Development of Key Performance Indicators for Process Safety Management System

by

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Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

____

(AP Dr. Azmi Mohd. Shariff)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
July 2010

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 original work contained herein have not been undertaken or done by unspecified sources or persons.

NORAZIMA BINTI MAT ZAIDI

ABSTRACT

Process Safety Management; also referred to as PSM is the application of management systems to the identification, understanding and control of process hazards to prevent process-related injuries and incidents. The major objective of process safety management (PSM) of highly hazardous chemicals is to prevent unwanted releases of hazardous chemicals especially into locations that could expose employees and others to serious hazards.

Most of the company or plant only uses lagging indicators to measure their process safety performance and it has disadvantages since it indicates process safety performance after accidents occur. Thus, the effort to integrate both lagging and leading indicators had been discussed in this project. Based on the 14 elements of Process Safety Management (PSM), the most relevant Key Performance Indicators are selected and the metrics associated with them are identified.

The focus of this project will be on Process Safety Incident for lagging indicators and Process Hazard Analysis for leading indicators. The calculations for both indicators are based on the guidelines and literature reviews available from the expertise of the process safety field. The main calculations are based on the severity level and score. Thus, a modified severity level and score had been developed to measure the safety performance system of the company or plant by using both lagging and leading indicators.

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First of all, the greatest thanks would go to the Most Merciful, Most Gracious, ALLAH S.W.T. that this project had been completed with His permission.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

"You can't manage what you can't measure" quoted by Dennis Hendershot [1] is very important quote in the development of process safety performance indicators. Process safety performance indicators are applied to monitor and improve the safety of process plants [2]. This indicators or also known as metrics are implemented to track safety performance, to compare or benchmark safety performance against other facilities performance and to set targets or goals for continuous improvement of safety performance.

In most practice, process safety performance indicators are divided into two categories which are lagging and leading indicators. Lagging indicators can be considered as reactive monitoring since it measures the outcomes or effectiveness of actions taken. Meanwhile, leading indicators are considered as proactive monitoring since it measures preparedness to manage emergency situation.

Process Safety Management (PSM) is the application of management systems to the identification, understanding and control of process hazards to prevent process-related injuries and incidents. The phrase Process Safety Management System is the adopted from OSHA Standard 29CFR 1910.119 *Process Safety Management of Highly Hazardous Chemicals* in 1992 [3].

Measuring injuries to people or lost work days are only one aspect of measuring safety performance and it is often considered to be part of occupational or personal safety measurement. However, the focus of process safety management is to prevent release of hazardous material or energy from the process equipment. An effective process safety management program requires a systematic approach to evaluate the whole chemical process.

This project is called as Development of Key Performance Indicators (KPI) for Process Safety Management System. It is based on the most relevant elements that could be selected from the system to make an actionable change to something with defined cause and effect relationship.

1.2 Problem Statement

Unexpected releases of toxic, reactive, or flammable liquids and gases in processes involving highly hazardous chemicals have been reported for many years. Incidents continue to occur in various industries that use highly hazardous chemicals which may be toxic, reactive, flammable, or explosive, or may exhibit a combination of these properties. Regardless of the industry that uses these highly hazardous chemicals, there is a potential for an accidental release any time they are not properly controlled. This, in turn, creates the possibility of disaster. On July 17, 1990, OSHA published in the *Federal Register* (55 FR 29150) a proposed standard,—"Process Safety Management of Highly Hazardous Chemicals"—containing requirements for the management of hazards associated with processes using highly hazardous chemicals to help assure safe and healthful workplaces. OSHA's proposed standard emphasized the management of hazards associated with highly hazardous chemicals and established a comprehensive management program that integrated technologies, procedures, and management practices [4].

Process industries rely heavily on failure data to monitor performance, so improvements or changes are only determined after an accident has occurred. In other words, corrective actions can only be initiated after the occurrence of accidents or incidents. These after effect scenarios (lagging indicators) are too late and costly. To compensate the disadvantages of lagging indicators, this project will focus on how to use integrated both lagging and leading indicators to measure and improve the effectiveness of process safety performance system. The proposed safety performance measurement process should be validated with either case studies or actual implementation.

1.3 Objectives

The main objective of the project is to develop Key Performance Indicators (KPIs) to drive Process Safety improvement. The other objectives are:

1. To provide a measure of how well the barriers or hazard controls related to preventing process safety incidents are working.
2. To develop safety performance indicators for specified PSM elements chosen.

1.4 Scope of Study

The Key Performance Indicators (KPIs) will be developed based on 14 elements of Process Safety Management system. Specifically, this project will develop KPI for based on focused elements of PSM which are:

1. Process Safety Incident
2. Process Hazard Analysis (PHA)

CHAPTER 2

LITERATURE REVIEWS

2.1 Process Safety Management (PSM)

2.1.1 Definitions

*Process Safety i*s a blend of engineering and management skills focused on preventing catastrophic accidents, particularly explosions, fires, and toxic releases, associated with the use of chemicals and petroleum products.

Process Safety Management—also referred to as PSM—is the application of management systems to the identification, understanding and control of process hazards to prevent process-related injuries and incidents. The goal is to minimize process incident by evaluating the whole process. The phrase Process Safety Management came into widespread use after the adoption of OSHA Standard 29 CFR 1910.119 *Process Safety Management of Highly Hazardous Chemicals* in 1992 [3].

2.1.2 Process Safety Management (PSM) Elements

There are 14 minimum elements [3] that the OSHA standard requires employers to do which are:

1. Employee participation
2. Process safety information
3. Process hazard analysis
4. Operating procedures
5. Training
6. Contractors
7. Pre-start up safety review
8. Mechanical integrity
9. Hot work permit
10. Management of change

11. Incident investigation
12. Emergency planning and response
13. Compliance audits
14. Trade secrets

Based on this project, the elements that will be discussed are:

Table 1: PSM elements

PSM Elements	**Description**
Process Safety Incident	Any releases of material and energy from a process unit and meets all the criteria such as; chemical or chemical process involvement, above minimum reporting threshold, location of incident and acute release.
Process Hazard Analysis	Specifies that process hazard analyses (PHA's) must be conducted as soon as possible for each covered process using compiled process safety in an order based on a set of required considerations

2.2 Process Safety Key Performance Indicators (KPIs)

2.2.1 Definition

Key Performance Indicators (KPI) are implemented to track safety performance and to set goals for continuous improvement of safety performance. The use of operating experience as a starting point to define indicators has been proposed [2].

The general criteria that all the indicators were required to meet were the following:

- They should be objective and safety significant
- They should be obtainable with the data available in the plant

This project is done based on several guidelines on how to develop Key Performance Indicators for Process Safety Management System available. The examples of the guidelines are listed in the table below.

Table 2: Main literature reviews for Key Performance Indicators

Title	**Description**	**Analysis**
Developing Process Safety Indicators [5]	A step-by-step guide for chemical and major hazard industries to develop performance indicators to give improved assurance that major hazard risks are under control.	Introduction to leading and lagging indicators. - Leading indicators: form of active monitoring focused on a few critical risk control systems to ensure their continued effectiveness. - Lagging indicators: form of reactive monitoring requiring the reporting and investigation of specific incidents and events to discover weaknesses in that system. - Implementation of 'dual assurance': Leading and lagging indicators are set in a structured and systematic way for each critical risk control system within the whole process safety management system.
Process Safety Leading and Lagging Metrics [6]	This document describe the recommendations assembled by the Center for Chemical Process Safety (CCPS) Process Safety Metric committee for a common set of company and industry leading and	There are three types of metrics can be considered as measurements at different levels of the "safety pyramid" illustrated by CCPS. The types and definitions of the metrics are: "Lagging" Metrics – a retrospective set of metrics that are based on incidents that meet the threshold of severity that should be reported as part of the industry-wide process safety metric. "Leading" Metrics – a forward looking set of metrics which indicate the performance of the key work processes, operating discipline, or layers of protection

	lagging metrics.	that prevent incidents. “Near Miss” and other internal Lagging Metrics – the description of less severe incidents, or unsafe conditions which activated one or more layers of protection. Although these events are actual events (i.e., a “lagging” metric), they are generally considered to be a good indicator of conditions which could ultimately lead to a severe incident.

2.2.2 Categories of Safety Performance Indicators

Key performance indicators or also known as metrics are implemented to track safety performance, to compare or benchmark safety performance against the performance of other facilities and to set goals for continuous improvement of safety performance. Generally, safety performance indicators can be classified into two categories: leading and lagging performance indicators. Leading indicators is the form of active monitoring focused on a few critical risk control systems to ensure their continued effectiveness. It is a retrospective set of metrics that are based on incidents that meet the threshold of severity that should be reported as part of the industry-wide process safety metric. Meanwhile, lagging indicators is form of reactive monitoring requiring the reporting and investigation of specific incidents and events to discover weaknesses in that system [7]. It is a forward looking set of metrics which indicate the performance of the key work processes, operating discipline, or layers of protection that prevent incidents [8].

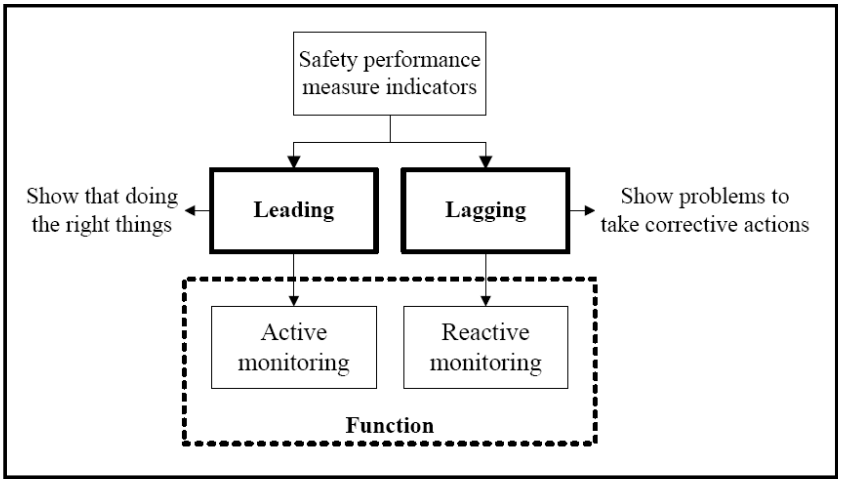


Figure 1: Two categories of Safety Performance Indicators [9]

2.2.1.1 Reactive Monitoring: Use of Lagging Indicators

Reactive monitoring of process safety includes the identification, reporting, and investigation of process-related injuries, incidents and property damage [10].Reactive monitoring allows an organization to identify and correct deficiencies in response to specific incidents or trends. Reactive monitoring uses lagging indicators to measure historical, after-the-fact performance [5]. These indicators show when the desired safety outcome has not been achieved and the safety control system has failed to prevent an accident.

However, they may not provide sufficient information to guide actions and ensure the success of management activities. They may fail to reveal latent hazards and failures that have significant potentials to cause accidents since they suggest corrective actions only after the accident. . In addition, the outcome rates are may be too low to measure and takes much time and work loading to review the usefulness and reliability of the information such as total number of reported incidents and dangerous occurrences.

2.2.1.2 Active Monitoring: Leading Indicators

Active monitoring evaluates the present state of a facility through the routine and systematic inspection and testing of work systems, premises, plant and equipment including rotating equipment, pressure vessels, piping, relief valves, and other safety-related equipment [10].

Although leading performance indicators are effective in improving performance and may compensate for shortcomings of lagging performance indicators, they still have some potential pitfalls when the following situations happen. The first is the effect of selecting irrelevant measurements which means targeting the wrong tasks through a lack of the understanding of the inputs that affect the outcomes. Secondly, leading performance indicators are deemed simply as a metric with actions being taken to get a good score rather than being used to guide actions that will correct weaknesses and improve the ultimate performance.

2.2.1.3 Combination of lagging and leading indicators

For avoiding the weakness and keeping the advantages of leading performance indicators, this project focuses on a combination of both categories of indicators. This combination may provide a systematic procedure to measure and evaluate the health and safety performance of organizations and to contribute to effective implementation.

The characteristics of the combination of both categories of indicators are objective and easy to measure and collect, relevant to activities considered to be important for future performance and critical to the organization. They have to provide immediate and reliable indication of the level of the performance and maintain efficiency. Most of all, they must be understood and provide a clear indication of a means to improve performance.

For this project, it will focus on elements under operational integrity category where it is intended to monitor parameters related to process and its operation. The elements that have been chosen for this category are Process Safety Incidents and Process Hazard Analysis (PHA – HAZOP). These elements are monitored through a set of leading and lagging parameters.

2.3 Development of Lagging and Leading Metrics

2.3.1 Definition

"Lagging" Metrics – a retrospective set of metrics that are based on incidents that meet the threshold of severity that should be reported as part of the industry-wide process safety metric.

"Leading" Metrics – a forward looking set of metrics which indicate the performance of the key work processes, operating discipline, or layers of protection that prevent incidents.

"Near Miss" and other Internal Lagging Metrics – the description of less severe incidents (i.e., below the threshold for inclusion in the industry lagging metric), or unsafe conditions which activated one or more layers of protection. Although these events are actual events, they are generally considered to be a good indicator of conditions which could ultimately lead to a severe accident [6].

2.3.2 Lagging Metrics: Process Safety Incident (PSI)

The common industry-wide lagging metrics [6] based on Center for Chemical Process Safety (CCPS) pamphlets are:

1. Count of Process Safety Incidents (PSI) — Any release of material or energy from a process unit resulting in injury, fire or explosion or chemical release from primary containment that exceed the defined threshold indicating significant process safety impact.
2. Process Safety Incident Rate (PSR) — a normalization of the PSI based on total plant work hours
3. Process Safety Incident Severity Rate (PSISR) — a weighting of the PSR based on the severity of each PSI.

From a process safety perspective, the three defined metrics are excellent choices for common lagging indicators. Moreover, the categories and severity levels are consistent with severity criteria commonly used in the industry for process hazard analysis. The usage of these metrics is appropriate and adequate for tracking process safety impacts. It is feasible to apply these metrics in this project since the definitions are quite clear.

Process Safety Incident: For reporting purposes, a Process Safety Incident (PSI) is an actual unplanned or uncontrolled Loss of Primary Containment (LOPC) that either [11] had an effect on people, property, or the environment; or was above a threshold amount in PSI reporting criteria.

An incident is reported as process safety incident if it meets all the following criteria:

1. Chemical or chemical process involvement
    - A chemical or chemical process must have been directly involved in the damage caused. The term “process” is used broadly to include the equipment and technology needed for petrochemical production, including reactors, tanks, piping, boilers, cooling towers, refrigeration systems, etc.
    - To identify incidents that are related to process safety, as distinguished from personnel safety incidents that are not process – related

2. Location
    - An employee injury occurs at a process location which is directly chemical process-related.
    - Incident occurs in production, distribution, storage, utilities or pilot plants of a facility includes tank farms, ancillary support areas and distribution piping under control of the site

3. Above minimum reporting threshold
    - An employee, contractor or subcontractor Fatality and/or Days Away from Work, or a third-party fatality or injury/illness that results in a hospital admission
    - A Fire or Explosion that causes $25,000 or more of direct cost, or
    - An acute release of flammable, combustible, or toxic chemicals from the primary containment (i.e., vessel or pipe) greater than chemical release threshold quantities described on the Table 3.

Table 3: Material Hazard Classification

Material Hazard Classification as Defined by the United Nations Dangerous Goods definition	**PSI threshold quantity**
All TIH Class A materials	5kg (11 lb.)
All TIH Class B Materials	25 kg. (55 lbs.)
All TIH Class C Materials	100 kg. (220 lbs.)
All TIH Class D Materials	200 kg. (440 lbs.)
All “Packing Group I” materials & “Flammable Gases/Vapors”	500 kg (1100 lbs.)
All “Packing Group II” materials & “Flammable Liquids”	1000 kg (2200 lbs.)
All “Packing Group III” materials & “Combustible Liquids”	2000kg (4400 lbs.)

For the purposes of applying these threshold values for “Flammable Gases/Vapors”, “Flammable Liquids”, and “Combustible Liquids”, the definitions commonly used are either within the petroleum refining industry (based upon National Fire Protection Association, NPFA-30, definitions), the UN Dangerous Goods (Class 2, Div. 2.1 and Class 3), or the Harmonized System of Classification and Labeling of Chemicals (GHS), Chapters 2.2 and 2.6. These different methods classify materials in a similar manner; therefore, most flammable materials will fall into the same category regardless of the definitions used [6].

2.3.3 Leading Metrics: Process Hazard Analysis – HAZOP

Process Hazard Analysis (PHA) (or, Process Hazard Evaluation) is a set of organized and systematic assessments of the potential hazards associated with an industrial process. A PHA provides information intended to assist managers and employees in making decisions for improving safety and reducing the consequences of unwanted or unplanned releases of hazardous chemicals. A PHA is directed toward analyzing potential causes and consequences of fires, explosions, releases of toxic or flammable chemicals and major spills of hazardous chemicals, and it focuses on equipment, instrumentation, utilities, human actions, and external factors that might impact the process [12].

The process hazard analysis is a thorough, orderly, systematic approach for identifying, evaluating, and controlling the hazards of processes involving highly hazardous chemicals. The employer must perform an initial process hazard analysis (hazard evaluation) on all processes covered by this standard. The process hazard analysis methodology selected must be appropriate to the complexity of the process and must identify, evaluate, and control the hazards involved in the process [13].

The selected PHA methodology to be done in this project is Hazard and Operability Study (HAZOP).A hazard and operability study (HAZOP) is a structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment, or prevent efficient operation. The HAZOP Study is an opportunity to correct these before such changes become too expensive, or impossible to accomplish [14].

The key feature is to select appropriate parameters which apply to the design intention. These are general words such as Flow, Temperature, Pressure, and Composition. In the above example, it can be seen that variations in these parameters could constitute Deviations from the design Intention. In order to identify Deviations, the Study Leader applies (systematically, in order) a set of Guide Words to each parameter for each section of the process. The current standard Guide Words are as follows:

Table 4: HAZOP Guide Words [15]

Guide Word	**Meaning**
NO OR NOT	Complete negation of the design intent
MORE	Quantitative increase
LESS	Quantitative decrease
AS WELL AS	Qualitative modification/increase
PART OF	Qualitative modification/decrease
REVERSE	Logical opposite of the design intent
OTHER THAN	Complete substitution
EARLY	Relative to the clock time
LATE	Relative to the clock time
BEFORE	Relating to order or sequence
AFTER	Relating to order or sequence

2.4 Existing Approaches

As per literature review and report by Chakraborty *et al.* [15], the status of safety performance indicators can be summarized as follows:

- There is no unified approach concerning terminology and definition of ‘performance indicators,” “safety indicators,” and “safety performance indicators.”
- There is no fixed suggested number of indicators.
- There is no calibration of safety performance indicators to give quantitative measure of plant safety.

- Evaluation of safety performance indicators is based on threshold values derived from past experience.
- There is no accepted approach to detect early signs of deterioration of safety, further relationship among different elements/parameters of safety need to be better understood and established.

In recent years, many efforts have been made to measure process safety. Indicators with a wide scope are relatively recent.

Table 5: Development of Process Safety Indicators

Developers/ Organizations involved	**Description**
The Center for Chemical Process Safety (CCPS) [6]	Defined process safety incident and proposed a draft metric to measure process safety
UK Health and Safety Executive [5]	Published a guide for development of leading and lagging process safety metrics
OECD [16]	Proposed guidance for the definition of safety performance indicators related to accident prevention, alert and emergency response
API [12]	Provide consistent lagging indicators and use to set performance targets, drive continuous improvement and permit benchmarking.
SCSB [17]	Investigation reports on BP Texas refinery accident has recommended that BP develop both leading and lagging process safety metrics as a tool for more effectively managing process safety.

However, most of these efforts are missing the coherence, quantification, audibility and logical integration of leading and lagging indicators. In subsequent section of this report, a simpler approach based on severity rate and risk matrix is presented to apply process safety performance indicators. This approach is built upon the guidelines from the Center for Chemical Process Safety (CCPS) with the cooperation of one of the fertilizer plants in Malaysia.

2.5 Combination of Lagging and Leading Process Safety Performance Indicators

It is commonly believed that a good occupational safety performance record indicates good safety management, including process safety. However, as noted in BP Texas Refinery accident investigation, it is possible to have a good occupational safety record and still have a high level of process safety incidents (releases of hazardous materials) which do not cause injuries [18]. Process safety incidents are always neglected to be indicate since it is rare and only noticed when events of catastrophic occurs. This is indeed true since major process safety incidents happened as a result of degradation safety performance which often goes unnoticed until it is too late since the events had occurred. Thus, a proficient and suitable system to measure process safety performance is required and the system must contain lagging and leading performance indicators for process safety.

Lagging indicators are the events that may and may not cause harm to personnel or property and it signify how well the process safety system is performing. Management can set goals for improvement using lagging indicators to determine where resources should be allocated to most effectively meet those goals and to determine which plants or units have the highest process safety incident rates. Meanwhile, leading indicators are measures of process or inputs essential to deliver the desired safety outcomes. By monitoring leading indicators, it shows the current state of the process safety and potential of future incidents. The subsequent chapter of this report will provide on how the approach for combination of both lagging and leading indicators is developed.

CHAPTER 3

METHODOLOGY

3.1 Data Acquisition

Accurate data must be gathered in order to successfully developed Key Performance Indicators for Process Safety Management System as required for the project. The gathered data are obtained from the research carried out and also the communication between the author and the company/plant.

3.2 Approach Selection and Evaluation

To develop Process Safety Indicators, it starts with the identification of potential failure scenarios and corresponding control measures that are in place to control the associated risks. Lagging indicators will denote the success of the risk control measures and number of events. Meanwhile, leading indicators monitor the importance of risk control measure and their successful operation. In this project, the combination of leading and lagging indicators are evaluated against an acceptance criterion and will be used for decision making. For this project, the selected elements from Process Safety Management to be evaluated are Process Safety Incident and Process Hazard Analysis. Both of these elements will be evaluated based on indicators developed by the author and the result will be compared to the existed approach using by the company/plant.

3.3 Case Study

This project is done with the help of one of the fertilizer plant located in Malaysia. From the data obtained, frequency of event (number of events in unit time) and severity of the event are the two characteristics monitored for each lagging parameters. Meanwhile, percentage of success (likelihood of success) and the importance of the success are the two characteristics monitored for each leading indicator parameter. However, not all data can be obtained from the company/plant due to confidentiality matters. Thus, several estimation of data had been done as part of the project.

3.4 Project Milestone

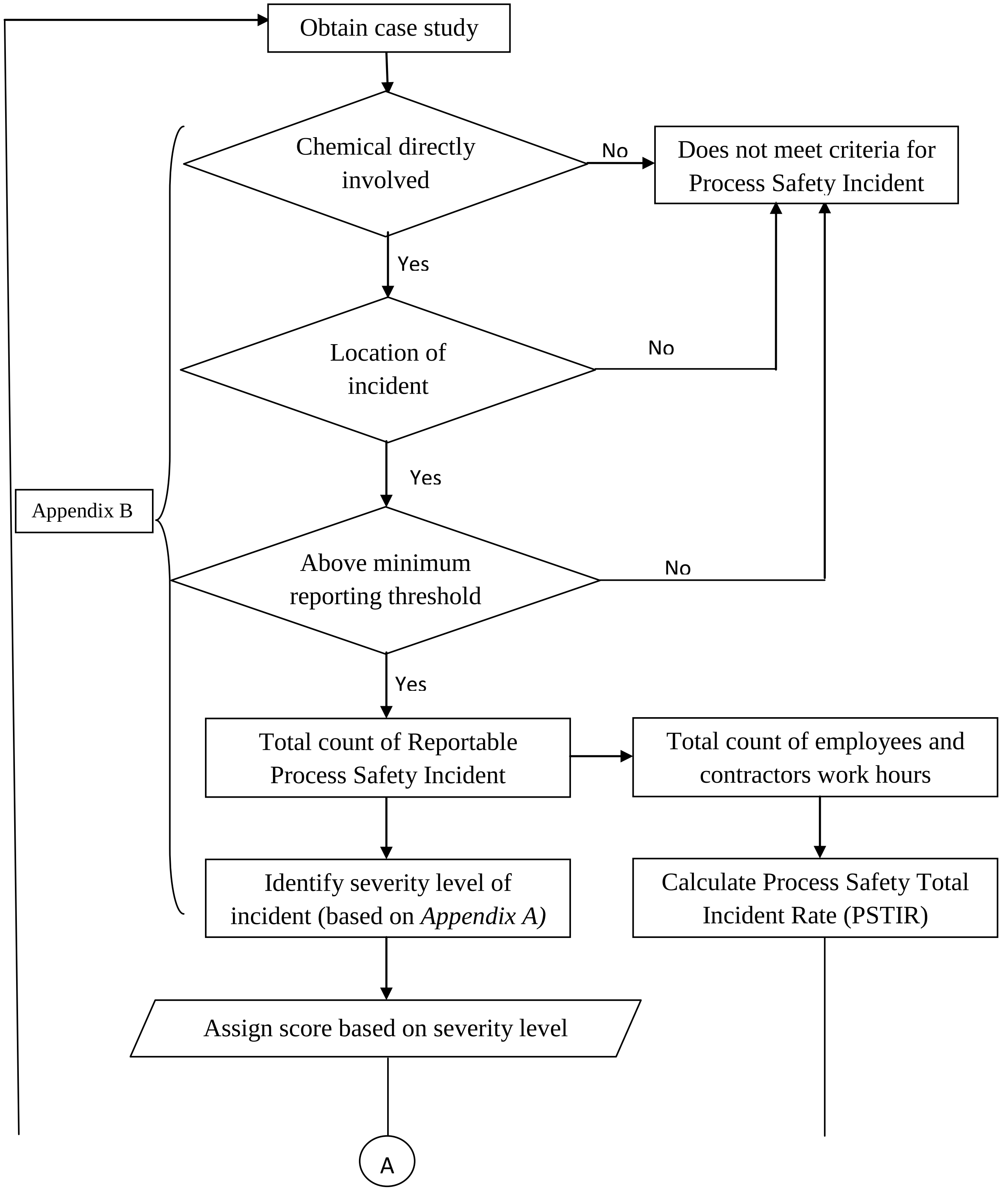
NO.	DETAILS / WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	**Selection of Project Topic** Title : Development of Key Performance Indicators for Process Safety Management System	■	■						Mid-semester break							
2	**Submission of FYP project title proposal**			■												
3	**Literature Reviews** Research work of : i) PSM elements, law and regulations ii) indicators : lagging and leading metrics		■	■	■	■	■	■								
4	**Project Work** i) Study of KPI development process ii) Continue research work					■	■	■								
5	**Seminar 1**									■						
6	**Submission of Progress Report**									■						
7	**Project Work continues**									■	■	■	■	■	■	
8	**Submission of Interim Report**															■
9	**Oral Presentation**															■

Figure 2: Gantt chart for Final Year Project I

	Detail/Week	**1**	**2**	**3**	**4**	**5**	**6**		**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	**Continuous research work**	■	■	■	■			**Mid Semester Break**								
2	**Obtain and study case study**				■	■	■									
3	**Submission of Progress Report 1**					√										
4	**Identify suitable information to be used**								■	■	■	■				
5	**Start to develop indicators**										■	■	■	■		
6	**Submission of Progress Report 2**									√						
7	**Seminar**										■	■	■			
8	**Poster Exhibition**											√				
9	**Submission of Dissertation (Soft Bound)**													√		
10	**Oral Presentation**														√	
11	**Submission of Dissertation (Hard Bound)**															√

Figure 3: Gantt chart for Final Year Project II

3.5 Lagging Indicators



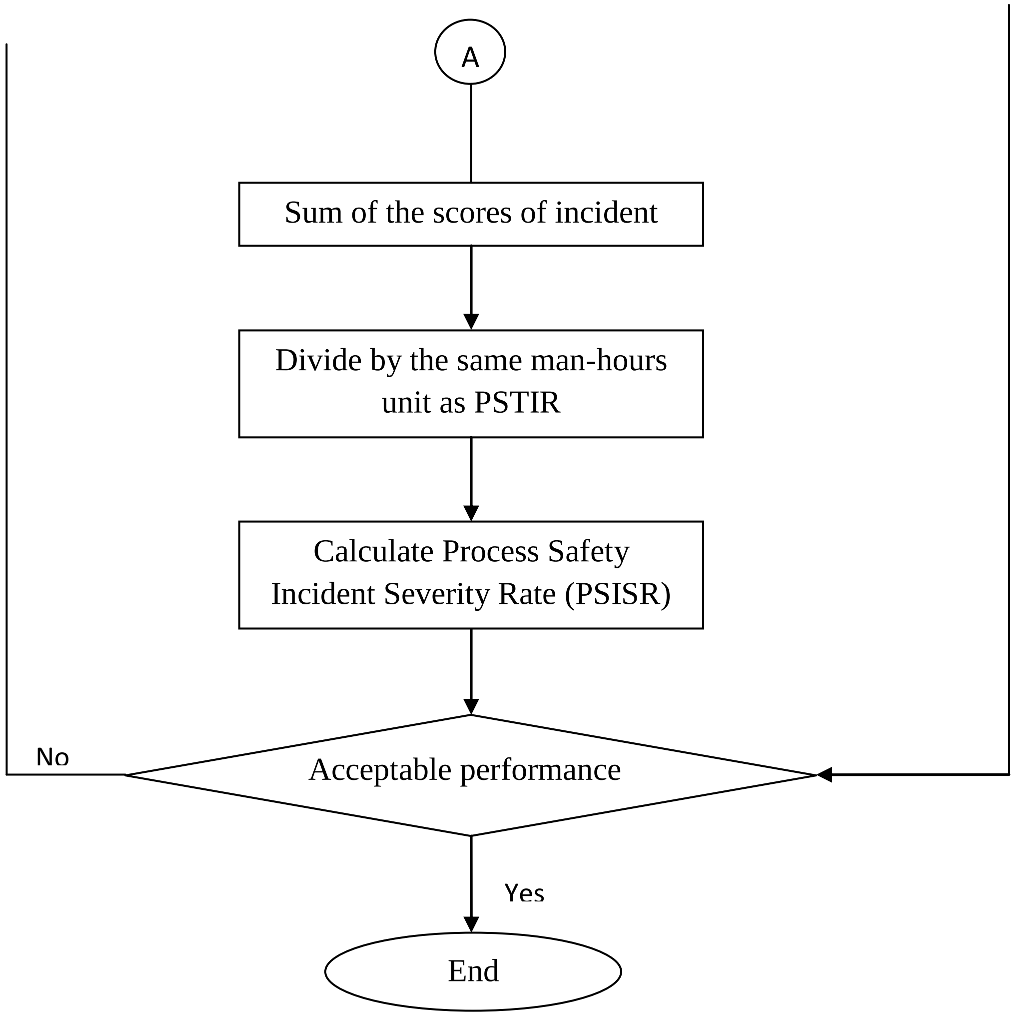


Figure 4: Determining Process Safety Total Incident Rate (PSTIR) and Process Safety Incident Severity Rate (PSISR)

Equation 1

Manhours = Number of employees x Number of workdays x Work hours per day

For lagging parameters, the metrics can be estimated by using equations below [6]:

Equation 2

Process Safety Total Incident Rate (PSTIR)

$$= \frac{\text{Total count of all process safety incidents x 200 000}}{\text{Total employee and contractor work hours}}$$

* Include both employee and contractor man hours

Equation 3

Process Safety Incident Severity Rate (PSISR)

$$= \frac{\text{Total severity score for all process safety incidents x 200 000}}{\text{Total employee and contractor work hours}}$$

* Assign score based on severity level

- Both incident rates are based on cases per 100 worker years
  - A worker year is assumed to contain 2000 hours (50 work weeks/year x 40 hours/week)

Thus, incident rate is based on 200000 hours (100 worker years x 2000 hours) of worker exposure to hazard.

Equation 4

Total Recordable Cases Rate (TRR)

$$= \frac{\text{Number of recordable cases x 200 000}}{\text{Total employee and contractor work hours}}$$

* Include both employee and contractor man hours

Equation 5

Lost Workdays Cases Rate (LWCR)

$$= \frac{\text{Number of Lost Time Accident Cases x 200 000}}{\text{Total employee and contractor work hours}}$$

Total employee, contractor and subcontractor work hours:

- Total hours worked for refining, petrochemical, or chemical manufacturing facilities.
- Using the same definitions that would be applicable for the OSHA injury/illness formula.
- Man-hours associated with major constructions project or corporate administration would not be included.

3.6 Leading Indicators

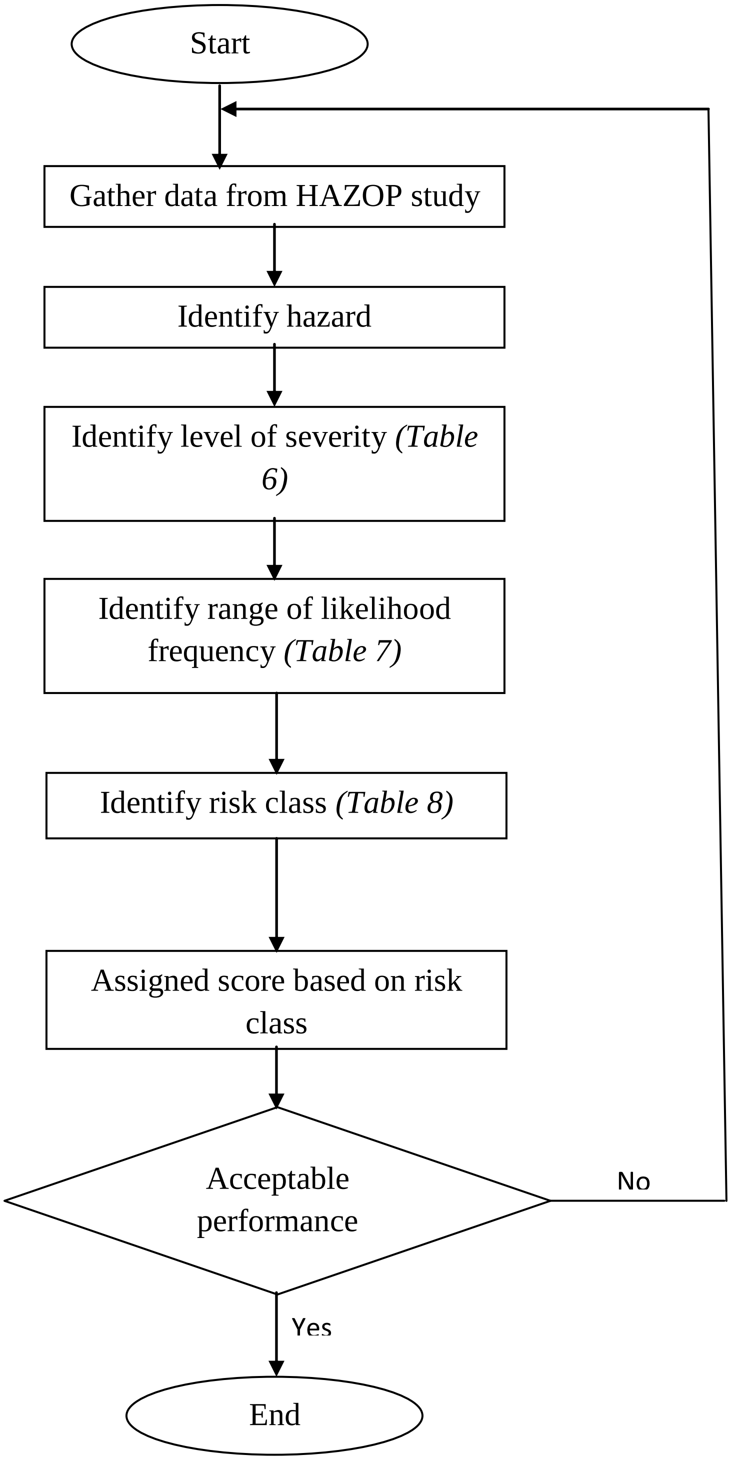


Figure 5: Determining performance level for leading indicators

For leading parameters, the metrics can be estimated by using Equation 3.

Table 6: Severity Table

Severity Level		**Severity Criteria**
From plant	***Assigned based on Appendix A***	
E	1	Minor
D	2	Not Serious
C	3	Serious
B	4	Very Serious
A	5	Catastrophic

Table 7: Likelihood Table

Likelihood	**Description of probability**
1	Extremely unlikely
2	Unlikely
3	Possible
4	Somewhat Likely
5	Very Likely

Table 8: Modified Risk Priority Matrix based on Severity Level

Severity	**5**	*Class C*	*Class B*	*Class A*	*Class A*	*Class A*
	4	*Class C*	*Class C*	*Class B*	*Class B*	*Class A*
	3	*Class D*	*Class C*	*Class C*	*Class B*	*Class B*
	2	*Class E*	*Class D*	*Class D*	*Class C*	*Class B*
	1	*Class E*	*Class E*	*Class D*	*Class D*	*Class C*
		1	**2**	**3**	**4**	**5**
Likelihood						

Table 9: Risk Class Including Assigned Score based on Severity

Risk Class	**Qualitative Employee Safety Consequence Criteria**	**Score (Percentage of severity score)**
Class A	Risk intolerable - needs to be mitigated within 2 weeks to at least a Class C, if that cannot be accomplished, process needs to be shutdown	0.27
Class B	Risk undesirable - needs to be mitigated within 6 months to at least a Class C	0.09
Class C	Risk tolerable with controls (engineering and administrative)	0.03
Class D	Risk acceptable - no further action required	0.01
Class E	Risk neglectable	0

Equation 3

$$\text{Leading index} = \frac{\text{Count of Risk Class x Severity Score}}{100}$$

3.7 Integration of lagging and leading indicators

Both lagging and leading indicators will be mapped on an acceptance scale where the target to be achieved is equal to. The values from 0 to 0.1 are characterized as green (acceptable - no concern), 0.1 to 0.3 are characterized as blue (acceptable – caution) and the value of 0.3 to 0.7 is characterized as yellow (requires attention). Meanwhile, the value of 0.7 to 1.0 is characterized as red (concern – requires immediate attention). Figure 6 represents the scale where it is used for both leading and lagging indicators. This scale is designed consistently parallel with company's risk matrix.

0 to 0.1 (green)	Acceptable (no concern)
0.1 to 0.3 (blue)	Acceptable (caution)
0.3 to 0.7 (yellow)	Requires attention
0.7 to 1.0 (red)	Concern (requires immediate attention)

Figure 6: Acceptance Scale for Process Safety Performance Indicator

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data Acquisition

An informal interview and email with person in charge for the safety department in one of the fertilizer plants in Malaysia had been done to obtain data required for this project. The input data for both indicators discussed are not all available in the required format. Some of the data are obtained from the refinery plant and some of the data are estimated based on typical refinery plant. The data presented also has been revised to preserve company confidentiality. The collected information was processed to validate the safety performance indicators that had been proposed for this project.

4.2 Lagging Indicators

4.2.1 Recordable Process Safety Incident

The table developed (Appendix B) was filled to record any incident happens in the plant. From the recordable incident, the total number of recordable process safety incident and the severity score for the incident can be identified. As shown, the recordable incidents in the plant occurred in year 2003, 2005 and 2010. From all of the incidents occurred, the criteria for the incidents to be counted as process safety incidents are evaluated.

Table 10: Recordable incidents for the plant

Date	Incident	Chemical / Chemical Process Involvement		Above minimum reporting threshold						Location		Reportable Process Safety Incident	
				Lost time injury/ fatality/ hospital admission and/or fatality of a third party		Fires/ explosions greater than or equal to $25000 of direct cost to the company		Acute release of flammable, combustible or toxic chemicals from primary containment					
		Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
2003	NH3 release. However, nobody is injured during this incident.	√			√		√	√		√		√	
10-May-05	One of the employees fell off the ladder in the plant and had to be taken to the hospital.		√	√			√		√	√			√
13-Oct-10	NH3 release (source of release still under investigation) causing several students (11) around the area vomiting and 4 students are warded. Nobody inside this plant is injured during the incident because the wind direction was directing to the north of the plant.	√		√			√	√		√		√	

The results from the evaluation based on the Table 10 shows that not all of the incidents are meeting the criteria for process safety incidents. One of the criteria for any incidents to be considered as process safety incidents is chemical/chemical process involvement during the incident. A chemical or chemical process must have been directly involved in the damage caused. Another criterion is the location where the incidents occurred. An employee injury must be occurs at a process location which is directly chemical process-related. The third criterion is the incidents to be above minimum reporting threshold. Thus, based on the table, only incidents occurred in year 2003 and 2010 are meeting the criteria as recordable process safety incident.

4.2.2 Process Safety Severity Score

Based on the recordable incidents shows by Table 10, severity score is assigned to process safety incidents recorded. The assigned score is given based on the modified process safety incidents and severity categories (Appendix A). The original table is obtained from CCPS Guidelines [6] and the author had modified the ranking of severity level for the simple observation to assign process safety incident severity score. The assigned severity score for recordable process safety incidents can be shows as below:

Table 11: Recordable incidents for the plant with assigned severity score

Year	**Incident**	**Potential Chemical Impact**		**Safety/ Human Health**		**Fire/Explosion (including overpressure)**		**Community environment impact**		**Reportable Process Safety Incident**		
		Severity Level	**Score**	**Severity Level**	**Score**	**Severity Level**	**Score**	**Severity Level**	**Score**	**Yes**	**No**	**Score**
2003	NH3 release	2	3	NA	0	1	1	1	1	√		5
10-May-05	One of the employee fell off the ladder	NA	0	1	1	NA	0	NA	0		√	NA
13-Oct-10	NH3 release (source of release still under investigation) causing several students (11) around the area vomiting and 4 students are warded. Nobody inside this plant are injured during the incident because the wind direction was directing to the north of the plant.	3	9	3	9	3	9	3	9	√		36

4.2.3 Number of employees and calculation of manhours

The current number of employees is given in Appendix C. It is also known that the plant operated for 24 hours per day and only will be shut down for maintenance purposes or severe incidents happen that required the plant to shut down. From the data obtained, calculation of manhours can be done by using Equation 1. For this project, assumptions that had been made to calculate the manhours are:

- The workdays per month are taken as 30 days.
- The number of workhours per day is assumed to be 24 hours.

However, the assumptions above is only used to calculate Process Safety Total Incident Rate (PSTIR) and Process Safety Incident Severity Rate (PSISR) that have been proposed for lagging indicators in this project. To compare the proposed approach with the conventional approach to indicate the safety performance in the plant, calculations for Total Recordable Rate (TRR) and Lost Workdays Cases Rate (LWCR) are also done. The assumptions that have been used for this calculation are:

- The workdays per month are taken as 22 days since it excluding weekend.
- The number of workhours per day is assumed to be 8 hours.

4.2.4 Total Recordable Rate (TRR) and Lost Workdays Cases Rate (LWCR)

Based on the data obtained, the calculations of Total Recordable Cases Rate (TRR) can be calculated by using Equation 4. For year 2002/2003, the TRR can be calculated as below:

Total Recordable Cases Rate (TRR)

$$= \frac{\text{Number of recordable cases x 200 000}}{\text{Total employee and contractor work hours}}$$

$$= (1 \times 200000) / 6800000$$

$$= 0.029$$

The rest of calculations are tabulated in Appendix C. The result for the calculation is shown by Figure 7 below:

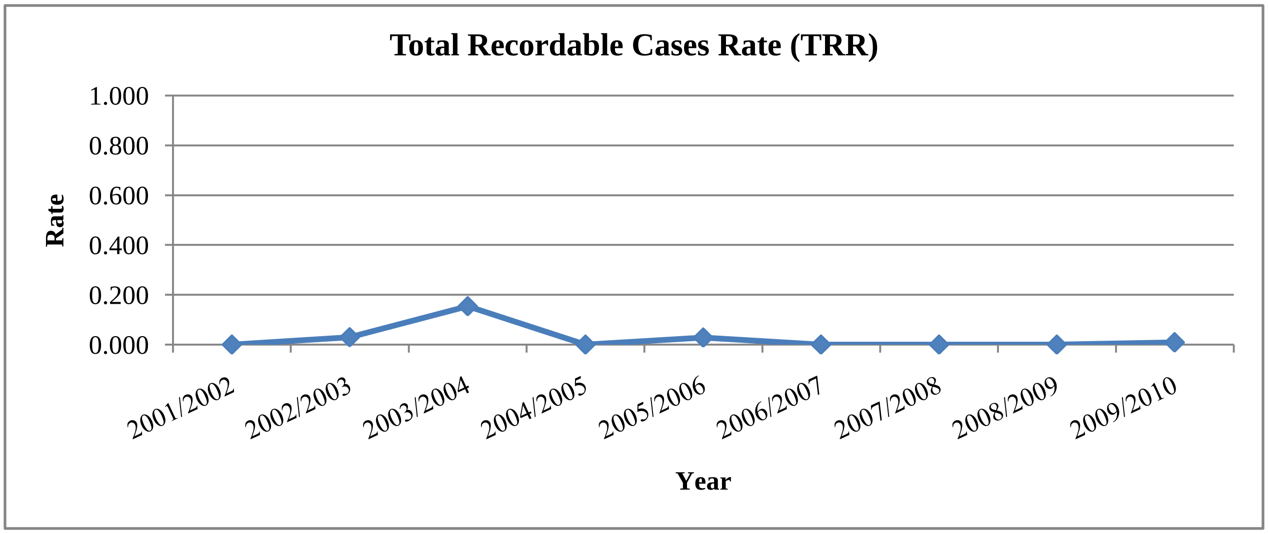


Figure 7: TRR performance for the fertilizer plant

Based on the graph, it shows that for the year 2002/2003 the TRR is 0.029. Meanwhile, for 2003, the TRR is increased due to lost time incident occurred. The TRR for this year is 0.154. For year 2004, the value of TRR is more or less equal to 2003 and increased again due to incident happened on 2005 where the value of TRR for 2004 and 2005 are 0.000 and 0.028 respectively. Throughout 2005 to 2009, the value of TRR is not change significantly due to no recordable incidents occurred. However, the value of TRR is changed for 2010 since recordable incidents occurred in the plant.

The calculation of LWCR is done based on the total recordable cases recorded in the plant. From the cases, it can be identified that the incidents are either can or cannot be considered as Lost Workdays Cases. For calculation of Lost Work Days Cases Incident Rate (LWCR), Equation 5 can be used to calculate the rate. For year 2002/2003, the LWCR can be calculated as below:

Lost Workdays Cases Rate (LWCR)

$$= \frac{\text{Number of Lost Time Accident Cases x 200 000}}{\text{Total employee and contractor work hours}}$$

$$= (1 \text{ x } 200000) / 6800000$$

$$= 0.029$$

The rest of the calculations are in Appendix C and the results of the calculation are shown below:

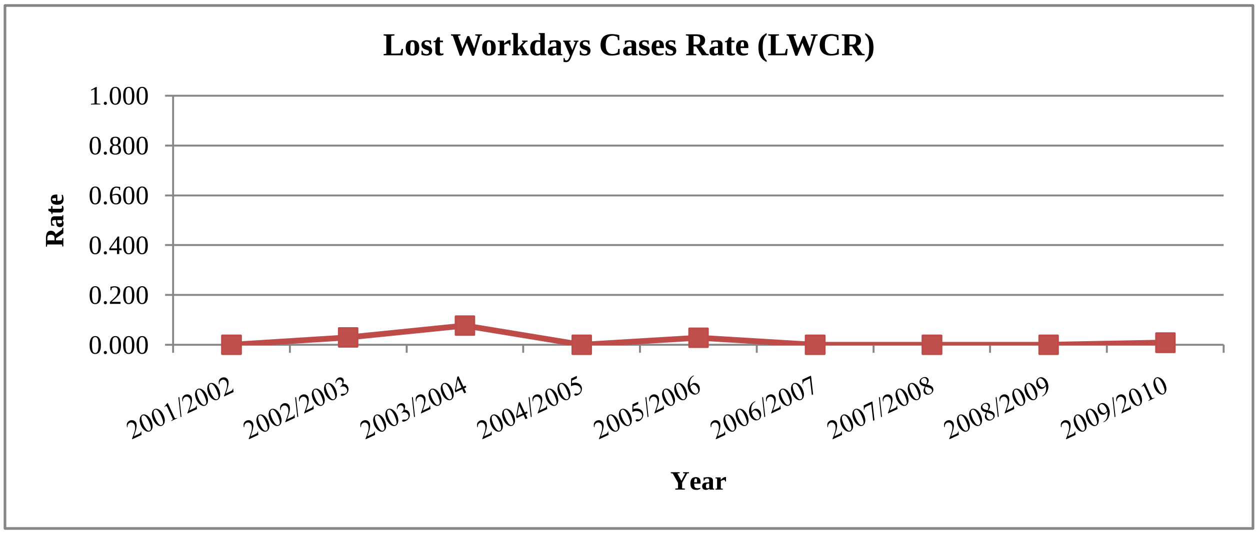


Figure 8: LWCR performance for the fertilizer plant

Based on the Figure 8 above, it shows that LWCR are proportional with TRR. For the year 2002 the LWCR is 0.029. Meanwhile for 2003, the LWCR is increased due to lost time incident occurred and the LWCR for the respective year is 0.077. For year 2004, the value of LWCR is more or less equal to 2003 and increased again due to incident happened on 2005 where the value of LWCR for 2004 and 2005 are 0.000 and 0.028 respectively. Throughout 2005 to 2009, the value of LWCR is not change significantly due to no recordable incidents occurred. However, the value of LWCR is changed for 2010 since recordable incidents occurred in the plant.

4.2.5 Process Safety Total Incident Rate (PSTIR) and Process Safety Incident Severity Rate (PSISR)

Based on the data from Table 11, the calculations of Process Safety Total Incident Rate (PSTIR) can be calculated by using Equation 2. For year 2002/2003, the calculation for PSTIR is shown as below:

Process Safety Total Incident Rate (PSTIR)

$$= \frac{\text{Total count of all process safety incidents x 200 000}}{\text{Total employee and contractor work hours}}$$

$$= (1 \times 200000) / 16041480$$

$$= 0.012$$

The rest of the calculations are shown in Appendix D and the results from the calculation are shows in the Figure 9 below:

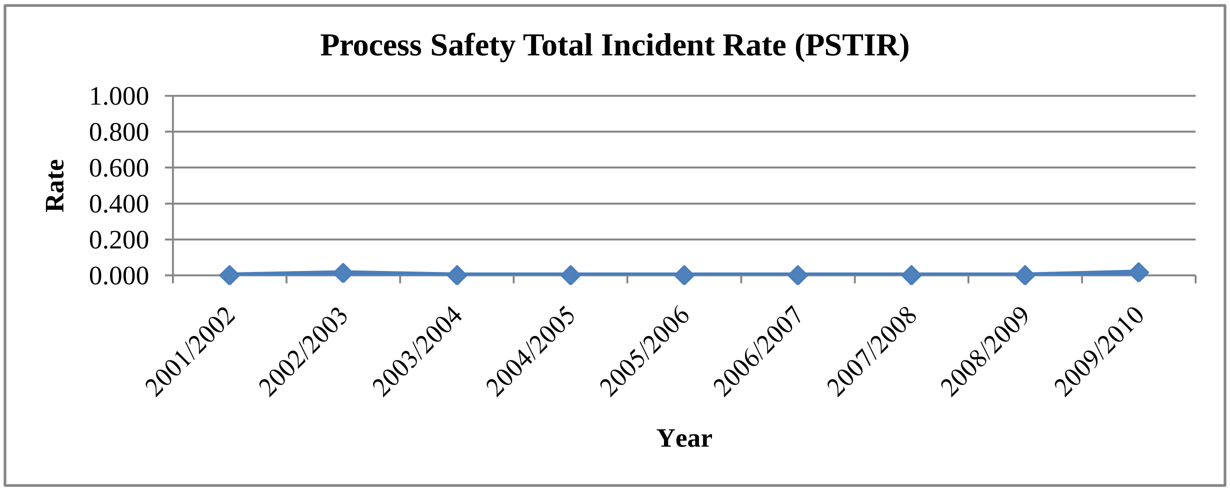


Figure 9: PSTIR performance for the fertilizer plant

Based on the graph above, it shows that PSTIR for both incidents occurred in 2003 and 2010 are the same which is 0.012. This is because the total count for process safety incidents for both years is only one.

Meanwhile, for PSISR, the values for both incidents are slightly different since the severity score for both incidents are different. The severity score is assigned based on Appendix A and can be shown as in the Table 11. The calculation for PSISR can be shown as below:

Process Safety Incident Severity Rate (PSISR)

$$= \frac{\text{Total severity score for all process safety incidents x 200 000}}{\text{Total employee and contractor work hours}}$$

$$= (9 \times 200000) / 16041480$$

$$= 0.112$$

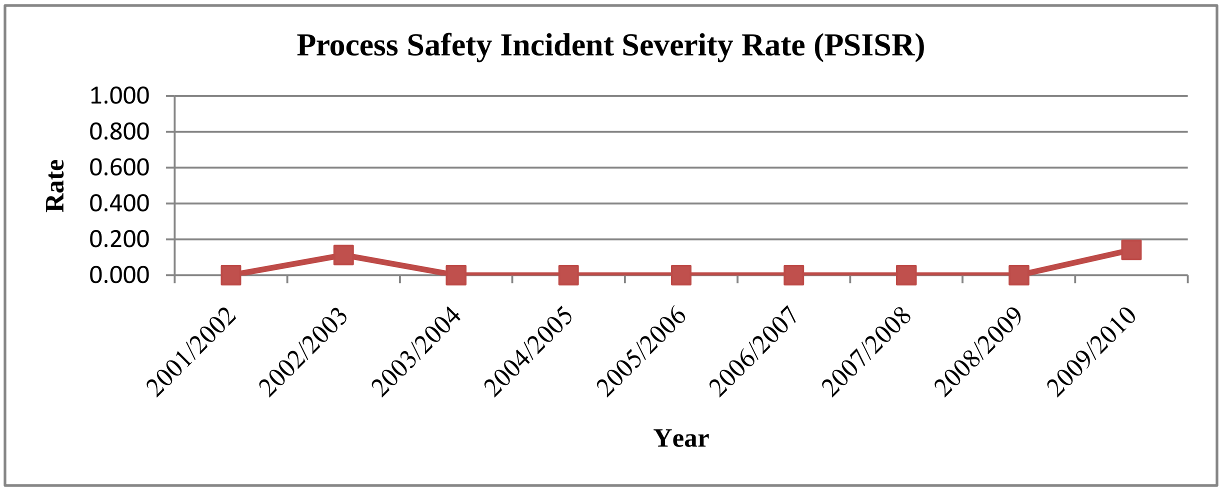


Figure 10: PSISR performance for the fertilizer plant

Based on the graph above, it shows that PSISR for 2003 and 2010 is 0.112.and 0.141 respectively. For the year 2004 until 2009, the PSISR has only little change for each year since no process safety incidents occurred during that those years.

For PSISR and PSTIR, the calculations for manhours are based on 24 workhours per day and 7 days per week. This is because a typical plant is usually operating 24 hours except when it has to be shut down for maintenance purposes. By using PSISR and PSTIR, the process safety incident can be monitored more adequately and this way is appropriate to indicate process safety performance for the plant.

4.2.6 Comparison between Total Recordable Cases Rate (TRR), Lost Workdays Cases Rate (LWCR) and Process Safety Total Incident Rate (PSTIR), Process Safety Incident Severity Rate (PSISR).

The comparison to evaluate safety performance by using conventional approach (TRR and LWCR) and the proposed approach (PSTIR and PSISR) can be shown in the Figure 11.

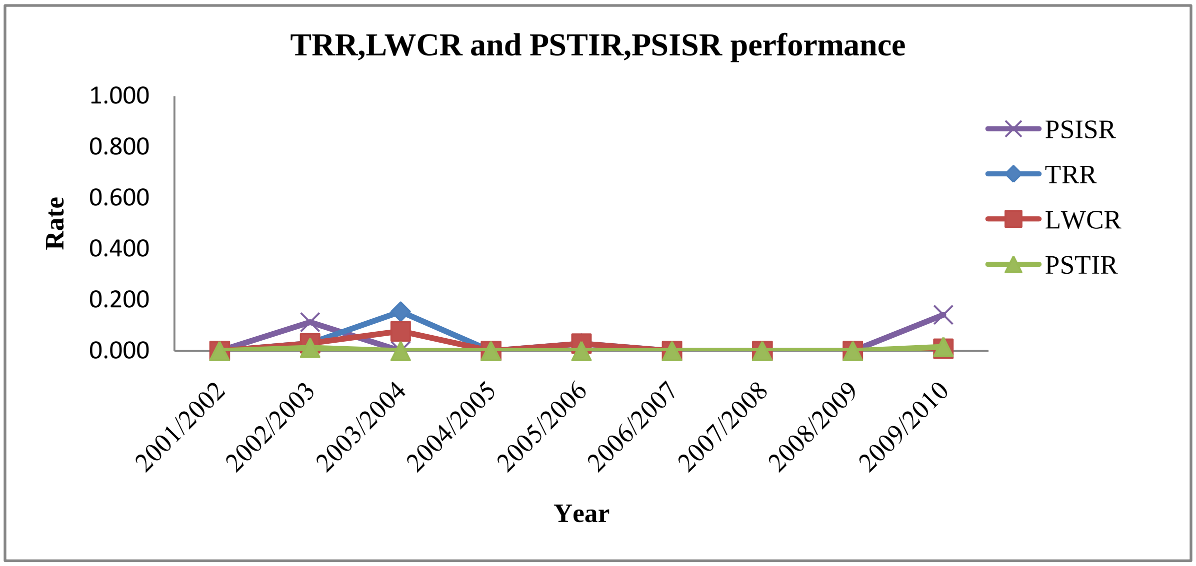


Figure 11: Comparison of TRR, LWCR and PSTIR, PSISR

By observing the graph above, it can be seen that even though the rate for TRR and LWCR sometimes is lower than PSTIR and PSISR, the calculations are still inadequate to indicate process safety performance as discussed beforehand. Besides, the rates for PSTIR and PSISR are still under acceptable region (based on Figure 6).

Generally, the calculation for TRR and LWCR is widely used by company/plant to indicate and evaluate their safety performance. However, the calculations for manhours are only based on 8 workhours per day and 5 days per week. Besides, total recordable accident includes in the calculation are based on personnel safety and not focusing on process safety specifically. Thus, it is inadequate and less relevant to use TRR and LWCR to indicate process safety performance in the plant.

4.3 Leading Indicators

The index for leading indicators is developed based on the methodology elaborated in the previous chapter. Since it is proactive monitoring, the data obtained for this indicator are from HAZOP study which is only done at any time during the design and operation of the plant. HAZOP analyses are usually to be revised when considerable modifications, upgrades or re-design of existing facilities are carried out or if events like accidents, critical situations or near misses. Some of the extracted data obtained from the refinery plant are listed in the Appendix E.

Based on the data, severity level for each HAZOP study is identified and the ranking is given based on Appendix A. Based on the Table 6, the alphabet A to E was obtained from company's raw data which is used to identify the severity of hazard identified. For this project, the ranking based on number 1 to 5 is given parallel to company's data. From the table, it can be seen that alphabet E represents minor severity and alphabet A represents major severity. Ranking 1 is given parallel to alphabet E which indicates minor severity. Meanwhile, ranking 5 is given parallel to alphabet A which indicates major severity.

For the Table 7, the ranking and the description of the likelihood is obtained from the fertilizer plant. Number 1 in the likelihood column represents the extremely unlikely probability and number 5 in the column represents very likely probability for the process safety incidents to happen. Table 8 is developed accordingly to company's risk matrix. The table is developed based on Table 6 and Table 7. Based on the Risk Priority Matrix, risk class for hazard can be identified. Table 9 shows the risk class and the description for each class. Based on the risk class, the safety performance level can be observed.

The calculation of leading index can be done by using Equation 3. Since the HAZOP study is applicable only during year 2004/2005, the calculation is only done for the particular year.

Table 12: Leading Index

Risk Class/Year	2004/2005
Class A	0
Class B	1.8
Class C	0.96
Class D	0.1
Class E	0
Total	0.572

Based on the Table 12 above, it shows that the leading index for year 2004/2005 is 0.572.

4.4 Integration of Lagging and Leading Indicators

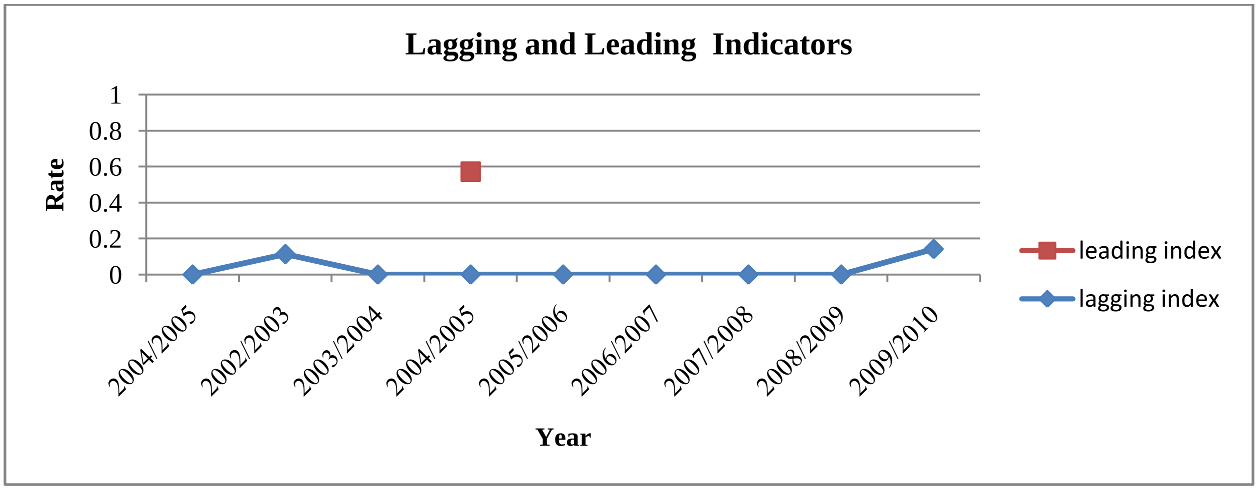


Figure 12: Lagging and Leading Indicators

Based on the graph above, it shows that operational integrity for lagging indicators are performing well compared to leading indicators. It means that there are issues in the cause of incidents, resulting in higher leading indicators rate. The results also show that there is an integrated relationship between the leading and lagging indicators. The relationship is simultaneously related since leading indicators monitor the preparedness of the safety measurement system meanwhile lagging indicators measure the safety measurement system after it fails. From the results, it is evident that process safety improves over time and symptom or causes of incidents required more attention to improve the safety performance of the plant.

From the results obtained, it can be observed that there is a codependent relationship between the leading and lagging indicators. Since leading indicators are acted as proactive monitoring as it measures the preparedness, lagging indicators acted as reactive monitoring as it measures the severity of accident occurs.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

One of the incidents that had raised the attention needed for process safety is the BP Texas refinery accident which occurred on March 23rd, 2005. This because in the past, process safety was taken for granted and only considered at design level. Most of the process industry only relies on personnel safety indicators to measure a process safety performance. This kind of approach had been proven as inadequate and inappropriate to measure the performance of process safety in the company or plant. For process industries, symptoms, causes and incidents are monitored to characterize process safety.

The integrated lagging and leading indicators to measure safety performance discussed in this article is built upon the guidelines developed by Center of Chemical Process Safety (CCPS). The particular approach had been proposed to satisfy most of the characterization needs to indicate process safety performance. The set of parameters had been simplified to only two elements of Process Safety Management system and parameters are developed based on references from the experts' opinion available. For a detailed data collection, a system in Microsoft Excel software had been developed to ensure this approach can be easily adopted for process facility.

The proposed approach is used to evaluate safety performance of a refinery plant. The particular approach is able to model process safety performance. The relationship between symptom, cause and incident can be observed based on the results obtained for both lagging and leading indicators. The usage of both lagging and leading indicators are reliable and can be implemented to measure the effectiveness of safety performance. The proposed approach needs to be further revised and tested to improve the system.

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APPENDICES

Appendix A: Modified Process Safety Incidents and Severity Categories

Severity Level (Note 4)	**Safety/Human Health (Note 5)**	**Fire or Explosion (including overpressure)**	**Potential chemical impact** (Note 3)	**Community environment impact** (Note 5)
NA	Does not meet or exceed Level 1 threshold	Does not meet or exceed Level 1 threshold	Does not meet or exceed Level 1 threshold	Does not meet or exceed Level 1 threshold
1 (**1 point** used in severity rate calculation for each of the attributes which apply to the incident)	Injury requiring treatment beyond first aid to employee or contractors (or equivalent,Note 1) associated with a process safety incident. (In USA, incidents meeting the definitions an OSHA recordable injury)	Resulting in $25,000 to $100,000 of direct cost	Chemical released within the secondary containment or contained within the unit - see Note 2A	Short-term remediation to address acute environmental impact. No long term cost or company oversight. Examples would include spill cleanup, soil and vegetation removal.
2 (**3 points** used in severity rate calculation for each of the attributes which apply to the incident	Lost time injury to employee or contractors associated with a process safety event	Resulting in $100,000 to 1MM direct cost	Chemical released outside of containment but retained on company property OR flammable release without potential vapor cloud explosives - see Note 2B	Minor off-site impact with precautionary shelter-in-place OR Enviromental remediation required wth cost less than $1MM. No other regulatory oversight required OR Local media coverage
3 (**9 points** used in severity rate calculation for each of the attributes which apply to the incident	On-site fatality-employee or contractors associated with a process safety event; multiple lost time injuries or one or more serious offsite injuries associated with a process safety event	Resulting in $1MM to $10MM of direct cost	Chemical release with potential for injury offsite or flammable release resulting in a vapor cloud entering a building or potential explosion site (congested/confined area) with potential for damage or casualties if ignited-see Note 2C	Shelter-in-place or community evacuation OR Environmental remediation required and cost in between $1MM - $2.5MM. State government investigation and oversight of process OR Regional media coverage or brief
4 (**27 points** used in severity rate calculation for each of the attributes which apply to the incident	Off-site fatality or multiple on-site fatalities associated with a process safety event	Resulting in direct cost > $10MM	Chemical release with potential for significant on-site or off-site injuries or fatalities - see Note 2D	National media coverage over multiple days OR Environmental remediation required and cost in excess of $2.5MM. Federal government investigation and oversight of process OR Other significant community impact

NOTE 1: For personnel located or working in process manufacturing facilities

NOTE 2: It is the intent that the “Potential Chemical Impact” definitions shown in Table 2 provide such sufficient definition such that plant owners or users of this metric can select from the appropriate qualitative severity descriptors without a need for dispersion modeling or calculations. The user should use the same type of observation and judgment typically used to determine the appropriate emergency response actions to take when a chemical release occurs. The following nodes are being provided, as examples, to clarify the type of hazard intended with the four qualitative categories:

A: AEGL-2/ERPG-2 concentrations (as available) or 50% of Lower Flammability Limits (LFL) does not extend beyond process boundary (operating unit) at grade or platform levels, or small flammable release not entering a potential explosion site (congested/confined are) due to limited amount of material released or location of release.

B: AEGL-2/ERPG-2 concentrations (as available) extend beyond unit boundary but do not extend beyond property boundary. Flammable vapors greater than 50% of Lower Flammability Limits (LFL) at grade may extend beyond unit boundaries but did not entering a potential explosion site (congested/confined area); therefore, very little chance of resulting in a VCE.

C: AEGL-2/ERPG-2 concentrations (as available) exceeded off-site OR flammable release resulting in a vapor cloud entering a building or potential explosion site (congested/confined area) with potential for VCE resulting in fewer than 5 casualties if ignited.

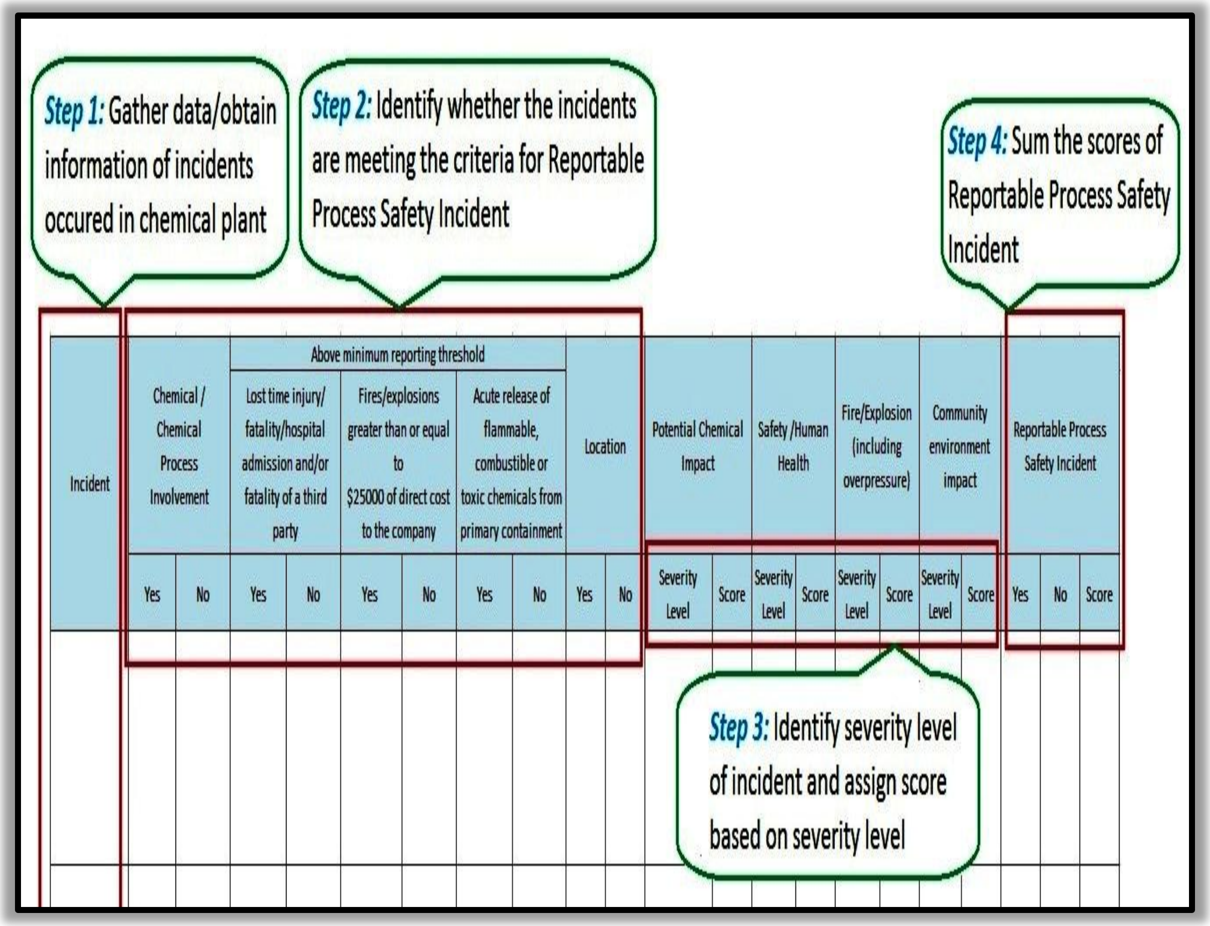
D: AEGL-2/ERPG-2 concentrations (as available) exceeded off-site over the defined 10/30/60 minute time frame OR flammable release resulting in a vapor cloud entering a building or potential explosion site (congested/confined area) with potential for VCE resulting in greater than 5 casualties if ignited.

NOTE 3: The Potential Chemical Impact table reflects the recommended criteria. This approach should be used consistently and used for all releases.

NOTE 4: The category labels can be modified to align with the severity order of other metrics. It is important to use the same severity point assignments shown.

NOTE 5: The severity index calculations include a category for “Community/Environmental” impact and first aid level of Safety/Human Health impact which are not included in the PSI threshold criteria. However, the purpose of including both of these values is to achieve greater differentiation of severity points for incidents that result in any form of injury, community, or environmental impacts.

Appendix B: Table for Reportable Process Safety Incidents Criteria



Step 1: Gather data/obtain information of incidents occured in chemical plant

Step 2: Identify whether the incidents are meeting the criteria for Reportable Process Safety Incident

Step 4: Sum the scores of Reportable Process Safety Incident

Incident	Chemical / Chemical Process Involvement		Above minimum reporting threshold						Location		Potential Chemical Impact		Safety /Human Health		Fire/Explosion (including overpressure)		Community environment impact		Reportable Process Safety Incident		
			Lost time injury/ fatality/hospital admission and/or fatality of a third party		Fires/explosions greater than or equal to $25000 of direct cost to the company		Acute release of flammable, combustible or toxic chemicals from primary containment														
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Severity Level	Score	Severity Level	Score	Severity Level	Score	Severity Level	Score	Yes	No	Score

Step 3: Identify severity level of incident and assign score based on severity level

Appendix C: Total Recordable Rate (TRR) and Lost Workdays Cases Rate (LWCR)

No of workers	2001/2002	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010
Employees	1183	1183	1183	1183	1284	1284	1284	1284	1284
Manhours									
Employees	2500000	6800000	2600000	900000	7100000	4100000	10100000	18900000	22700000
Number of Recordable Cases	0	1	2	0	1	0	0	0	1
Total Recordable Cases Rate (TRR)	0.000	0.029	0.154	0.000	0.028	0.000	0.000	0.000	0.009
Number of Lost Time Accident Cases	0	1	1	0	1	0	0	0	1
Lost Workdays Incident Rate (LWCR)	0.000	0.029	0.077	0.000	0.028	0.000	0.000	0.000	0.009

Appendix D: Process Safety Total Incident Rate (PSTIR) and Process Safety Incident Severity Rate (PSISR)

No of workers	2001/2002	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010
Employees	1183	1183	1183	1183	1284	1284	1284	1284	1284
Manhours									
Employees	10363080	16041480	7751016	17649824	22272224	17873280	29121120	36979200	12757824
Reportable Process Safety Incident	0	1	0	0	0	0	0	0	1
Process Safety Total Incident Rate (PSTIR)	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.016
Severity Score for Reportable Process Safety Incident	0	9	0	0	0	0	0	0	9
Process Safety Incident Severity Rate (PSISR)	0.000	0.112	0.000	0.000	0.000	0.000	0.000	0.000	0.141

Appendix E: One of the samples data for HAZOP study

NODE	DESCRIPTION	DEVIATION	CAUSES	CONSEQUENCES	RISK MATRIX		
					S	P	RR
		Less Flow	V-31-01-01/V-31-02/V-31-03/V-31-04 Separator demister partially choked	High discharge temperature at all stages lead to compressor damage and loss of Urea production	A	2	A2
			Suction strainer ST-3101/02/03/04 partially blocked	Starved suction to CO2 compressor K-31-01 lead to compressor damage and loss of Urea production	A	2	A2
			Drain line isolation valve of V-31-01-01/V-31-02/V-31-03/V-31-04 fully opened	Less Urea production	C	3	C3
			Anti-surged valve passing		C	3	C3
			33-HV-01 stuck during load increase		C	2	C2
			Suction strainer ST-3101/02/03/04 partially blocked	Starved suction to CO2 compressor K-31-01 lead to compressor damage and loss of Urea production	A	2	A2
		No Flow	No CO2 supply from battery limit	Compressor surged lead to loss of production	A	2	A2
			Solenoid valve, 33-HV-01 fail closed		A	2	A2
			Loss of process Air to the system due to some fault condition on K-12-01 result in loss of plant	Corrosion occurs on the UR Synthesis Unit.	A	2	A2

			Air.				
		More Flow	No issue identified	-			
		Reverse Flow	Synthesis pressure higher than CO2 discharge pressure	Carbamate back flow to CO2 line lead to line blockage and compressor damage	A	2	A2
		High Temperature	Failure/fouling of interstage cooler	Compressor damage and loss of Urea production	A	2	A2
			Anti-surged valve 31-FV-04 passing	Less Urea production	C	3	C3
			V-31-01-01/V-31-02/V-31-03/V-31-04 Separator demister partially choked	High discharge temperature at all stages lead to compressor damage and loss of Urea production	A	2	A2
		Low temperature	31-TV-08 fail opened	CO2 phase change at suction 4th stage lead to compressor damage	A	2	A2
			Low temperature of CO2 supply	Condensation and carry over of water lead to compressor damage	A	2	A2
		High Pressure	Solenoid valve 33-HV-01 fail closed	Compressor damage due to no flow lead to loss of Urea production	A	2	A2
				Pipe, interstage cooler, separator and compressor casing burst lead to loss of Urea production	A	2	A2
		Low Pressure	Low supply pressure from battery limit	Less Urea production	C	3	C3
				High N/C ratio lead to high NH3 venting through HP vent and environmental effect	A	2	A2

		Vacuum Pressure	Suction valve upstream of V-31-01-01 closed	Implode of separator V-31-01-01 and piping of suction 1st stage K-31-01	A	2	A2
		High Level	Failure of condensate drain trap DT-3103 lead to high level at Condensate Collector Pot (suction of 1st stage K-31-01)	Possible ingress of liquid to the 1st stage of CO2 compressor K-31-01 resulting in machine damage.	A	2	A2
			Isolation valve drain line close at separators V-31-01-01/V-31-02/V-31-03/V-31-04	High level at separator lead to liquid carry- over that will damage K-31-01 and cause loss of urea production	A	2	A2
			31-LV-04 at V-31-03 fail closed		A	2	A2
			DT-3102 at V-31-02 malfunction		A	2	A2
			High level at V-31-01-01/V-31-02/V-31-03/V-31-04 during shutdown due to intercooler tube leak		A	2	A2
		Low Level	No issue identified				
		No Level	Drain valve (1") of V-31-04 fully opened	CO2 breakthrough lead to less CO2 flow and cause less of urea production	C	3	C3
			Bypass drain valve of V-31-02 (3/4") and V-31-03 (1") fully opened/passing		C	3	C3

			DT-3102 at V-31-02 stuck open/passing		C	3	C3
		Shut down	High level at V-31-01-01/V-31-02/V-31-03/V-31-04 during shutdown due to intercooler tube leak	High level at separator lead to liquid carry- over that will damage K-31-01 and cause loss of urea production	A	2	A2
		Emergency	No issue identified				
		Testing / Monitoring / Sampling	No issue identified				
		Maintenance	DT-3102 and DT-3103 not registered in SAP	No preventive maintenance plan lead to possibility of failure	A	2	A2
		Static Electricity	No issue identified				
		Composition	No issue identified				
		Contamination	Benfield carry over due to excessive foaming at Benfield Unit	Fouling of K-31-01 lead to compressor damage	A	2	A2
		Additional Phase	31-TV-08 fail opened	CO2 crystallization at suction 4th stage lead to compressor damage	A	2	A2
		Change of State	No issue identified				
		Loss of Phase	No issue identified				
		Wrong Concentration	No issue identified				
		Wrong Material	No issue identified				
		Corrosion / Erosion / Fouling	Refer to Contamination Deviation				

		Safety	Trips and falls by operating/maintenance personnel due to lube oil spillage in area of K-31-01	Personnel injury			
			33-PV-02 vent line height	CO2 suffocation to working personnel nearby	C	3	C3