Root Cause Failure Analysis (RCFA) Root Causes Categorization and Generation of Recommended Data for RCFA Investigation

by

Tan Huat Chai

15886

Dissertation submitted in partial fulfilment of

requirement for the

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(Mechanical)

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CERTIFICATION

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Approved by,

_____

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JANUARY 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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TAN HUAT CHAI

ABSTRACT

Root Cause Failure Analysis (RCFA) is a process used to identify and investigate the root cause of a particular failure. It has been studied and applied for over a long period of time in the industries as a problem solving tool. Numbers of multinational company such as Shell Oil Company, Petroliam Nasional Berhad (PETRONAS), BESIX and BP formulate their own tool to aid RCFA process. The tools are list of causes listing down all the possible immediate causes and possible system or latent causes. The existing list of causes from each company are usually unique and not comprehensive plus it is tailored to the need of each company. To make the list more comprehensive and generic so that it can be used by any company in oil and gas industry, there is a need to make some improvement in term of possible immediate causes and possible system causes categorization and listing. Furthermore, as a matter of fact that there are various guidelines available to guide RCFA data collection process and to set focus on type of data should be collected. But, currently there is no specific guideline that can guide the investigator straight forwardly to the data to be collected that is specifically related to a certain failure in a plant. The first objective of the study is to propose a generic comprehensive categorization of possible immediate causes and possible system or latent causes for oil and gas industry. Plus, using the comprehensive list to design an application by using Microsoft Access as a storage and analysis tool to identify the significant root causes related to incidents happened. The second objective is to formulate list of recommended specific data to be collected based on system or unit in a plant and the associated failure under the system or unit by analysing past RCFA reports from industries. Plus, introducing the recommended data list in an application form by using Microsoft Access. In the first part of this study, a comprehensive RCFA list of causes was formulated after the RCFA list of causes from PETRONAS, BESIX, Shell, and BP were analysed and restructured. The comprehensive list of causes was transformed into application form by using Microsoft Access. The developed application acts as a storage plus analysis tool to identify the significant root causes related to incidents happened. In second part of this study, twelve RCFA reports from oil and gas industries were reviewed and analysed to identify the crucial data required in RCFA investigation. The identified data was utilised to design an application by using Microsoft Access as a tool to aid

data collection in future RCFA investigation based on failure associated to system or unit in a plant. This study have a significant implications on the improvement of RCFA process and data management. Having an updated comprehensive list of causes can lead to easier identification of failure root causes associated to incidents due to more standardise and comprehensive categorization of the factors. It appears that an application that can analyse the significant root causes based on previous incidents may help an organization to tackle the root causes and minimize the chance for the same incidents to happen again in the next future. Nevertheless, data collection process for failure incident in plant can be improved by having an application that provides a list of recommended data to be collected in RCFA investigation.

ACKNOWLEDGEMENT

The completion of this Final Year Project has been a culmination of various acts of assistance and goodwill. I take this opportunity to express my greatest gratitude to them.

Thus, I take this opportunity to express my profound appreciation and deep regards to my direct supervisor, Dr. Hilmi Hussin for his exemplary guidance, motivational nature and for his willingness to share his knowledge as well as experience throughout my time of need.

Subsequently, I would like to thank my friends and family who have been supporting me throughout this project. Their direct and indirect interaction as well as gestures have kept me going.

Last but not least, I would like to thank the almighty for granting me this opportunity and for all around good health. It is undeniable, that only with the support and assistance of all the parties mentioned above, that I have been able to complete by project.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background Study

Reliability engineering focuses on preventing catastrophic failure of critical plant production systems and maintaining the acceptable performance levels in term of capital, product quality, environmental, and safety [1]. Even though full effort is given to maintain the objectives, unfortunately events that lead to violation of the objectives are still happening. The industry still paying huge sum of cost due to equipment unreliability despite many plant owners have improved the reliability of their operating facilities. It is impossible to fully terminate the occurrence in real situation. Therefore, a logical approach of resolving the problem through correction of the root cause that lead to events is vital to improve plant performance.

A method that can define and isolate the root cause of the failure events plus preventing recurrence through proposing a cost-effective corrective action promises a brighter future in achieving reliability engineering objectives. The philosophy has led to discovery of root cause failure analysis (RCFA). RCFA is a process formulated to investigate and identify the root cause of a particular failure and enhancing the information to solve the problem, in term of corrective or preventive action [2].

Aware of the importance of RCFA, there are numbers of multinational company such as Shell Oil Company, Petroliam Nasional Berhad (PETRONAS), BESIX and BP formulate their own tool to aid RCFA process. The tools are list of causes listing down all the possible immediate causes and possible system or latent causes. The idea of having these tools was, to aid RCFA investigators to have a clearer path in determining the root cause of a certain failure or incident.

Data collection is an investment to organization, combination of standardized data and enhanced data management system can result in improved quality of data for reliability engineering [3]. Generally, there are various guidelines available to guide RCFA data collection process and to set focus on type of data should be collected. The importance of these guidelines are to make sure correct data for RCFA is collected.

1.2 Problem Statement

RCFA was formulated to serve as a process that can contributes to company improvement. However it possess its own weakness, not in term of the RCFA process but on how the RCFA process is achieved or conducted. One of the reasons behind the failure in RCFA is due to inaccurate and inadequate data collection and analysis. Furthermore, lack of focus in consideration of the failure root cause is another reason that lead to unsuccessful RCFA [4]. In this sense, data collection and categorization including identification of possible root causes have become crucial to secure a successful RCFA process.

Even though megacorporation such as Shell Oil Company, Petroliam Nasional Berhad (PETRONAS), BESIX and BP have their own initiatives to improve RCFA process delivery by formulating list of causes, listing down the possible immediate causes and possible system or latent causes associated to failure but the lists still can be improvised. Existing list of causes from each company are not comprehensive enough and require some improvement in term of possible immediate causes and possible system causes categorizations and details of each categorization.

Availability of multiple guidelines to aid data collection in RCFA is surely be the main key to highlight and execute preventative plus corrective actions that result in sustainable improvements in reliability, leading to improved profitability and safety of a plant. However, the fact that there is currently no specific guideline that can guide the investigator straight forwardly to the data to be collected that is specifically related to a certain failure in a plant.

1.3 Objectives

In this project, the purposes of the study are:

- To propose a generic comprehensive categorization of possible immediate causes and possible system or latent causes for oil and gas industry. Plus, using the comprehensive list to design an application by using Microsoft Access as a storage and analysis tool to identify the significant root causes related to incidents happened.
- To formulate list of recommended specific data to be collected based on system or unit in a plant and the associated failure under the system or unit by analysing past RCFA reports from industries. Plus, introducing the recommended data list in an application form by using Microsoft Access.

1.4 Scope of Study

This study focuses on two parts as according to the objectives stated. First part of the study focused on comparing and analysing list of causes from Shell Oil Company, Petroliam Nasional Berhad (PETRONAS), BESIX and BP. Then, the activity proceeded with proposing and developing a new comprehensive categorization of list of possible immediate causes and possible system or latent causes that significantly lead to an incident. The new formulated list was transformed into application form by using Microsoft Access.

Second part of this study was to review and compare previous RCFA reports from oil and gas industries, specifically oil and gas plant followed by identifying the data needed to conduct RCFA for a certain failure. Then, the findings were used to formulate list of recommended specific data to be collected based on system or unit in a plant and the associated failure under the system or unit. Plus, introducing the recommended data list in an application form by using Microsoft Access.

CHAPTER 2
LITERATURE REVIEW

2.1 RCFA

RCFA process is a branch of root cause analysis (RCA), focusing more on failure mostly related to industrial associate with reliability and maintenance department. This reliability technique is formulated to identify the root cause for component, equipment, or system failures [5]. RCFA process is separated into several steps, which are identification of the failure, incident classification, data collection, design review, application review, determining the root cause and finally suggestion of potential corrective actions [1]. The process consists of five phases which are data collection, assessment, correction actions, report findings and follow up, which is applying correction action on the root cause [6].

RCFA can be divided into three major phases. The three major phases are data collection, analysis, and solution [2]. Initial step of determining a successful RCFA is through quality data collection. Collecting, managing and extracting the data for RCFA can be a challenging and tedious task. Analysing and proposing the solution for RCFA is another challenges to be overcome. Conducting an RCFA also requires people from different field of expertise due to the variation of events that might lead to failure and sacrificing plenty of precious time [2].

2.2 Data Categories

Classified data collection according to three categories, the inventory data, failure data and maintenance data [7]. Inventory data consists of operating data, environmental data and technical of equipment unit for instance the equipment's specification, capacity, and surrounding condition. Failure effect, failure cause, failure mode and failure mechanism are specified under failure data. The third data, which is maintenance data comprise of data for preventive and corrective maintenance action taken to tackle each and every equipment failure [7].

Data categories can be separated under three parts. First is equipment unit data, followed by failure data and maintenance data [3], [7]. All of these data are essential

for RCFA process. Any misleading or misjudge during data collection and categorization may lead to failure of the RCFA process itself. Equipment data comprise of classification data, equipment attributes and operation data. Noted that even though inventory data and equipment data were identified with different names, but both of them carry the same definition. Classification data is equivalent to environment data while technical of equipment unit also known as equipment attributes. Failure data are mainly the failure date, items failed, failure impact, failure mode, failure cause and failure mechanism. The third data category is maintenance data. In maintenance data, recording shall be focused on maintenance identification for instance date of maintenance, maintenance resources, active maintenance time and down time.

Above sources are valid to support the argument that equipment data, failure data and maintenance data are essential in RCFA process. However, this particular study will only focus on equipment data and failure data.

2.2.1 Failure Data

As per earlier discussion, failure data can be categorized into failure cause, failure effect, failure mode and failure mechanism. Failure cause is the condition where failure is the circumstances during design, manufacturing, or operation that lead to a failure [8]. In simpler words, failure cause is the reason of why an equipment fail. Failure cause and failure root cause are always been misunderstood by people, even for those who are directly involved in reliability and RCFA. As the name goes, failure cause is a more direct or noticeable cause that happen on an equipment, while root cause is the main reason behind the failure cause. Taking a situation for rotary dryer is leaking for an example, many people will come out with a statement saying that the root cause of the leaking is due to sealing element leakage, however that is the failure cause. The root cause can be due to human error during installation process or procurement department purchased the sealing material that is not according to original specification. Failure root cause is further discussed in Section 2.3. Failure effect or failure impact is described as the outcome of a failure. Failure cause will lead to an equipment failure, resulting an observable condition of the failure which is failure mode and followed by failure effect. Back to the example of rotary dryer

leakage, possible failure effects from the condition shall be pressure drop and decreasing of production. The relationship between failure cause, root cause, failure effect, failure mode and failure mechanism is shown in Figure 2.1.

In collecting failure data, failure mode and failure mechanism of equipment are an essential key elements to categorize and identify the failure root cause in RCFA. Failure mode and failure mechanism normally being understood by people from having the same definition and carries the same meaning on equipment. Failure mode is defined as the behaviours by which the failure can be observed [9]. Failure mechanism on the other hand is the processes by which the physical, chemical, electrical, and mechanical stresses induce the failures or it describes the fundamental manners of equipment can fail [9], [10]. Failure mode of equipment in petrochemical industry can be categorized into three parts [3]. First failure mode is when the desired function of the equipment is failed to be obtained. Second, the equipment is functioning, but out of the expected operational limits or can be said as specified function lost. Last category of failure mode is the early identification of the equipment losing its expected operating function, but at that time the equipment is still able to deliver the expected function [3]. Failure mechanism is classified into mechanical failures, material failures, instrumentation failures, electrical failures, electrical failures, external influence, and miscellaneous.

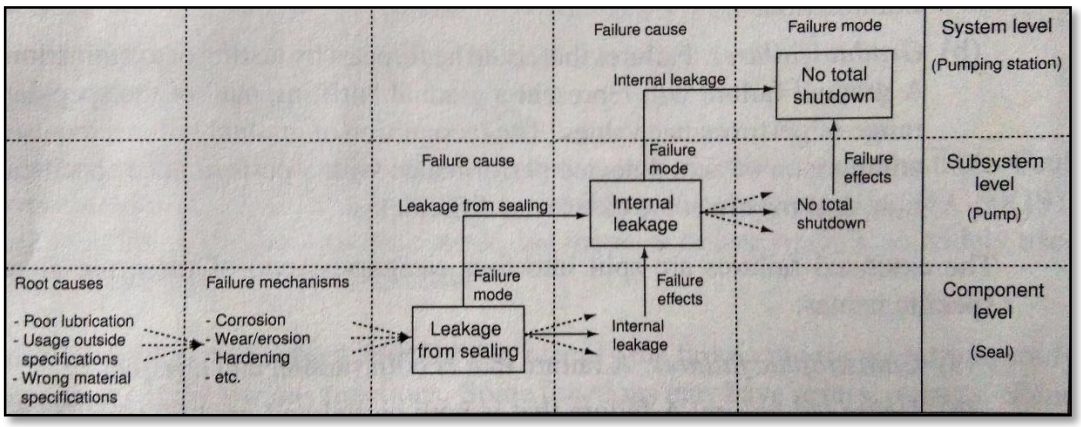

FIGURE 1. Relationship between failure causes, failure mode, failure mechanism and failure effect [8]

2.2.2 Equipment Data

As per discussed in earlier section, equipment or inventory data can be classified into several categories. Table 2.1 shows the detail classification together with example of data to be collected.

TABLE 1. Classification of equipment data [3]

No	Data category	Data	Element example
1	Classification data	Industry type	Petrochemical
		Production	Purified Terephthalic Acid
		Geographical location	Malaysia
		Plant unit category	Compressor station
		Section/ system	Compression
		Operation category	Remote control
2	Equipment attributes	Equipment class	Compressor
		Equipment type	Centrifugal
		Equipment identification/ tag number	BA-705
		Equipment description	Main compressor
		Manufacturer's name	Wiley
		Model designation	LamaxComp ZT-1000
		Manufacturer data (i.e. technical drawings, power, capacity, pressure, speed, temperature etc.)	Equipment-specific
		P&ID	Equipment-specific
3	Operating data	Normal operating state	Intermittent
		Initial commissioning date	10-10-2010
		Surveillance time	7000 hours
		Operating parameters (i.e. power, capacity, pressure, speed, temperature etc.)	Equipment-specific

2.3 Failure Root Cause

Failure root cause of equipment can initiate from various factors, not only necessarily from the equipment itself. Three categorization of causes that lead to failure, which are physical root cause, human root cause, and latent root cause [6]. Physical root cause is more directly related to the equipment, the physical reason of why the equipment fail which is tangible and observable. For an example, pump overheat because of mechanical seal leakage. This situation shows that justification for the pump overheat is due to the mechanical seal problem, which is physically observable on what is happening on the pump. Human root cause is related to human decision which result in the equipment failure and can be defined as the error of omission or commission. Root cause that related to the organization or management flaws is known as latent root causes. Normally, latent root causes is the lease that people will focus on when dealing with RCFA, and that is the misjudgement that lead to failure of RCFA process.

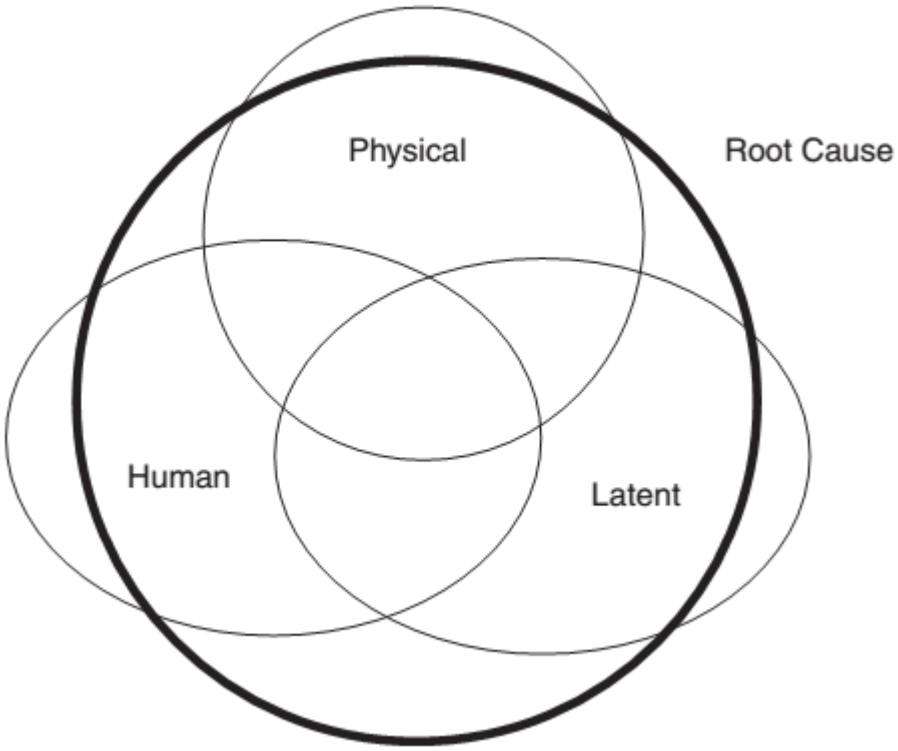

FIGURE 2. Relationship between categories of causes [11]

Root cause hierarchy start from latent root cause, then human root causes, finally end with physical root cause. Most physical failures are the negative result of human error. Human error however is hugely influence by the latent causes [12]. So, a conclusion can be made that the root causes of equipment failures is influenced by the latent forces, which is normally being ignored in RCFA process.

2.3.1 RCFA Tool: List of Causes

List of Causes is a tool formulated by organizations to ease root cause analysis. It has been used in various industries and organizations to aid RCFA process. With this, investigation process can be done with consuming less time and more focus on the problem that should be tackled. Major parts of the List of Causes are separated into few categories and arrangements as can be observed in Figure 3 to Figure 6. As observed, the List of Causes from companies are focusing on two main area, which are immediate causes and system or latent causes. Immediate causes can be defined as substandard acts or conditions that lead directly to the accident. These might be removal of a machine guard, employee error, non-use of personal protective equipment, lack of concentration, stress, fatigue and poor housekeeping [13]. While, system or latent causes may be defined as inadequacies in the management system that allow the immediate causes to arise unchecked, leading to the accidents [13].

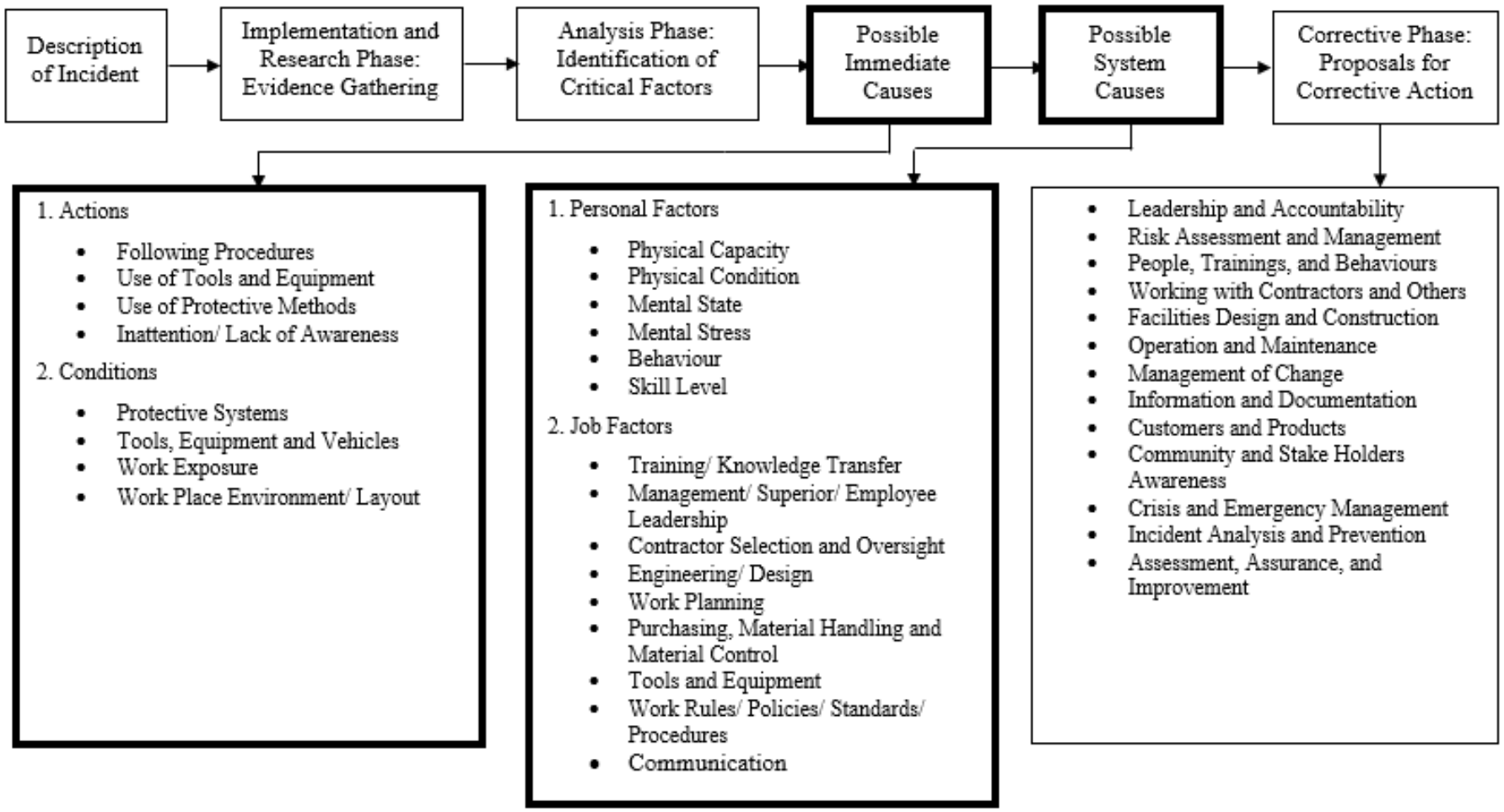

FIGURE 3. BP List of Causes [14]

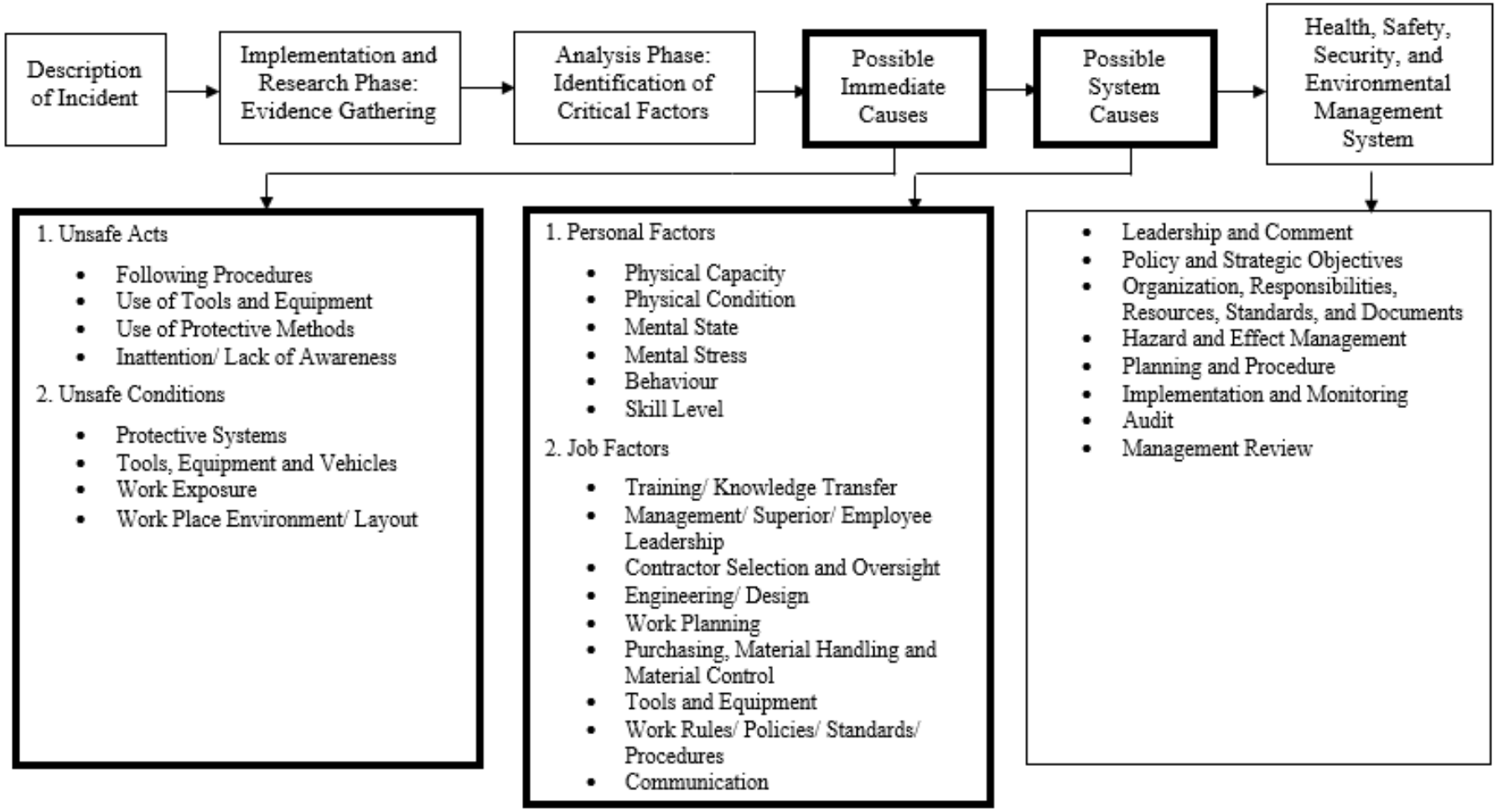

FIGURE 4. Shell List of Causes [15]

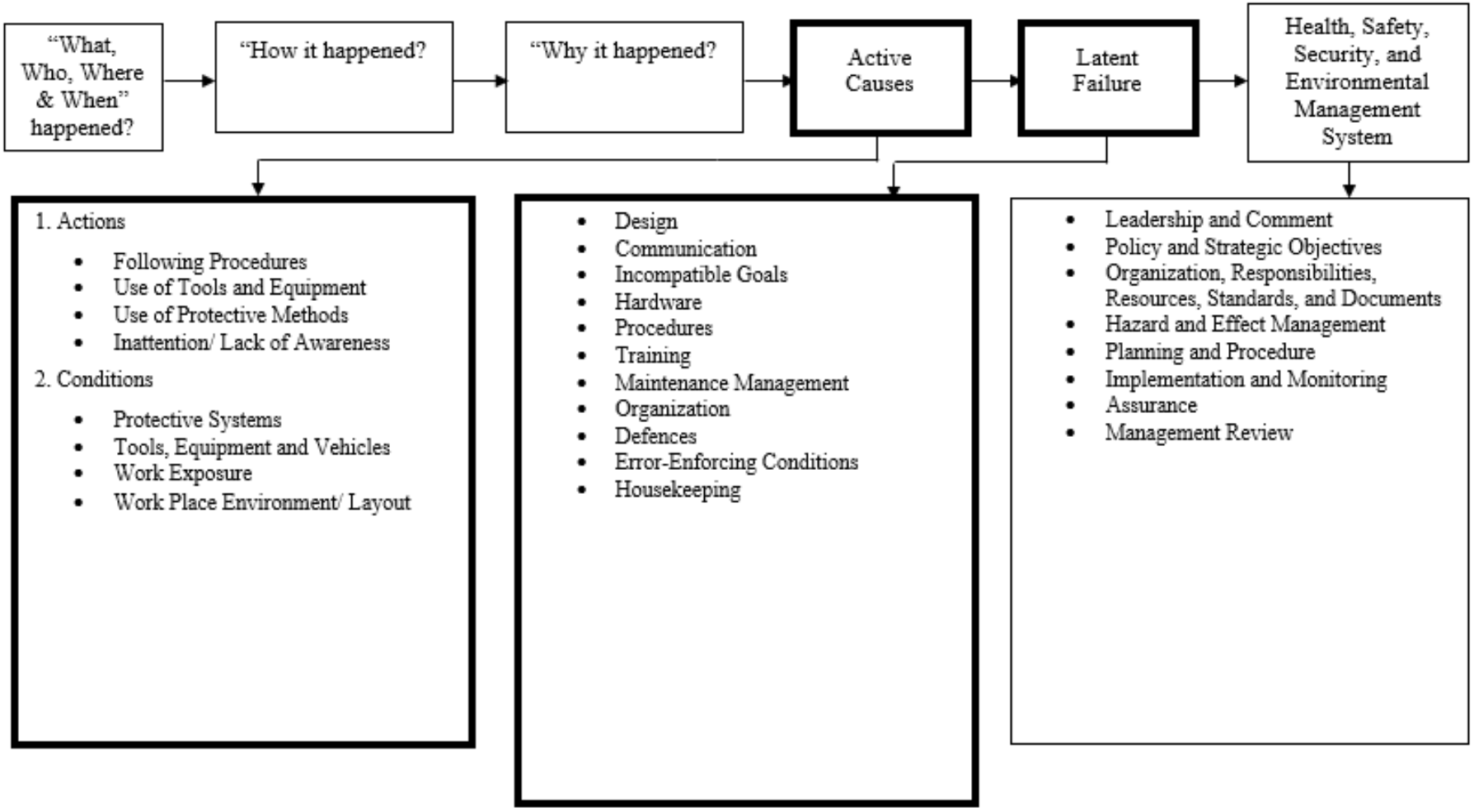

FIGURE 5. PETRONAS List of Causes [16]

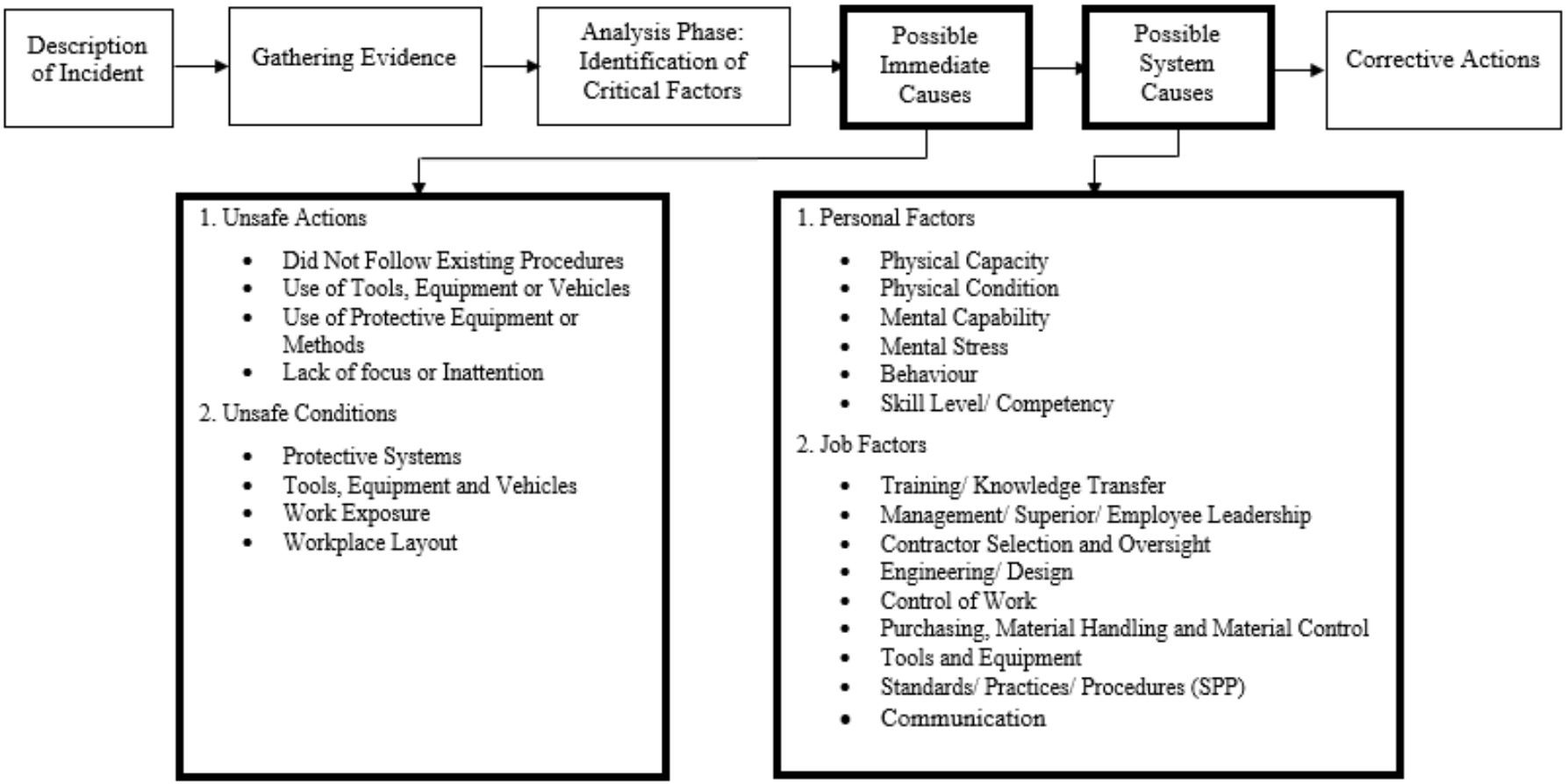

FIGURE 6. BESIX List of Causes [17]

CHAPTER 3
METHODOLOGY

3.1 Project Methodology and Project Flow Diagram

As this project comprises of two objectives, the approach to tackle each of the objectives was done differently. The methods used throughout this study are discussed as per listed below. Figure 7 and Figure 8 show the summarization of the methodologies throughout completion of this study.

3.1.1 Comprehensive List of Causes Categorization

3.1.1.1 Review List of Causes from Companies

RCFA tools in this study, which are the lists of causes from Shell Oil Company, Petroliam Nasional Berhad (PETRONAS), BESIX and BP were gathered and reviewed. The lists of causes comprises of possible immediate causes and possible system or latent causes.

3.1.1.2 Categorization of Causes

Possible immediate causes and possible system or latent causes in the tools had their own categorization of factors associated to the two causes, immediate and system or latent. Each of the factors had their own specific details. The factors and its specific details were differed based on company. After careful comparison and analysis between the lists of causes, new categorization of factors and the details of factors that associated to immediate and system or latent caused was formulated.

3.1.1.3 Design Application through Microsoft Access

After the categorization was done, the new comprehensive list was transformed into application form by using Microsoft Access. Apart from functioning as a tool to aid investigators in RCFA process, the developed application also acts as storage plus analysis tool to identify the significant root causes related to incidents happened.

3.1.1.4 Application Testing

Application testing was done to identify flaws in the design and tested for the functionality

3.1.2 RCFA Evidence Data Identification and Categorization

3.1.2.1 Review RCFA Reports

Twelve RCFA reports from PETRONAS were reviewed to identify the data that had been collected for a certain failure or incident happened.

3.1.2.2 Determine Categorization Method

According to the twelve RCFA report reviewed, the data were proposed to be categorized based on system or unit in the plant, and associated to failure occurred. For example, under acid gas removal unit, failure associated is hydrocarbon bypassed, the data recommended to be collected for hydrocarbon bypassed in acid gas removal unit are plant process flow diagram, operator logbook, safeguarding record, etc.

3.1.2.3 Determine RCFA Data for Each Categorization

RCFA data were extracted from the twelve RCFA report and categorized under failure based on system or unit in the plant.

3.1.2.4 Design Application through Microsoft Access

After the data identification and categorization were done, the recommended data were transformed into application form by using Microsoft Access. In the application, recommended data were shown according to system or unit and specific failure associated. The outcome from the application was expected to be able to act as a tool to assist data collection in plant incident or failure associated to systems or units in the plant.

3.1.2.5 Application Testing

Application testing was done to identify flaws in the design and tested for the functionality

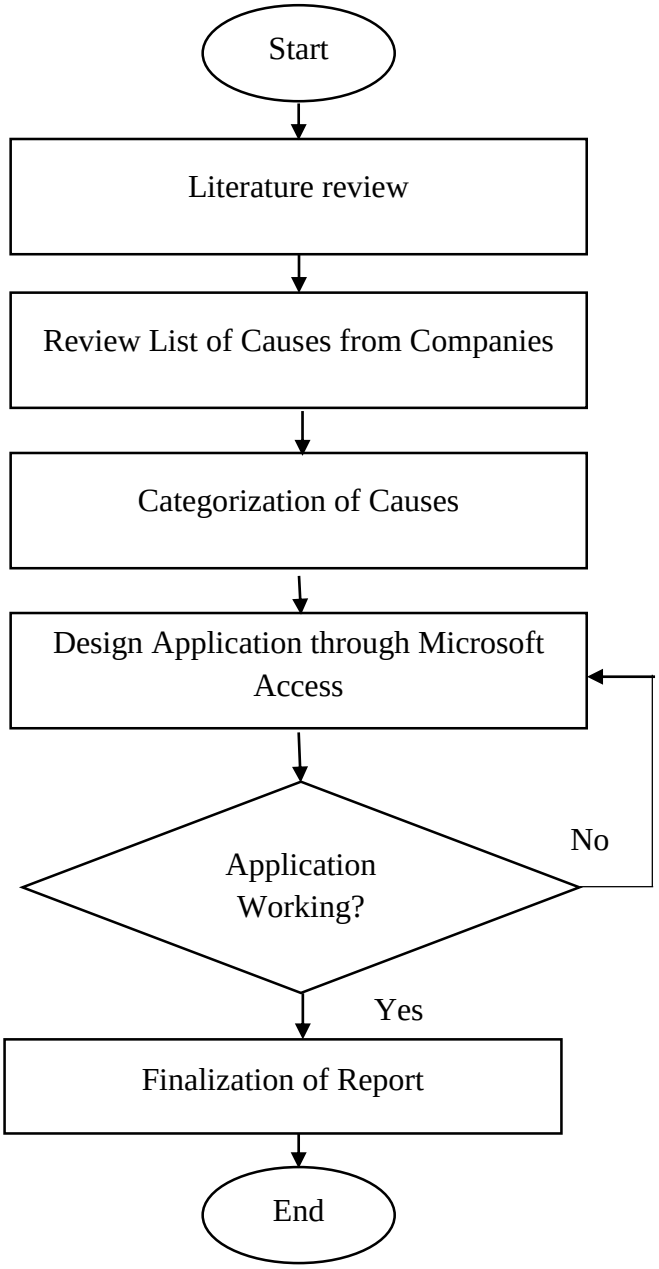

FIGURE 7. Project flow chart for Comprehensive List of Causes Categorization

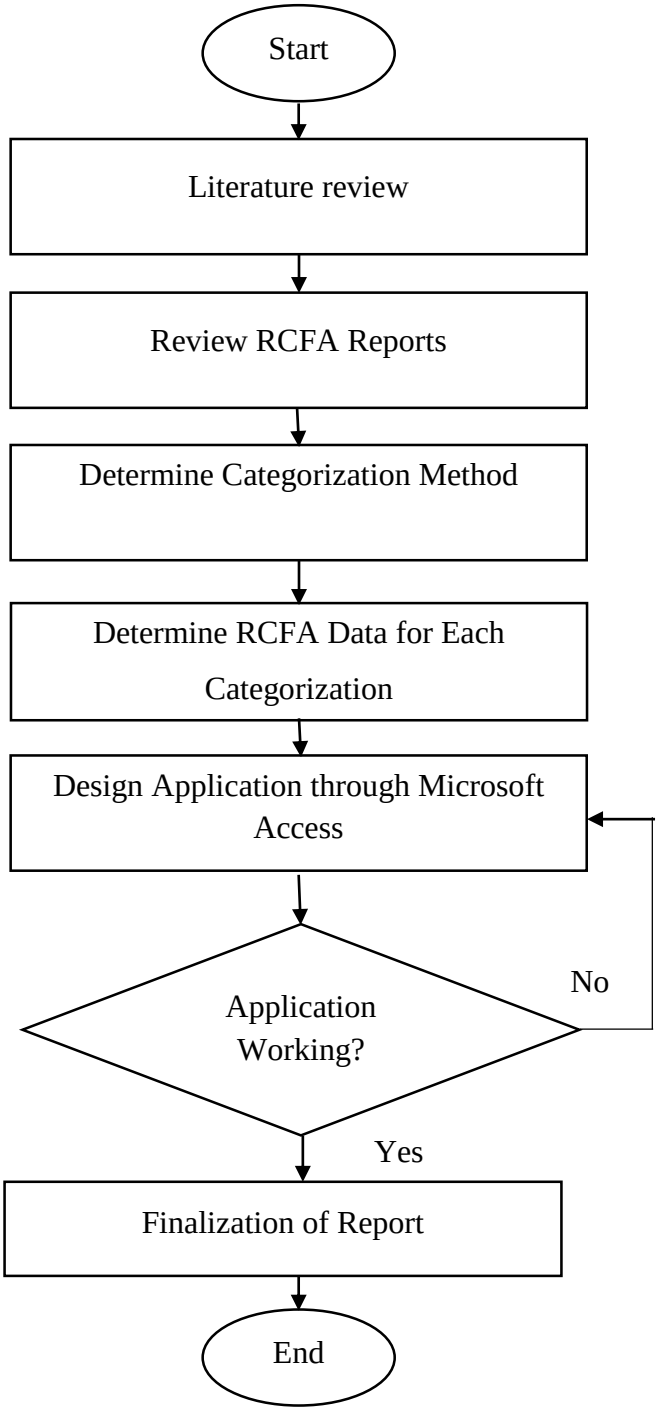

FIGURE 8. Project flow chart for RCFA Evidence Data Identification and Categorization

3.2 Gantt Chart and Key Milestones

TABLE 2. Project Gantt chart

No	Activities	FYP 1														FYP 2													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Root Causes Categorization									↔					↔														
1	Gather List of Causes from Companies																												
2	Review List of Causes from Companies																												
3	Categorization of Causes															▲													
	Recommended Data List													↔							↔								
4	Gather RCFA Reports																												
5	Review RCFA Reports																												
6	Determine Categorization Method																												
7	Determine RCFA Data for Each Categorization																				▲								
8	Application Design																												
9	Application Testing																									▲			
	Key Milestones: ▲																												

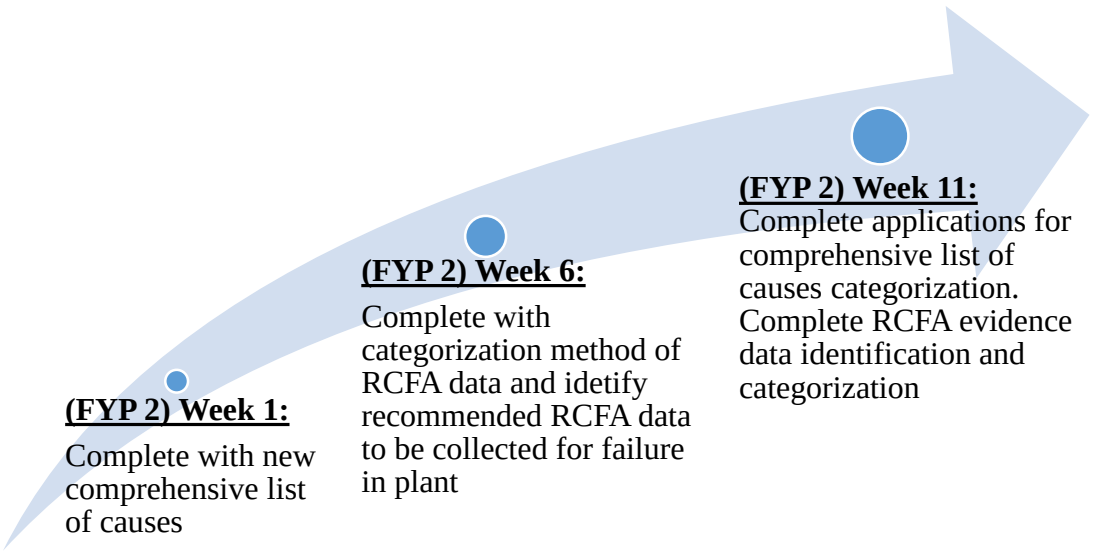

FIGURE 9. Key Milestones

CHAPTER 4
RESULTS AND DISCUSSION

A proposed generic comprehensive list of possible immediate causes and possible system or latent causes was successfully formulated. Information obtained to identify the new categorization of factors leading to possible causes of failure and the details of the factors were based on list of causes from Shell Oil Company, Petroliam Nasional Berhad (PETRONAS), BESIX and BP. Figure 10 to Figure 20 show the new comprehensive list of causes, with updated categorizations of factors leading to possible causes of failure and the details of each factor. In this case, the list can be used by RCFA investigators to aid identification of root causes of a certain failure or incident that happened in the industry. Figure 21 and Figure 22 show the example of application developed by using Microsoft Access. In the application, the user is able to input the title of incident, the failure event, consequences and the causes associated to the failure. The information then can be stored in another file acting as a database system, which is shown in Figure 23. This feature is functioning as a recording and storing application for the investigators to have a proper record of past RCFA report in a database storage. Figure 24 shows the extra feature of the application, which acts as an analysis tool to identify the most significant cause leading to the failure. This feature is able to act as a tool for management to identify the critical root cause that leads to failure or incident. The information from the analysis allows the organization to take appropriate actions and solve the problem. As per shown in Figure 24, the pie chart shows 25% of the incidents are due to “Inadequate preventive maintenance”, which leads back to “Control of Work” under possible system or latent causes. The result in pie chart Figure 24 utilized the twelve RCFA reports from PETRONAS as case study.

Figure 25 is showing the application for recommendation of RCFA evidence data to be collected according to system or unit and the failure associated. In this application, the user will need to select the system or unit in the plant, then from the system the list will focus on failure associated. From this application, recommended data to be collected are shown according to failure associated to the system or unit in a plant. Hence, it is useful for RCFA investigators whenever a failure investigation is

carried out, especially when a system or unit plus the failure associated to the system or unit is known. Instead of starting to identify and collect the data randomly, this application acts as a guide for the investigators to collect the specific data related to the failure. Not only able to set a clear focus on the data to be collected, but this application also able to minimized the data collection time and this helps to reduce the total investigation time, which in return identification of the root cause can be done in shorter time. For current result, the list is still not yet well developed due to constraint in resource, which is RCFA reports. Only twelve RCFA reports were managed to obtain from the industry, which limit our findings on more comprehensive categorization and data. Table 3 shows the list of system or unit and the failure associated to each system or unit. The finding was based on twelve RCFA reports from PETRONAS.

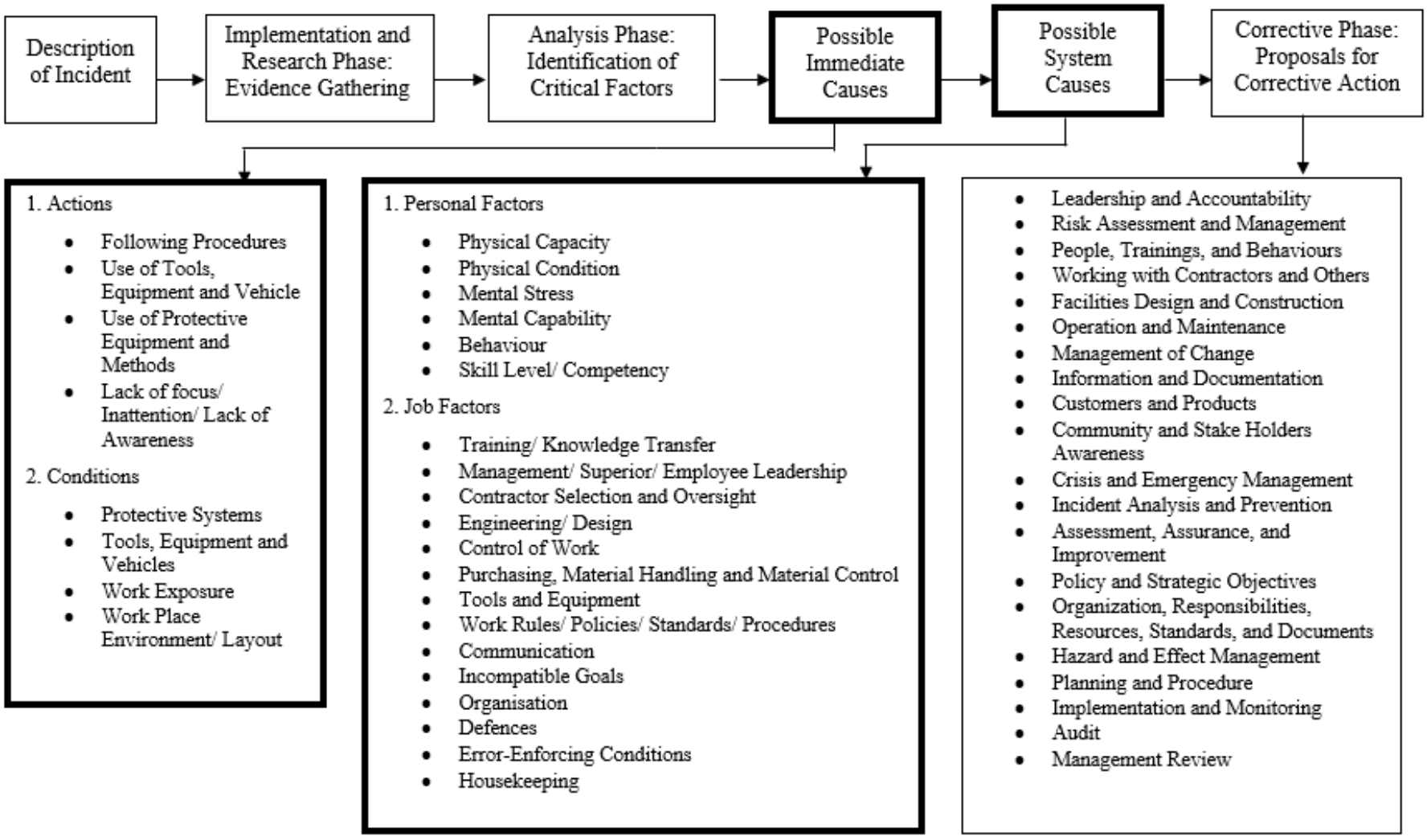

FIGURE 10. Formulated Comprehensive List of Causes

Possible Immediate Cause: Actions			
Following Procedures	Use of Tools, Equipment and Vehicle	Use of Protective Equipment and Methods	Lack of Focus/ Inattention/ Lack of Awareness
1. Violation by individual 2. Violation by group 3. Violation by supervisor 4. Operation of equipment without authority 5. Improper position or posture for the task 6. Overexertion of physical capability 7. Work or motion at improper speed 8. Improper lifting 9. Improper loading 10. Shortcuts 11. Improper load vehicle capacity 12. Improper use if handrail 13. Other	1. Improper use of equipment 2. Improper use of tools 3. Use of defective equipment 4. Use of defective tools 5. Improper placement of tools, equipment or materials 6. Operation of equipment at improper speed 7. Disrespect the speed limit 8. Servicing of equipment in operation 9. Other	1. Lack of knowledge of hazards present 2. Personal protective equipment not used 3. Lack of use of seat belt 4. Improper breathing apparatus, wind socks for a H2S exposed work environment 5. Improper use of proper personal protective equipment 6. Improper use of fall arrestor equipment 7. Servicing of energized equipment 8. Equipment or materials not secured 9. Disabled guards, warning systems or safety devices 10. Removal of guards, warning systems or safety devices 11. Personal protective equipment not available 12. Other	1. Improper decision making or lack of judgement 2. Improper decision making of unnecessary confined space entry 3. Improper decision making of unnecessary work at height 4. Distracted by other concerns 5. Inattention to footing and surroundings 6. Distracted by use of mobile phone while driving 7. Horseplay 8. Acts of violence 9. Failure to warn 10. Use of drugs or alcohol 11. Routine activity without thought 12. Inattention to housekeeping 13. Other

FIGURE 11. Possible Immediate Causes - Actions

Possible Immediate Cause: Conditions			
Protective Systems	Tools, Equipment and Vehicle	Work Exposure	Work Place Environment/ Layout
1. Inadequate guards or protective devices 2. Defective guards or protective devices 3. Inadequate personal protective equipment 4. Defective personal protective equipment 5. Inadequate warning systems 6. Defective warning systems 7. Inadequate isolation of process or equipment 8. Inadequate isolation of lifting area 9. Inadequate safety devices 10. Defective safety devices 11. Other	1. Defective equipment 2. Defective oxygen/ gas detector equipment 3. Inadequate equipment for work at height 4. Inadequate equipment 5. Improperly prepared equipment 6. Defective tools 7. Inadequate tools 8. Improperly prepared tools 9. Defective vehicle 10. Inadequate vehicle for the purpose 11. Improperly prepared vehicle 12. Other	1. Fire or explosion 2. Noise 3. Energized electrical systems 4. Energized systems, other than electrical 5. Radiation 6. Temperature extremes 7. Hazardous chemicals 8. Mechanical hazards 9. Cutter or debris 10. Acts of nature 11. Slippery floors or walkways 12. Other	1. Congestion or restricted motion 2. Inadequate or excessive illumination 3. Inadequate ventilation 4. Inadequate constant atmospheric test for confined space entry 5. Inadequate atmospheric tests for the H2S exposed space 6. Unprotected height 7. Inadequate work place layout • Controls less than adequate • Displays less than adequate • Labels less than adequate • Locations out of reach or sight • Conflicting information is presented 8. Other

FIGURE 12. Possible Immediate Causes - Conditions

Possible System Causes/ Latent Causes: Personal Factors					
Physical Capacity	Physical Condition	Mental Capability	Mental Stress	Behaviours	Skill Level/ Competency
1. Vision deficiency 2. Hearing deficiency 3. Other sensory deficiency 4. Reduced respiratory capacity 5. Other permanent physical disabilities 6. Temporary disabilities 7. Inability to sustain body position 8. Restricted range of body movement 9. Substance sensitivities or allergies 10. Inadequate size or strength 11. Diminished capacity due to medication 12. Other	1. Previous injuries or illness 2. Fatigue • Due to workload • Due to lack of rest • Due to sensory overload 3. Diminished performance • Due to temperature extremes • Due to oxygen deficiency • Due to atmospheric pressure variation 4. Blood sugar insufficient 5. Impairment due to drug or alcohol 6. Other	1. Poor judgement 2. Memory failure 3. Poor coordination or reaction time 4. Emotional disturbance 5. Fears or phobias 6. Low mechanical aptitude 7. Low learning aptitude 8. Influenced by medication 9. Other	1. Preoccupation with problems 2. Frustration 3. Confusing directions/ demands 4. Conflicting directions/ demands 5. Meaningless or degrading activities 6. Emotional overload 7. Extreme judgement/ decision demands 8. Extreme concentration/ perception demands 9. Extreme boredom 10. Other	1. Improper performance is rewarded • Saves time or effort • Avoids discomfort • Gains attention 2. Improper supervisory example 3. Inadequate identification of critical safe behaviours 4. Inadequate reinforcement of critical safe behaviours • Proper performance is criticised • Inappropriate peer pressure • Inadequate performance feedback • Inadequate disciplinary process 5. Inappropriate aggression 6. Improper use of production incentives 7. Supervisor implied haste 8. Employee perceived haste 9. Inadequate housekeeping behaviour 10. Other	1. Inadequate assessment of required skills 2. Inadequate practice of skill 3. Infrequent performance of skill 4. Lack of coaching on skill 5. Insufficient review of instruction to establish skill 6. Other

FIGURE 13. Possible System or Latent Causes - Personal Factors

Possible System Causes/ Latent Causes: Job Factors			
Training/ Knowledge Transfer	Management/ Superior/ Employee Leadership	Contractor Selection and Oversight	Engineering/ Design
1. Inadequate knowledge transfer • Inability to comprehend • Inadequate training equipment • Misunderstanding instructions 2. Inadequate recall of training material • Training not reinforced on the job • Inadequate refresher training frequency 3. Inadequate training for working with hazardous chemical substances 4. Inadequate training effort • Inadequate training program design • Inadequate training goals/ objectives • Inadequate new employee orientation • Inadequate initial training • Inadequate means to determine if qualified for job • Inadequate resources to conduct training program (time, money, man power) • Guidelines on establishing the requirements of training and educational courses were lacking or inadequate 5. No training provided • Need for training not identified • Training records incorrect or out of date • New work methods introduced without training	1. Management policy guidance/ expectations not well-defined, understood or enforced 2. Job performance standards not adequately defined 3. Management direction created insufficient awareness of impact of actions on safety/ reliability 4. Management follow-up or monitoring of activities did not identify problems 5. Management assessment did not determine causes of previous event or known problems 6. Previous industry of in-house experience was not effectively used to prevent recurrence 7. Responsibilities of personnel not wee-defined or not held accountable 8. Corrective actions response to a known or repetitive problem was untimely 9. Corrective actions for previously identified problem or event was not adequate to prevent recurrence 10. Conflicting roles/ responsibilities • Unclear reporting relationships • Conflicting reporting relationship • Unclear assignment of responsibility • Conflicting assignment of responsibility • Improper or insufficient delegation of authority 11. Supervisory problem • Tasks and individual accountability not make clear to workers • Progress/ status of task not adequately tracked	1. Lack of contractor pre-qualification 2. Inadequate contractor pre-qualification 3. Inadequate contractor selection 4. Use of non-approved contractor 5. Lack of job oversight 6. Inadequate oversight 7. Other	1. Inadequate technical design • Design input obstacle • Design input not correct • Design input not available • Design output inadequate • Design input infeasible • Design output unclear • Design output not correct • Design output inconsistent • No independent design review 2. Inadequate control in design process (design change controls, checks on compliance with standards/guidelines, quality controls) 3. Insufficient design provisions were made for the operating external environment (extreme temperatures, humidity, particulates etc.) 4. Inadequate standards, specifications, and design criteria 5. Inadequate assessment of potential failure 6. Inadequate ergonomic design 7. Inadequate design of excavation

FIGURE 14. Possible System or Latent Causes - Job Factors

• Decision made not to train 6. Incompetent trainer/ trainer with lack of experience 7. Test of the effectiveness of training or education given were inadequate (no final test on the material or skills taught) 8. There was insufficient standardization of training courses, educational standards and competence requirements between companies and countries 9. No training course were authorized/organized (lack of management concern regarding competence) 10. Training for supervisors and managers about how information and knowledge could best be shared was ineffective 11. Knowledge and experience levels among the maintenance personnel were insufficient (no specific training or on-the-job training given) 12. Other	• Job performance and self-checking standards not properly communicated • Too many concurrent tasks assigned to worker • Contact with personnel too infrequent to detect work habit. Attitude changes 12. Inadequate leadership • Standards of performance missing or not enforced • Inadequate accountability • Inadequate or incorrect performance feedback • Inadequate work site walk through • Inadequate safety promotion 13. Inadequate risk assessment • Confined space entry • Chemical substances • Dropped object • Excavation • Work at heights 14. Inadequate correction of prior hazard/ incident 15. Inadequate correction of worksite/ job hazards 16. Inadequate man power to support identified goal/ objective 17. Inadequate management of change system 18. Inadequate incident reporting/ investigation system 19. Inadequate or lack of safety meetings 20. Inadequate performance measurement and assessment 21. Other		8. Inadequate monitoring of construction 9. Inadequate assessment of operational readiness 10. Inadequate monitoring of initial operation 11. Inadequate evaluation and documentation change 12. Procedure format specifications were inadequate (the presence of a 'revision date', an index, name of the author) 13. Faulty adjustment or construction or lack of insulation in material caused noise, vibration or extreme temperatures 14. Tools or equipment could not be cleaned or were difficult to keep clean because of their shape or nature (equipment that attracted or retained dirt) 15. There were insufficient cleaning areas or opportunities for waste disposal (insufficient or badly located containers) 16. Other

FIGURE 15. Possible System or Latent Causes - Job Factors

Possible System Causes/ Latent Causes: Job Factors				
Control of Work	Purchasing, Material Handling and Material Control	Tools and Equipment	Work Rules/ Policies/ Standards/ Procedures (PSP)	Communication
1. Inadequate work planning (planning not coordinated with inputs from walk-downs/ task analysis) 2. Inadequate time given for worker to prepare task/ time allotted 3. Duties not well-distributed among personnel 4. Insufficient number of trained or experienced workers assigned for task 5. Inadequate journey risk assessment 6. Inadequate use of the "buddy system' for a confined space entry 7. Job scoping did not identify potential task interruptions and environmental stress or other special circumstances and conditions (heat,	1. Incorrect item received • Inadequate specifications to vendor • Inadequate specifications on requisition • Inadequate control on changes to orders • Unauthorized substitution • Inadequate requirements • No acceptance verification performed 2. Inadequate research on materials/ equipment 3. Inadequate mode or route of shipment 4. Improper handling of materials 5. Improper storage of materials or spare parts	1. Inadequate assessment of needs and risks 2. Inadequate human factor/ ergonomics consideration 3. Inadequate standards or specifications 4. Inadequate availability 5. Inadequate inspection/ adjustment/ repair/ maintenance 6. Inadequate salvage and reclamation 7. Inadequate removal/ replacement or unsuitable items 8. Inadequate equipment record history 9. Inadequate introduction of a new or modified design (too little information provided, implementation badly planned, insufficient time allocated for implementation)	1. Lack of PSP for the task 2. Lack of "Permit To Work" system 3. Inadequate development of PSP 4. Inadequate implementation of PSP, due to deficiencies 5. Inadequate enforcement of PSP • Procedure implementation was inadequately supervised (inadequate timing, insufficient verification that the procedure introduced was actually understood) 6. Inadequate communication of PSP 7. Inadequate excess to PSP 8. Inadequate accountability for the "Permit To Work" system 9. Work procedures for maintenance tasks were ineffective (out-of-date, non-effective, incorrect) 10. Procedures were drawn up by people not suited to the task (no specific operational	1. Inadequate horizontal communication between peers 2. Inadequate vertical communication between supervisor and person • Suspected problems not communicated to supervision 3. Inadequate communication between work groups 4. Inadequate communication methods 5. Inadequate communication of safety and health data, regulations or guidelines 6. Incorrect instructions • Facts wrong/ requirements not correct • Data/ computations wrong/ incomplete 7. Inadequate communication due to job turnover 8. Standard terminology not used 9. Inadequate communication between shift 10. Inadequate feedback (work progress, hazard, training etc.) 11. Inadequate designer-user communication during the design or modification phase 12. Inadequate feedback about the use of the procedures in practice (about the

FIGURE 16. Possible System or Latent Causes - Job Factors

chemical exposure, work space, wind, height etc.) 8. Inadequate preventive maintenance 9. Inadequate repair 10. Excessive wear and tear 11. Inadequate references materials or publications 12. Inadequate audit/ inspection/ monitoring 13. Inadequate inspection of lifting equipment and safety devices 14. Inadequate emergency plan in place 15. Inadequate job placement 16. Poor job hand over management 17. Other	6. Inadequate material packaging 7. Material shelf life exceeded 8. Improper identification of hazardous materials 9. Improper salvage and waste disposal 10. Inadequate use of safety and health data 11. Improper labelling and marking 12. Defective or failed (material or part) 13. End of life failure 14. Contamination (carbon contamination on carbon steel material etc.) 13. Other	10. The supply system for tools or equipment was ineffective (inventory, administration, ordering, issuing) 11. The physical circumstances in which the tools or equipment used were unsuitable 12. Tools or equipment were not properly stored or insufficiently cleaned (items were lost, damaged or become very dirty) 13. Specifications and requirements that the tools or equipment should meet were insufficient (functionality, quality, brand, material, size, and other details) 14. Other	knowledge, no knowledge or experience of how procedures should be drafted) 11. There were constraints on making improvements, renewals or corrections to procedures (budget was too small, time was too short, too few personnel) 12. The quality and quantity of procedures within the organization was insufficiently controlled (no-one was responsible for 'maintenance' of the procedures, no 'overview' of the whole package of procedures, no quality control of contractor procedures) 13. Emergency procedures/operational disaster plans were ineffective (out-of-date, insufficiently informative or not flexible enough about what to do in what situation, last lines defenses not included) 14. Other	correctness, comprehensibility, usefulness, effectiveness) 13. Inadequate opportunity to comment and adapt the procedures (valid remarks and criticisms about the procedures are not catered for in revisions) 14. Insufficient notification regarding areas/materials (hazard, risk etc.) 15. Inadequate quality or quantity of the communications equipment (many disruptions, too small capacity, too little communications equipment, too few (reserve) communications channels) 16. Personal factors (hearing problem, stutter, intoxication etc.) 17. There were language problems (different native language, dialects, jargon) 18. Communications during the emergency were ineffective (ineffective communications structure, inaccessibility, disruptions) 19. Unclear/ complex wording or grammar in written communication 20. Recent changes not made apparent to user 21. Other

FIGURE 17. Possible System or Latent Causes - Job Factors

Possible System Causes/ Latent Causes: Job Factors				
Incompatible Goals	Organisation	Defences	Error-enforcing Condition	House-keeping
1. Financial restrictions or pressure of time during the design or modification (cost-related exclusions or modifications, acceptance testing short-cuts) 2. The procedure was drafted for non-operational reasons (to cover liability, for insurance purposes or to meet the ISO 9000 minimum requirements) 3. The decision to work in this (unacceptable) environment was taken for financial or production-technical reasons 4. The employees experienced pressure to conform to the informal group norms (norms not accepted by management) 5. External individual circumstances made priority setting more difficult (family problems, other activities that took priority)	1. There was insufficient employee discipline with regard to use procedures (procedures were not returned, become dirty or were lost) 2. There was insufficient involvement of the organization with optimum safe working practice (safety was not integrated in work methods, no policy that stimulated safe working) 3. Planning and demarcation of locations and tasks was unclear or inadequate (which department or shift was responsible for cleaning with location, overviews and duty rosters) 4. The selection process of the hiring of employees was ineffective (no medical investigations were carried out, no suitable investigation made of the abilities of the employee) 5. Employees were hired on the basis of special considerations (financial consideration, positive discrimination policies, regionalization programmed) 6. Guidelines on minimum training and experience requirements for specific functions/tasks were inadequate 7. The employees considered themselves not empowered to stop the activities	1. Inadequate personal protective measures against external disturbing influences (no sunshades, air conditioning, ear plugs, insulating suits etc.) 2. Evacuation or rescue plans were ineffective (out-of-date, insufficiently informative or not flexible enough about what to do in what situation) 3. Congestion or chaos in the operating environment hindered the emergency operation or preventative measures (inability to find the necessary equipment,	1. Employees were insufficiently accustomed to or familiarized with the physical environment, weather or climatic conditions 2. Inadequate resources to make improvement in the working environment (budget too small, too little time or too few personnel made available) 3. Inadequate arrangements were made for (the recognition of) persons with serious personal problems 4. Inadequate arrangements were made for (the recognition of) person who were ill or who used or failed to use medicines that affect their functioning 5. Inadequate arrangements were made for (the recognition of) person	1. Inadequate housekeeping • Inadequate cleaning of work floor and tidied up (hazardous chemical, oil, debris, rubbish, unwanted material, spanner etc.) • Inadequate cleaning of equipment or cleaning of working material 2. Insufficient resources were allocated for keeping the work floor clean and tidy (purchasing budget was too small, time allowed was too short, too few personnel) 3. The corporate policy concerning tidiness of the work environment was inadequate; visible involvement of management was lacking (no management visit to look at the tidiness of the location or no 'follow-up' after a working visit)

FIGURE 18. Possible System or Latent Causes - Job Factors

6. Management commitment to the maintenance of optimal working conditions was insufficient (because of short-term profit seeking, meeting immediate production targets) 7. There was insufficient recognition by management of existing contradictory goals (operational priorities not made clear enough, annual program creating requirements not compensated by safety plan) 8. There were failures on the part of management to manage external pressures (political pressures, national policies on hiring incompatible with necessary competencies) 9. Conflicting goals hindered the transmission and receipt of information (not wishing to be the bearer of or to hear bad news, pressure of time)	(management did not make it clear how important safety was) 8. Internal factors linked to individuals made priority setting more difficult (shyness, over-motivation, addiction, personal goals intruding in work) 9. Management priorities were wrongly assigned (unsound company management, willfully following the wrong policy) 10. Organizational objectives were ineffectively defined ('quality' was not an objective or was not operationalized) 11. Company style was inadequately or insufficiently defined (company management lacks direction, deviation from core business, blurring of business branch 12. Job description was insufficiently defined (work requiring activities outside job description, training limited to formal job definitions) 13. The company structure/organogram was insufficiently defined (interrelationships between persons and departments unclear or not effective) 14. The company organization and communications structure was not effective (too much bureaucracy and rigidity, small scale, lack of flexibility, shareholders'/stakeholders' demands not aimed at improving quality)	emergency exits or evacuation routes were blocked) 4. Release of money, personnel or other means was inadequate to guarantee effective preventative measures, emergency procedures or safety equipment 5. Other	with problems in the social environment (boredom, no prospects, colleagues) 6. Employees with non-desirable working attitude were inadequately supervised or insufficiently corrected (no training in delegation, no attention to motivation and fear of failure, no way of dealing with macho culture 7. Inadequate arrangements were made for the recognition and management of unsuitable working conditions (management did not want to hear) 8. The condition of people at the time of emergency operations was unfavorable (people were ill, drunk, very frightened, stressed) 9. Other	

FIGURE 19. Possible System or Latent Causes - Job Factors

10. Bodies outside the organization exerted a dominating influence (governments, multinational organizations) 11. A conflict between production, financial, government or individual objectives and safety measures hindered the emergency response (waiting too long before shutting down, failure to inform outside bodies, guidelines not hard enough) 12. Other	15. Responsibilities or accountabilities were incorrectly or ineffectively defined (lack of clarity about who or which department had the responsibility for what, responsibility and accountability lying with different people) 16. There had been too many departmental re-organizations or changes of senior management 17. The control system within the company was ineffective: structure, resources, approach (supervisor(s) over-stretch, execution and control lying with one person, supervision ineffective) 18. The organization was insufficiently involved with safety (lack of systematic registration of who was working where, safety not integrated in working methods, no policy that stimulated safety) 19. The structure of emergency response organization was unsound (hierarchy, responsibilities, delegation) 20. Other			

FIGURE 20. Possible System or Latent Causes - Job Factors

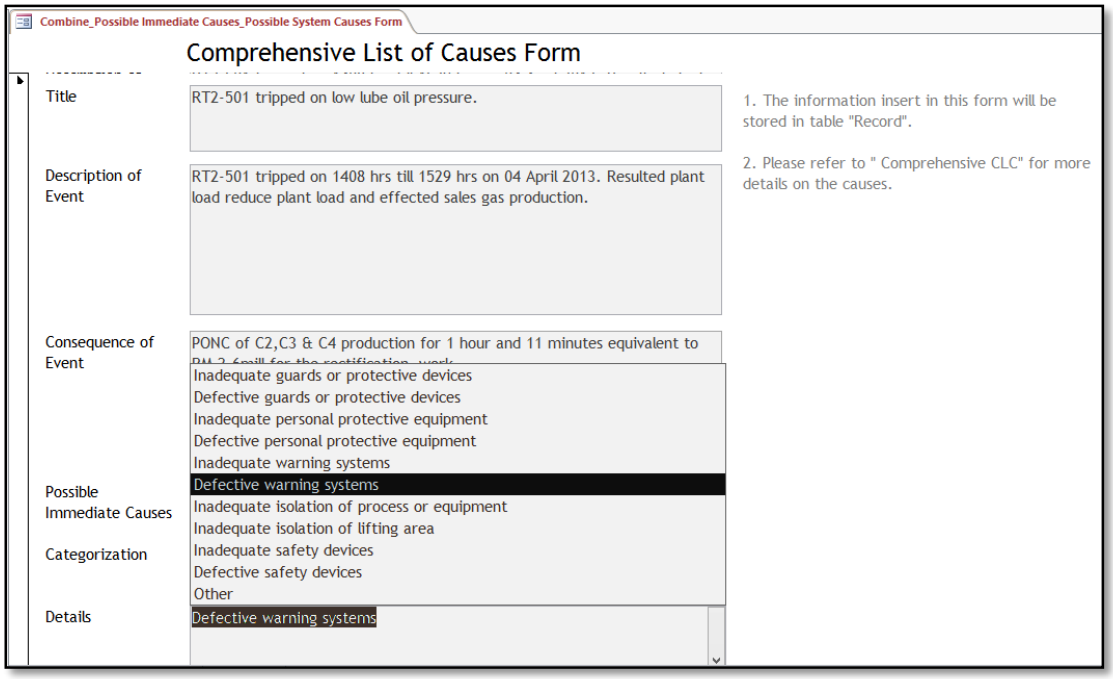

FIGURE 21. Example of application for Comprehensive List of Causes

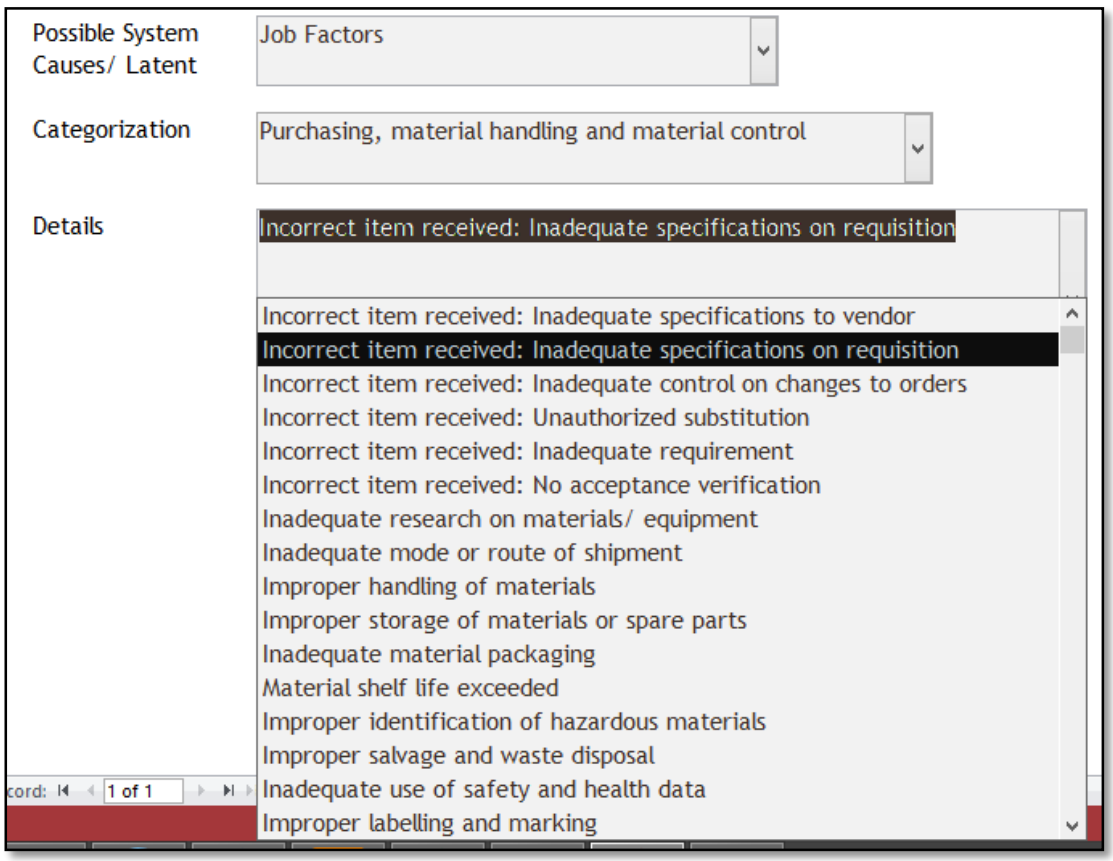

FIGURE 22. Example of application for Comprehensive List of Causes

Combine_Possible Immediate Causes_Possible System Causes Form | Record

Title	Description_of_Event	Consequence_of_Event	Possible_	Categori	Details_of	Possibl	Categorizatic	Details_of_Cat
Gas Processing Plant 6 tripped on TMR Communication Failure resulting in production loss of RM 1.7	Gas Processing Plant 6 tripped on 7th January 2013 @ 1040 hrs ausing Gas Processing Plant 6 production interrupted i.e. zero load. The system managed to be put back online and handover to operation at 1500hrs. The failure was due to Communication Module (Robust Datacom Module) fault at bB6-2312 TMR ESD System (Obsolete system)	Total Shutdown of Gas Processing Plant 6 with delayed start up to C2 mode due to equipment problem causing total PONC of Rm 1.7 Mil	Conditions	Work exposure	Temperatur e extremes	Job Factors	Purchasing, material handling and material control	Defective or failed (material or part)
Segamat Compression Station Experience Unit #1 USDL and Station SSDL.	Segamat Compression Station Experience Unit #1 USDL and Station SSDL on 15th November 2013 at 1255hrs and 2355hrs respectively.	Total Shutdown of station and causing no gas compression for total of 7 hours and 35 minutes with cost of approximately Rm700k.	Conditions	Protective systems	Defective guards or protective devices	Job Factors	Training/ Knowledge transfer	No training provided: New work methods introduced without training
RT2-501 tripped on low lube oil pressure.	RT2-501 tripped on 1408 hrs till 1529 hrs on 04 April 2013. Resulted plant load reduce plant load and effected sales gas production.	PONC of C2,C3 & C4 production for 1 hour and 11 minutes equivalent to RM 2.6mill for the rectification work.	Conditions	Protective systems	Defective warning systems	Job Factors	Purchasing, material handling and material control	Incorrect item received: Inadequate specifications on requisition

FIGURE 23. Incident or failure record storage

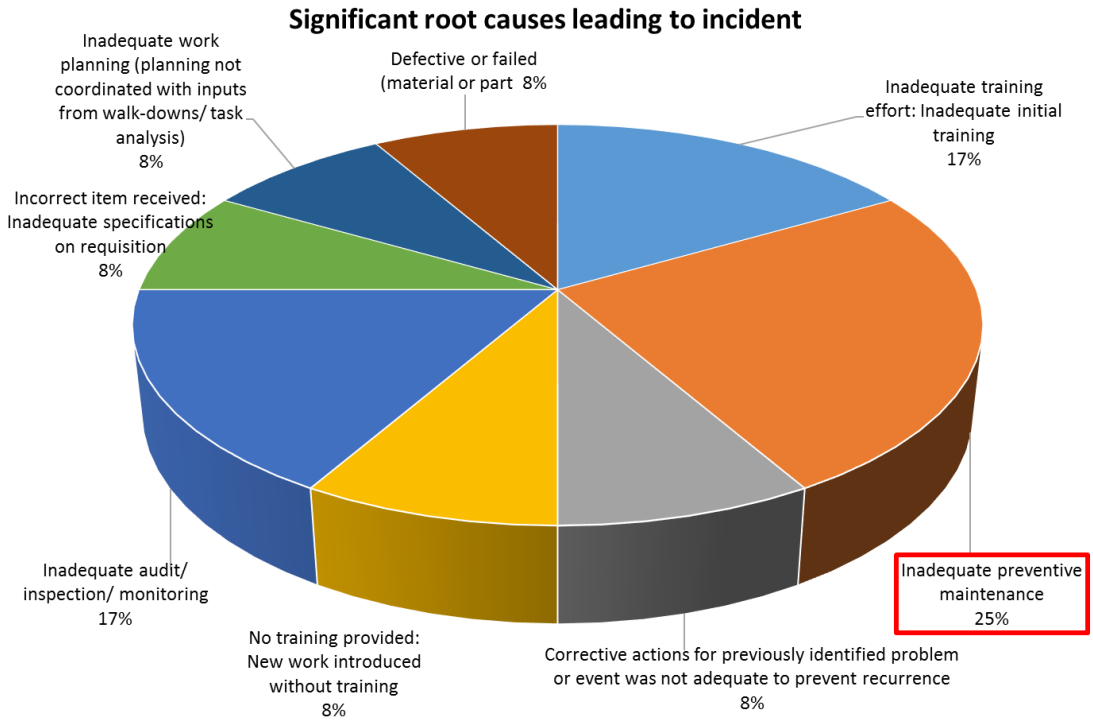

FIGURE 24. Pie chart showing the highest system cause leading to failure in plant

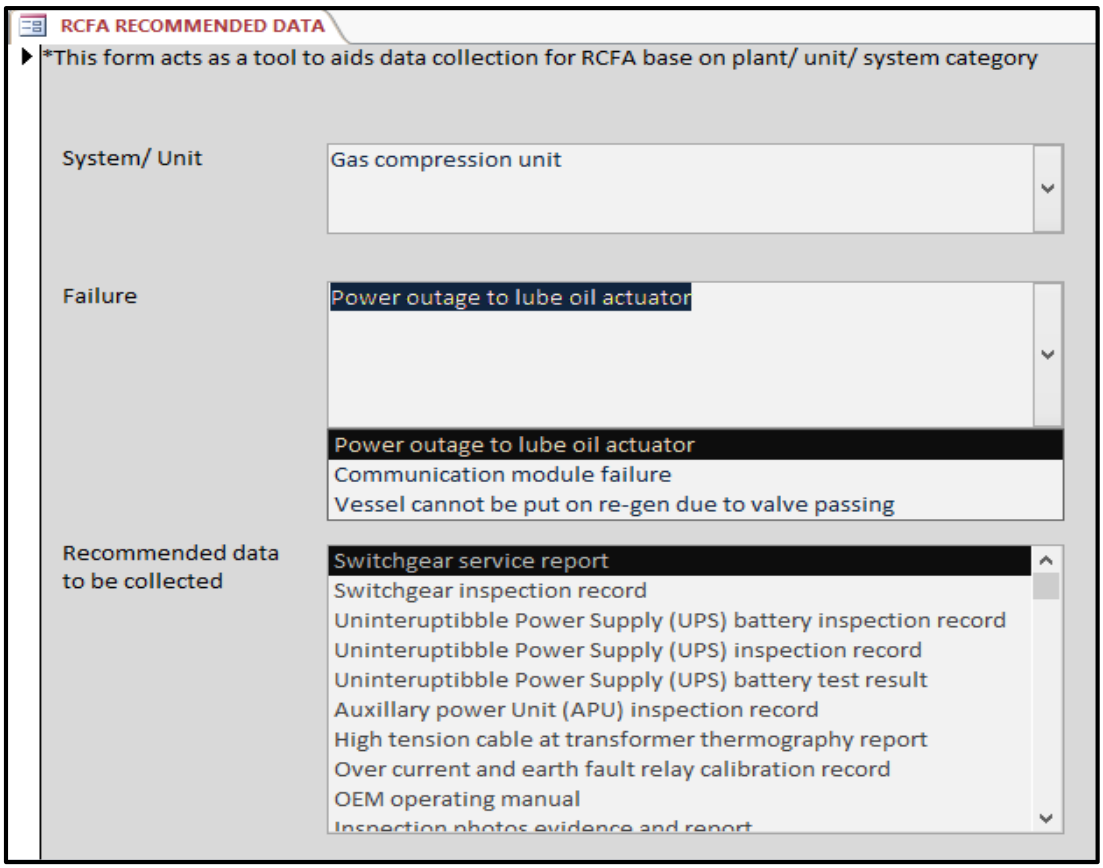

FIGURE 25. Example of application for RCFA recommended data

TABLE 3. List of system or unit in a plant and failure associated to the system or unit

System/ Unit	Failure associated
Acid gas removal unit	Unit bypassed on hydrocarbon carry over
Acid gas removal unit	Unit bypassed on high pressure differential indication (PDI)
Sales gas compressor package	Gas compressor tripped
Gas compression unit	Power outage to lube oil actuator
Gas compression unit	Communication module failure
Gas compression unit	Vessel cannot be put on re-gen due to valve passing
Gas production unit	Loss of power causing group of equipment tripped
Gas transportation line	Transport block valve fail to open on demand
Undefine unit (piping)	Piping: Loss of Containment (LOC)
Air separation unit	Air booster compressor tripped
Refrigerant compressor package	Compressor: External leakage - Process medium
33kV busbar system	Power outage

CHAPTER 5
CONCLUSION AND RECOMMENDATION

As a conclusion, both stated objectives were achieved. New comprehensive list of causes, with updated categorization of factors in possible immediate causes and possible system or latent causes based on list of causes from Shell Oil Company, Petroliam Nasional Berhad (PETRONAS), BESIX and BP was done successfully. Plus, an application acting as storage and analysis tool to identify the significant root causes related to incidents happened also completed. Last but not least, formulation of list of recommended specific data to be collected based on system or unit in a plant and the associated failure under the system or unit by also was completed with utilizing twelve RCFA reports from PETRONAS. For this part also, an application was successfully completed by using Microsoft Access.

For this study, it is recommended to have more RCFA reports to identify the evidence data for RCFA. Current study only utilizing twelve reports, and all from PETRONAS. It is good if same objective to be done in the future, try to have more RCFA reports and preferable from various companies, not focusing only to one specific corporation. In this sense, more system or unit can be listed down, and having a clearer view on the failures that associated to each system or unit. From here, more comprehensive categorization and recommended data can be suggested.

Furthermore, for the analysis tool to identify significant root cause leading to the incident, instead of using pie chart, Pareto chart seems to be a better option in representing the data. If Pareto chart is utilized to represent the data, 80% -20% rule of Pareto can be applied. Meaning that, the graphical representation is able to show the significant 20% of the root cause that lead to 80% of the incident or failure. Hence, the organization only need to eliminate 20% of the root cause to eliminate 80% of the incident or failure.

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