAZOP spent times and costs rather than the method of What-if analysis and Checklist, respectively. The hazard identification and risk assessment of the 3 methods were shown in table 4.2.

Table 4.2 Comparisons of hazard identification and risk assessment

Criteria	Methods of hazard identification and risk assessment		
	Checklist	**What-if Analysis**	**HAZOP**
the number of identified risks	7	25	54
the cost of eliminating intolerable risks	0	Low	Moderate
the number of identified human errors	0	56%	20.4%
the identified high risk levels	0	16%	35.2%
the time required to perform the assessment	7 hours	16 hours	25 hours
the budget required to perform the assessment	12,810 baht	29,280 baht	45,750 baht

Note :

1. The cost of eliminating intolerable risks divided in 3 levels as below;

Low	less than 10,000 baht
Moderate	10,000 – 100,000 baht
High	Over 100,000 baht

2. The budget required to perform the assessment refers to salary / wages of Risk Assessment Team, which consists of 1 safety section manager, 2 plant operation engineers, 2 operators, 1 mechanical engineer, 1 electrical engineer, 1 civil engineer, 1 chemist, and 1 safety officer. The average cost for hazard identification is approximately 1,830 baht per hour.

4.3 The result of decision making by Analytic Hierarchy Process: AHP

4.3.1 Creating the hierarchical chart of decision making

The hierarchical chart enables to select the most effective risk assessment methods, which consists of 3 alternatives such as Checklist , What-if analysis , and

HAZOP. There are 6 criteria use for making decision are the number of identified risks, the cost of eliminating intolerable risks, the number of identified human errors, the identified high risk levels, the time and budget required to perform the assessment. The structure of hierarchy chart as details in figure 4.2.

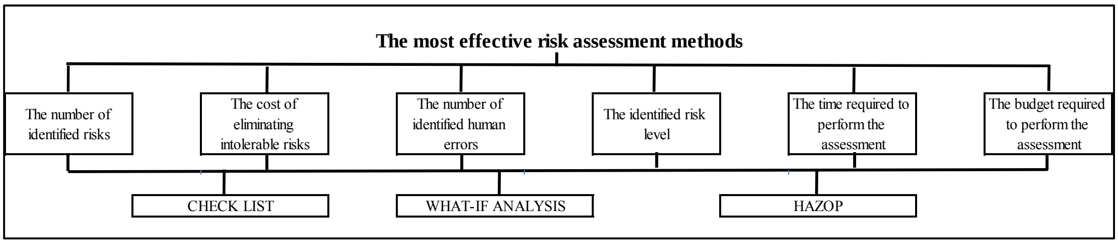


Figure 4.2 The Hierarchical chart of decision making for risk assessment methods

4.3.2 Develop the weights for the criteria

4.3.2.1 Develop a pairwise comparison matrix for each criterion

The team created a pairwise matrix to compare the importance of each criterion for decision making as shown in table 4.3.

Table 4.3 The pairwise comparison matrix for each criterion

Criteria	The number of identified risks	The cost of eliminating intolerable risks	The number of identified human errors	The identified high risk levels	The time required to perform the assessment	The budget required to perform the assessment
The number of identified risks	1	3	1/3	1/5	3	3
The cost of eliminating intolerable risks	1/3	1	1/3	1/5	3	3
The number of identified human errors	3	3	1	1/3	5	5
The identified high risk levels	5	5	3	1	7	7
The time required to perform the assessment	1/3	1/3	1/5	1/7	1	1
The budget required to perform the assessment	1/3	1/3	1/5	1/7	1	1

Meaning of the numbers added to the table are as follow;

- Diagonal rows in the table are always equal to number 1 due to the same criteria comparison and has equally important
- Row 1 Column 2 is equal to 3, which means the team focuses on the number of identified risks “more than” the cost of eliminating intolerable risks “lightly”
- Row 1 Colume 3 is equal to 1/3, which means the team focuses on the number of identified risks “less than” the number of identified human errors “lightly”
- Row 4 Column 1 is equal to 5, which means the team focuses on the identified high risk levels “more than” the number of identified risks “moderately”
- Row 4 Column 5 is equal to 7, which means the team focuses on the identified high risk levels “more than” the time required to perform the assessment “excessively”
- Row 6 Column 3 is equal to 1/5, which means the team focuses on the budget required to perform the assessment “less than” the number of identified human errors “moderately”
- Row 6 Column 4 is equal to 1/7, which means the research team focuses on the budget required to perform the assessment “less than” the identified high risk levels “excessively”, etc.

4.3.2.2 Calculate the criteria weights

Calculate the criteria weights start with summarize all number in the each column then divide the each number of the each column by that summarize number. Next, calculate the summarize of the each row and divide the result of summarize by the amount of criteria for decision making, which is the number 6 for this study. The result of the criteria weights as shown in table 4.4.

Table 4.4 The criteria weights

Criteria	The number of identified risks	The cost of eliminating intolerable risks	The number of identified human errors	The identified risk level	The time required to perform the assessment	The budget required to perform the assessment	Total	The criteria weights
The number of identified risks	0.100	0.237	0.066	0.099	0.150	0.150	0.802	0.134
The cost of eliminating intolerable risks	0.033	0.079	0.066	0.099	0.150	0.150	0.577	0.096
The number of identified human errors	0.300	0.237	0.197	0.165	0.250	0.250	1.399	0.233
The identified risk level	0.500	0.395	0.592	0.495	0.350	0.350	2.682	0.447
The time required to perform the assessment	0.033	0.026	0.039	0.071	0.050	0.050	0.270	0.045
The budget required to perform the assessment	0.033	0.026	0.039	0.071	0.050	0.050	0.270	0.045
Total	1.000	1.000	1.000	1.000	1.000	1.000	6.000	1

Calculate the Consistency Ratio : C.R.

C.R. = C.I. / R.I.

By C.I. = $\frac{(\lambda_{max} - n)}{(n-1)}$

$$\begin{bmatrix} 1 & 3 & 1/3 & 1/5 & 3 & 3 \\ 1/3 & 1 & 1/3 & 1/5 & 3 & 3 \\ 3 & 3 & 1 & 1/3 & 5 & 5 \\ 5 & 5 & 3 & 1 & 7 & 7 \\ 1/3 & 1/3 & 1/5 & 1/7 & 1 & 1 \\ 1/3 & 1/3 & 1/5 & 1/7 & 1 & 1 \end{bmatrix} * \begin{bmatrix} 0.134 \\ 0.096 \\ 0.233 \\ 0.447 \\ 0.045 \\ 0.045 \end{bmatrix} = \begin{bmatrix} 6.430 \\ 6.006 \\ 6.524 \\ 6.544 \\ 6.160 \\ 6.160 \end{bmatrix}$$

λ_{max} = $\frac{(6.430 + 6.006 + 6.524 + 6.544 + 6.160 + 6.160)}{6}$

= 6.304

C.I. = $\frac{(6.304-6)}{(6-1)}$

= 0.0608

In table 2.12 shown Random Consistency Index (R.I) and size of the reciprocal matrix for this study is 6, so R.I. is equal to 1.24.

So, C.R. = 0.0608 / 1.24

= 0.049

Conclusion, C.R. = 0.049, which is less than 0.1. Thereby, the consistency of the comparison is an acceptable value.

According to the result of the calculation, indicates that the team focused on “the identified high risk levels” the most (0.447). The second is the number of identified human errors (0.233), next to the number of identified risks (0.134), the cost of eliminating intolerable risks (0.096), the time required to perform the assessment (0.045), and the budget required to perform the assessment (0.045), respectively.

4.3.3 Develop the ratings for each decision alternative under the criteria “the number of identified risks”

4.3.3.1 Develop the ratings for each decision alternative under the criteria “the number of identified risks”

Create a pairwise matrix to compare the importance of each alternatives, under the criteria “the number of identified risks”, references from the table 4.2.

Table 4.5 The number of identified risks

Criteria	Checklist	What-if Analysis	HAZOP
The number of identified risks	7	25	54

Table 4.6 The pairwise comparison matrix for each alternative under “the number of identified risks”

The number of identified risks	Checklist	What-if analysis	HAZOP
Checklist	1	1/5	1/7
What-if analysis	5	1	1/3
HAZOP	7	3	1

Meaning of the numbers added to the table are as follow;

- Row 1 Column 1 is equal to number 1 due to the same alternative comparison and has equally important
- Row 1 Column 2 is equal to 1/5, which means the number of identified risks by Checklist is “less than” the number of identified risks by What-if analysis “moderately”
- Row 3 Column 1 is equal to 7, which means the number of identified risks by HAZOP “more than” the number of identified risks by Checklist “excessively”
- Row 3 Column 2 is equal to 3, which means the number of identified risks by HAZOP “more than” the number of identified risks by What-if analysis “lightly”, etc.

4.3.3.2 Calculate the alternative weights under “the number of identified risks”

Calculate the weights start with summarize all number in the each column then divide the each number of the each column by that summarize number. Next, calculate the summarize of the each row then divide the result of summarize by the amount of alternatives, which is the number 3 for this study. The result of the alternative weights under "the number of identified risks" as shown in table 4.7

Table 4.7 The alternative weights under "the number of identified risks"

The number of identified risks	Checklist	What-if analysis	HAZOP	Total	The alternative weights
Checklist	0.077	0.048	0.097	0.221	0.074
What-if analysis	0.385	0.238	0.226	0.849	0.283
HAZOP	0.538	0.714	0.677	1.930	0.643
Total	1.000	1.000	1.000	3.000	1

Calculate the Consistency Ratio : C.R.

$$C.R. = C.I. / R.I.$$

By $$C.I. = \frac{(\lambda_{max} - n)}{(n-1)}$$

$$\begin{bmatrix} 1 & 1/5 & 1/7 \\ 5 & 1 & 1/3 \\ 7 & 3 & 1 \end{bmatrix} * \begin{bmatrix} 0.074 \\ 0.283 \\ 0.643 \end{bmatrix} = \begin{bmatrix} 3.013 \\ 3.062 \\ 3.121 \end{bmatrix}$$

$$\lambda_{max} = \frac{(3.013 + 3.062 + 3.121)}{3}$$

$$= 3.066$$

$$C.I. = \frac{(3.066-3)}{(3-1)}$$

$$= 0.0328$$

In table 2.12 shown Random Consistency Index (R.I) and size of the reciprocal matrix for this study is 3, so R.I. is equal to 0.58.

So, $$C.R. = 0.0328 / 0.58$$

$$= 0.056$$

Conclusion C.R. = 0.056, which is less than 0.1. Thereby, the consistency of the comparison is an acceptable value.

According to the calculation, under the criteria for decision making "the number of identified risks" indicates that HAZOP has the most importance (0.643), What-if analysis is the second (0.283), and the third is Checklist (0.074).

4.3.4 Develop the ratings for each decision alternative under the criteria "the cost of eliminating intolerable risks"

4.3.4.1 Develop a pairwise comparison matrix for each alternative under the criteria "the cost of eliminating intolerable risks"

Create a pairwise matrix to compare the importance of each alternatives, under the criteria "the cost of eliminating intolerable risks", references from the table 4.2.

Table 4.8 The cost of eliminating intolerable risks

Criteria	**Checklist**	**What-if Analysis**	**HAZOP**
The cost of eliminating intolerable risks	0	Low	Moderate

Table 4.9 The pairwise comparison matrix for each alternative under "the cost of eliminating intolerable risks"

The cost of eliminating intolerable risks	Checklist	What-if analysis	HAZOP
Checklist	1	3	5
What-if analysis	1/3	1	3
HAZOP	1/5	1/3	1

4.3.4.2 Calculate the alternative weights under "the cost of eliminating intolerable risks"

Calculating the weights start with summarize all number in the each column then divide the each number of the each column by that summarize number. Next, calculating the summarize of the each row then divide the result of summarize by the amount of alternatives, which is the number 3 for this study. The result of the alternative weights under "the cost of eliminating intolerable risks" as shown in table 4.10.

Table 4.10 The alternative weights under "the cost of eliminating intolerable risks"

The cost of eliminating intolerable risks	Checklist	What-if analysis	HAZOP	Total	The alternative weights
Checklist	0.652	0.692	0.556	1.900	0.633
What-if analysis	0.217	0.231	0.333	0.781	0.261
HAZOP	0.130	0.077	0.111	0.318	0.106
Total	1.000	1.000	1.000	3.000	1

Calculate the Consistency Ratio : C.R.

$$C.R. = C.I. / R.I.$$

By $$C.I. = \frac{(\lambda_{max} - n)}{(n-1)}$$

$$\begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 3 \\ 1/5 & 1/3 & 1 \end{bmatrix} * \begin{bmatrix} 0.633 \\ 0.261 \\ 0.106 \end{bmatrix} = \begin{bmatrix} 3.072 \\ 3.033 \\ 3.011 \end{bmatrix}$$

$$\lambda_{max} = \frac{(3.072 + 3.033 + 3.011)}{3}$$

$$= 3.039$$

$$C.I. = \frac{(3.039-3)}{(3-1)}$$

$$= 0.0194$$

In table 2.12 shown Random Consistency Index (R.I) and size of the reciprocal matrix for this study is 3, so R.I. is equal to 0.58.

So, $$C.R. = 0.0194 / 0.58$$

$$= 0.033$$

Conclusion, C.R. = 0.033, which is less than 0.1. Hence, the consistency of the comparison is an acceptable value.

According to the calculation, under the criteria for decision making "the cost of eliminating intolerable risks" indicates that Checklist is the most importance (0.633), What-if analysis is the second (0.261), and the third is HAZOP (0.106)

4.3.5 Develop the ratings for each decision alternative under the criteria "the number of identified human errors"

4.3.5.1 Develop a pairwise comparison matrix for each alternative under the criteria "the number of identified human errors"

Create a pairwise matrix to compare the importance of each alternatives, under the criteria "the number of identified human errors", references from the table 4.2.

Table 4.11 The number of identified human error

Criteria	Checklist	What-if Analysis	HAZOP
The number of identified human errors	0	56%	20.4%

Table 4.12 The pairwise comparison matrix for each alternative under "the number of identified human errors"

The number of identified human errors	Checklist	What-if analysis	HAZOP
Checklist	1	1/5	1/3
What-if analysis	5	1	3
HAZOP	3	1/3	1

4.3.5.2 Calculate the alternative weights under "the number of identified human errors"

Calculating the weights start with summarize all number in the each column then divide the each number of the each column by that summarize number. Next, calculating the summarize of the each row then divide the result of summarize by the amount of alternatives, which is the number 3 for this study. The result of the alternative weights under "the number of identified human errors" as shown in table 4.13.

Table 4.13 The alternative weights under "the number of identified human errors"

The number of identified human errors	Checklist	What-if analysis	HAZOP	Total	The alternative weights
Checklist	0.111	0.130	0.077	0.318	0.106
What-if analysis	0.556	0.652	0.692	1.900	0.633
HAZOP	0.333	0.217	0.231	0.781	0.261
Total	1.000	1.000	1.000	3.000	1

Calculate the Consistency Ratio : C.R.

C.R. = C.I. / R.I.

By C.I. = $\frac{(\lambda_{max} - n)}{(n-1)}$

$$\begin{bmatrix} 1 & 1/5 & 1/3 \\ 5 & 1 & 3 \\ 3 & 1/3 & 1 \end{bmatrix} * \begin{bmatrix} 0.106 \\ 0.633 \\ 0.261 \end{bmatrix} = \begin{bmatrix} 3.011 \\ 3.072 \\ 3.033 \end{bmatrix}$$

λ_{max} = $\frac{(3.011 + 3.072 + 3.033)}{3}$

= 3.039

C.I. = $\frac{(3.039-3)}{(3-1)}$

= 0.0194

In table 2.12 shown Random Consistency Index (R.I) and size of the reciprocal matrix for this study is 3, so R.I. is equal to 0.58.

So, C.R. = 0.0194 / 0.58

= 0.033

Conclusion, C.R. = 0.033, which is less than 0.1. Hence, the consistency of the comparison is an acceptable value

According to the calculation, under the criteria for decision making "the number of identified human errors" indicates that What-if analysis has the most importance (0.633), HAZOP is the second (0.261), and the third is Checklist (0.106)

4.3.6 Develop the ratings for each decision alternative under the criteria "the identified high risk levels"

4.3.6.1 Develop a pairwise comparison matrix for each alternative under the criteria "the identified high risk levels"

Create a pairwise matrix to compare the importance of each alternatives, under the criteria "the identified high risk levels", references from the table 4.2

Table 4.14 The identified high risk levels

Criteria	**Checklist**	**What-if Analysis**	**HAZOP**
The identified high risk levels	0	16%	35.2%

Table 4.15 The pairwise comparison matrix for each alternative under "the identified high risk levels"

The identified high risk levels	Checklist	What-if analysis	HAZOP
Checklist	1	1/3	1/5
What-if analysis	3	1	1/3
HAZOP	5	3	1

4.3.6.2 Calculate the alternative weights under "the identified high risk levels"

Calculating the weights start with summarize all number in the each column then divide the each number of the each column by that summarize number. Next, calculating the summarize of the each row then divide the result of summarize by the amount of alternatives, which is the number 3 for this study. The result of the alternative weights under "the identified high risk levels" as shown in table 4.16.

Table 4.16 The alternative weights under "the identified high risk levels"

The identified high risk levels	Checklist	What-if analysis	HAZOP	Total	The alternative weights
Checklist	0.111	0.077	0.130	0.318	0.106
What-if analysis	0.333	0.231	0.217	0.781	0.261
HAZOP	0.556	0.692	0.652	1.900	0.633
Total	1.000	1.000	1.000	3.000	1

Calculate the Consistency Ratio : C.R.

$$\text{C.R.} = \text{C.I.} / \text{R.I.}$$

By $$\text{C.I.} = \frac{(\lambda_{\max} - n)}{(n-1)}$$

$$\begin{bmatrix} 1 & 1/3 & 1/5 \\ 3 & 1 & 1/3 \\ 5 & 3 & 1 \end{bmatrix} * \begin{bmatrix} 0.106 \\ 0.261 \\ 0.633 \end{bmatrix} = \begin{bmatrix} 3.011 \\ 3.033 \\ 3.072 \end{bmatrix}$$

$$\lambda_{\max} = \frac{(3.011 + 3.033 + 3.072)}{3}$$

$$= 3.039$$

$$\text{C.I.} = \frac{(3.039-3)}{(3-1)}$$

$$= 0.0194$$

In table 2.12 shown Random Consistency Index (R.I) and size of the reciprocal matrix for this study is 3, so R.I. is equal to 0.58.

So, $$\text{C.R.} = 0.0194 / 0.58$$

$$= 0.033$$

Conclusion C.R. = 0.033, which is less than 0.1. Hence, the consistency of the comparison is an acceptable value.

According to the calculation, under the criteria for decision making "the identified high risk levels" indicates that HAZOP is the most importance (0.633), What-if analysis is the second (0.261), and the third is Checklist (0.106)

4.3.7 Develop the ratings for each decision alternative under the criteria "the time required to perform the assessment"

4.3.7.1 Develop a pairwise comparison matrix for each alternative under the criteria "the time required to perform the assessment"

Create a pairwise matrix to compare the importance of each alternatives, under the criteria "the time required to perform the assessment", references from the table 4.2

Table 4.17 The time required to perform the assessment

Criteria	**Checklist**	**What-if Analysis**	**HAZOP**
The time required to perform the assessment	7 Hours	16 Hours	25 Hours

Table 4.18 The pairwise comparison matrix for each alternative under "the time required to perform the assessment"

The time required to perform the assessment	Checklist	What-if analysis	HAZOP
Checklist	1	3	5
What-if analysis	1/3	1	3
HAZOP	1/5	1/3	1

4.3.7.2 Calculate the alternative weights under "the time required to perform the assessment"

Calculating the weights start with summarize all number in the each column then divide the each number of the each column by that summarize number. Next, calculating the summarize of the each row then divide the result of summarize by the amount of alternatives, which is the number 3 for this study. The result of the alternative weights under "the time required to perform the assessment" as shown in table 4.19.

Table 4.19 The alternative weights under "the time required to perform the assessment"

The time required to perform the assessment	Checklist	What-if analysis	HAZOP	Total	The alternative weights
Checklist	0.652	0.692	0.556	1.900	0.633
What-if analysis	0.217	0.231	0.333	0.781	0.261
HAZOP	0.130	0.077	0.111	0.318	0.106
Total	1.000	1.000	1.000	3.000	1

Calculate the Consistency Ratio : C.R.

$$C.R. = C.I. / R.I.$$

By $$C.I. = \frac{(\lambda_{max} - n)}{(n-1)}$$

$$\begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 3 \\ 1/5 & 1/3 & 1 \end{bmatrix} * \begin{bmatrix} 0.633 \\ 0.261 \\ 0.106 \end{bmatrix} = \begin{bmatrix} 3.072 \\ 3.033 \\ 3.011 \end{bmatrix}$$

$$\lambda_{max} = \frac{(3.072 + 3.033 + 3.011)}{3}$$

$$= 3.039$$

$$C.I. = \frac{(3.039-3)}{(3-1)}$$

$$= 0.0194$$

In table 2.12 shown Random Consistency Index (R.I) and size of the reciprocal matrix for this study is 3, so R.I. is equal to 0.58.

So, $$C.R. = 0.0194 / 0.58$$

$$= 0.033$$

Conclusion, C.R. = 0.033, which is less than 0.1. Hence, the consistency of the comparison is an acceptable value.

According to the calculation, under the criteria for decision making "the time required to perform the assessment" indicates that Checklist is the most importance (0.633), What-if analysis is the second (0.261), and the third is HAZOP (0.106)

4.3.8 Develop the ratings for each decision alternative under the criteria "the budget required to perform the assessment"

4.3.8.1 Develop a pairwise comparison matrix for each alternative under the criteria "the budget required to perform the assessment"

Create a pairwise matrix to compare the importance of each alternatives, under the criteria "the budget required to perform the assessment", references from the table 4.2

Table 4.20 The budget required to perform the assessment

Criteria	**Checklist**	**What-if Analysis**	**HAZOP**
The budget required to perform the assessment	12,810 Baht	29,280 Baht	45,750 Baht

Table 4.21 The pairwise comparison matrix for each alternative under "the budget required to perform the assessment"

The budget required to perform the assessment	Checklist	What-if analysis	HAZOP
Checklist	1	3	5
What-if analysis	1/3	1	3
HAZOP	1/5	1/3	1

4.3.8.2 Calculate the alternative weights under "the budget required to perform the assessment"

Calculating the weights start with summarize all number in the each column then divide the each number of the each column by that summarize number. Next, calculating the summarize of the each row then divide the result of summarize by the amount of alternatives, which is the number 3 for this study. The result of the alternative weights under "the budget required to perform the assessment" as shown in table 4.22.

Table 4.22 The alternative weights under "the budget required to perform the assessment"

The budget required to perform the assessment	Checklist	What-if analysis	HAZOP	Total	The alternative weights
Checklist	0.652	0.692	0.556	1.900	0.633
What-if analysis	0.217	0.231	0.333	0.781	0.261
HAZOP	0.130	0.077	0.111	0.318	0.106
Total	1.000	1.000	1.000	3.000	1

Calculate the Consistency Ratio : C.R.

$$C.R. = C.I. / R.I.$$

By

$$C.I. = \frac{(\lambda_{max} - n)}{(n-1)}$$

$$\begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 3 \\ 1/5 & 1/3 & 1 \end{bmatrix} * \begin{bmatrix} 0.633 \\ 0.261 \\ 0.106 \end{bmatrix} = \begin{bmatrix} 3.072 \\ 3.033 \\ 3.011 \end{bmatrix}$$

$$\lambda_{max} = \frac{(3.072 + 3.033 + 3.011)}{3}$$

$$= 3.039$$

$$C.I. = \frac{(3.039-3)}{(3-1)}$$

$$= 0.0194$$

In table 2.12 shown Random Consistency Index (R.I) and size of the reciprocal matrix for this study is 3, so R.I. is equal to 0.58.

So, $C.R. = 0.0194 / 0.58$

$$= 0.033$$

Conclusion, C.R. = 0.033, which is less than 0.1. Hence, the consistency of the comparison is an acceptable value.

According to the calculation, under the criteria for decision making "the budget required to perform the assessment" indicates that Checklist is the most importance (0.633), What-if analysis is the second (0.261), and the third is HAZOP (0.106)

4.3.9 Calculate the weighted average rating for each decision alternative and choose the one with the highest score

According to the analysis results of all criteria used in decision making, the each alternative has different strengths. The conclusion of the criteria weights and the alternative weights for each criterion as shown in table 4.23.

Table 4.23 The conclusion of the criteria weights and the alternative weights for each criterion

Criteria/ Alternative	The number of identified risks	The cost of eliminating intolerable risks	The number of identified human errors	The identified high risk levels	The time required to perform the assessment	The budget required to perform the assessment
The criteria weights	0.134	0.096	0.233	0.447	0.045	0.045
Checklist	0.074	0.633	0.106	0.106	0.633	0.633
What-if analysis	0.283	0.261	0.633	0.261	0.261	0.261
HAZOP	0.643	0.106	0.261	0.633	0.106	0.106

Calculate the weighted average rating for the 3 alternatives by added the multiple results between the criteria weights and alternative weights for each criterion.

Checklist = (0.134*0.074) + (0.096*0.633) + (0.233*0.106) + (0.447*0.106) + (0.045*0.633) + (0.045*0.633)
= 0.2

What-if analysis = (0.134*0.283) + (0.096*0.261) + (0.233*0.633) + (0.447*0.261) + (0.045*0.261) + (0.045*0.261)
= 0.35

HAZOP = (0.134*0.643) + (0.096*0.106) + (0.233*0.261) + (0.447*0.633) + (0.045*0.106) + (0.045*0.106)
= 0.45

According to the results, HAZOP is the most weight (0.45), What-if analysis is the second (0.35), and Checklist is the lowest importance (0.2).

4.3.10 Conclusion of decision making by using Analytic Hierarchy Process

According to the result of Analytic Hierarchy Process under the 6 criteria (the number of identified risks, the cost of eliminating intolerable risks, the number of identified human errors, the identified high risk levels, the time and budget required to perform the assessment), HAZOP has the most weight among 3 alternatives as well as has a consistency ratio of less than 0.1, which is an acceptable.

CHAPTER V
DISCUSSION

The results of hazard identification and risks assessment in tank farm at power plant by Checklist , What-if analysis, and HAZOP techniques, 54, 25, and 7 risks were recognized by HAZOP, What-if analysis, and Checklist respectively. HAZOP has the highest number of identified risks due to this technique determine the consequences of the failure by apply the guide words and parameters, enables more systematic and comprehensive results than the others. Checklist identify hazards by implementation is the number of non-compliance with the power plant's tank farm checklist, that created from the relevant laws, regulations, and working procedures. If the team did not provide enough information, the checklist won't cover all operations in tank farm. Moreover, the power plant is law compliance that causes to the checklist can find only small number of identified risks. In terms of identified high risk levels by three methods, the results demonstrated that the percentage of high risk levels identified by HAZOP was more than What-if analysis and Checklist, which HAZOP identified 35.2%, What-if analysis 16%, and Checklist 0% of risks as high risks. It seems that HAZOP has more ability to identify the high risk levels than What-if analysis and Checklist. HAZOP finds the failure from equipment, which can find hazards and risks more than the others. Moreover, mostly equipment failure were high probability of occurrence that causes to HAZOP can identify the greatest percentage of high risk levels.

In terms of controlling cost, HAZOP requires the higher costs than What-if analysis and Checklist. Due to HAZOP desires for inspection and cleaning of the relevant equipment before operate with the fuel oil in the each cycle. This reason causes HAZOP to require the high controlling cost, unlike What-if analysis and Checklist that prepare a pre-operation checklist and perform an operational audit to consistent with the working procedures or safety rules, which less controlling cost.

Reviewing the identified human errors by three methods indicated that, What-if analysis and HAZOP identified 56% and 20.4% of errors, respectively, while there was no number of human errors identified by Checklist. Thus, the study can be concluded that What-if analysis has more ability to identify human errors than HAZOP and Checklist. The reason that What-if analysis can encounters the greatest number of human errors because this method evaluates by asking relevant questions about the working procedures. Creating the questions require the experience and knowledge of the team, which can see the holistic of human action rather than HAZOP that analyzes a failure of machinery and equipment. Checklist cannot find the number of identified human errors at all due to this method is done by legal inspection, which is rarely involved with actions of the operators.

In terms of time and budget required to perform the assessment, considering hours used to evaluate the each method and all wages of the teams, which was average in 1,830 Baht per hour. Checklist spent lowest budget and time for hazard identification due to this method is easy and can be perform by inexperienced workers, while time and budget spent for What-if analysis and HAZOP are 2 and 3 times more than Checklist, respectively.

According to the Analytic Hierarchy Process for decision making to select the most effective risk assessment method, HAZOP has the most weight, next are What-if analysis and Checklist, respectively. It indicates that HAZOP is more effective than What-if analysis and Checklist to perform risk assessment of tank farms in power plant.

CHAPTER VI
CONCLUSION

6.1 Conclusion of the research

The hazard identification and risks assessment in the tank farm at power plant by Checklist, What-if analysis, and HAZOP, 54, 25, and 7 risks were recognized by HAZOP, What-if analysis, and Checklist respectively. HAZOP found 19 high risk levels or 35.2% of all risks. What-if analysis found 4 high risk levels or 16% of all risks. Checklist has no high risk levels.

According to the cost for controlling or reducing risks, HAZOP spent higher cost than What-if analysis and Checklist. For the number of identified human errors found that What-if analysis and HAZOP identified 56% and 20.4% of errors, while Checklist had no human errors found.

According to the time and budget required to perform the assessment, Checklist spent lowest budget and time, while What-if and HAZOP spent more than 2 and 3 times, respectively. In accordance with the Analytic Hierarchy Process (AHP) for select the most effective risk assessment method was based on six criteria (the number of identified risks, the cost of eliminating intolerable risks, the number of identified human errors, the identified high risk levels, the time and budget required to perform the assessment), HAZOP is the most effective method for risks assessment in the tank farm of power plant, but some hazards were found by only What-if analysis or Checklist. Consequently, using the multiple methods together for hazard identification and risk assessment enable to identify the hazards more extensive than using only one method, as well as more ability for risks control, eliminate hazard, and prevent accidents.

6.2 Recommendations

Before the processing of hazard identification and risk assessment should train the team by the specialists in order to strengthen the team member to have more skills and enable the more accurate for risks assessment. In addition, the research team should come from several departments in order to get the cover all the relevant issues.

6.3 Suggestion for future researches relevant to this research

Those interested should study the hazard identification and risks assessment in other more complex methods such as Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Energy Trace and Barrier Analysis (ETBA),etc., in order to compare the results with this study.

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APPENDICES

APPENDIX A

RELATED FORM FOR RISK ASSESSMENT

บัญชีรายการสิ่งที่เป็นความเสี่ยงและอันตราย

โรงงาน ....

วันที่ทำการศึกษา วิเคราะห์ และทบทวนการดำเนินงานในโรงงาน ....

การดำเนินงานในโรงงาน	สิ่งที่เป็นความเสี่ยงและอันตราย	ผลกระทบที่อาจเกิดขึ้น	หมายเหตุ

23 Jan 2017

คณะกรรมการพิจารณาจริยธรรมการวิจัยในมนุษย์
คณะสาธารณสุขศาสตร์ มหาวิทยาลัยมหิดล
COA. No. MUPH 2017-016
วันที่รับรอง 7 ก.พ. 60

Figure A.1 Risk and Hazard form

แบบการชี้บ่งอันตรายด้วยวิธี Checklist

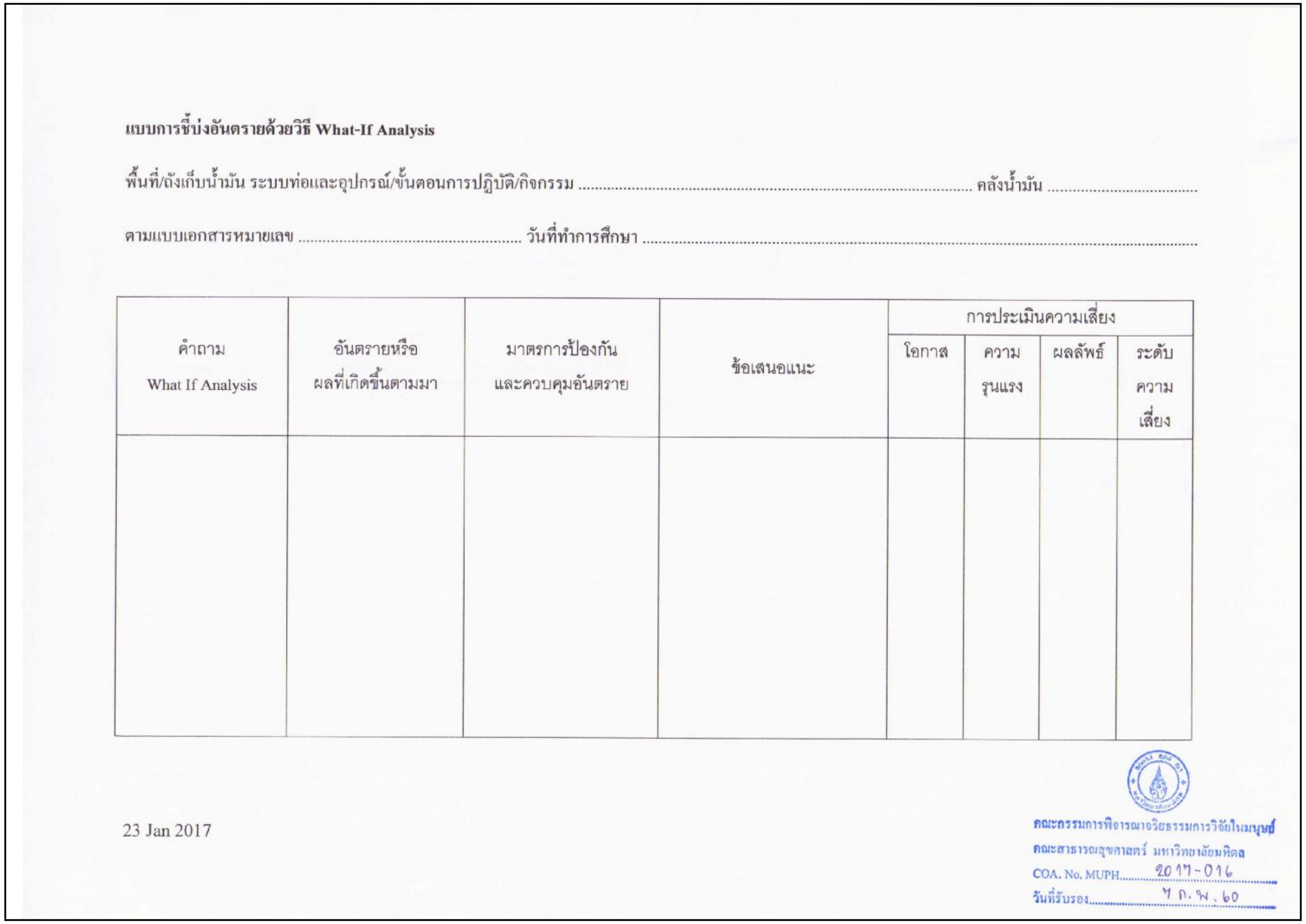
พื้นที่/ถังเก็บน้ำมัน ระบบท่อและอุปกรณ์/ขั้นตอนการปฏิบัติ/กิจกรรม .... คลังน้ำมัน ....

ตามแบบเอกสารหมายเลข .... วันที่ทำการศึกษา ....

ผลจากการทำ Checklist	อันตรายหรือผลที่เกิดขึ้นตามมา	มาตรการป้องกันและควบคุมอันตราย	ข้อเสนอแนะ	การประเมินความเสี่ยง			
				โอกาส	ความรุนแรง	ผลลัพธ์	ระดับความเสี่ยง

23 Jan 2017

Figure A.2 Checklist form



แบบการชี้บ่งอันตรายด้วยวิธี What-If Analysis

พื้นที่/ถังเก็บน้ำมัน ระบบท่อและอุปกรณ์/ขั้นตอนการปฏิบัติ/กิจกรรม .... คลังน้ำมัน ....

ตามแบบเอกสารหมายเลข .... วันที่ทำการศึกษา ....

คำถาม What If Analysis	อันตรายหรือ ผลที่เกิดขึ้นตามมา	มาตรการป้องกัน และควบคุมอันตราย	ข้อเสนอแนะ	การประเมินความเสี่ยง			
				โอกาส	ความรุนแรง	ผลลัพธ์	ระดับความเสี่ยง

23 Jan 2017

คณะกรรมการพิจารณาจริยธรรมการวิจัยในมนุษย์
คณะสาธารณสุขศาสตร์ มหาวิทยาลัยมหิดล
COA. No. MUPH 2017-016
วันที่รับรอง 7 ก.พ. 60

Figure A.3 What-If Analysis form

แบบการชี้บ่งอันตรายด้วยวิธี Hazard and Operability Study (HAZOP)

หน่วย .... รายละเอียด ....

ปัจจัยการผลิต .... ค่าควบคุม ....

ถังเก็บน้ำมัน ระบบท่อและอุปกรณ์	ความล้มเหลว	สาเหตุของความล้มเหลว	ผลที่จะเกิดขึ้น	มาตรการป้องกัน/ควบคุม/แก้ไข	การประเมินความเสี่ยง			
					โอกาส	ความรุนแรง	ผลลัพธ์	ระดับความเสี่ยง

23 Jan 2017

คณะกรรมการพิจารณาจริยธรรมการวิจัยในมนุษย์
คณะสาธารณสุขศาสตร์ มหาวิทยาลัยมหิดล
COA. No. MUPH 2017-016
วันที่รับรอง 7 ก.พ. 60

Figure A.4 Hazard and Operability Study (HAZOP) form

APPENDIX B

CHECKLIST FOR TANK FARM

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
1	Is the distance of oil tanks far from the area more than 30 meters?	✓				The distance of oil tanks must far from the area more than 30 meters.
2	Is the distance of oil tanks far from the other buildings more than 20 meters?	✓				The distance of oil tanks must far from the other buildings more than 20 meters.
3	Is the distance of each oil tank far from each other at least 15 meters?	✓				The distance of the each oil tank must far from each other at least 15 meters.
4	Is the distance of oil tanks far from the inside edge of the oil reservoir at least 7.86 meters?	✓				The distance of oil tanks must far from the inside edge of the oil reservoir at least 7.86 meters.
5	Is the distance of oil receiving point far from the building or land area at least 15 meters?	✓				The distance of oil receiving point must far from the building or land area at least 15 meters.
6	Are the oil tanks area surrounded by a fence made from strong and non-combustible material with higher than 3 meters and far from the oil tanks at least 15 meters? And is the Fence’s door made from strong and non-combustible material?	✓				The fence must higher than 3 meters, made from strong and non-combustible material, far from the oil tanks at least 15, and the Fence’s door made from strong and non-combustible material

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
7	Is the oil reservoir big enough to store oil from the largest tank? And is it strong?	✓				The oil reservoir must big enough to store oil from the largest tank at least 10 million liters.
8	Is the oil reservoir high no more than 3 meters?	✓			The reservoir is high 4.4 meters, but was approved by the Department of Energy.	The oil reservoir must high no more than 3 meters by measuring from the outer edge of the reservoir.
9	Is the interior floor around the oil reservoir has a slope from oil tanks to the wall of oil reservoir or drainage ditch more than 1:100?	✓				The interior floor around the oil reservoir must have a slope from oil tanks to the wall of oil reservoir or drainage ditch more than 1:100
10	Drainage from the oil reservoir to treatment system or separating oil contaminated with water, does the process have a shut-off valve with sufficient size for drainage?	✓				Drainage from the oil reservoir to treatment system or separating oil contaminated with water must have a shut-off valve and the valve must close at all times by only open when draining.
11	Is the group of oil tanks set in rows and not overlay more than 2 rows?	✓				The group of oil tanks is set in rows and not overlay more than 2 rows
12	Is the group of oil tanks having total capacity no more than 60 million liters?	✓				The group of oil tanks must have total capacity no more than 60 million liters

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
13	Does inside of the oil reservoir have no oil pumps to receive or dispense oil, no pick up or delivery point, and do not store any materials or equipment?	✓				Inside of the oil reservoir must have no oil pumps to receive or dispense oil, no pick up or delivery point, and do not store any materials or equipment.
14	Is there a bridge across to the pipeline or oil reservoir?	✓				A bridge is a must for across to the pipeline or oil reservoir that stable, made from strong and non-combustible material by installing at least 2 points in opposite positions and located near the fire hydrant.
15	Is the oil tanks made from steel, which follow the law?	✓				1. The oil tanks must make from steel 2. Steel plates and structural steel used to make oil tanks must be certified from international standards. 3. Steel wall plates must have a yield stress more than 206 N / mm2.
16	Is the vent of the oil tank designed to have a pressure less than 7.5 milliliters and vacuum pressure less than 2.5 milliliters?	✓				The vent of the oil tank must design to have a pressure less than 7.5 milliliters and vacuum pressure less than 2.5 milliliters.

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
17	Is there the messages stick on the side of the outer oil tanks to specify diameters, height, width, length, type of product, oil volume allowed, last date/month/year allowed, and last inspection?	✓				The oil tanks wall must indicate the visible message or clearly marked, with readable within 25 meters by specify diameters, height, width, length, type of product, oil volume allowed, last date/month/year allowed, and last inspection.
18	Do the tank contain the fuel oil not over than 90% of its volume?	✓				The oil tank must contain the fuel oil no more than 90% of its volume.
19	Is there install warning devices to prevent the oil tank overflow?	✓				The large oil tank must install warning devices to prevent the oil tank overflow.
20	Are the oil tanks tested and inspected before and after used for one and fifteen years?		✓		There are testing before used, but had no one year tested.	The oil tanks must be tested and inspected before and after used for one and fifteen years
21	Is the oil tanks installed a shut-off valve, fire extinguishing equipment, other safety equipment, and also inspected once a year?		✓		There are equipment installed, but no annual check.	- The oil tanks must install a shut-off valve, fire extinguishing equipment, and other safety equipment. - The oil tanks must be checked at least once a year.

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
22	Are the oil tanks tested and inspected by testers and inspectors who meet the legal requirements?	✓				The oil tanks must test and inspect by testers and inspectors who meet the legal requirements and keep the record for one year.
23	Is the oil pipe made from steel?	✓				The oil pipe must make from steel.
24	Does the oil pipe system that connects to the oil pump have a shut-off valve to stop the oil pumping in emergency case?	✓				The oil pipe system that connects to the oil pump must have a shut-off valve to stop the oil pumping in emergency case.
25	Does the oil pipe have corrosion resistance or anti-corrosion?	✓				The oil pipe must have corrosion resistance or anti-corrosion.
26	Is there a clear marked on the pipeline?	✓				The pipeline must have a clearly marked.
27	Is the installing of shutters or other equipment under the ground can monitored and maintained easily?	✓				The installing of shutters or other equipment under the ground must be monitored and maintained easily.
28	Are the materials used in the oil pipeline system, such as the shut-off valve, gasket, and waterproofing material, especially used with oil and have no reaction with the oil?	✓				The materials used in the oil pipeline system, such as the shut-off valve, gasket, and waterproofing material, must especially use with oil and have no reaction with the oil.

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
29	Is the oil receiving point installed the protection system for electrostatic?	✓				The oil receiving point must installed the protection system for electrostatic.
30	Do the shut-off valves, hoses, and oil pumps that are installed in oil pipe system be checked at least once a year?		✓		Have no annual check	The shut-off valves, hoses, and oil pumps that are installed in oil pipe system must be checked at least once a year by inspectors who meet the legal requirements.
31	Do the oil pipeline systems and equipment be tested and inspected before used and after used fifteen years by inspectors who meet the legal requirements?	✓				The oil pipeline systems and equipment must be tested and inspected before used and after used fifteen years by inspectors who meet the legal requirements.
32	Are there a fire extinguishing system with a diameter more than 100 mm. and a fire hydrant more than two locations?	✓				The fuel depot must have a fire extinguishing system with a diameter more than 100 mm., which is equivalent to the size of the water supply pipe for the fire brigade of the local government organization, and a fire hydrant more than two locations.

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
33	Does a dry chemical fire extinguisher or fire extinguisher inside the fuel depot contain a minimum of 6.8 kg and has ability for extinguishing more than 3A40B?		✓		A dry chemical fire extinguisher has ability for extinguishing less than 3A40B	The fuel depot must have a dry chemical fire extinguisher or fire extinguisher contain a minimum of 6.8 kg and has ability for extinguishing more than 3A40B
34	Does the oil pump area have at least one fire extinguisher per two oil pumps?	✓				1. The oil pump area must have at least one fire extinguisher per two oil pumps 2. In case there are more than eight oil pumps, the fuel depot must have at least four fire extinguishers.
35	Does the oil receiving point have at least one fire extinguisher per two lines of the receiving point?	✓				The oil receiving point must have at least one fire extinguisher per two lines of the receiving point
36	Is there extinguisher installation around the fuel depot with can see and use it easily?	✓				The extinguisher must install around the fuel depot with can see and use it easily.
37	Is the fuel depot has the concentrated foam used as a foam solution at any time?	✓				- The amount of foam solution to be injected into a large oil tank is 245,295 liters. - The volume of foam solution must fill in a foam pipe until it full. - The fuel depot must install at least 5 points of foam injection equipment.

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
	Is the fuel depot has the concentrated foam used as a foam solution at any time? (cont.)					- The amounts of foam solution used for spot injection are 26,460 liters. - The foam solutions must be suitable for firefighting according to the type of fuel.
38	Is there another concentrated foam to be store more than one time?	✓				The amount of concentrated foam to be stored is calculated from the number of foam solutions to be injected into the tank + volume of foam solution must fill in a foam pipe + foam solution used for spot injection of the oil tank that uses the highest foam intense.
39	Is there a concentrated foam and fire-fighting components stored around the fuel depot where can be easily seen and used, as well as ready to use at any time?	✓				The concentrated foam and fire-fighting components must stores around the fuel depot where can be easily seen and used, as well as ready to use at any time.
40	Is there enough water supply system for the fire extinguishers to use for the foam solution?	✓				The fuel depot must provide enough water supply system for the fire extinguishers to use for the foam solution.

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
41	Is there enough water supply system for the fire extinguishers use as a coolant?	✓				The fuel depot must provide enough water supply system for the fire extinguishers use as a coolant 1,382,974 liters.
42	Is there enough water supply system for the fire extinguishers use to support injection foam solution and coolant more than 1,900 liters per minute and not less than 30 minutes?	✓				The fuel depot must provide enough water supply system for the fire extinguishers use to support injection foam solution and coolant more than 1,900 liters per minute and not less than 30 minutes.
43	Is there water source or water storage more than the maximum water consumption for a fire fighting system?	✓				The fuel depot must provide water source or water storage more than the maximum water consumption for a fire fighting system.
44	Are foam injection systems and cooling systems installed? Or are the nozzles that can be cooled around the tank ready to use at any time?	✓				The fuel depot must install foam injection systems and cooling systems, as well as provide the nozzles that can be cooled around the tank to be ready to use at any time.
45	Does the fire pump have a pressure and flow rate that consistent to the amount of foam solution, coolant and equipment used?	✓				The fire pump must have a pressure and flow rate that consistent to the amount of foam solution, coolant and equipment used

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
46	Is there at least one fire engine pump with a pipe for water pumping from a water source or a water reservoir with diameter not less than 100 mm.?	✓				The fuel depot must have at least one fire engine pump with a pipe for water pumping from a water source or a water reservoir with diameter not less than 100 mm.
47	Are the ‘on’ and ‘off’ position of the fire pump place in the area that easy to use and available at any time?	✓				The ‘on’ and ‘off’ position of the fire pump must place in the area that easy to use and available at any time.
48	Are there the fire pumps checked at least once a year?		✓		Have no annual checked for the fire pumps	The fuel depot must check the fire pumps at least once a year.
49	Are the fire extinguishers and fire equipment installed or placed away from the group of oil tank and the oil receiving point not less than 30 meters?	✓				The fire extinguishers and fire equipment must be installed or placed away from the group of oil tank and the oil receiving point not less than 30 meters
50	Do the fuel depot have sample test for quality check of the dry chemical fire extinguishers or wet chemical fire extinguishers and concentrate foam at least once a year?		✓		There is a quality check for the concentrate foam, but no for the dry chemical fire extinguishers.	The fuel depot must have the sample test for quality check of the dry chemical fire extinguishers or wet chemical fire extinguishers and concentrate foam at least once a year.

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
51	Is the fire hose painted red color and the foam pipe painted yellow throughout the line?	✓				The fire hose and foam pipe must be painted throughout the line, by red for the fire hose and yellow for the foam pipe.
52	Are there the alarm systems that can be heard or recognized thoroughly by installing a notification device next to the oil tanks with no less than two positions, as well as installed a notification device in office building one position?	✓				The fuel depot must provide the alarm systems that can be heard or recognized thoroughly by installing a notification device next to the oil tanks with no less than two positions, as well as installed a notification device in office building one position
53	Are there the alarm systems tested at least once a year?		✓		Have no annual alarm systems test	There are the alarm systems tested at least once a year.
54	Are there a fire suppression plan and a train the plan at least once a year?	✓				There are a fire suppression plan and a train the plan at least once a year.
55	Is there a procedure for getting oil in the oil receiving point?	✓				There is a procedure for getting oil in the oil receiving point.
56	Does the oil tank contain the system of lightning protection?	✓				The oil tank must contain the system of lightning protection.
57	Is there prevention for the oil tanks movable while getting the oil, such as pull hand brake, or use a wedge to prevent the wheels?	✓				The fuel depot must prevent the tanks movable while getting the oil.

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
58	While getting the oil, do not do anything that causes a flare or sparks around the area?	✓				While getting the oil, must not do anything that causes a flare or sparks around the area.
59	Is an operator close the lid of oil tank tightly after getting the oil?	✓				The lid of oil tank must be closed tightly after getting the oil.
60	Is the oil pump used for getting the oil specifically for diesel?	✓				The oil pump used for getting the oil must be specifically for diesel.
61	Is the oil pump used for getting the oil has system to prevent the pressure that is not exceeding from standard?	✓				The oil pump used for getting the oil must have system to prevent the pressure that is not exceeding from standard.
62	Is the electric motor pump be an explosion proof?	✓				The electric motor pump must be an explosion proof.
63	Before connect the oil dispenser from the tank to the oil pipe, Is there connected the ground wire of tank truck with oil tank at all time until remove the nozzle?	✓				Before connect the oil dispenser from the tank to the oil pipe, operator must connect the ground wire of tank truck with oil tank at all time until remove the nozzle.
64	When connect the oil dispenser to the filler, is there checking for tightness and leakage before the oil dispensing?	✓				When connect the oil dispenser to the filler, operator must check for tightness and leakage before the oil dispensing.

No.	Question	Result			Comments	Inspection Criteria
		Yes	No	N/A		
65	Before the oil dispensing, does an operator check the shut-off valves, which control the oil distribution system to close immediately after finish the process?	✓				Before the oil dispensing, an operator must check the shut-off valves, which control the oil distribution system to close immediately after finish the process.
66	Does the oil tank truck have at least one point for the ground wire connection?	✓				The oil tank truck must have at least one point for the ground wire connection
67	Does the oil tank truck has at least 2 machines of dry powder fire extinguisher or liquid fire, contained not less than 6.8 kilograms, with fighter rating not less than 2A 20B, or at least 1 machine in case the fire fighter rating not less than 4A 40B?	✓				The oil tank truck must have a dry powder fire extinguisher or liquid fire contained not less than 6.8 kilograms at least 2 machines (fire rating 2A20B), or at least 1 machine (fire rating 4A40B)

APPENDIX C
RESULT OF HAZARD IDENTIFICATION AND RISK ASSESSMENT

Risk assessment form by Checklist

Area / Oil Tanks Pipe systems and equipment/Procedures/Activities ....Tank farm...........

According to the document no.....The checklist for Tank Farm..... Date of study ....20 Feb. 2017...........

The result from Checklist	Hazards or Consequences	Existing preventive and control measures	Recommendations	Risk assessment						
				Probability	Severity				Result	Risk level
					people	community	environment	assets		
1. The oil tanks didn't tested and inspected after used for one year	The oil tanks worn out caused oil spills	No	Provide annual test and inspection for oil tanks	1	1	1	2	3	3	Acceptanble
2. No annual inspection for fire fighting and safety equipments	The fire fighting and safety equipments worn out and inoperative	No	Provide annual inspection for fire fighting and safety equipments	2	1	1	1	3	6	Acceptanble
3. No annual inspection for valves, hoses, and pumps in oil pipe system	The valves, hoses, and pumps in oil pipe system worn out and inoperative	No	Provide annual inspection for valves, hoses, and pumps in oil pipe system	2	1	1	1	3	6	Acceptanble
4. Dry chemical fire extinguishers have fire rating less than 3A40B	Low fire fighting performance	Increase the number of fire extinguishers to cover all areas based on existing fire extinguishers	Change the fire extinguishers to the new one that fire rating more than 3A40B	1	1	1	1	1	1	Less
5. No annual inspection for fire pumps	Fire pumps worn out and inoperative in emergency case	No	Provide annual inspection for fire pumps	2	1	1	1	2	4	Acceptanble
6. Didn't have quality check dry chemical of fire extinguishers	Low fire fighting performance in emergency case	No	Provide annual quality check dry chemical of fire extinguishers	1	1	1	1	1	1	Less
7. Didn't have the alarm systems test	The alarm systems inoperative	No	Provide annual test for the alarm systems	3	1	1	1	1	3	Acceptanble

Figure C.1 Result of hazard identification and risk assessment using Checklist

Risk assessment form by What-if analysis

Area / Oil Tanks Pipe systems and equipment/Procedures/Activities .... unloading diesel oil from oil truck..

According to the document no. ....M1001.. Date of study ....21-22 Feb. 2017..

What-if analysis questions	Hazards or Consequences	Existing preventive and control measures	Recommendations	Risk assessment						
				Probability	Severity				Result	Risk level
					people	community	environment	assets		
1. What would happen if an operator does not catch the railing when walking up to measure the oil level in the oil tank?	Operator falls down from a ladder and get injured.	The operational approach of oil receiving assigns that operators must catch the railing while walking up to the ladder every time.		3	2	1	1	1	6	Acceptable
2. What would happen if an operator does not wear a mask while gauging the oil level in the oil tank?	Operator inhales the oil gas cause to irritate the respiratory system.	The operational approach of oil receiving assigns that operators must wear a mask in order to prevent the respiratory system while working.	Supervisor checks the availability of employees to wears personal protective equipment before start working every time.	3	2	1	1	1	6	Acceptable
3. What would happen if truck drivers drive into the oil receiving point in the same time?	Oil tanker trucks collide cause to the property damage.	There are organizing the line of oil tanker trucks start from the entrance.		3	1	1	1	2	6	Acceptable
4. What would happen if a truck driver does not use the wheel chock?	Operators who are working around the area get accident from the runaway tanker truck, cause to injured.	The operational approach of oil receiving assigns that the truck drivers must use the wheel chock before the oil receiving process.	Prepare a form for checking the avalibility of oil tanker truck before oil receiving process.	3	2	1	1	2	6	Less

Figure C.2 Result of hazard identification and risk assessment using What-if analysis: unloading diesel oil from oil truck process

Risk assessment form by What-if analysis

Area / Oil Tanks Pipe systems and equipment/Procedures/Activities .... unloading diesel oil from oil truck..........

According to the document no. ....M1001.............. Date of study ....21-22 Feb. 2017..........

What-if analysis questions	Hazards or Consequences	Existing preventive and control measures	Recommendations	Risk assessment						
				Probability	Severity				Result	Risk level
					people	community	environment	assets		
5. What would happen if a truck driver does not connect the ground wired?	There is the static electricity, which chance of fire or explosion.	The operational approach of oil receiving assigns that operators must connect the ground wired before the oil receiving.	Prepare a form for checking the avalibility of oil tanker truck before oil receiving process.	3	2	1	1	3	9	High
6. What would happen if a truck driver does not wear gloves while connecting a ground wired?	Ground wire cut the hand cause to injured.	The operational approach of oil receiving assigns that everyone must wear the nitrile gloves while working.	Supervisor checks the availability of employees to wears personal protective equipment before start working	2	2	1	1	1	4	Acceptable
7. What would happen if a ground wired worn out?	There is the static electricity, which chance of fire or explosion.	There are checking the availability of the ground wired before using every time.		3	2	1	1	3	9	High
8. What would happen if a truck driver does not wear gloves while connecting a flexible hose?	A flexible hose cut the hand cause to injured.	The operational approach of oil receiving assigns that everyone must wear the nitrile gloves while working.	Supervisor checks the availability of employees to wears personal protective equipment before start working	2	2	1	1	1	4	Acceptable

Figure C.3 Result of hazard identification and risk assessment using What-if analysis: unloading diesel oil from oil truck process (cont.)

Risk assessment form by What-if analysis

Area / Oil Tanks Pipe systems and equipment/Procedures/Activities .... unloading diesel oil from oil truck..........

According to the document no. ....M1001.. Date of study ....21-22 Feb. 2017..........

What-if analysis questions	Hazards or Consequences	Existing preventive and control measures	Recommendations	Risk assessment						
				Probability	Severity				Result	Risk level
					people	community	environment	assets		
9. What would happen if a truck driver connected the flexible hose of the power plant with the oil tanker truck with not tight?	The flexible hose falloffs cause to the oil splashs to an operator or spills on the floor.	Supervisor checks the correctness of the flexible hose connection before open the valve at oil tanker truck.	Prepare sand to stop oil spilling and oil lining to clean in case of the oil spills on the floor.	3	1	1	1	2	6	Acceptable
10. What would happen if a flexible hose is worn out?	Oil spills on the floor.	There are checking the availability of the flexible hose before using every time.	Prepare sand to stop oil spilling and oil lining to clean in case of the oil spills on the floor.	3	1	1	1	2	6	Acceptable
11. What would happen if the valve of oil tanker truck is worn out?	Oil cannot flow out of the tanker truck.	There are checking the availability of the truck's equipment before sent the oil to power plant.		2	1	1	1	3	6	Acceptable
12. What would happen if an unloading pump does not work?	Oil cannot flow to the system	There are checking the availability of the equipment within the fuel depot before the oil receiving.	Prepare a form for checking the avalibility of the equipment within the fuel depot before the oil receiving process.	2	1	1	1	3	6	Acceptable

Figure C.4 Result of hazard identification and risk assessment using What-if analysis: unloading diesel oil from oil truck process (cont.)

Risk assessment form by What-if analysis

Area / Oil Tanks Pipe systems and equipment/Procedures/Activities .... unloading diesel oil from oil truck..

According to the document no. ....M1001... Date of study ....21-22 Feb. 2017...

What-if analysis questions	Hazards or Consequences	Existing preventive and control measures	Recommendations	Risk assessment						
				Probability	Severity				Result	Risk level
					people	community	environment	assets		
13. What would happen if the fuel depot does not have an oil container while removing a flexible hose?	Oil falls donw on the floor.	The operational approach of oil receiving assigns that removing a flexible hose must have an oil container every time.	Prepare sand to stop oil spilling and oil lining to clean in case of the oil spills on the floor.	3	1	1	1	1	3	Acceptable
14. What would happen if an operator does not guage the oil level in the oil tank after the oil pumping from tanker truck?	Oil overflows from a tank and when it meets with heat or sparks could be cuase of fire or explosion.	- The operational approach of oil receiving assigns that operators must guage the oil level in the oil tank before and after the oil receiving. - There is a warning device when an oil tank overflow.	Prepare a form for checking the avalibility of the equipment within the fuel depot before the oil receiving process.	1	1	1	3	3	3	Acceptable
15. What would happen if a truck driver or operator is smoking while getting the oil?	Fire or explosion might occur.	- There is rule to prohibit smoking within the oil depot area. - There are "no smoking" signed within the oil depot area. - There are Fire extinguisher and mobile foam car within the oil depot area.	Creating the regulation to prohibit the cigarette into the fuel depot.	2	1	1	1	3	6	Acceptable

Figure C.5 Result of hazard identification and risk assessment using What-if analysis: unloading diesel oil from oil truck process (cont.)

Risk assessment form by What-if analysis

Area / Oil Tanks Pipe systems and equipment/Procedures/Activities .... diesel oil storage..........

According to the document no. ....M1006.......... Date of study ....21-22 Feb. 2017..........

What-if analysis questions	Hazards or Consequences	Existing preventive and control measures	Recommendations	Risk assessment						
				Probability	Severity				Result	Risk level
					people	community	environment	assets		
1. What would happen if the oil tank leaks?	Oil leaks when it meets with heat or sparks could be cuase of fire or explosion.	There is fire fighting system around the oil tank	- Provide weekly visual check for the oil tank - Prepare oil lining to clean in case of the oil spills on the floor.	1	1	1	2	3	3	Acceptable
2. What would happen if an operator has an activity that cause heat or sparks?	If that area have oil vapor could be cause of fire or explosion.	- There is rule to prohibit smoking within the oil depot area. - Work permit system for hot work - There is fire fighting system around tank farm	Creating the regulation to prohibit the cigarette into the fuel depot.	3	2	1	1	3	9	High
3. What would happen if electric devices around the oil tanks shock?	It could be cause of fire.	- Electrical devices are standardized and explosion proof. - Ground system - There is fire fighting system around tank farm	Provide monthly check for electrical devices.	2	2	1	1	3	6	Acceptable
4. What would happen if lightning protection system don't cover all area of tank farm ?	- Lightning cause the oil tanks and equipments around tank farm are damaged. - If oil leaks, cause to be fire	Install standardized lightning protection system		1	2	1	1	3	3	Acceptable
5. What would happen if lightning protection system is damaged ?	- Lightning cause the oil tanks and equipments around tank farm are damaged. - If oil leaks, cause to be fire	Provide monthly check for lightning protection system		1	2	1	1	3	3	Acceptable

Figure C.6 Result of hazard identification and risk assessment using What-if analysis: diesel oil storage process

Risk assessment form by What-if analysis

Area / Oil Tanks Pipe systems and equipment/Procedures/Activities .... pumping diesel oil to gas turbine...

According to the document no. ....M1007... Date of study ....21-22 Feb. 2017...

What-if analysis questions	Hazards or Consequences	Existing preventive and control measures	Recommendations	Risk assessment						
				Probability	Severity				Result	Risk level
					people	community	environment	assets		
1. What would happen if the pipe leaks?	Oil spill when it meets with heat or sparks could be cuase of fire or explosion.	There is fire fighting system around tank farm	Prepare sand to stop oil spilling and oil lining to clean in case of the oil spills on the floor.	2	2	1	2	3	6	Acceptable
2. What would happen if an operator has an activity that cause heat or sparks?	If that area have oil vapor could be cause of fire or explosion.	- There is rule to prohibit smoking within the oil depot area. - Work permit system for hot work - There is fire fighting system around tank farm	Creating the regulation to prohibit the cigarette into the fuel depot.	3	2	1	1	3	9	High
3. What would happen if electric devices around the oil tanks shock?	It could be cause of fire.	- Electrical devices are standardized and explosion proof. - Ground system - There is fire fighting system around tank farm	Provide monthly check for electrical devices.	2	2	1	1	3	6	Acceptable
4. What would happen if an operator doesn't wear hearing protective equipment while pumping fuel oil to gas turbine?	Exposure noise could be cause of hearing loss.	Area regulation required all operators wear hearing protective equipment while pumping fuel oil to gas turbine.		3	2	1	1	1	6	Acceptable
5. What would happen if an operator doesn't wear mask while pumping fuel oil to gas turbine?	Operator inhales the oil gas cause to irritate the respiratory system.	Area regulation required all operators wear mask while pumping fuel oil to gas turbine.		3	2	1	1	1	6	Acceptable

Figure C.7 Result of hazard identification and risk assessment using What-if analysis: pumping diesel oil to gas turbine process

Hazard identification form by Hazard and Operability Study

Node ....1.................... Node description ....diesel oil unloading system..............................

Production factor ....Flow.................... Control limit ....Normal = 5 - 45 m^3/h..............................

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Unloading pump	High flow	Discharge valve close and protection switch is inoperative	Oil leaks around the joints	Protection stop pump system	Checking the availability of the equipment before fuel oil unloading.	2	1	1	2	3	6	Acceptable
	Low flow	The system leaks	Pump is hot and cause to the equipment damage	Protection stop pump system	Checking the availability of the equipment before fuel oil unloading.	2	1	1	2	3	6	Acceptable
		Oil truck empty but pump is still working	Pump is hot and cause to the equipment damage	Protection stop pump system	Checking the availability of the equipment before fuel oil unloading.	3	1	1	1	3	9	High
		Dirty filter	Pump is hot and cause to the equipment damage	Protection stop pump system	Clean filter before fuel oil unloading.	3	1	1	1	3	9	High

Figure C.8 Result of hazard identification and risk assessment using HAZOP: NODE 1

Hazard identification form by Hazard and Operability Study

Node ....1.. Node description ....diesel oil unloading system...

Production factor ....Flow... Control limit ....Normal = 5 - 45 m^3/h...

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Unloading pump	No flow	Clogged filter	Pump is working but cannot pump the oil cause to the pump damage	Install flow alarm system	Checking the availability of the equipment before fuel oil unloading.	2	1	1	1	3	6	Acceptable
		Pump is inoperative	No oil pass into the fuel oil storage system		Checking the availability of the equipment before fuel oil unloading.	2	1	1	1	3	6	Acceptable
		Flexible hose is worn out	No oil pass into the fuel oil storage system and oil leaks	Install flow alarm system and choose a quality hose	Checking the availability of the equipment before fuel oil unloading.	3	1	1	2	3	6	Acceptable
		Power failure	Pump is inoperative and oil don't pass into the fuel oil storage system			1	1	1	1	4	4	Acceptable
	Back flow	Non return check valve have trouble	Oil flows backward into oil truck	Checking the availability of the equipment before fuel oil unloading.		2	1	1	1	3	6	Acceptable
		Discharge valve closed	Oil flows backward into oil truck	Checking the availability of the equipment before fuel oil unloading.		2	1	1	1	3	6	Acceptable

Figure C.9 Result of hazard identification and risk assessment using HAZOP: NODE 1 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....1.. Node description ....diesel oil unloading system..

Production factor ....Pressure.. Control limit ....Normal : 1 - 3.8 Bar...

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Unloading pump	High pressure	Discharge valve cannot open because control valve have trouble	- Pump damage - Oil leaks around the joints	Protection stop pump system	Check discharge valve is open before start working	2	1	1	2	3	6	Acceptable
		Pressure transmitter have trouble and inoperative	- Pump damage - Oil leaks around the joints	Protection stop pump system	Check pressure switch befor start working	3	1	1	2	3	9	High
	Low pressure	Suction filter is dirty	Oil transfer to unloading tank less than normal	Protection stop pump system	Clean filter before fuel oil unloading.	3	1	1	1	2	6	Acceptable
		Flexible hose is worn out	No oil pass into the fuel oil storage system and oil leaks	Protection stop pump system	Checking the availability of the equipment before fuel oil unloading.	3	1	1	2	2	6	Acceptable
		Pump have trouble	Pressure less than control limit cause to the pump is hot	Protection stop pump system	Checking the availability of the equipment before start working	3	1	1	1	3	9	High

Figure C.10 Result of hazard identification and risk assessment using HAZOP: NODE 1 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....1.. Node description ....diesel oil unloading system...

Production factor ....Pressure.. Control limit ....Normal : 1 - 3.8 Bar...

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Unloading pump	No pressure	Clogged filter	Pump is working but cannot pump the oil cause to the pump damage	Pressure alarm system alarms	Clean filter before fuel oil unloading.	2	1	1	1	3	6	Acceptable
		Pump is inoperative	No oil transfer to unloading tank		Checking the availability of the equipment before start working	2	1	1	1	3	6	Acceptable
		'Flexible hose is worn out	No oil pass into the fuel oil storage system and oil leaks	Install flow alarm system and choose a quality hose	Checking the availability of the equipment before start working	2	1	1	2	3	6	Acceptable

Figure C.11 Result of hazard identification and risk assessment using HAZOP: NODE 1 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....1... Node description ....diesel oil unloading system...

Production factor ....Temperature... Control limit ....Normal : 25 - 40 oC...

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Unloading pump	High temperature	Discharge valve is close but the pump is working, cause to the pump is hot and oil is hot too	Fire	Checking the availability of the equipment before start working		2	1	1	1	3	6	Acceptable
		Flexible hose is worn out cause oil flow is less than normal, the pump is hot and oil is hot too	Fire	Checking the availability of the equipment before start working		2	1	1	1	3	6	Acceptable

Figure C.12 Result of hazard identification and risk assessment using HAZOP: NODE 1 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....1.. Node description ....diesel oil unloading system...

Production factor ....Level... Control limit ....Normal : 1,450 - 6,660 mm...

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Unloading tank	High level	Pump is running all time and operator doesn't check oil level at unloading tank	Oil overflow from unloading tank	Level protection system, if oil is high level, unloading pump will stop working	Operator have to checl oil level before and after unloading oil from truck	3	1	1	3	3	9	High
		Level tank have trouble	Oil overflow from unloading tank	Level protection system, if oil is high level, unloading pump will stop working	Operator have to checl oil level before and after unloading oil from truck	2	1	1	3	3	6	Acceptable
	Low level	Oil tank leaks	Oil leaks	Level protection system, if oil is low level, transfer pump will stop working	Operator have to checl oil level before and after unloading oil from truck	1	1	1	2	3	3	Acceptable
	No level	Oil tank leaks	Oil leaks	Level protection system, if oil is low level, transfer pump will stop working	Operator have to checl oil level before and after unloading oil from truck	1	1	1	2	3	3	Acceptable

Figure C.13 Result of hazard identification and risk assessment using HAZOP: NODE 1 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....1.................... Node description ....diesel oil unloading system..........

Production factor ....Ignition.................... Control limit ....

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Unloading pump	Ignition	Operator has an activity that cause sparks in unloading area	Fire	Work permit system for hot work		3	2	1	1	3	9	High
		There is the static electricity in unloading area	Fire	Grounding system	Prepare a checklist for checking the truck driver connect the ground wire before start working	3	2	1	1	3	9	High

Figure C.14 Result of hazard identification and risk assessment using HAZOP: NODE 1 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....2.. Node description ....diesel oil transfer and storage system...

Production factor ....Flow... Control limit ....Normal = 10 - 150 m^3/h..

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Transfer pump	High flow	Discharge valve close and protection switch is inoperative	Oil leaks around the joints	Protection stop pump system	Checking the availability of the equipment before fuel oil unloading.	2	1	1	2	3	6	Acceptable
	Low flow	Suction filter is dirty	Pump is hot and cause to damage	Protection stop pump system	Clean filter before start working	3	1	1	1	3	9	High
		Less oil in unloading tank	Pump is hot and cause to damage	Protection stop pump system	Checking the oil level all time	3	1	1	1	3	9	High
	No flow	Suction pipes is damage	Oil leaks	Protection stop pump system	Checking the availability of the equipment before start working	2	1	1	2	3	6	Acceptable
		No oil in unloading tank	Pump is hot and cause to damage	Protection stop pump system	Checking the oil level all time	1	1	1	1	1	3	Acceptable
		Clogged filter	Pump is hot and cause to damage	Protection stop pump system	Clean filter before start working	2	1	1	1	3	6	Acceptable

Figure C.15 Result of hazard identification and risk assessment using HAZOP: NODE 2

Hazard identification form by Hazard and Operability Study

Node ....2... Node description ....diesel oil transfer and storage system...

Production factor ....Pressure... Control limit ....Normal : 1 - 5 Bar...

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Transfer pump	High pressure	Check valve have trouble	- Pump works very hard - Oil leaks around the joints - Equipment damage	Protection stop pump system	Checking the availability of the equipment before start working	2	1	1	2	3	6	Acceptable
		Discharge valve is close	- Pump works very hard - Oil leaks around the joints - Equipment damage	Protection stop pump system	Checking the availability of the equipment before start working	2	1	1	2	3	6	Acceptable
		Discharge pipe is clog	- Pump works very hard - Oil leaks around the joints - Equipment damage	Protection stop pump system	Checking the availability of the equipment before start working	2	1	1	2	3	6	Acceptable

Figure C.16 Result of hazard identification and risk assessment using HAZOP: NODE 2 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....2.. Node description ....diesel oil transfer and storage system...

Production factor ....Pressure.. Control limit ....Normal : 1 - 5 Bar...

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Transfer pump	Low pressure	Suction or discharge pipe leaks	Decrease pump performance	Protection stop pump system	Checking the availability of the equipment before start working	3	1	1	1	3	9	High
	No pressure	Pump is inoperative	Pump run dry cause pump is hot	Protection stop pump system	Checking the availability of the equipment before start working	2	1	1	1	3	6	Acceptable
		Clogged filter	Pump run dry cause pump is hot	Protection stop pump system	Clean filter before start working	2	1	1	1	3	6	Acceptable
		No oil in unloading tank	Pump run dry cause pump is hot	Protection stop pump system	Operator have to check oil level all time	1	1	1	1	3	3	Acceptable

Figure C.17 Result of hazard identification and risk assessment using HAZOP: NODE 2 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....2.......... Node description ....diesel oil transfer and storage system..........

Production factor ....Level.......... Control limit ....Normal : 2,150 - 13,300 mm..........

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Storage tank	High level	Pump is running all time and operator doesn't check oil level at unloading tank	Oil overflow from storage tank	Level protection system, if oil is high level, transfer pump will stop working	Checking the availability of the equipment before start working	3	1	1	3	3	9	High
		Level tank is inoperative	Oil overflow from storage tank	Level protection system, if oil is high level, transfer pump will stop working	Checking the availability of the equipment before start working	2	1	1	3	3	6	Acceptable
	Low level	Storage tank leaks	Oil leaks	Level protection system, if oil is high level, forwarding pump will stop working	Checking the availability of the equipment before start working	1	1	1	2	3	3	Acceptable

Figure C.18 Result of hazard identification and risk assessment using HAZOP: NODE 2 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....3.................... Node description ....diesel oil forwarding and return system..........

Production factor ....Flow.................. Control limit ....Normal = 20 - 300 m^3/h..........

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Forwarding pump	Low flow	Filter is dirty	Operating system is malfunction / no ignite	Protection stop pump system	Clean filter before start working	3	1	1	1	4	12	Non-acceptable
		Pipe leaks	Oil leaks	Protection stop pump system	Checking the availability of the equipment before start working	3	1	1	2	3	9	High
	No flow	Clogged filter	- If forwording pump is working cause pump is hot - Forwarding system is inoperative	Protection stop pump system	'Clean filter before start working	2	1	1	1	4	8	High
		Suction pipe is damage	- If forwording pump is working cause pump is hot - Forwarding system is inoperative	Protection stop pump system	Checking the availability of the equipment before start working	2	1	1	1	4	8	High

Figure C.19 Result of hazard identification and risk assessment using HAZOP: NODE 3

Hazard identification form by Hazard and Operability Study

Node ....3.. Node description ....diesel oil forwarding and return system..

Production factor ....Pressure.. Control limit ....Normal : 3 - 10 Bar...

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment						
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Forwarding pump	High pressure	Discharge valve is close	- Pump is hot cause pump damage - Oil leaks	Protection stop pump system	Checking the availability of the equipment before start working	2	1	1	2	3	6	Acceptable
	Low pressure	Pipe and valve leak	- Oil leaks - Decrease pump performance	Protection stop pump system	Checking the availability of the equipment before start working	3	1	1	2	3	9	High
	No pressure	Forwarding pump is inoperative	No oil feed to transfer to the system	Protection stop pump system	Checking the availability of the equipment before start working	2	1	1	1	4	8	High
		No oil in storage tank	No oil feed to transfer to the system	Protection stop pump system	Checking the oil level all time	1	1	1	1	4	4	Acceptable
		Suction pipe leaks	No oil feed to transfer to the system	Protection stop pump system	Checking the availability of the equipment before start working	3	1	1	1	4	12	Non-acceptable

Figure C.20 Result of hazard identification and risk assessment using HAZOP: NODE 3 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....3... Node description ....diesel oil forwarding and return system...

Production factor ....Temperature... Control limit ....Normal : 25 - 40 oC..

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment							
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Forwarding pump	High temperature	Discharge valve is close	Pump works very hard	Checking the availability of the equipment before start working	-	2	1	1	1	3	6	Acceptable

Figure C.21 Result of hazard identification and risk assessment using HAZOP: NODE 3 (cont.)

Hazard identification form by Hazard and Operability Study

Node ....3... Node description ....diesel oil forwarding and return system...

Production factor ....Contamination , Ignition.. Control limit ....-...

Oil Tanks / Pipe systems / equipment	Deviation	Possible causes	Potential consequence	Existing preventive and control measures	Recommendations	Risk assessment							
						Probability	Severity				Result	Risk level
							people	community	environment	assets		
Forwarding pump	Contamination	Oil is contaminate from vendor	Combustion system is clog , ignition have trouble or cause soot more than normal	Operator check oil quality before operate the system		1	1	1	1	2	2	Less
	Ignition	Operator has an activity that cause sparks in tank farm	Fire	Work permit system for hot work		3	2	1	1	3	9	High

Figure C.22 Result of hazard identification and risk assessment using HAZOP: NODE 3 (cont.)

APPENDIX D
DOCCUMENTARY PROOF OF ETHICAL CLEARANCE

Certificate of Approval
Ethical Review Committee for Human Research
Faculty of Public Health, Mahidol University

COA. No. MUPH 2017-016

Protocol Title :	COMPARATIVE RISK ASSESSMENT WITH HAZOP , WHAT-IF ANALYSIS AND CHECKLIST : CASE STUDY OF TANK FARM IN POWER PLANT
Protocol No. :	156/2559
Principal Investigator :	Miss Phatchayanee Detchang
Co-Investigator(s) :	Asst. Prof. Dr.Chaiyanun Tangtong Assoc. Prof. Vichai Priektaratikul Lect. Dr. Densak Yogyorn
Affiliation :	Master of Science Program in Industrial Hygiene and Safety Faculty of Public Health, Mahidol University
Approval Includes :	1. Project proposal 2. Information sheet 3. Informed consent form 4. Data collection form/Program or Activity plan
Date of Approval :	7 February 2017
Date of Expiration :	6 February 2018

The aforementioned project have been reviewed and approved according to the Declaration of Helsinki by Ethical Review Committee for Human Research, Faculty of Public Health, Mahidol University.

(Assoc. Prof. Dr. Sutham Nanthamongkolchai)
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