Development of Incident Investigation System for Process Safety Management in Process Industries

By

Ismail Bin Nasir

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Prof. Dr. Azmi Mohd Shariff)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2013

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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(ISMAIL BIN NASIR)

ABSTRACT

Recurrence of past major accidents, injuries and fatalities are often reported in process industries which resulted in significant losses in terms of lives and property. Although proper incident investigation has been performed to identify the causes of an accident, but the failure to perform investigation thoroughly by identifying the root cause of an incident causes lack of relevant investigation findings and gives opportunity for incident to reoccur. The objective of this project is to develop an incident investigation root cause analysis model, Tripod Beta, to help industries investigation team to thoroughly investigate and identify the root cause of an incident thus confirming the necessity of a root cause analysis in performing incident investigation. The scope of this project involves development of the incident investigation system framework based on OSHA PSM, perform case study based on process plant investigation report in order to develop the root cause model, and establishing a data storing and sharing system for better communication of incident inside organization. The result of the constructed tripod beta model will help confirming the necessity of a root cause model, which is a powerful tool in order to identify the root cause of an incident, thus giving industry a more reliable preventive action measure to avoid accident recurrence. This will result in cost saving in terms of reduce compensation claim and property losses from an accident. and also serves as a reference precaution measures for other similar processing unit.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 Background of Study

Unexpected release of flammable, reactive, or toxic liquids and gases in process industries involving highly hazardous chemicals have been reported for many years. As the scale of process industries continues to grow to meet the demand of customer, the risk of accident in a process plant also increases. Incident continues to occur in process industries that uses toxic, flammable, reactive, or explosive, or combination of all these properties (Spellman, 1996). Whenever industry uses these highly hazardous chemicals, there is always potential for an accidental release any time when it is not monitored or controlled properly. As a result, the possibility of disaster to occur is imminent.

History have recorded a few major disaster such as Bhopal, India (1984), which had taken thousands of innocent lives working in a Union Carbide plant due to inhaling poisonous gas. Other major disaster includes Phillips Petroleum Company, Pasadena, Texas (October 1989), resulting 23 deaths and 132 injuries; Union Carbide's Institute, West Virginia (August 1985), injured at least 135 people (OSHA, 1994).

Hazardous chemical release continue to pose a major threat to employees and provide impetus, internationally and nationally, for authorities to develop or consider developing legislation and regulations to eliminate or minimize the potential for such event. Promulgated by the Occupational Safety and Health Administration (OSHA) under section 29 1910.119 of the Federal Code of Regulations (CFR), Process Safety Management (PSM) of Highly Hazardous Chemicals was put into effect in February 1992 to protect workers from injury and accident due to the release of this highly hazardous chemicals (USEPA, 1996).

The purpose of this standard is to prevent the occurrence of, or minimize the consequences of catastrophic releases by stating the policies and procedures for the management of process hazards in design, construction, start-up, operation, inspection, maintenance and the other matters addressed in the OSHA standard (Moran, 1996). OSHA PSM 29 CFR 1910.119 is a regulatory standard comprises of 14 elements which is shown in Table 1 below:

Table 1: OSHA PSM Elements

OSHA PSM REGULATION	ELEMENTS
29 CFR 1910.119	Process Safety Information
	Process Hazard Analysis
	Operating Procedures
	Employee Training
	Contractors
	Pre-Startup Safety Review
	Mechanical Integrity
	Management of Change
	INCIDENT INVESTIGATION
	Emergency Planning and Response
	Employee Participation
	Hot Work Permit
	Compliance Audit
	Trade Secrets

An accident is an unfortunate incident (event), such as a forklift truck hit a worker, which has resulted in actual injury or illness and/or damage (loss) to assets, the environment or third party. An incident is an unplanned event or chain of events, which has or could have caused injury or illness and/or damage (loss) to assets, the environment or third party (Muhamed Jamil Khan, Syed Razif, 2009). Incidents include work-related injuries, occupational illnesses, property damage, spills, fires or near miss events that could have resulted in any of these. Known problems should not be allowed to persist. A failure to investigate and fix the root cause allows the opportunity for the problem to reappear, or for that problem to lead to an accident.

Organizations should focus on preventing accidents, not just reporting problems, and this requires root cause analysis (Earnest, 1997). Root Cause Analysis (RCA) is a data (facts) driven incident investigation tool to find out the failure mechanism, contributory as well as underlying causes for the incident (Muhamed Jamil Khan, Syed Razif, 2009) .

This study will focus on the development of incident investigation root cause analysis Beta Tripod model following the OSHA PSM standard 29 CFR 1910.119(m) - Incident Investigation. Reading of the past major accident occurred in process industries, understanding the current OSHA PSM standard on incident investigation, integrate it with the Beta Tripod model, and analysis on the incident investigation root cause model has been done to better understand the topic of study in order to develop the incident investigation model. Next, a framework of the root cause analysis model based on the standards under 29 CFR 1910.119(m) - Incident Investigation will be established that is in compliance with the PSM regulation. Followed by that, a conceptual root cause analysis Beta Tripod model will be developed which uses investigation facts to describe the hazard management aspects of the incident using a tree diagram. Case study will be conducted using industrial data to validate the effectiveness of the conceptual model.

1.2 Problem Statement

Failure to perform investigation thoroughly by using root cause analysis to identify the root cause of an incident contribute to the lack of relevant incident investigation findings and give rise to the opportunity for the incident to reoccur. Organization should focus on preventing incidents through critically analyze the root cause (underlying causes) of an incident and identifying the core elements of incident when performing incident investigation in order to effectively eliminate accident from recurring.

1.3 Significant of Project

This project is significant in that it provides incident investigation teams method to effectively identify and confirming the relevance of the data (facts) gathering of an incident investigation, thus pointing to the identification of the root cause (latent & active failures). The result of this analysis should be a deeper and more comprehensive incident investigation and a clearer understanding of the failures that needs to be addressed in order to make significant and lasting improvements in preventing similar accidents.

1.4 Objective of Research Study

The objective of this project is to develop an incident investigation root cause analysis model, Tripod Beta, to help industries investigation team to thoroughly investigate and identify the root cause of an incident thus confirming the necessity of a root cause analysis in performing incident investigation.

1.5 Scope of Study

The scope of this project is doing research and literature review on OSHA Process Safety Management (PSM) incident investigation and incident investigation root cause analysis. Next, a framework on the Root Cause Analysis (RCA) model which is the Tripod Beta will be established that is in compliance with the PSM incident investigation regulation. After that, a Tripod Beta tree diagram will be constructed according to the framework to identify the root cause of an accident, and finally a case study will be conducted based on real plant data in order to validate the effectiveness of the model.

1.6 Relevancy of Project

Incident continues to occur even though process industries have adopted proper safety management system established by OSHA. This project will focus on identifying the root cause of an incident in order to eliminate the possibility of recurrence of past incident. Once causes of incidents has been identified, organization can find a way to correct the failure barrier of the existing process design, and break the sequence of events which may lead to the incident, thus eliminate the possibility of the incident recurrence.

1.7 Feasibility of Project

This project will be done in two semesters which basically includes three basic areas, which are research on literature, model development and also case study for conceptual model verification at a selected process industries. The Tripod Beta model will uses a tree diagram to explain the cause-effect logic of the incident event. Microsoft Office tools (Microsoft Excel) will be used for data storing and generating the Beta Tripod tree diagram. Once the tree diagram is constructed, case study will be conducted to see the effectiveness of the model. Based on the description above, it is very clear that this project is feasible to be carried out within the time frame.

CHAPTER 2

LITERATURE REVIEW

In recent years, chemical accidents that involved the release of toxic substances have claimed the lives of hundreds of employees and thousands of other worldwide (Spellman, 1996). Recent major disasters include the 1984 Bhopal, India, incident resulting in more than 2,000 deaths; Flixborough (1974), chemical plant explosion that killed 28 people and seriously injured 36; Seveso (1976); the October 1989 Phillips Petroleum Company, Pasadena, Texas, incident resulting in 23 deaths and 132 injuries; the July 1990 BASF, Cincinnati, Ohio, incident resulting in 2 deaths, and the May 1991 IMC, Sterlington, Los Angeles, incident resulting in 8 deaths and 128 injuries (OSHA, 1994). In order to prevent repeat occurrences of catastrophic chemical incident, the Occupational Safety and Health Administration (OSHA) and the United State Environmental Protection Agency (USEPA) have joined forces to bring about the OSHA Process Safety Management Standard (PSM) and the USEPA Risk Management Program (RMP) (USEPA, 1996). Preventing accidental releases of hazardous chemicals is the shared responsibility of industry, government, and the public. The first step toward accident prevention are identifying the hazards and assessing the risks. Once information about chemicals, accidents and hazards are openly shared, industry, government, and the community can work together toward reducing the risk to public health and the environment (AIChE, 2007). The American Institute of Chemical Engineer (AIChE) Center for Chemical Process Safety (CCPS) defines PSM as a management system focused on prevention of, preparedness for, mitigation of, response to, and restoration from catastrophic releases of chemicals or energy from a process associated with a facility (AIChE, 2007). Promulgated by OSHA under section 29 1910.119 of the Federal Code of Regulations (CFR), PSM has been in effect since February 1992. PSM was put into effect to protect workers from injury from accidents due to the release of highly hazardous chemicals (Spellman, 1997). The purpose of this standard is to prevent the occurrence of, or minimize the consequences of, catastrophic releases by stating the policies and procedures for the management of process hazards in design, construction, start-up, operation, inspection, maintenance and the other matters addressed in the OSHA standard (Moran, 1996). PSM require that all responsible parties survey their industrial complexes where covered chemical processes to determine if any of the 137 Highly Hazardous Chemicals listed in OSHA's Process Safety Management Standard (Appendix A) are stored, handled, used or produced on site (Moran, 1996). The OSHA PSM standard contains 14 elements including employee participation (EP), process safety information (PSI), process hazards analysis (PHA), operating procedures (OP), training, contractors, pre-startup safety review (PSSR), mechanical integrity (MI), hot work permit (HWP), management of change (MOC), incident investigation (II), emergency planning and response (EPR), compliance audits and trade secrets (Spellman, 1997).

This project will focused on the element CFR 1910.119 (m) - Incident Investigation. Incident Investigation is the process of identifying the underlying causes of incidents and implementing steps to prevent similar events from occurring (Moran, 1996). Accident is defined as an undesired event that results in harm to people, damage to property or loss to process. Incident is defined as an undesired event that, under slightly different circumstances, could have resulted in harm to people, damage to property or loss to process (Bird, 1992). The intent of an incident investigation is for employers to learn from past experiences and thus avoid repeating past mistakes. PSM requires the investigation of each incident that resulted in, or could reasonably have resulted in, a catastrophic release of a highly hazardous chemical in the workplace. These events are sometimes referred to as "near misses", meaning that a serious consequence did not occur, but could have occur (OSHA, 2000).

Welborn & Boraiko define an incident investigation as "a reactive procedure performed after an incident occurs" (Welborn, 2009). More effective safety programs utilize both reactive and proactive methods when investigating incidents. The reactive approach to incident investigations most often focuses on the corrective actions after an incident occurs. Whereas, the proactive approach aims to prevent incidents from happening in the first place (Earnest, 1997). Organizations conduct incident investigations in order to eliminate the probability that the given type of incident will reoccur. To ensure this, "information obtained during the investigation about the conditions and actions that caused the event must be accurate. Otherwise, a subsequent intervention may not address the real cause(s)" (Boraiko, 2008). When used properly, an incident investigation will identify the chain of events leading up to the accident, determine the immediate and root causes, develop correctable solutions, provide management oversight, and ensure that reporting requirements are met. An underlying concern regarding incident investigations is that they are often perceived as a means to place blame on an individual (Hilden, 1996). However, "a thorough investigation will often help: show concern for employees, prevent repeat accidents, address liability issues, expose errors in processes, identify and eliminate hazards, decrease worker compensation costs, correct unsafe acts and conditions, aid in crisis planning, and provide information to make recommendations" . Therefore, organizations need to understand that the purpose of conducting an investigation is to gather the facts that cause incidents, and not to find fault (Hilden, 1996).

Incident analyses serve as effective and valuable tools for solving the problems which create incidents. Spear states that "using structured problem-solving techniques, safety professionals can define the problem, gather and prioritize related data, analyze solutions, and evaluate the benefits and cost-effectiveness of available prevention options" (Spear, 2002).

A Root Cause Analysis (RCA) is essentially a process that is aimed to identify the primary cause(s) that contribute to the occurrence of an incident or problem. It is a systematic approach and calls for analytical thinking about interrelated cause-effect relationships within a system or process which has failed (Okes, 2008). The primary purpose of performing a RCA is to minimize risk by solving problems and eliminating causes that contribute to risk (Hughes, 2009). When performing a RCA, it is important to keep in mind that when accidents or incidents do occur, they are typically complex and multi-causational. Many organizations fail to address the root cause because they tend to focus on the presenting problem and not the underlying cause. According to Williams, "the only way to avoid jumping to a premature conclusion that leads to inadequate corrective actions is by taking time to conduct a proper RCA" (Williams, 2008).

When a RCA is performed properly it will allow an organization to pinpoint the circumstances that increased the risk of an accident or incident from occurring (Williams, 2008). Determine who or what was involved in the situation; and prioritize risk management decisions. A poorly performed RCA makes it unlikely that the right solutions will be identified and implemented (Hughes, 2009). Many organizations utilize RCAs. However, each RCA used will differ from one organization to the next and each scope of a RCA will be specific to a defined problem. In general, a RCA is a four step systematic process. The four general steps include:

I. Defining the problem;
II. Developing a causal understanding as to why the problem occurred;
III. Identifying corrective solutions; and
IV. Implement the best solutions and monitor their effectiveness.

The first step, defining the problem, is the most important step in the RCA process. It is important for the problem to be defined in a clear, concise, and complete definition which includes where and when it occurred, its frequency, and severity (Hilden, 1996). A clear definition of the problem will reduce the likelihood of focusing on what is non-relevant for mitigating the problem.

The second step of performing a RCA involves identifying and understanding the causes which allowed the problem to occur and the evidence for proving it (Hilden, 1997). This step can be supplemented by creating a cause-effect diagram. A cause-effect diagram can assist in brainstorming potential causes, and help determine solutions. The third step, which is identifying corrective solutions, focuses on challenging each cause by generating ideas that will mitigate the problem. All causes should be considered and it's important to not overlook causes because they could lead to future incidents. Once corrective solutions are identified, evaluate the effectiveness of the solutions relative to the cost of the problem and the solution's likelihood for success.

Lastly, the fourth step of the RCA process deals with implementing the best solutions and monitoring their effectiveness. Once the best solutions are found, they need to be implemented into the system. It is equally important that the solutions, once implemented, do not create new or additional problems. And from a process improvement standpoint, the effectiveness of the solutions should be continually monitored and measured (Hilden, 1996).

There are couple of incident analysis methods practice by different industries. These methods are Root Cause Analysis (TOP-SET), the '5 Why" Method, Tripod Beta, Fault Tree and Event Tree. The method is aimed at finding the root causes of the event. By solving the problem described in the root causes, the probability of the incident reoccurring is lowered. This will prevent the incident from happening again. The root cause analysis diagram makes a distinction between three types of causes: Immediate Causes, Underlying Causes and Root Causes (Goraya, 2008).

Under PSM, each facility utilizing a covered process must develop in-house capability to investigate incidents that occur in the facility. In order to accomplish this a team should be assembled by the employer and thoroughly trained in the techniques of investigation including how to conduct interviews of witnesses, compile needed documentation, and write clear reports (Spellman, 1997). When this team investigates an incident in a covered process area, it is important to consult employees who were in or around the incident area. These employees can provide valuable insight into what actually occurred during the incident. It is important to point out that the focus of the investigation must be to obtain facts and not to place blame. The investigative process should clearly deal with all involved individuals in a fair, open, and consistent manner (OSHA, 2000). Each incident should be investigated as soon as possible; normally within 48 hours. The investigation team should submit a written report to the appropriate authority (Moran, 1996).

The Tripod Beta uses investigation facts to construct a tree diagram known as Tripod Beta Tree Diagram. It is a model describing the hazard management aspects of the incident. The classification and linkage of tree element represent cause-effect logic of the tree diagram. The tree reflects three phases in a incident investigation which are (PTS, 2006):

1. The core model of a Tripod Beta tree defines incident mechanism which is represented by 3 main elements: Hazards, Objects and Events. Hazards represent a situation that poses a threat to life, property or environment. Object can be classify as worker, contractors, equipment & environment. Events is the outcome of the combination of Hazard and Object which involves or could have involved (threatened) the life, damage to property or environment.

2. Failed or missing hazard management measures (control and defenses) such as machine guarding, control devices and Personal Protective Equipment (PPE), are added to the core model in tree building process.
3. The final phase of Tripod Beta Analysis tree building is to plot a Tripod causal paths for each failed or missing hazard management measures, leading from immediate failures to underlying causes.

The structure of Tripod Beta tree defines scope of investigation. It verifies the relevance of the findings of an incident investigation. The model develop which is the tree help investigation team to uncover the latent failure (root cause) of an incident. The core diagram of a Beta Tripod model is shown in Figure 1 below:

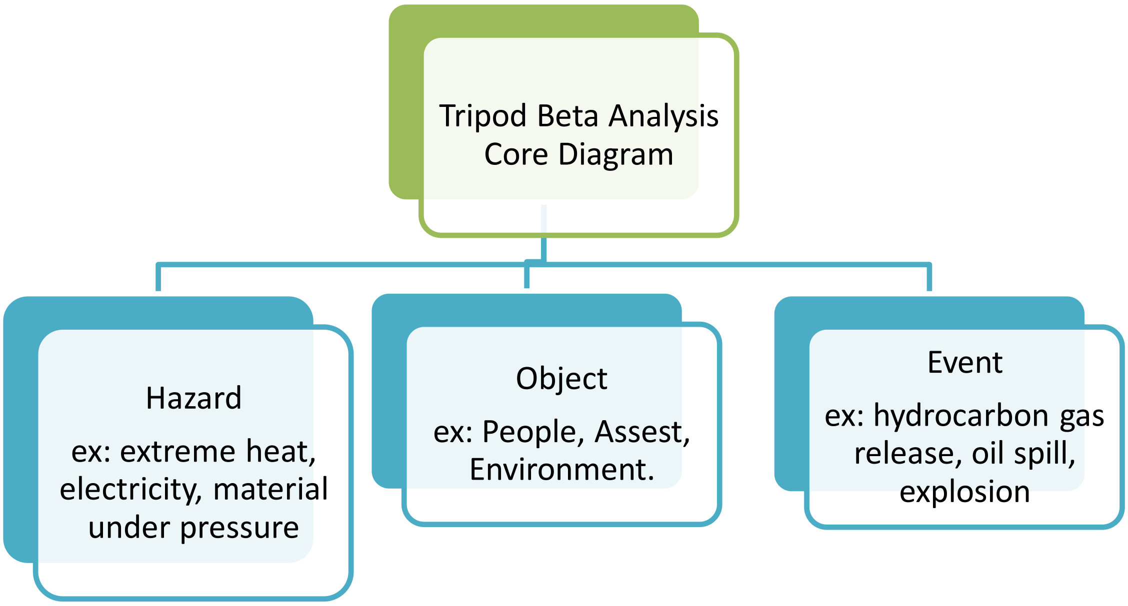

Figure 1: Core Diagram Element

Building The Core Diagram

Core diagram starts with an incident event. The hazard and object are placed to the left of the event and joined by an "and" connection as shown in figure 2 below.

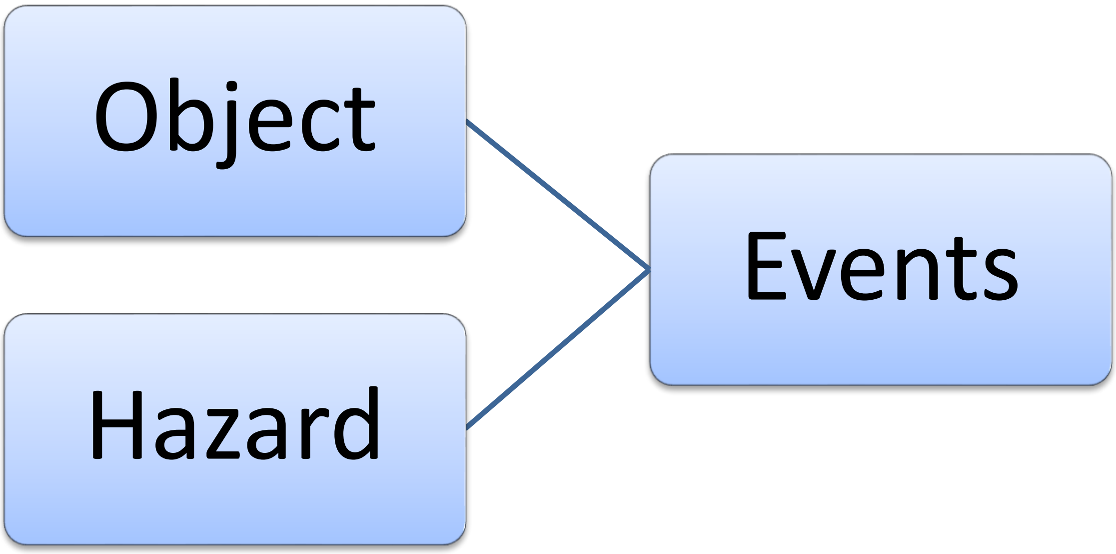

Figure 2: Event occurred through combination "and" of hazard & object

Before an incident event occur, a prior event that leads up to it occur first. When the hazard or object was the outcome of the "Prior Event", another hazard and object combination needs to be included in the scope of investigation. If, for example, the main event is fire damage to equipment, the event causing the hazard (fire) needs to be accounted for. The core diagram would show two hazard - object - event construction as shown in Figure 3 below:

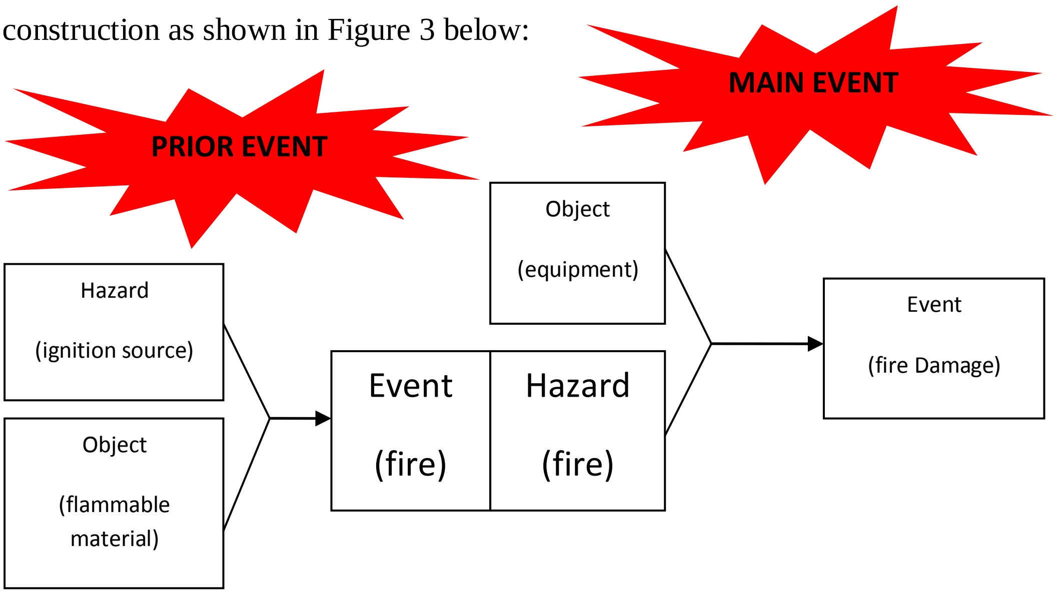

Figure 3: Event constructed based on two Hazard and Object

If the presence of the flammable material was itself caused by another event (ex. a pipe leak), a further hazard/object combination would need to be identified.

It should be noted that a fire can be considered as both hazard and event. In the Tripod Beta model, it is represented by a combined "event-hazard" node. Similarly, if an event creating an object is represented by a combined "event-object" nodes. All hazards and object should be examined for possible prior events. If no prior events take place, the hazard and object end node represent a logical limit to the investigation scope. If a prior event is added to an incident investigation due to the evident of its occurrence, a subsequent events may be added in a similar manner if escalation occurs.

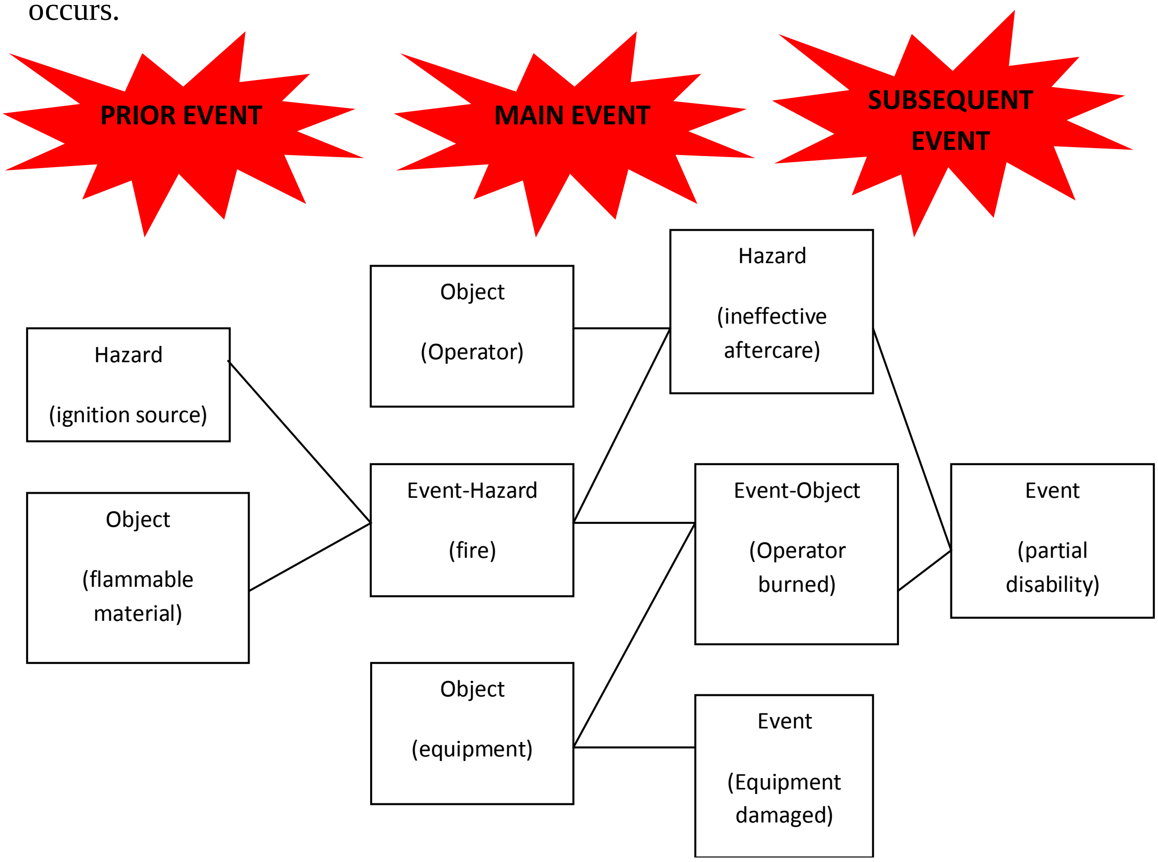

Figure 4: Damage and injury resulting from a fire incident. Prior, main and subsequent event sequence.

From this sequence of incident analysis tree, we can see that the burn victim becomes an "object" for ineffective aftercare (not given proper fire treatment after incident). Construction of the core diagram is essential for a successful root causes analysis to determine the underlying causes for an incident investigation. The diagram sets out the scope of the investigation, the hazard, object and event "end nodes" indicating points where no further investigation is considered necessary.

Controls / Defenses

When incident occur, the trigger event is the last control or defenses to fail. In most cases, a control or defense present had failed to protect the object from hazard. The investigation needs to identify all failures so that they can be addressed. The Core Diagram defines the chain of events, where hazard management measures must have been ineffective to protect the system from hazards. To complete the model of WHAT happened it is necessary to establish what measures were in place but failed, and what should have been in place. This requires a detail examination of the operation, including design aspects. In this research, measures addressing hazards are called "controls" and measures addressing objects are called "defenses" which can be represented by Figure 5 below:

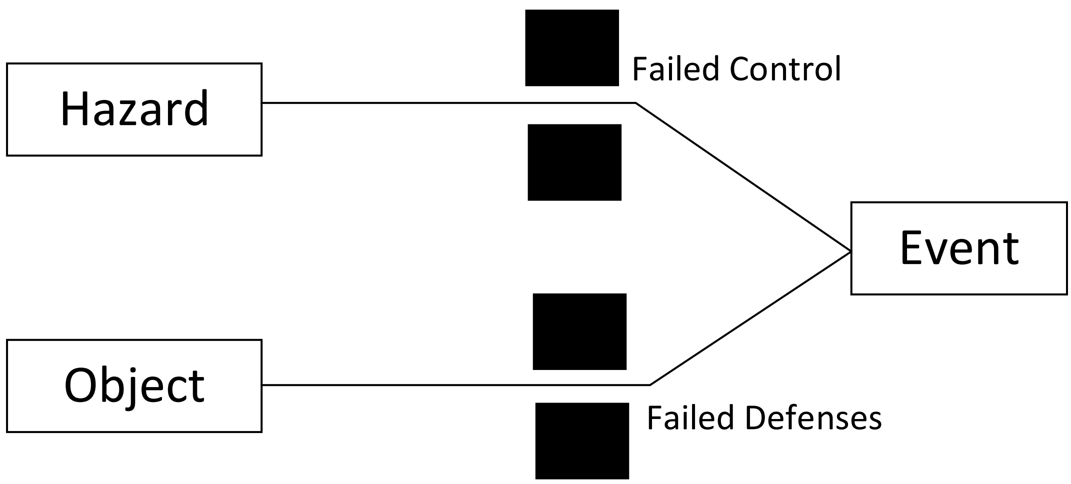

Figure 5: Failed control and defense contributes to event

Knowing WHAT happened is only part of the investigation. Effective recommendations to avoid similar incident requires WHY the failures occurred.

Tripod Causation Paths

Tripod theory is based on relating accidents to multiple causes. Active failures ex: unsafe act, do not occur in isolation, but are influenced by external factors - the preconditions. These factors originates from failure elsewhere in the process industries which is called latent failures. Latent failures come from decision or action taken by planner, designer or managers in location from the front line of operations, where most accidents occur. Other model or concept (such as fault tree, 5 WHY Method) also uses this accident causation theories to identify the 'immediate and underlying causes' as accident elements. The Tripod used in this research shows that latent failures can actually encourage active failures as well as increase it consequences. The Tripod Theory can be represented as shown in Figure 6 below:

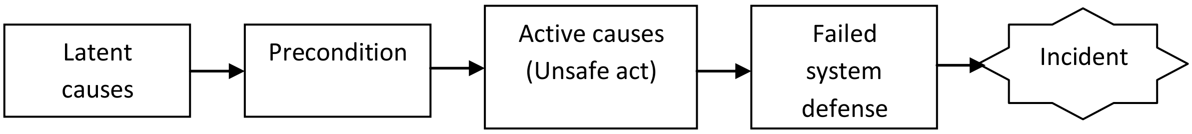

Figure 6: Tripod causation model

Once incident investigation report data is received from a selected process industries, a case study will be conducted in order to validate whether the model help assist in identifying the root cause of an incident. The case study will uses the method discuss above in order to identify the sequence of event that leads to incident. From there, underlying causes (root cause) of an incident can be identify thus prompting an effective and more improved corrective actions which helps in preventing recurrence of past incident. An example of a Tripod Beta Tree Diagram case study is as shown below where the accident report is on permanent disable injury for a worker involving in vehicle rollover accident (PTS, 2006).

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The intention of this project is to provide process industries an opportunity to improve the current method and procedures of investigating and analyzing incidents. This opportunity could results in deeper and more comprehensive investigation and a clearer understanding of the failure that must be addressed in order to make significant and lasting improvements in accident prevention. By identifying the root cause of an incident, we can effectively eliminate the possibility of its recurrence. This chapter discusses the primary methods employed to conduct this research. The flowchart of the overall research methodology in FYP I & II is shown in Figure 7. Based on the OSHA PSM Incident Investigation standards, a framework was developed which shows integration between each of the standards and the Beta Tripod model used in the root cause analysis to ensure that compliance with the standard is achieved. From incident investigation, a root cause analysis was performed in order to identify and understand the reason why the problem occur, and provide solution and recommendation using Tripod Beta model which is shown in Figure 8. Case study will be conducted using the developed models to validate the effectiveness of the concept. The structured model will guide process industries to systematically identify the root cause of an incident, find solutions related to it and eliminate the possibility of its recurrence in the future and at the same time comply with OSHA PSM regulation. Therefore industries can effectively prevent and eliminate major accidents such as explosion, toxic release and employee injuries.

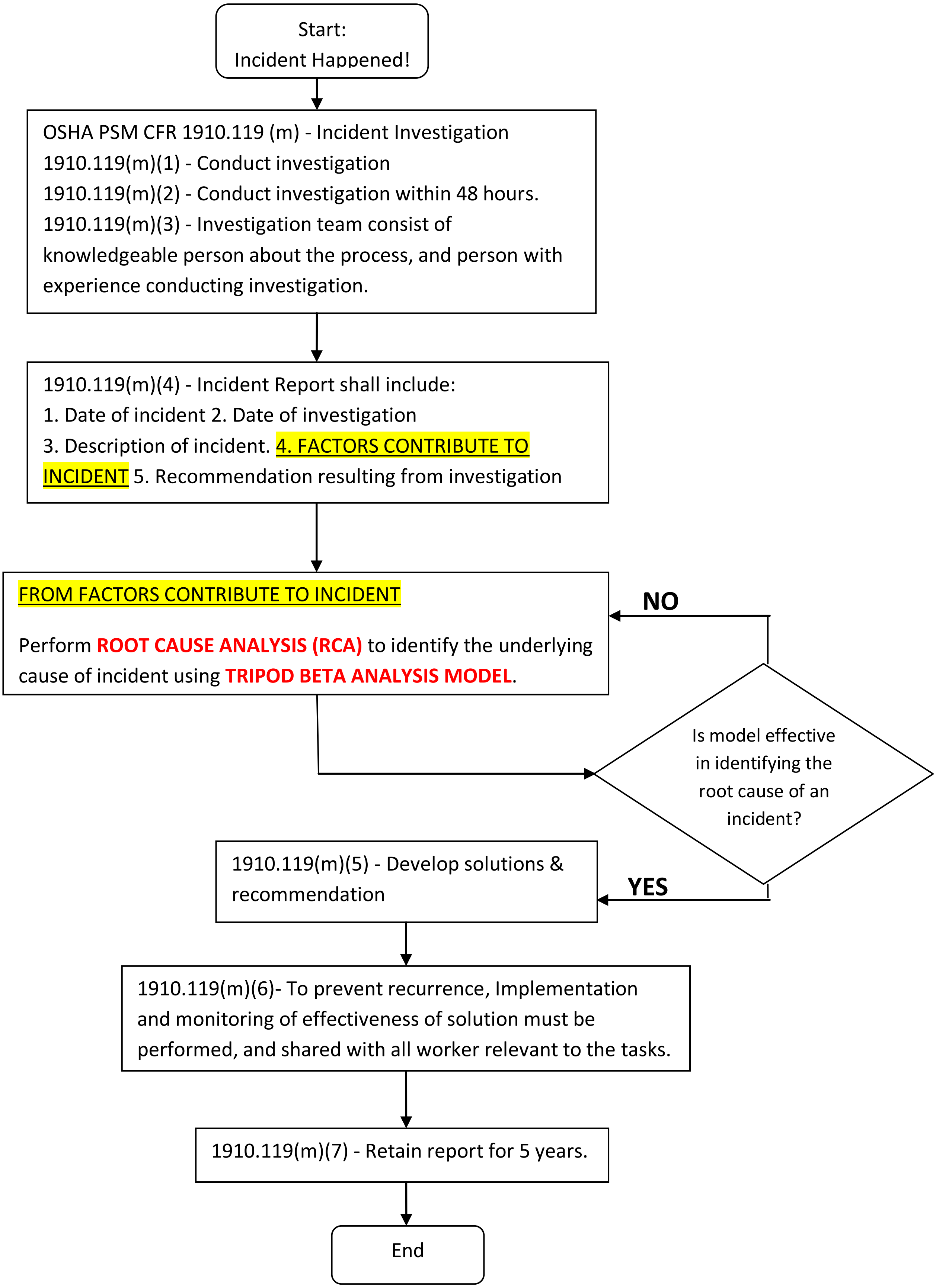

Figure 7: Framework of OSHA PSM Incident Investigation System

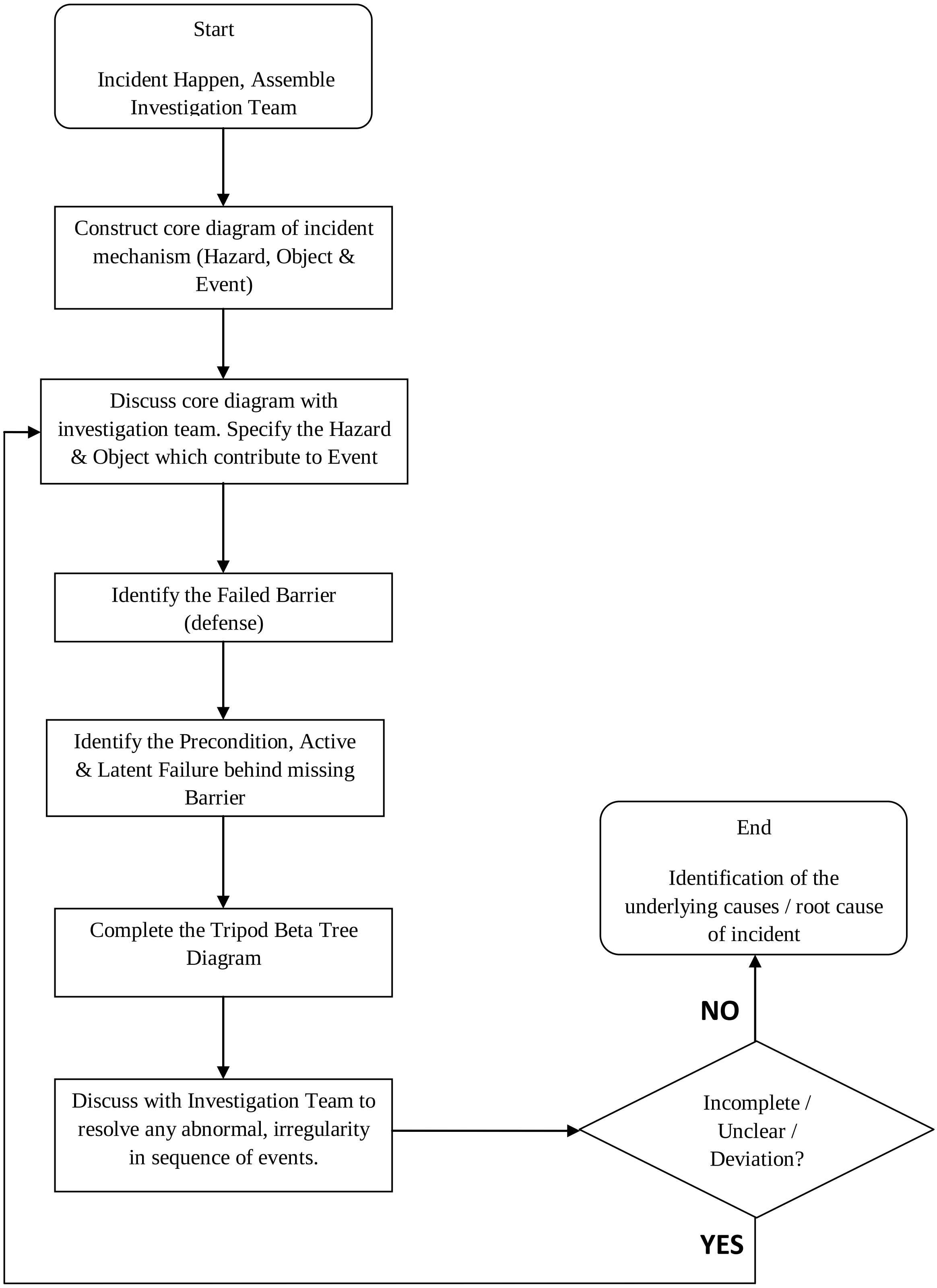

Figure 8: Flowchart of carrying out root cause analysis using Tripod Beta

In order to effectively conduct the project, a Gantt chart consisted of two semesters duration has been constructed and the milestones of FYP I & II has been established as shown in Table 2 below:

Table 2: Gantt chart for Final Year Project I

	Semester 1				Semester 2			
Activities	Jan	Feb	Mar	Apr	May	June	July	August
Literature Review								
Proposal Defence			X					
Analysis of PSM Standards								
Framework Development								
Interim Report				X				
Model Development								
Submission Progress Report						X		
Case Studies								
Pre-SEDEX							X	
Submission of Technical Paper								X
Oral Presentation								X
Submission of Report								X

Milestones of Final Year Project 1:

Table 3: Milestones of the Final Year Project I

Activities	Date
Topic selection	Week 1-2
Research on topic & Literature Review	Week 3-14
Proposal Defense	Week 8
Establish Framework	Week 4-7

Table 4: Gantt chart for Final Year Project II.

ACTIVITIES	FINAL YEAR PROJECT II													
	WEEK NO													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Model Development	■	■	■	■	■	■	■							
Case study on model developed in process industries						■	■	■	■	■	■	■	■	
Report Writing										■	■	■	■	■

Milestones of Final Year Project II:

Table 5: Milestones of the Final Year Project II.

Activities	**Date**
Model Development	Week 1-7
Case study on model developed in process industries	Week 6-14
Report Writing	Week 10-14

Tools

The main tools used are Microsoft Office (Word, Excel & Access) which is used to construct the Tripod Beta Tree Diagram and to store data of the incident investigation for easier information retrieving in the future.

Project Schedule

The planned schedule for Final Year Project I and Final Year Project II are as follows.

Table 6: Project schedule for Final Year Project I

Title selection	Week 1
Extended proposal	Week 6
Proposal defense and progress evaluation	Week 9
Draft report	Week 13
Final report	Week 14

Table 7: Project schedule for Final Year Project II

Pre-SEDEX	Week 8
Draft report	Week 13
Final report	Week 14
VIVA	Week 15

CHAPTER 4

RESULT AND DISCUSSION

Case Study 1

The case study is based on a real incident investigation report retrieved from Terengganu Crude Oil Terminal (TCOT) PETRONAS Carigali Sdn Bhd (PCSB) through collaboration with the company during previous internship program. The host company has given permission to the author in using one of its incident investigation full report as a guidance in order to develop the Tripod Beta model. The case study is based on actual accident case in TCOT PCSB on 17 September 2004. A LP Hydrogen Compressor K-31201 was manually stopped after high vibration alarm V1801 had triggered, causing abnormal noise and vapor cloud was released. The failure was in cylinder 1 of the first stage inside the compressor. Assessment on the failed compressor had showed that it was catastrophic failure. Cylinder 1 components i.e. piston rod assembly and cross-head were broken/severely damaged. The compressor was anticipated to be out of service for few months due to its major component cross-head was broken and unfortunately no spare component was kept. Delivery of new item is 10 - 12 weeks. Cost to repair was approximated at RM 700k. Concern by the Management is that this incident is categorized as Safety Near Miss, Loss of containment and Release/Impact to the Environment. However as long as the other compressors K-31201 B & C are running fine and in healthy condition, no Production Loss is expected. (This is the 3rd time the same problem occurred. Previously the findings of the investigation report suggest it is due to fatigue caused by process upset which resulted in piston overload). First failure: March 2000 cylinder 3. Second failure: Jun 2000 cylinder 3).

The damaged or failed items are primarily on 1st stage cylinder (cylinder 1) which are:

i. Piston half's, rod, nut and collars
ii. Crosshead assembly
iii. Partition packing case
iv. Oil wiper packing case & stuffer plate

v. Connecting rod bearings

The core diagram focuses on what happened. If there is evidence at this stage of why any of the events happened it should be ignored for the time being. It should be placed in the Fact List for later use. The diagram can be built from any event in the incident sequence. The usual place to start is the main event, why the incident is being investigated. The vapor cloud released and severe damage to equipment (compressor) is a rational start point in this case.

The initial Hazard, Object and Event (HOE) trio is straight forward; the event is the vapor cloud released and damaged to equipment, the object is the component of the compressor which is cylinder 1 piston rod & cross head, the hazard is the piston hub fracture, and crosshead bending.

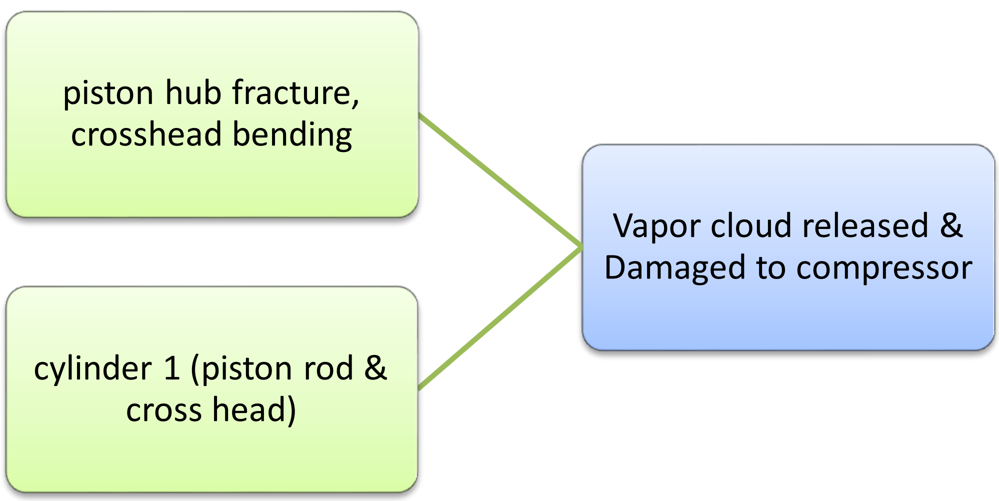

Figure 9: HOE Prime Event Diagram

Now examine each of the three 'nodes' in turn to determine whether there were prior or subsequent elements that need to be accounted for. The piston hub fracture and crosshead bending is an Event-Object and the subsequent event is as shown in figure below:

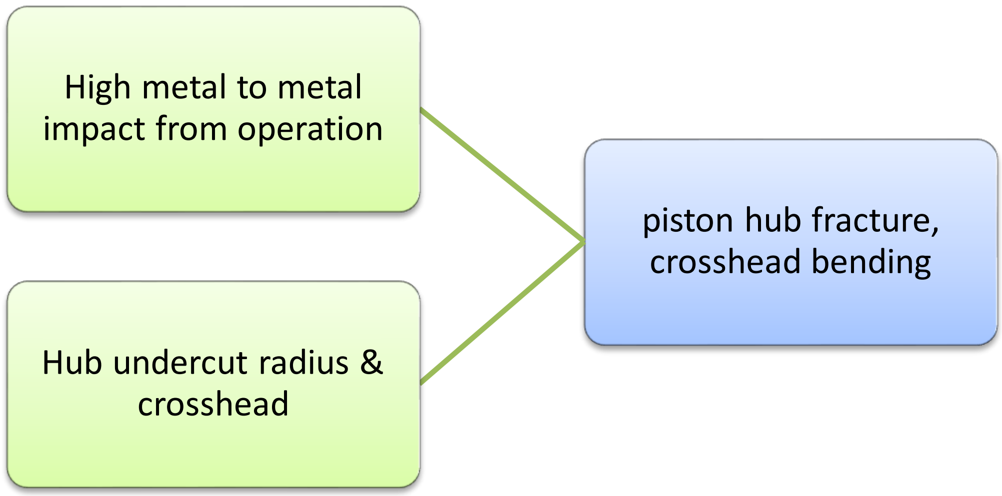

Figure 10: Subsequent event from Piston Hub event

In this sequence of event, the piston hub fracture and crosshead bending is due to the high metal to metal impact from operation which causes fatigue cracking on hub undercut radius and propagated to the ribbed area crosshead. From this event, it was found out that the high metal to metal impact is caused by deviation of the process mode. The deviation causes a failed in material due to the fact that the crosshead was casted, designed to sustain tension and compression load as it is subjected to under normal operating condition. it would not stand bending or shearing load. Inspection of the failed crosshead indicated that it failed under bending and/or shearing load. This event lead to the metal-to-metal high impact as a Hazard-Object event which has primary causes that leads to its occurrence. The event can be explain in figure below:

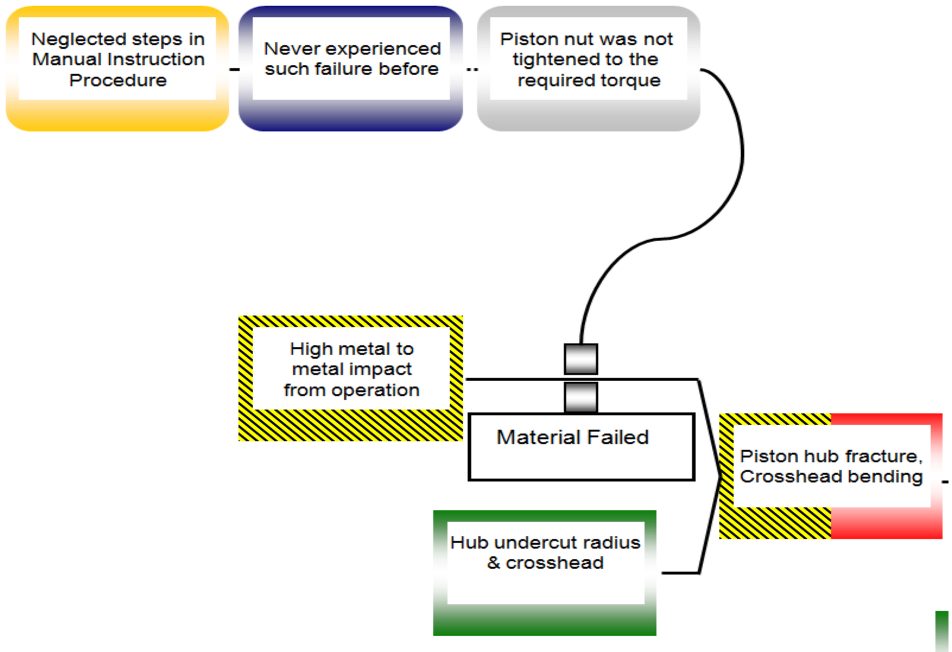

Figure 11: Subsequent event from Material Failed event.

Further investigation shows that the material failed is caused by 3 basic causes, which is the root cause of this incident. The active causes (immediate cause leading to the problem) is the piston nut was not tightened to the required torque value (which is tightened to 30 ^{o} instead of 63^{o}). By not tightening to the correct torque it created gaps between associated mating parts. Cyclic impact load by collar/rod shoulder on hub faces under normal load led to fatigue cracking. Multiple cracks were initiated from piston bore inner radius and traveled radially to the cast ribs. The Pre-condition that lead to the event is the operator never experienced such failure before during his 3 years of working. The latent causes (deficiency in management system promoting condition for active causes) was thought to be the supervisor that instructed the operator to tightened the piston nut to 30° torque value had neglected the steps in Manual Instruction Procedure to tightened it to 63°. The overall diagram of the Tripod Beta model can be represent in figure below:

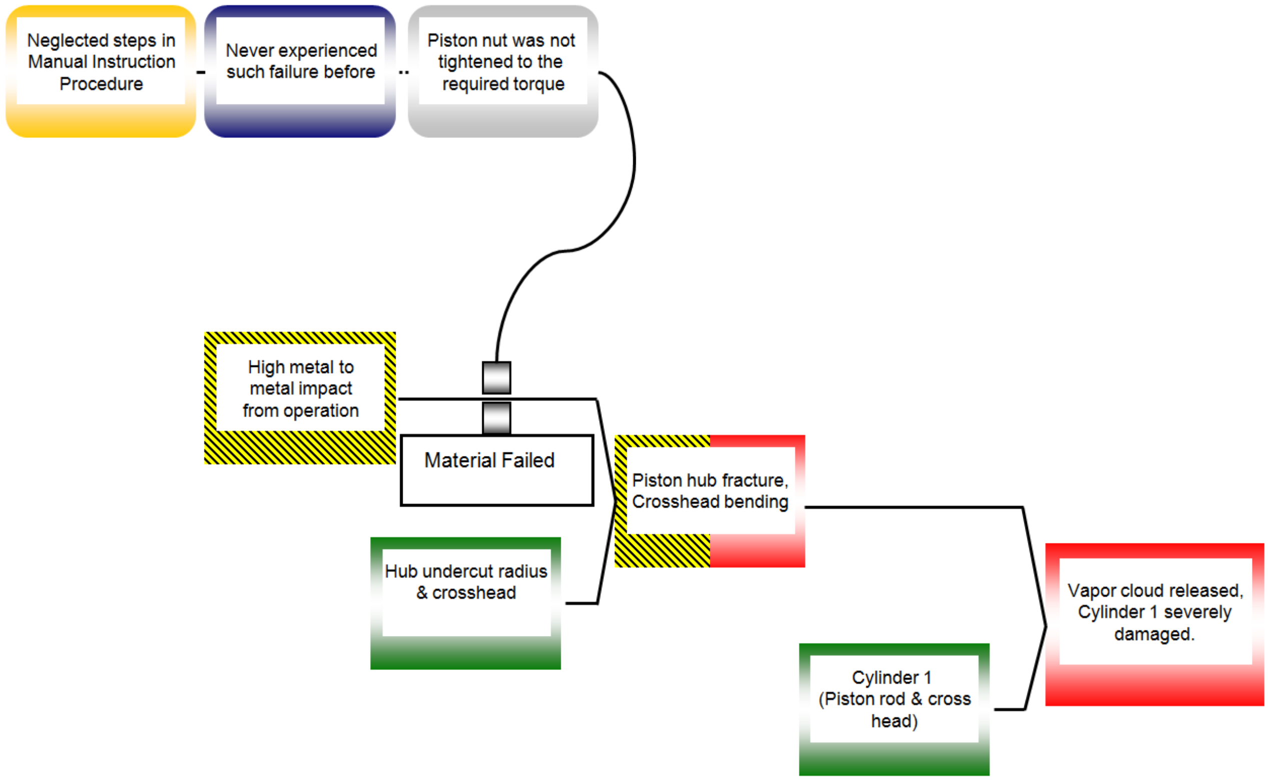

Figure 12: Tripod Beta diagram of Compressor K-31201A Failure.

Case Study 2

The second case study is about Jet-A1 particulates causing frequent filter change-out at KAFS (KLIA Fueling System Sdn Bhd). Based on the report, it stated that KAFS lodged a complaint to PP(M)SB on Jet-A1 suspected to contain unidentified fine particles, causing KAFS Microfilters to clog frequently. The complaint was supported by Millipore tests conducted by KAFS between October 2000 to April 2001. From the outcome of the incident investigation, the root causes, active cause, pre-condition and latent cause, are Insufficient push for review of maintenance strategy, never experienced such failure before and insufficient knowledge on clay change out procedure respectively. (Complain based on microfilter clog quicker than normal life, between October 2000-April 2001)

The steps in performing the root cause analysis is the same as the first case study. The overall Tripod Beta can be presented as shown in Figure 13 below:

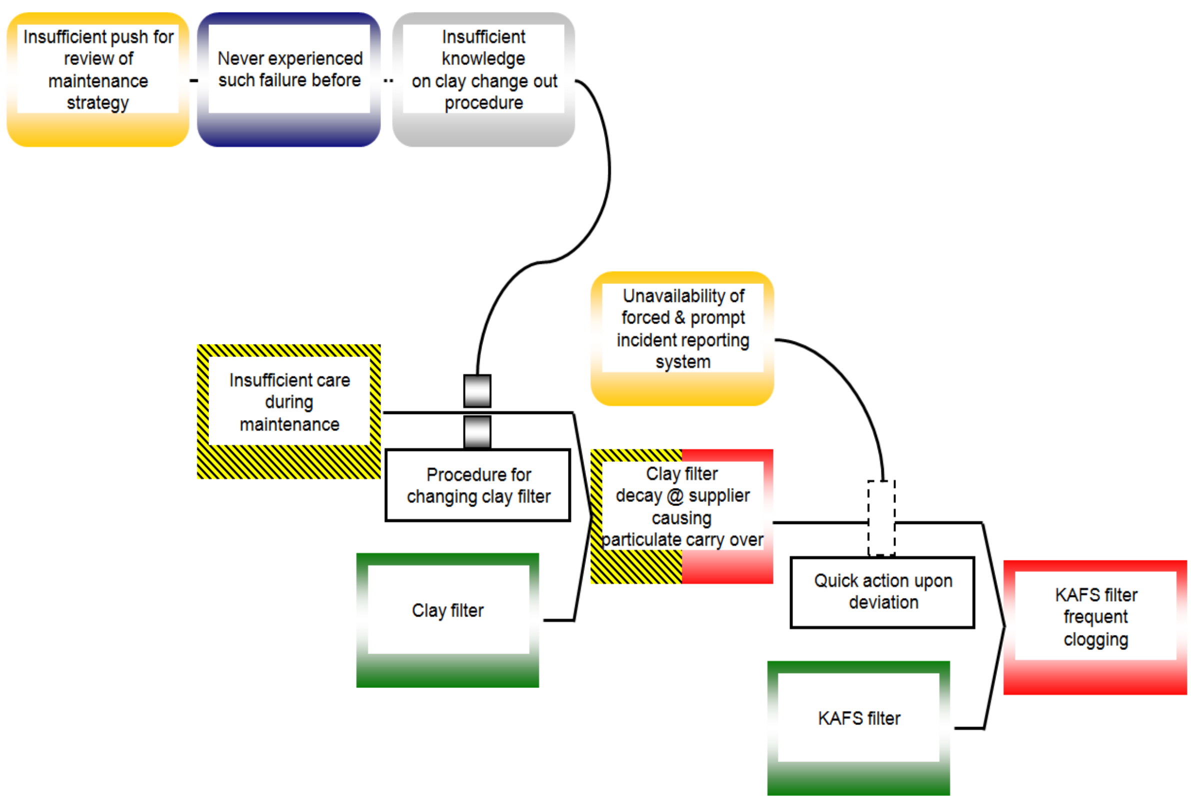

Figure 13: Tripod beta diagram of frequent filter changeout causes.

Once the tripod beta diagram is constructed, it will be stored inside company management system files for future reference and for distribution among company worker, and to those involved / responsible to ensure that corrective action are performed in a timely manner in order to prevent similar incident from occurring. After that, management needs to conduct inspection / KPI on the corrective action taken in order to validate its effectiveness. The system files will be as follows:

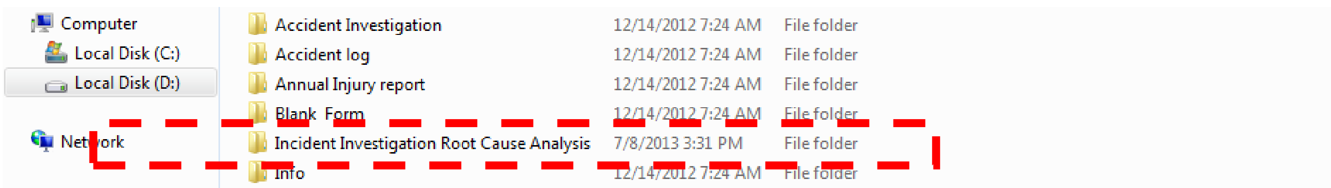

Figure 14: Incident Investigation System Files.

Inside the files will be the findings of Incident Investigation Tripod Beta Root Cause Analysis and incident investigation report in Microsoft Word. In order to ensure that the incident investigation is performed as per intend in this project, a checklist needs to completed so that the company will know that the incident investigation is performed as per required in OSHA PSM standards. The system developed makes data storing easier, user friendly and easy to be retrieved for future reference to the company.

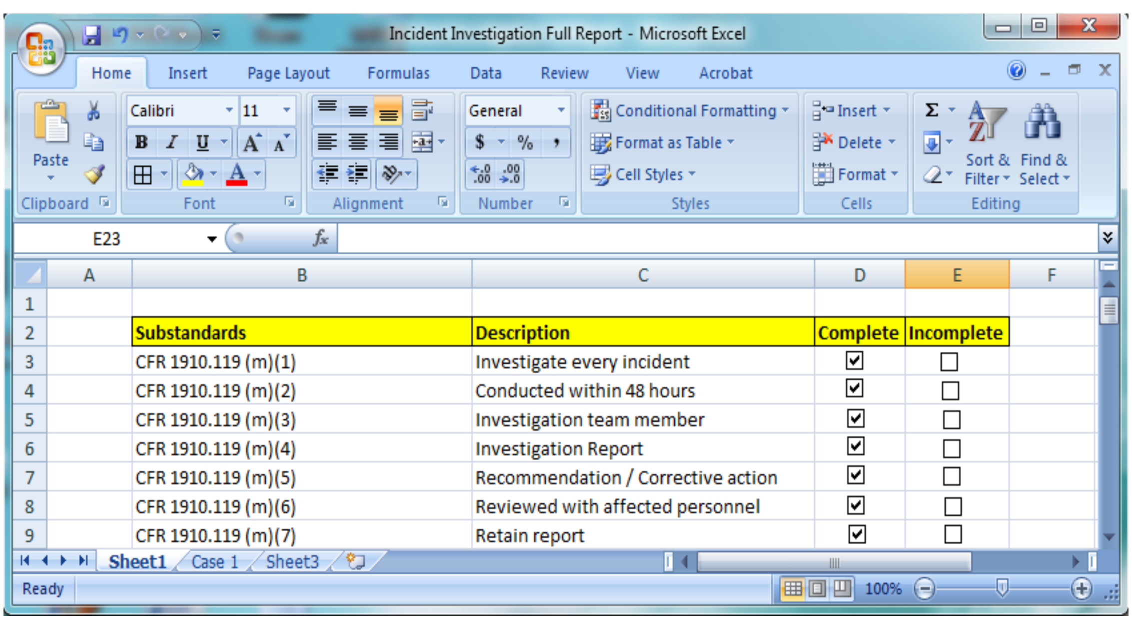

Figure 15: Checklist of Incident Investigation

The lack of incident investigation fact findings and unable to identify the root cause of an accident is the main reason why past incident reoccur. A thorough investigation with a root cause analysis will result in a deeper, more comprehensive investigation and a clearer understanding of the failures such as active and latent failure. This will make the incident investigation corrective action implementation more reliable and significant in terms of lasting accident prevention. This just shows that a root cause analysis is a powerful tool for a company incident investigation to identify the root cause of an incident. Lesson learned from incident not properly shared is another factor that contributes to repeating of the same accident. A proper incident investigation data sharing is important in order to share the findings of incident, thus avoiding the same mistake from happening again.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Process Safety Management (PSM) is a proactive management and engineering approach to protect employees, contractors, and other personnel from the risks associated with hazardous chemicals. These hazardous chemicals have the potential for catastrophic consequences if not properly controlled. The PSM Standard contains 14 key elements - all these elements are critical to safety in hazardous chemical processing. One of the element is Incident Investigation. This project focuses on the incident investigation element which its sole purpose is to avoid the occurrence and reoccurrence of past incident which causes unintended injuries to employees, death and damage to property. The incident investigation model developed in this project will help process industries in identifying the root cause of an incident, and prompt for corrective action to avoid recurrence of the past incident. This help industry to minimize its losses from compensation claim, property damage and losses, and also serves as a reference precaution measure for other similar processing unit. Data sharing within the company and also with other company can contribute to elimination of unwanted injury and losses to property.

As a conclusion, it can be said that this project is able to be completed within the given time frame to achieve the required objectives.

5.2 Recommendation

Further studies may include performing more case study in process plant to identify the validity of the model. It would be interesting to know if the implementation of this model proved to be successful for identifying, controlling, and preventing the reoccurrence of incidents at workplace.

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Glossary

Active Failure - An act or occurrence that renders a control or defense ineffective, thereby increasing the potential for release or exposure of a hazard or increasing the potential harm caused by the release.

Latent Failure - A defect or deficiency in a hazard management system that creates a condition promoting unsafe acts or increasing the chance of active failure.

General Failure Type - An element of a system for categorizing latent failures. An indicator of an aspect of hazard management where a failure exists, and by implication where the remedy lies.

Precondition - A system state that promotes unsafe acts or increases the chance of active failure.

Object - The object of harm (injury, damage or loss) caused by a hazard.

Unsafe Act - An action, error or omission that renders a control or defence ineffective: an active failure caused by human action.

APPENDICES

This Appendix contains a listing of toxic and reactive highly hazardous chemicals which present a potential for a catastrophic event at or above the threshold quantity.

CHEMICAL name	CAS*	TQ**
Acetaldehyde	75-07-0	2500
Acrolein (2-Propenal)	107-02-8	150
Acrytyl Chloride	814-68-6	250
Allyl Chloride	107-05-1	1000
Allylamine	107-11-9	1000
Alkylaluminums	Varies	5000
Ammonia, Anhydrous	7664-41-7	10000
Ammonia solutions (>44% ammonia by weight)	7664-41-7	15000
Ammonium Perchlorate	7790-98-9	7500
Ammonium Permanganate	7787-36-2	7500
Arsine (also called Arsenic Hydride)	7784-42-1	100
Bis(Chloromethyl) Ether	542-88-1	100
Boron Trichloride	10294-34-5	2500
Boron Trifluoride	7637-07-2	250
Bromine	7726-95-6	1500
Bromine Chloride	13863-41-7	1500
Bromine Pentafluoride	7789-30-2	2500
Bromine Trifluoride	7787-71-5	15000
3-Bromopropyne (also called Propargyl Bromide)	106-96-7	100
Butyl Hydroperoxide (Tertiary)	75-91-2	5000
Butyl Perbenzoate (Tertiary)	614-45-9	7500
Carbonyl Chloride (see Phosgene)	75-44-5	100
Carbonyl Fluoride	353-50-4	2500
Cellulose Nitrate (concentration > 12.6% nitrogen	9004-70-0	2500
Chlorine	7782-50-5	1500
Chlorine Dioxide	10049-04-4	1000
Chlorine Pentrafluoride	13637-63-3	1000
Chlorine Trifluoride	7790-91-2	1000
Chlorodiethylaluminum (also called Diethylaluminum Chloride)	96-10-6	5000
1-Chloro-2, 4-Dinitrobenzene	97-00-7	5000
Chloromethyl Methyl Ether	107-30-2	500
Chloropicrin	76-06-2	500
CHEMICAL name	CAS*	TQ**

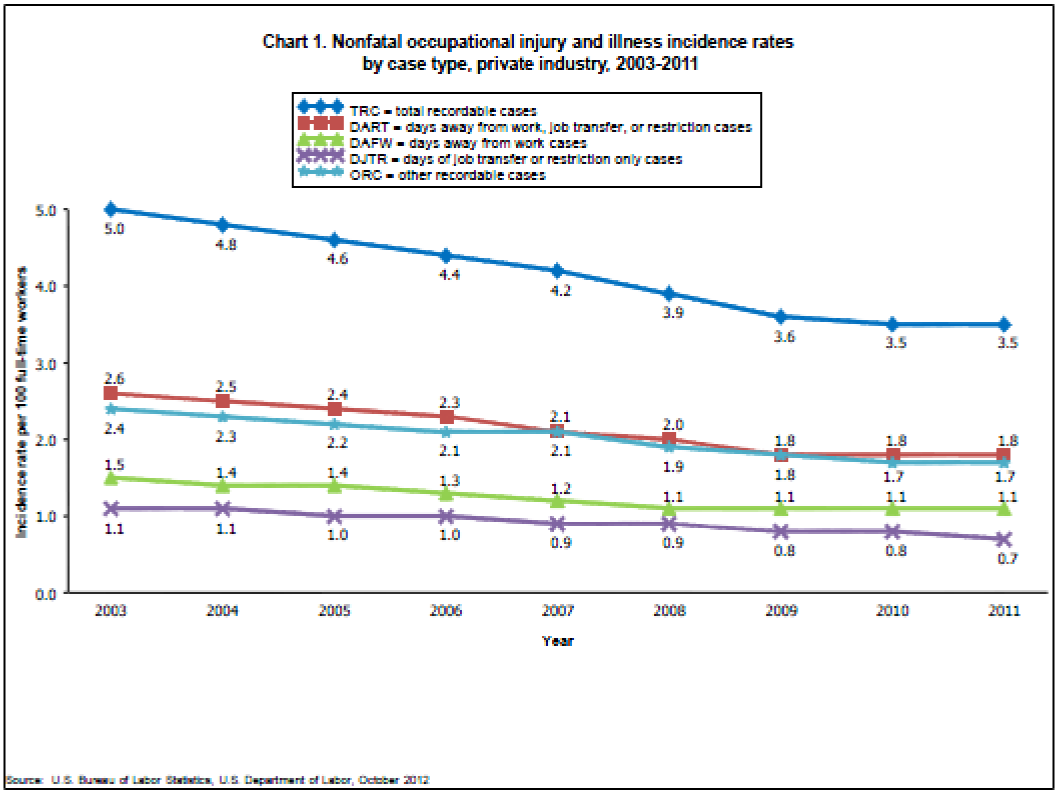
CHEMICAL name	CAS*	TQ**
Chloropicrin and Methyl Bromide mixture	None	1500
Chloropicrin and Methyl Chloride mixture	None	1500
Cumene Hydroperoxide	80-15-9	5000
Cyanogen	460-19-5	2500
Cyanogen Chloride	506-77-4	500
Cyanuric Fluoride	675-14-9	100
Diacetyl Peroxide (concentration >700%)	110-22-5	5000
Diazomethane	334-88-3	500
Dibenzoyl Peroxide	94-36-0	7500
Diborane	19287-45-7	100
Dibutyl Peroxide (Tertiary)	110-05-4	5000
Dichloro Acetylene	7572-29-4	250
Dichlorosilane	4109-96-0	2500
Diethylzinc	557-20-0	10000
Diisopropyl Peroxydicarbonate	105-64-6	7500
Dilaluroyl Peroxide	105-74-8	7500
Dim ethy Id ich lorosi lane	75-78-5	1000
Dimethylhydrazine, 1,1	57-14-7	1000
Dimethylamine, Anhydrous	124-40-3	2500
2,4-Dinitroanitine	97-02-9	5000
Ethyl Methyl Ketone Peroxide (also Methyl Ethyl Ketone Peroxide; concentration >60%)	1338-23-4	5000
Ethyl Nitrite	109-95-5	5000
Ethylamine	75-04-7	7500
Ethylene Fluorohydrin	371-62-0	100
Ethylene Oxide	75-21-8	5000
Ethyleneimine	151-56-4	1000
Fluorine	7782-41-4	100
Formaldehyde (Formalin')	50-00-0	1000
Furan	110-00-9	500
Hexafluoroacetone	684-16-2	5000
Hydrochloric Acid, Anhydrous	7647-01-0	5000
Hydrofluoric Acid, Anhydrous	7664-39-3	1000
Hydrogen Bromide	10035-10-6	5000
Hydrogen Chloride	7647-01-0	5000
Hodrogen Cyanide, Anhydrous	74-90-8	1000
Hydrogen Fluoride	7664-39-3	1000
Hydrogen Peroxide (52% by weight or greater	7722-84-1	7500
Hydrogen Selenide	7783-07-5	150
Hydrogen Sulfide	7783=06-4	1500

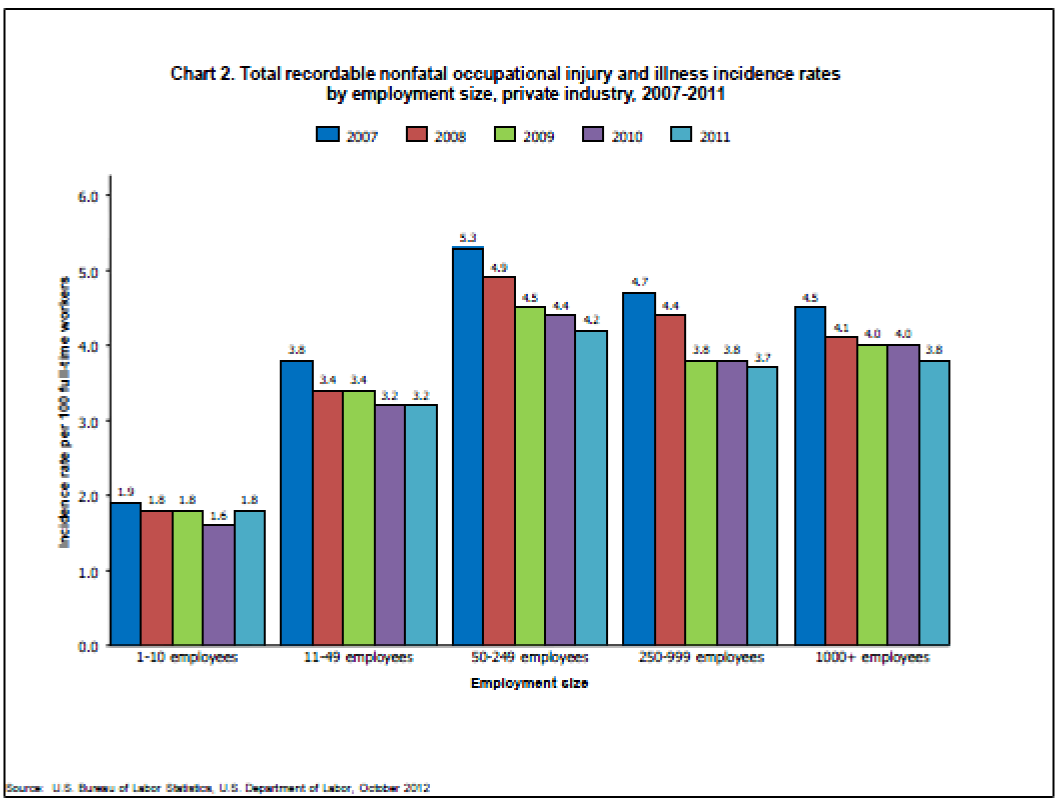
CHEMICAL name	CAS*	TQ**
Hydroxlamine	7803-49-8	2500
Iron, Pentacarbonyl	13463-40-6	250
Isopropylamine	75-31-0	5000
Ketene	463-51-4	100
Methacrylaldehyde	78-85-3	1000
Methacryloyl Chloride	920-46-7	150
Methacryloyloxyethyl Isocyanate	30674-80-7	100
Methyl Acrylonitrile	126-98-7	250
Methylamine, Anhydrous	74-89-5	1000
Methyl Bromide	74-83-9	2500
Methyl Chloride	74-87-3	15000
Methyl Chloroformate	79-22-1	500
Methyl Ethyl Ketone Peroxide (concentration >60%)	1338-23-4	5000
Methyl Fluoroacetate	453-18-9	100
Methyl Fluorosulfate	421-20-5	100
Methyl Hydrazine	60-34-4	100
Methyl Iodide	74-88-4	7500
Methyl Isocyanate	624-83-9	250
Methyl Mercaptan	74-93-1	5000
Methyl Vinyl Ketone	79-84-4	100
Methyltrichlorosilane	75-79-6	500
Nickel Carbonly (Nickel Tetracarbonyl)	13463-39-3	150
Nitric Acid (94.5% by weight or greater)	7697-37-2	500
Nitric Oxide	10102-43-9	250
Nitroaniline (para Nitroaniline)	100-01-6	5000
Nitromethane	75-52-5	2500
Nitrogen Dioxide	10102-44-0	250
Nitrogen Oxides (NO; NO_2; N204; N203)	10102-44-0	250
Nitrogen Tetroxide (also called Nitrogen Peroxide)	10544-72-6	250
Nitrogen Trifluoride	7783-54-2	5000
Nitrogen Trioxide	10544-73-7	250
Oleum (65% to 80% by weight; also called Fuming Sulfuric Acid	8014-94-7	1000
Osmium Tetroxide	20816-12-0	100
Oxygen Difluoride (Fluorine Monoxide)	7783-41-7	100
Ozone	10028-15-6	100
Pentaborane	19624-22-7	100

CHEMICAL name	CAS*	TQ**
Peracetic Acid (concentration >60% Acetic Acid; also called Peroxyacetic Acid)	79-21-0	1000
Perchloric Acid (concentration >60% by weight)	7601-90-3	5000
Perchloromethyl Mercaptan	594-42-3	150
Perchloryl Fluoride	7616-94-6	5000
Peroxyacetic Acid (concentration >60% by Acetic Acid; also called' Paracetic Acid)	79-21-0	1000
Phosgene (also called Carbonyl Chloride)	75-44-5	100
Phosphine (Hydrogen Phosphide)	7803-51-2	100
Phosphorus Oxychloride (also called Phosphoryl Chloride)	10025-87-3	1000
Phosphorus Trichloride	7719-12-2	1000
Phosphoryl Chloride (also called Phosphorus Oxychloride	10025-87-3	1000
Propargyl Bromide	106-96-7	100
Propyl Nitrate	627-3-4	100
Sarin	107-44-8	100
Selenium Hexafluoride	7783-79-1	1000
Stibine (Antimony Hydride)	7803-52-3	500
Sulfur Dioxide (liquid)	7446-09-5	1000
Sulfur Pentafluoride	5714-22-7	250
Sulfur Tetrafluoride	7783-60-0	250
Sulfur Trioxide (also called Sulfuric Anhydride)	7446-11-9	1000
Sulfuric Anhydride (also called Sulfur Trioxide)	7446-11-9	1000
Tellurium Hexafluoride	7783-80-4	250
Tetrafluoroethylene	116-14-3	5000
Tetrafluorohydrazine	10036-47-2	5000
Tetramethyl Lead	75-74-1	1000
Thionyl Chloride	7719-09-7	250
Trichloro (chloromethyl) Silane	1558-25-4	100
Trichloro (dichlorophenyl) Silane	27137-85-5	2500
Trichlorosilane	10025-78-2	5000
Triflurochloroethylene	79-38-9	10000
Trimethyoxysilane	2487-90-3	1500

*Chemical Abstract Service Number.
**Threshold Quantity in Pounds (Amount necessary to be covered by this standard).

Workplace Accident Statistics (OSHA, 2012)





Comparison of RCA tools, which is the best suited (Gano, 2007)

Method/Tool	Type	Defines problem	Defines all causal relationships	Provides a causal path to root causes	Delineates evidence	Explains how solutions prevent recurrence	Easy to follow report	Score
Events & Causal Factors	Method	yes	Limited	no	no	no	no	1.5
Change Analysis	Tool	yes	no	no	no	no	no	1
Barrier Analysis	Tool	yes	no	no	no	no	no	1
Tree Diagrams	Method	yes	no	no	no	no	no	1
Why-Why Chart	Method	yes	no	yes	no	no	no	2
Pareto	Tool	yes	no	no	no	no	no	1
Storytelling	Method	Limited	no	no	no	no	no	0.5
Fault Tree	Method	yes	yes	yes	no	yes	no	4
FMEA	Tool	yes	no	Limited	no	Limited	no	2
RealityCharting®	**Method**	**yes**	**yes**	**yes**	**yes**	**yes**	**yes**	**6**

Figure A.2. Comparison of Selected RCA Methods and Tools

OSHA PSM 29 CFR 1910.119 - Incident Investigation element

1910.119(m)
Incident investigation.

1910.119(m)(1)
The employer shall investigate each incident which resulted in, or could reasonably have resulted in a catastrophic release of highly hazardous chemical in the workplace.

1910.119(m)(2)
An incident investigation shall be initiated as promptly as possible, but not later than 48 hours following the incident.

1910.119(m)(3)
An incident investigation team shall be established and consist of at least one person knowledgeable in the process involved, including a contract employee if the incident involved work of the contractor, and other persons with appropriate knowledge and experience to thoroughly investigate and analyze the incident.

1910.119(m)(4)
A report shall be prepared at the conclusion of the investigation which includes at a minimum:

1910.119(m)(4)(i)
Date of incident;
1910.119(m)(4)(ii)
Date investigation began;
1910.119(m)(4)(iii)
A description of the incident;
1910.119(m)(4)(iv)
The factors that contributed to the incident; and,
1910.119(m)(4)(v)
Any recommendations resulting from the investigation.

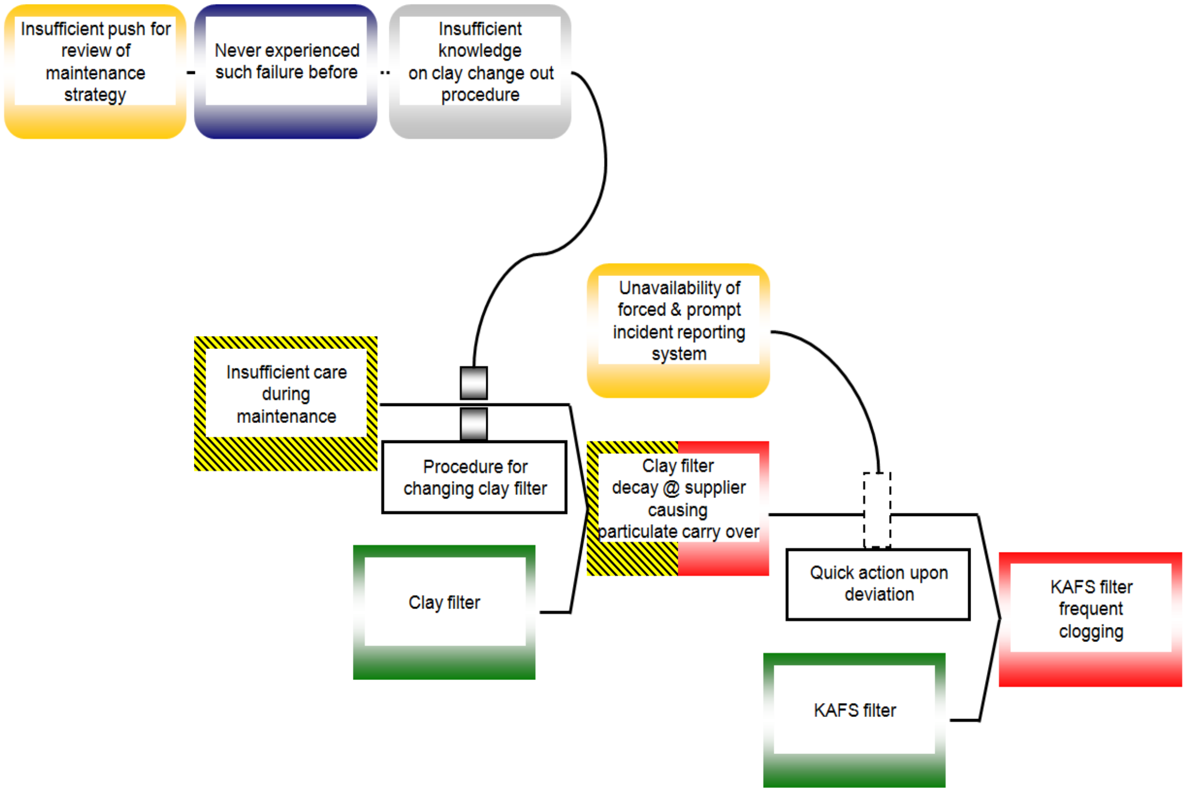
1910.119(m)(5)
The employer shall establish a system to promptly address and resolve the incident report findings and recommendations. Resolutions and corrective actions shall be documented.

1910.119(m)(6)
The report shall be reviewed with all affected personnel whose job tasks are relevant to the incident findings including contract employees where applicable.

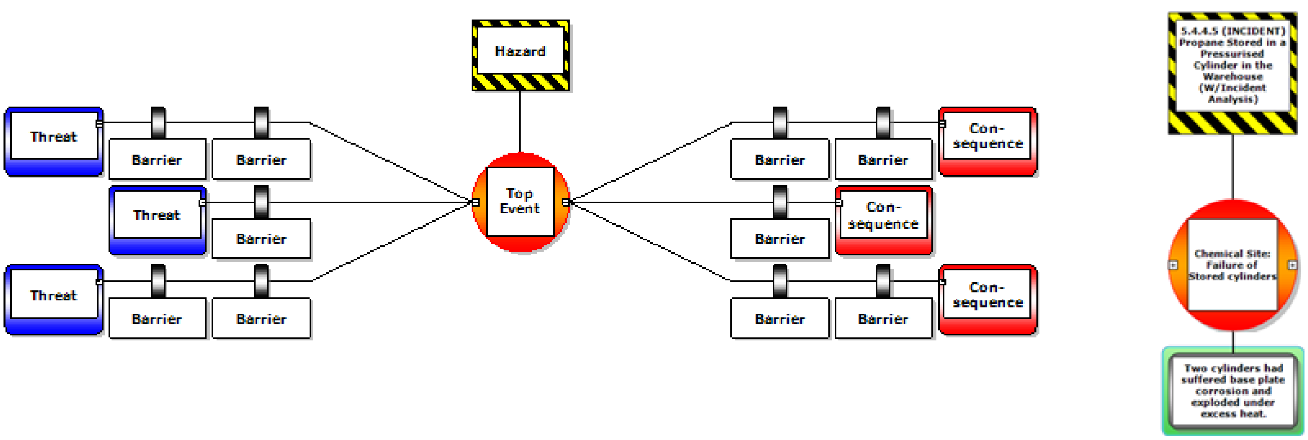
1910.119(m)(7)
Incident investigation reports shall be retained for five years.

Example of Root Cause Analysis Model

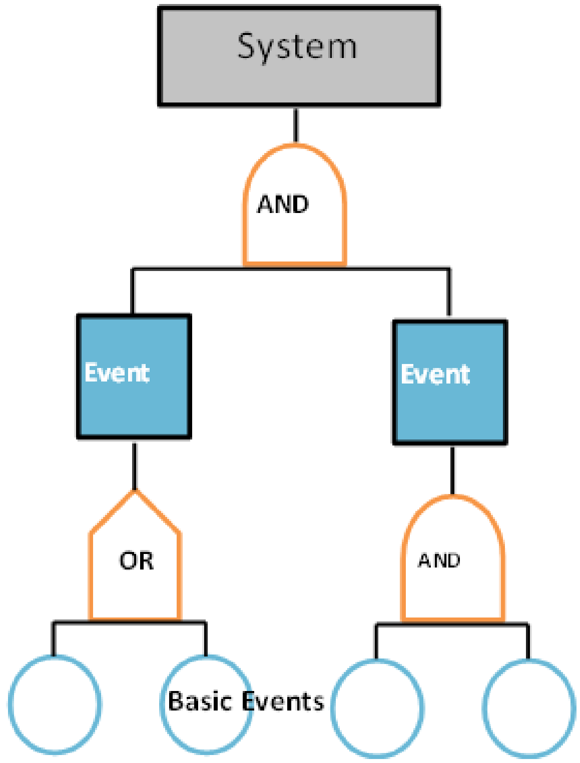
1. Tripod Beta



2. Incident Bow-Tie



3. Fault Tree



4. Scat Analysis