NORMALIZATION OF PROCESS SAFETY METRICS

A Thesis

by

MENGTIAN WANG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2012

Major Subject: Safety Engineering

Normalization of Process Safety Metrics

NORMALIZATION OF PROCESS SAFETY METRICS

A Thesis

by

MENGTIAN WANG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	M. Sam Mannan
Committee Members,	Mahmoud El-Halwagi
	Martin A.Wortman
Head of Department,	Charles Glover

August 2012

Major Subject: Safety Engineering

ABSTRACT

Normalization of Process Safety Metrics. (August 2012)

Mengtian Wang, B.Eng, Zhejiang University of Technology

Chair of Advisory Committee: Dr.M. Sam Mannan

This study is aimed at exploring new process safety metrics for measuring the process safety performance in processing industries. Following a series of catastrophic incidents such as the Bhopal chemical tragedy (1984) and Phillips 66 explosion (1989), process safety became a more important subject than ever. These incidents triggered the development and promulgation of the Process Safety Management (PSM) standard in 1992. While PSM enables management to optimize their process safety programs and organizational risks, there is an emerging need to evaluate the process safety implementation across an organization through measurements. Thus, the process safety metric is applied as a powerful tool that measures safety activities, status, and performance within PSM.

In this study, process safety lagging metrics were introduced to describe the contribution of process related parameters in determining the safety performance of an organization. Lagging metrics take process safety incidents as the numerator and divide it by different process-related denominators. Currently a process lagging metric (uses work hours as denominator) introduced by the Center for Chemical Process Safety (CCPS) has been used to evaluate the safety performance in processing industries. However, this lagging metric doesn't include enough process safety information.

Therefore, modified denominators are proposed in this study and compared with the existing time-based denominator to validate the effectiveness and applicability of the new metrics. Each proposed metric was validated using available industry data. Statistical unitization method has converted incident rates of different ranges for the convenience of comparison. Trend line analysis was the key indication for determining the appropriateness of new metrics. Results showed that some proposed process-related metrics have the potential as alternatives, along with the time-based metric, to evaluate process safety performance within organizations.

DEDICATION

To

My dear parents for their unconditional love, encouragement, and endless support throughout my life.

My good friends and relatives for their encouragement to pursue this master study.

Dr. Mannan and the members of the Mary Kay O’Connor Process Safety Center for their support and guidance.

ACKNOWLEDGEMENTS

I would like to thank my academic advisor, Dr. Sam Mannan, for his endless encouragement and support throughout my graduate life. He is the person you cannot learn enough from, and he will remain a role model in my future. Also, I would like to express my gratitude to my committee members, Dr. El-Halwagi and Dr. Martin Wortman, for advisement and guidance for my research.

I would like give my special thanks to Dr. Ray Mentzer for his assistance and support in my research. He always gives brilliant ideas and points out the direction for me.

I am grateful to Dr. Dedy Ng and Dr. Xiaodan Gao, who have gone beyond their job responsibilities to help me in reviewing this thesis. I appreciate the staffs, visiting scholars, and my colleagues at the Mary Kay O'Connor Process Safety Center, especially Roberto Ruiz, Shubharthi Barua, Sally Nicola, Jiaojun Jiang, Dr. Victor Carreto, Dr. Yi Liu, Dr. Subramanya Nayak, Valerie Green, and Donna Startz for all their help and making my experience at the Center a memorable one. Thanks also go to Towanna Arnold for her help with all my paperwork.

NOMENCLATURE

ACC	American Chemistry Council
API	American Petroleum Institute
CCPS	Center for Chemical Process Safety
EHS	Environmental Health and Safety
EIA	Energy Information Administration
HAZID	Hazard Identification Study
HAZOP	Hazard and Operability Study
HSE	Health and Safety Executive
IADC	International Association of Drilling Contractor
LOPC	Lost of Primary Containment
LTIR	Lost Time Injury Rate
OSHA	Occupational Safety and Health Administration
PHA	Process Hazard Analysis
PSM	Process Safety Management
SIL	Safety Integrity Level
TRIR	Total Recordable Injury Rate

TABLE OF CONTENTS

LIST OF FIGURES

Page

Page

LIST OF TABLES

1. INTRODUCTION AND LITERATURE REVIEW

Due to the growth of process complexity in equipment and plant design, many chemical incidents have been triggered by human errors, technological and process failures rather than natural disasters. In the meantime, the concept of “safety” associated with worker safety has been replaced by a new interpretation: “loss prevention.” The loss prevention concept emphasizes identifying hazardous chemicals, inappropriate behaviors and procedures leading to process barrier deficiencies, incidents, and mishaps (Crowl & Louvar, 2011).

Over the last few decades, personal safety has been identified as a key indication of safety performance in organizations. The primary processing industry practice for measuring personal safety performance is by using the Lost Time Injury Rate (LTIR) introduced by Occupational Safety and Health Administration (OSHA) or other similar occupational safety metrics such as the Total Recordable Injury Rate (TRIR). However, these metrics do not reflect the safety performance of plant operations and most importantly, do not provide an early warning for preventing any near-misses and/or chemical incidents. Because of some catastrophic incidents such as Bhopal chemical tragedy (1984), Phillips 66 explosion (1989), and Texas City disaster (2005), process industries have extended their concerns from personal safety to process safety.

This thesis follows the style of *Journal of Loss Prevention in the Process Industries.*

1.1 The Limitation of Personal Safety Metrics

Worker-related fatalities, injuries, and illnesses have long time used as the statistical numbers for tracking personal safety incidents. The advantage of chasing lower occupational injury and illness rates did spur companies to achieve superior safety performance. However, this statistics provided only concerns about personal safety and thus, little can be inferred about the success of process incident prevention. Kletz (Kletz, 1993) mentioned that process industries placing too much emphasis on personal safety statistics would lead to over confidence about the safety performance, at the meantime, there are more can be controlled besides personal safety. Though personal safety is often labeled as process safety, the difference between the two is quite apparent. Personal safety is concerned with various hazards that could endanger plant workers. It is used as a valuable indicator to understand how safe the workplace is. The risks associated with personal safety are identifiable and manageable, because workers can avoid risk through training or by using appropriate personal protection equipment. On the contrary, process safety refers to the quality, status, actions or preventative controls to mitigate process hazards on personnel, property and environment. Groeneweg (Groeneweg, 2006) also checked the correlations between all personal rates (fatal accident rate, lost time injury frequency, total recordable injury frequency and near-misses), and the results showed that injury rates can hardly help preventing the “primary process” incident.

Although the occupational injury and illness estimation rates have been widely used to track the execution of PSM program, this approach was found to be ineffective (Morrison, Fecke & Martens, 2011). This is because most process safety accidents are not easily comprehended and often require some assistance from Environmental Health and Safety (EHS) experts. Therefore, the personal safety approach is not suitable for measuring process safety performance.

1.2 The Implementation of Process Safety Metrics

The occurrence of Bhopal chemical tragedy and Phillips 66 explosion spurred people to initiate a PSM. While the most recent catastrophic incident at BP Texas City warned industries about the importance of maintaining an effective PSM program and the serious impacts of PSM failures. The process industries should improve the deficiency or weakness of their PSM programs, by periodic audit and site inspection. The BP Texas City incident also represents the typical management style that puts more emphasis on personal safety and environmental performance rather than process safety, which depicts the deficiencies existing in PSM systems, management, leadership and oversight (Allars, 2007).

In the investigation report of BP’s five U.S. refineries conducted by an independent safety review panel (Baker, 2007), the report points out that corporate leadership is accountable for operational safety and safety culture stands at the top of the safety pyramid. Moreover, specific recommendations from the Baker report have given strong indications that it is time to revisit and transform process safety programs across the process industry. In addition, the US Chemical Safety Board (CSB, 2005) highlights the urgent need for better metrics to identify process safety issues.

Process industries (refinery, oil and gas, petrochemical, chemical, drilling) often deal with one or more hazardous materials, such as flammable and combustible liquids, and reactive chemicals. How can we ensure these processes or operations can be carried out in a safe controlled manner? The implementation of process safety management is a strategy to maintain process operating conditions, to match demands of production and to keep personnel and equipment safe. Technological advances combined with increased process complexities continue to challenge process engineers in identifying hidden threats. Different hazard analysis methods such as process hazard analysis (PHA), hazard identification (HAZID) study, hazard and operability (HAZOP) study, and safety integrity level (SIL) classification and verification have been used to assure the protection of all safety critical elements. Particularly, the process safety metrics are expected to be indicators of the failures of PSM systems. The intent of metrics development is to provide the assessment of outstanding or deficiencies of the intended program. Using process safety metrics as the assessment elements can identify where the improvements are needed and where the impacts are occurring.

1.2.1 Lagging and leading indicators

Process safety metrics can be interpreted as tracking lagging and leading performance indicators in certain forms (absolute or normalized, and operational or strategic), these metrics can help people understand the system weaknesses and deficiencies. Lagging indicators are outcome-oriented indicators, they represent past events that have greater or less consequences (HSE, 2006). The statistical data of incidents and reported near-misses is treated as lagging indicators which are analogous to personal safety statistics. Examples of lagging indicators are employee or contractor days away from work injury or fatality caused by process operations, fire or explosion cause property damage, and unplanned toxic release over threshold quantities.

On the other hand, leading indicators are more forward-looking. They can be treated as a systematic probe. This probe can provide process and practice change information; it also helps personnel identify safety performance in order to avoid mishaps (EPRI, 2001). Typical fields of leading indicators can be generated from mechanical integrity, action items follow-up, management of change, process safety training, fatigue and process safety culture (CCPS, 2007). These lagging and leading indicators are expected to make a significant contribution in lowering near-misses and chemical incidents.

It is extremely rare to encounter a process incident caused by a single failure .Usually it happens due to the failures of multiple protective barriers at the same time. British psychologist, James T. Reason (Reason, 1990), illustrated the chronology of an incident in his “Swiss chess model” as shown in Fig. 1. Each slice of the Swiss cheese represents a protective barrier (engineering controls, administration practices or passive alarm), while the holes in each cheese layer represent the existing gaps or weaknesses within each barrier. When the holes from each layer align coincidentally as depicted in a straight-line pattern in Fig. 1, it will result in an accident.

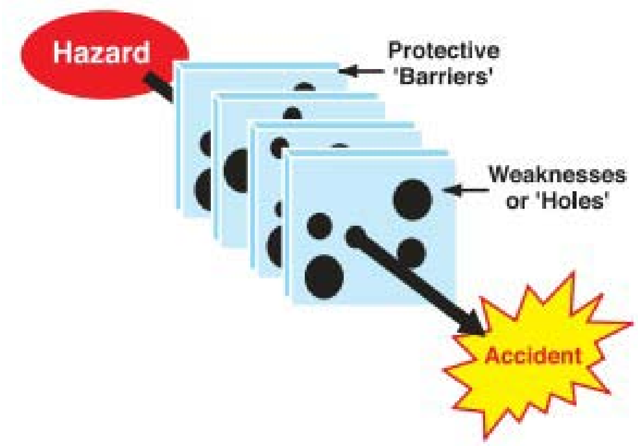

Fig. 1. "Swiss Cheese Model" (CCPS, 2011)

From the process metrics viewpoint, lagging indicators describe incidents that meet the threshold of severity, such as loss of containment. Meanwhile, leading indicators identify the failures of protective barriers prior to the incident. Being the integral part of the PSM system, process safety metrics play the role of measuring consequence severity and detecting low-impact events such as near misses and systemic flaws.

1.2.2 The development of process safety indicators

To improve the limitations of existing process safety metrics, many agencies or organizations have proposed improved process safety metrics, involving leading and lagging indicators as the assessment elements. The contribution of leading and lagging metrics would be pertinent to improve safety performance either from past incidents or through the current implementation of PSM programs.

Much effort to develop the process safety metrics has originated from the U.S. and Europe. The United Kingdom Health and Safety Executive developed a Step-By-Step Guide to Developing Process Safety Performance Indicators (HSE, 2006) to help management track performance indicators within an organization to assure that major hazard risks are controlled or eliminated. In this guide, lagging indicators are the indications that decide whether desired safety target has failed or has not been accomplished. Meanwhile, leading indicators incorporate substantial information which reflects the health of safety systems and barriers. The Center for Chemical Process Safety (CCPS)'s Guidelines for Risk Based Process Safety (CCPS, 2007) suggests 21 process safety metrics, which cover almost every aspect of safety systems. Subsequently, CCPS published the book entitled 'Guidelines for Process Safety Metrics' (CCPS, 2009), which gives guidelines for organizations to implement process safety metrics into existing safety programs and to identify three major lagging metrics: process safety incident count, process safety incident rate, and process safety severity rate. Leading metrics are considered as the tool to indicate key elements of production process, operating discipline or control system. As an early signal of process deviations that against protective barriers, leading metrics provide corrective actions to avoid accidents. In addition, the American Petroleum Institute released the Recommended Practice 754 (API, 2010), which provides guidance on process safety performance indicators for refining and petrochemical industries. Process safety incidents with consequences such as fires, releases, and explosions are identified as lagging indicators. API also concludes leading indicators can be treated as performance indicators that represent the challenges to incident prevention, management systems, and safety objectives. The definition of CCPS metrics guidelines and the API document are well documented. CCPS recently updated their Process Safety Leading and Lagging Metrics to consolidate the definition of process safety metrics from both API and CCPS.

More importantly, the differentiation of lagging and leading indicators is not very important. Simply separating them as two independent items is not accepted. They are working together as a whole system to enhance the implementation of PSM. The correlation of lagging and leading can be displayed in Fig. 2 as below. Fig. 2 illustrates the fact that lagging and leading indicators should be tracked in the same scale. In this scale arrow, lagging indicators are listed on the left side, while leading indicators are shown on the right side. The direction of the arrow states lagging indicators represent process or behavioral deficiencies, gaps, or losses. The occurrence of past incident events help us to identify lessons learned. While, leading indicators evaluate the process safety management completeness and improve risk elimination in the organizations.

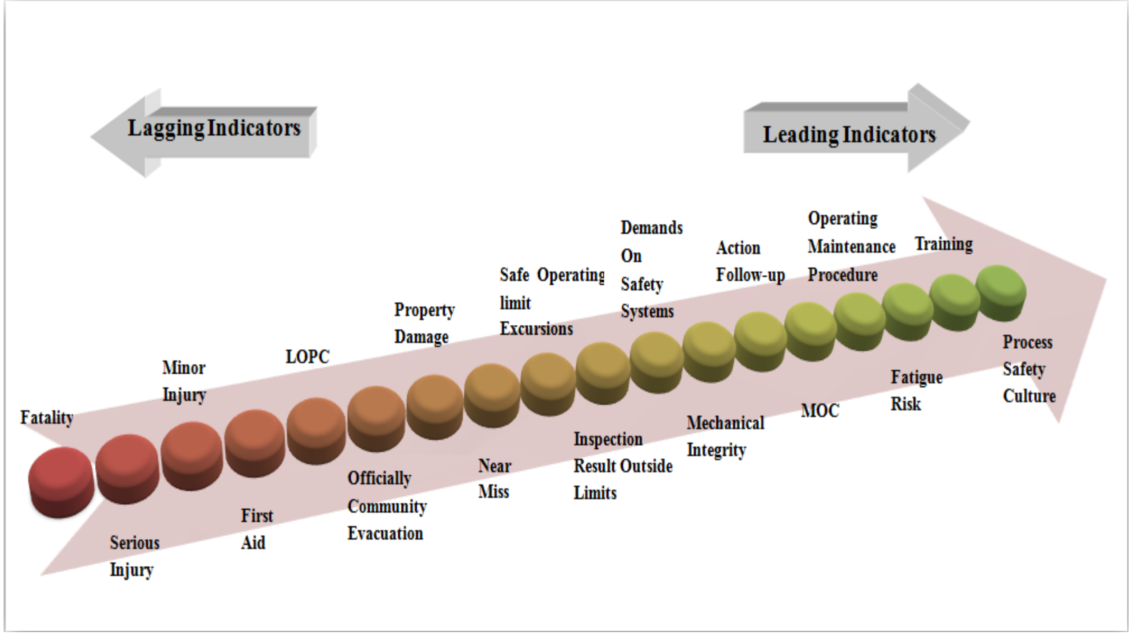

Fig. 2. Process Safety Lagging and Leading Synthesis Scale

1.3 Motivation and Objective

As aforementioned, although lagging and leading metrics share equivalent importance in measuring process safety activities, the aim of this research is dedicated to propose novel process safety lagging metrics. By comparing various normalization methods, this research observes what methods can give better profiles in describing process safety performance. There are two major reasons that encourage us to focus on lagging metrics normalization: the advantages of lagging metrics and the inadequacy of existing lagging metrics.

1.3.1 The advantages of lagging metrics

Lagging metrics are typically used to display incident statistics and inputs in risk analysis. The incident information offers valuable data for revealing potential hazards or near misses before major incidents manifest, as indicated by lagging indicators. The lagging metrics have been used as ultimate measurements to help management understand system deficiencies at an early stage.

Compared with leading metrics, lagging metrics have several advantages to be studied. First of all, process lagging metrics have been broadly accepted and used as a well-defined, practical, and efficient tool by organizations. A well-defined lagging metric means it has a clear definition and certain criteria. Lagging metrics are practical, because they can be easily used by any employee to access the indicators by following the criteria and documentation. Lagging metrics also capture valuable process information and give correct results through simple calculation.

Secondly, various types of lagging metrics (such as absolute, indices or normalized metrics) have been used frequently to communicate the incident learning. Particularly, it was found that normalization of incident profiles is the preferred method to convey the finding appropriately. Normalizing process safety lagging indicators through additional process-related values provides a comprehensive interpretation for incidents data. However, leading metrics tend to detect a completeness of operational or management activities, and this approach can hardly involve process information into data statistics.

Next, lagging indicators could be used to benchmark an organization’s performance by showing the trends, improvements or degradations against safety goals within or outside organizations. Lagging metrics can provide the potential list of contributing hazards, events, or failures for management to fix. “Incident rate” from the metrics allow an effective benchmark since the dimensionless scale eliminates the issues that differ in organization size and process-difference. Moreover, normalized lagging metrics are easily understood by non-technical personnel, such as administration officials, stakeholders and general parties. On the contrary, leading metrics show their limitations when comparisons for sites, organizations, or industries are required.

Finally, the effectiveness of process safety indicators requires an accurate reporting system and follows the right metrics. Processing industries started collecting information on equipment reliability, process failures, operator failures and other incident details decades ago. However, the development of leading indicators is a rising topic which has not been fully implemented for every industry. Currently, adopting the comprehensive process lagging metrics will meet the expectation of establishing good safety culture. Decision-making equipped with proper process lagging metrics results often provides the cost-effective solution.

1.3.2 The inadequacy of existing lagging metrics

As mentioned above, the normalization of incident rates is a powerful tool to compare the safety performance within or outside companies. CCPS and API RP 754 suggest using the total work hours as the normalization factor. Process safety total incident rate is the core normalization method as shown below:

$$\text{Process Safety Total Incident Rate} = \frac{\text{Total Process Safety Incidents} \times 200{,}000}{\text{Total Employee \&Contractor Work Hours}} \tag{1}$$

where, the 200,000 stands for 200,000 hours per year as a standard factor. The factor is calculated from 100 workers working 8 hours a day, 5 days a week, and 50 weeks per year. In order to incorporate detailed information for process safety incidents, a severity-weighted matrix has been developed to score the severity of each incident (see Appendix A). The process safety incident severity rate is displayed as following:

$$\begin{aligned}&\text{Process Safety Incident Severity Rate}\\&\qquad = \frac{\text{Total Severity Score for all PS Incidents} \times 200{,}000}{\text{Total Employee \& Contractor Work Hours}}\end{aligned} \tag{2}$$

Utilizing the definition of process safety incidents described in CCPS and API RP 754, a variety of rate-based metrics can be generated for process safety performance benchmarking. However, only work hours have been used as a denominator for lagging metrics normalization. The reasons for CCPS and API RP 754 to use the total work hours as the normalization factor are it is still widely used and accepted, easily understood and recognized by external parties. However, the reliance on work hours has been argued within industries, there is an urgent need to explore alternative denominators by understanding the incident rate and the corresponding process deficiencies. In some cases, the total work hours are calculated by only accounting the number of employees and contractors. However, the actual works hours of employees and contractors are usually more than the product of workforce numbers and the work hours per worker. This action certainly degrades the precision of normalized incident rates. Moreover, this denominator only reflects limited and unspecified process information. New metrics should be developed to meet the need of acquiring specified metrics in different process industries. Normalization factors reflect process information, risks, and manufacturing complexity, which should be considered in new lagging metrics trial. Motivated by this purpose, this research is trying to find more consistent, broad, and unbiased metrics for a process safety measurement. Good process safety metrics must consider the reality of the organization; metrics should be captured upon real situations and indeed needs. Uniformed comparisons of metrics could be broadly applied across companies, these metrics should also be easily understood by operators, management or top executives by simplified or visualized form. Potential denominators have been tested and verified via companies' published data. A benchmark between existing and proposed metrics is expected to provide insight on how to determine metrics' appropriateness.

1.3.3 Objectives

As aforementioned, lagging metrics play an important role by describing organizational process safety performance. The determination of lagging metrics forms could help an organization in conducting an effective benchmark. However, using the unitary form to normalize process lagging indicators should be avoided. More relevant denominators can be introduced in expanding a diversity of process lagging metrics. To address the issues mentioned above, the objectives of this research are as follows:

1. Categorizing oil & gas processing industries into several sections depending on their specified products or processes. Currently, all processing industries adopt the same metric to normalize incident rate. However, due to the differences of each classification, specialized metrics which involve every category’s detailed process information and typical parameters are required.

2. Employing lagging metrics normalization method in process safety measurement. To address this issue, the research effort focuses on finding more consistent, broad, and unbiased metrics for tracking process safety using validated data, particularly data related to the process related risks involved in the individual industry segments.

3. Performing quantitative and/or qualitative analysis for proposed process lagging metrics to ensure their appropriateness. How to determine the feasibility of potential metrics is the key issue which needs to be solved by the assessment. The acceptable lagging metric uses work hours as the denominator would be treated as the standard when benchmarking occurs for every possible metric.

2. RESEARCH METHODOLOGY

This research focuses on selecting appropriate process lagging metrics to evaluate and monitor the organizational process safety performance. The research hypothesis is that effective process safety metrics should be sensitive in analyzing any change and reliable in helping the industries to prevent any near-miss or accident. The methodology used in this research is summarized in Fig. 3.

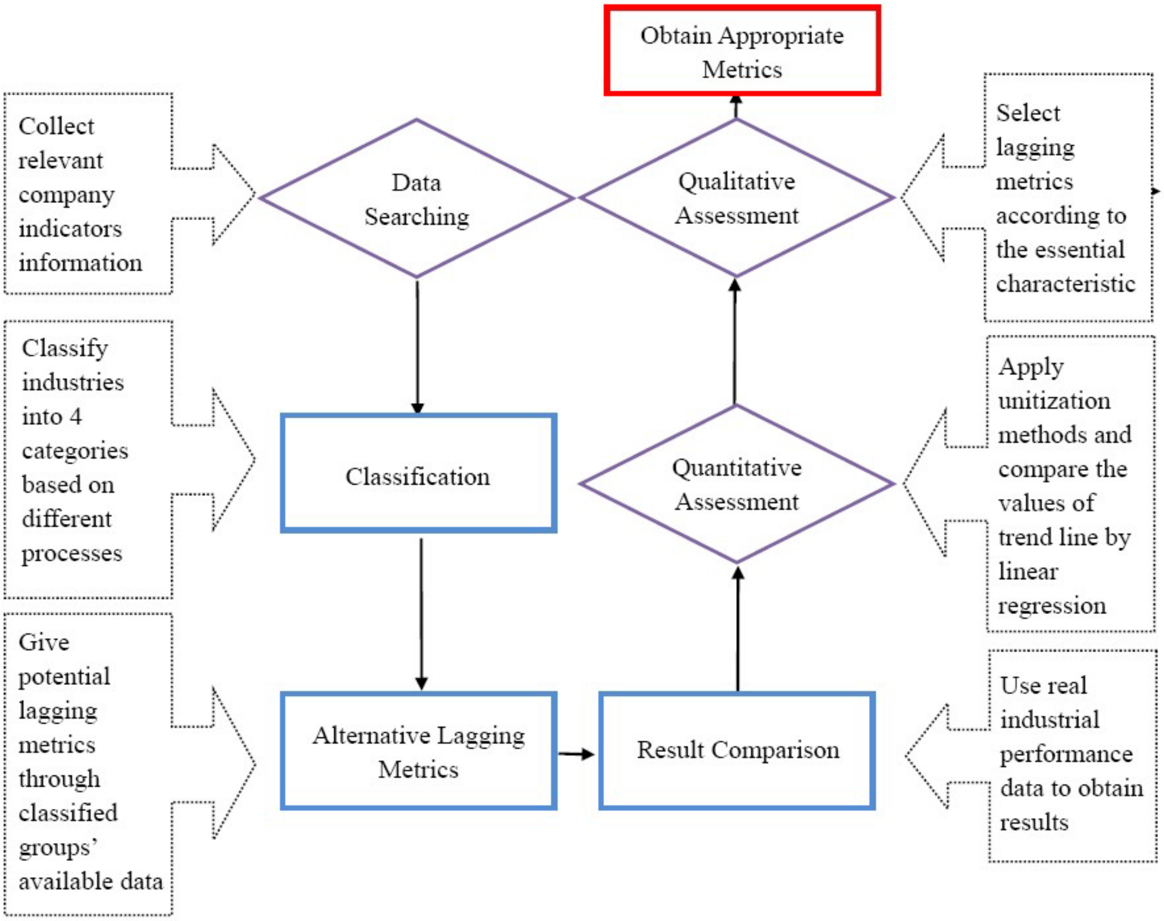

Fig. 3. Research Methodology Diagram

An explicit description of process safety lagging metric functions, along with its definition and criteria, were covered in the first section. The methodology diagram is developed to achieve the three objectives. Similarly, three major procedures have been identified as: classification and data collection, alternative metrics application, and results analysis and comparison.

2.1 Classification and Data Collection

The first step is to search and identify industry data for metrics normalization. Over 45 companies' information has been integrated into data collection. Subsequently, effort had been made to classify process industries into four business segments (integrated oil and gas, exploration and production, chemicals, and drilling contractors). Those four categories represent most typical oil & gas processing industries, thus the selection of data from those four classified categories becomes more specified.

2.2 Alternative Metrics Application

The normalization of incident rates is a powerful benchmarking method; it compares the safety performance either within or outside process plants. Potential lagging metrics were assigned to each industrial category based on different process information. The corresponding incident rate was obtained by applying company data for proposed process-related metrics. CCPS and API RP 754 suggest using of the total work hours as the normalization denominator in lagging metric. This thesis explored the possibility of applying alternative metrics, setting time-based metric as standard.

2.3 Results Analysis and Comparison

Incident profiles that were generated from existing and proposed metrics have been analyzed through quantitative and qualitative assessment. During the quantitative analysis, a unitization method was employed to transfer original incident rate profiles into the same range. The normalized process safety incident rates were presented in a time-series graph. Trend line of each metric was used to compare between potential and existing process metrics. Moreover, the coefficient determination values of trend line model have been obtained to depict the fitness of linear regression. The results of quantitative assessment showed that proposed metrics could have the potential to describe process safety performance. Finally, the qualitative approach identified some criteria for deciding an effective metric. Qualitative features were discussed for selecting process metrics. Metrics that only satisfy the quantitative validation but do not contain process characteristics have been excluded. The combined quantitative and qualitative assessment ensured the appropriateness of conclusions.

3. PROCESS CLASSIFICATION AND DATA COLLECTION

API (API, 2010) provides the process safety indicators pyramid that includes lagging and leading indicators in Fig. 4:

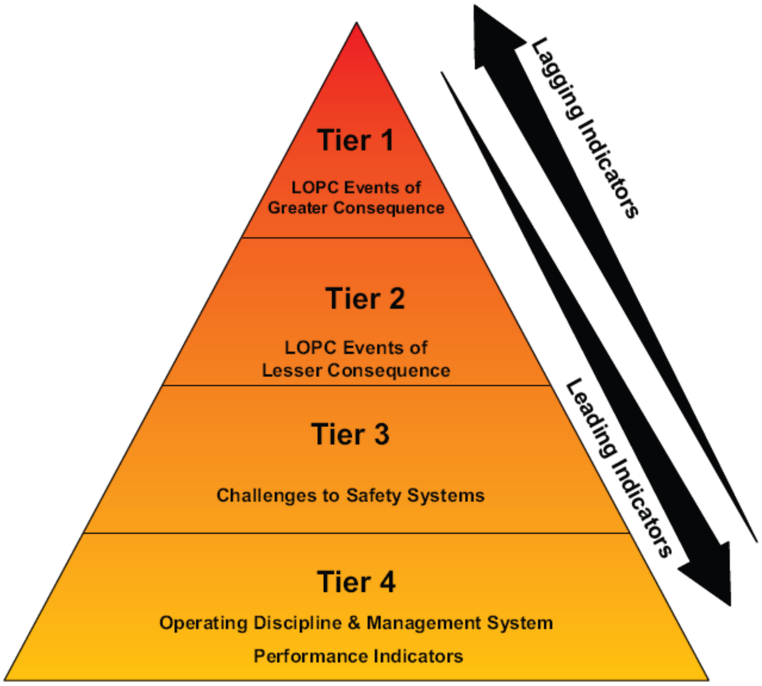

Fig. 4. Process Safety Indicators Pyramid (API, 2010)

This 4 tiers pyramid categorizes Lost of Primary Containment (LOPC) events of greater or lesser consequence as lagging indicators in Tier 1 and 2, while challenges to safety systems, operating discipline & management system performance indicators are recognized as leading indicators in Tier 3 and 4. Driven by the similar philosophy of Heinrich's (Heinrich, 1931) famous accident pyramid, a correlation exists between less-severe and major personal incidents that can lead to a pyramid hierarchy. In this pyramid, leading indicators (lower level indicators) identify deficiencies and suggest corrective solutions before high consequence events (top level indicators) happen.

The typical normalized process metric form has been displayed in equation 1. A normalization method divides numerator by any reasonable denominator to obtain dimensionless rates for comparison. In this thesis, the number of process safety incidents is used as the numerator, along with various denominators (such as production volume, energy consumption, work hours, drilling depth capacity, etc) have been studied to construct potential process lagging metrics.

3.1 Process Safety Incidents Definition

CCPS categorize process safety incidents (Tier-1as API-754) and process safety events (Tier-2 as API-754) as lagging indicators. An incident is reported as a process safety incident based on certain criteria (CCPS, 2011):

- Any occurrence of employee or contractor “day away from work” injury, fatality, or hospital admission must have a process directly involved. For most process and production industries, it is important to have this criterion applied to exclude non-process incidents.
- An unwanted release of material includes toxic, flammable or non-hazardous material but could cause potential consequences over thresholds. Those uncontrolled releases might impact personal safety, environment and property.

- Accidents that happen in employee or contractor operating areas (production, refining, transportation, refrigeration, utilities) can be identified as process safety incidents.

Process safety events follow the same criteria of process safety incidents which have less consequence. With the definition of process safety incidents and events by CCPS, lagging metrics represent not only the catastrophic but also less severe process incidents. In this research, the number of process safety incidents is used as a numerator for all proposed process lagging metrics. Unfortunately, the exact process safety incident data under the definition of CCPS and API cannot be found in all industries. Process safety incident is a new lagging indicator which has not been emphasized for long time. Therefore, similar or substituted lagging indicators have been plugged as the numerators in metrics testing. However, it strongly suggests revalidate those process metrics once adequate process safety incidents have been obtained.

3.2 Data Collection

Validating the feasibility of alternative denominators needs sufficient historical data. Industrial performance data can be collected through company publications. In order to select appropriate data for testing the magnitude and function of potential lagging metrics, all the industrial companies have been classified into 4 categories. They are: integrated oil and gas, exploration and production, chemicals, and drilling contractors. Over 45 representative companies have been evaluated to sustain credible data. The major portion of the candidates are U.S based companies, but quite big and influential enterprises world-wide (UAE, Australia, Canada, UK, Papua New Guinea, Taiwan, etc) are involved in data searching. Moreover, most U.S companies have been involved in CCPS's process safety incident database program. Data from those companies is valuable and convincing. All the data can be found through companies' websites, annual reports, annual sustainability reports, corporate social responsibility reports and performance data charts. Table 1 provides a summary of the companies by category.

Table 1 Processing Company by Category

Integrated Oil and Gas		
Abu Dhabi National Oil Company (UAE)	BG Group (U.K)	BP
Cairn Energy (United Kingdom)	Chesapeake Energy	Cheniere Energy
Chevron	ConocoPhillips	Devon Energy
Encana	El Paso Corp	ExxonMobil
Hess Corporation	Oil Search (Papua New Guinea)	Shell
Statoil (Norway)	Total	W&T Offshore
Exploration and Production		
Anadarko Petroleum	Apache	BHPbilliton Petroleum (Australia)
Cabot Oil & Gas	Marathon Oil	Nexen (Canada)
New Field Exp	OXY	Talisman (Canada)
Woodside Petroleum Limited(Australia)		

Table 1 Continued

Chemicals		
Air Product	Akzo Noble (Dutch)	Bristol-Myers Squibb
Celanese	The Dow Chemical Company	Dupont
Eastman Chemical Company	Huntsman	Formosa
Lyondellbasell		
Drilling Contractor		
Nobel Corporation	Parker Drilling	Rowan
Transocean		

In this research, historical data is a major resource that provides the basis for process-related lagging metrics. Although over 45 enterprises have been reviewed for the data collection, not all companies' data can be utilized. A lack of long period records or no appropriate data is the critical issue. Typical data is selected for this research based on its consistent availability. By doing this, the results become more convincing and suitable for industries. All available data (may also include calculated data) is summarized in Appendix B-E for reference.

3.3 Data Acquisition for Different Categories

3.3.1 Integrated oil and gas

Oil and natural gas industries make up most of the world-wide energy production. Basically, integrated oil and gas industries have multiple processes and products, including oil and natural gas production, refinery throughput, and petrochemical production. The data used for metrics testing in this section is gathered from over 20 companies. American Petroleum Institute (API) Recommended Practice 754 states process safety management is important for refinery and petrochemical companies. This documentation also advocates that refinery and petrochemical companies should record process safety incidents as the key indicator after 2010. In addition, sufficient data records and various process related indices are provided from those company reports. Unfortunately, for this research, the number of process safety incidents is not available; since all the companies just started recording process safety incidents after API RP 745 was issued. Therefore, the most similar reported indicator-operational oil spills is used for lagging metrics testing as a proper substitute. The major related data was obtained for this section as follows:

- Process and environmental incidents (operational oil spills)
- Total oil production volume
- Total natural gas production volume
- Total oil and gas equivalent production volume
- Total refinery throughput volume
- Total petrochemical production volume
- Exposure time for employees and contractors

3.3.2 Exploration and production

This section is considered as a single process derived from integrated oil and gas industries. Due to a lack of process safety incident data, an assumption has been made. For the exploration and production group, a personal incident case such as days-away from work or recordable injury and illness is the major safety indicator. Personal safety data has been applied as the numerator for lagging metrics testing, because it is also an element of process safety incidents. The data for this group contains:

- Personal incident data (as comparison)
- Total oil and gas equivalent production volume
- Total direct energy consumption
- Exposure time for employees and contractors

3.3.3 Chemicals

The American Chemistry Council (ACC) encourages U.S. chemical companies to track annual process safety incidents since 1995. However, some historical data do not follow the same definition as CCPS suggested. Most chemical companies have recorded at least 5 years of process safety incidents (under CCPS's definition) which are helpful for metrics validation. The following information was obtained within the chemical industries:

- Process safety incidents
- Total chemical production volume

- Total direct energy consumption
- Total net chemical sales
- Exposure time for employees and contractors

3.3.4 Drilling contractors

Similar to the exploration and production industries, drilling companies have not typically recorded related process incidents. The International Association of Drilling Contractor (IADC), the international organization for drilling industries, shows no data collection for process safety incidents. Thus, the assumption that uses personal safety data as a numerator will be applied for drilling contractors. Drilling business differs from those industries shown above. Rig utilization and operating time are critical indicators for drilling industries rather than production volume. Data to be obtained within this section are:

- Personal incident data (as comparison)
- Total drilling depth capacity
- Total operating days
- Total drilling depth
- Exposure time for employees and contractors

4. ALTERNATIVE METRICS APPLICATION

Process safety metrics aim to track process-related lagging indicators, and their corresponding activities versus a target that identifies areas for improvement. Biased or short-term metrics may lead to misunderstanding of safety performance. BP Texas City incident is the strong evidence that adequate personal safety indications can cause overconfidence for process safety performance. Process safety metrics ensure the magnitude of performance monitoring, while using a single metric should be avoided in case of possible complacency. The fulfillment of process safety metrics identifies the way to measure past or current performance against a threshold.

4.1 Proposed Metrics Demonstration for Each Category

4.1.1 Integrated oil and gas

After reviewing over 20 integrated oil and gas enterprises' annual reports, the daily production volume has been used as an important operating indicator. Thus, daily production volume can severe as a potential denominator for the process lagging metrics in this category.

As discussed in the data collection section, the process and environmental incident (operational oil spills) is used instead of process safety incident (under CCPS definition). This assumption is made for two reasons: first of all, actual process safety incidents are not available since not enough data has been reported by oil and gas enterprises. Secondly, operational oil spill is a critical process-related incident, which has been emphasized by most companies. Therefore, although several products' volume is found, only denominators relevant with an oil production process can be used for testing metrics. Crude oil production along with oil and gas equivalent production are considered as suitable denominators.

Appropriate scale factors are needed for normalization. Standard factor is used to enlarge the rates when the value of denominators is too big. As seen in equation 1, 200,000 work hours have been multiplied with the number of process safety incidents. The selection of standard factors should consider the unit and magnitude of their corresponding denominators.

Production volume of crude oil is usually measured by barrels per day. Natural gas production volume is measured by cubic feet of production per day. Production volume of oil and natural gas intends to reflect process performance. Integrated oil and gas industries typically combine crude oil and natural gas volumes in the same unit- Barrel of Oil Equivalent (BOE). This unit converts natural gas production to equivalent crude oil production. One BOE is roughly equivalent to 5,800 cubic feet of natural gas. However, there are no certain criteria for determining the value of a standard factor. Applying a standard factor for process lagging metrics avoids generating too small numerical value, but the actual value of this standard factor would not impact the estimation of an incident rate as long as the value is reasonable. Thus, in this research, assigning a standard factor value which enables a proper incident rate in process lagging metrics is more important. In other words, the given standard factors would be accepted when they can adjust incident rates into a relative close range. Particularly, since the time-based metric is broadly applied in real industries and treated as a standard in latter analysis, its incident rate's numeric magnitude can be considered for other metrics. The determination of standard factor values in this category are based on the report of Daniel Johnston (Johnston, 1996), US Energy Information Administration (EIA, 2011), and companies' real data. For scale consideration, a value of 300 thousand barrels has been used for Equation 3:

Process Safety Incidents/Total Crude Oil Production:

$$\text{Process Safety Incident Rate} = \frac{\text{Total Process Safety Incidents} \times 300{,}000 \text{ Barrels}}{\text{Total Oil Production Volume}} \tag{3}$$

Similarly, a value of 500 thousand barrels is adopted as standard factor for metric of Equation 4. Since the denominator used in this metric incorporates natural gas production, the standard factor value has been amplified by considering this issue.

Process Safety Incidents/Total Oil and gas equivalent production:

$$\text{Process Safety Incident Rate} = \frac{\text{Total Process Safety Incidents} \times 500{,}000 \text{ Barrels}}{\text{Total Oil and gas equivalent production Volume}} \tag{4}$$

By doing this, those incident profiles that are generated from our proposed metrics would be generally close to each other, which is very important for industries to use friendly. Obtaining relative close incident rate magnitude is a key criterion in determining standard factors' value. In this research, all standard factor values are acquired based on this criterion for their proposed metrics.

In addition, natural gas production, refinery throughput, and petrochemical production are potential denominators that can be tested if data is available. This research gives their corresponding metrics as follows:

Process Safety Incident/Refinery Throughput:

$$\text{Process Safety Incident Rate} = \frac{\text{Total Process Safety Incidents} \times 1{,}000{,}000 \text{ Barrels}}{\text{Total Refinery Throughput}} \tag{5}$$

Process Safety Incident/Total Natural Gas Production:

$$\text{Process Safety Incident Rate} = \frac{\text{Total Process Safety Incidents} \times \text{Billion Cubic Feet}}{\text{Total Natural Gas Production Volume}} \tag{6}$$

Process Safety Incident/Total Petrochemical Production:

$$\text{Process Safety Incident Rate} = \frac{\text{Total Process Safety Incidents} \times 10{,}000 \text{ Tons}}{\text{Total Petrochemical Production Volume}} \tag{7}$$

Currently, those three process safety lagging metrics cannot be tested because no corresponding numerators can be found. As mentioned before, operational oil spills are used as the numerator in metrics testing. Denominators such as natural gas production, refinery throughput, and petrochemical might not truly reflect their relationship with oil spill incidents. Thus, those three are not the most suitable metrics in normalizing operational oil spills. With additional study of process safety incidents, more comparisons could be carried out to extend the diversity of metrics.

4.1.2 Exploration and production

Exploration and production industries usually report their production capacity by using BOE (Barrel of Oil Equivalent), which is the same unit mentioned in integrated oil and gas category. Unfortunately, process safety incidents record cannot be found for this section. To test the metrics' appropriateness, an assumption has been introduced. Personal safety data has been used for the metric in exploration and production industries. The metric suitable for this section is:

Injury or Illness Incident/Total Oil and gas equivalent production:

$$\text{Injury or Illness Incident Rate} = \frac{\text{Total Injury or Illness Incidents} \times 500{,}000\ \text{Barrels}}{\text{Total Oil and Gas Prodution Volume}} \tag{8}$$

4.1.3 Chemicals

Process safety incidents statistics are readily found for chemical companies. The American Chemistry Council (ACC) suggests that process safety incidents should be reported by all its member companies. However, chemical production volume is rarely reported based on an examination of chemical companies' reports. Production volume of chemicals could be tested when corresponding data is available. In addition, financial indicators and energy consumption have been analyzed by their metrics. Alternative metrics that have been explored for chemical industries are:

Process Safety Incident/Total Chemical Production:

$$\text{Process Safety Incident Rate} = \frac{\text{Process Safety Incidents} \times 10{,}000 \text{ Tons}}{\text{Chemical Products Volume}}$$

(9)

Process Safety Incident/Total Net Income or Net Sale:

$$\text{Process Safety Monetary Loss Ratio} = \frac{\text{Total Process Safety Incidents} \times 1{,}000{,}000}{\text{Total Net Income or Net Sale}}$$

(10)

Process Safety Incident/Total Energy Consumption:

$$\text{Process Safety Incident Rate} = \frac{\text{Process Safety Incidents}}{\text{Energy Comsuption (Tera} - \text{joules)}}$$

(11)

4.1.4 Drilling contractor

Drilling industries' unique characteristic has been described in the data collection section, this particularity inspires the trial for several metrics. In the drilling sector, companies' data includes drilling depth capacity, total operating days, and drilling depth, which are critical indices reflecting the work capability of a company. The total drilling depth capacity is calculated by considering annual utilization:

$$\begin{aligned}&\text{Total Drilling Depth Capacity}\\&\quad = \text{Drilling Depth Capacity of Each Rig } \times \text{Average Rig Utilization}\end{aligned}$$

(12)

Table 2 shows the example of annual utilization of a rig for Noble Corporation.

Table 2 Average Rig Utilization Data for Noble Corporation

Average Rig Utilization Percentage							
Year	2004	2005	2006	2007	2008	2009	2010
Jackups	97%	97%	97%	97%	92%	82%	79%
Semisubmersibles>6,000(1)	72%	95%	100%	99%	96%	98%	86%
Semisubmersibles<6,000	100%	95%	87%	89%	100%	100%	86%
Drillships	60%	91%	100%	89%	67%	91%	89%
Submerisibles	94%	81%	92%	73%	66%	51%	11%

(1) Semisubmersibles have drilling depth capacity greater than 6,000 feet

Again, no process safety incidents have been reported within all drilling contractors. Thus, the same assumption for exploration and production works here for revealing personal safety performance. Metrics developed for drilling contractors are as follows:

Total Injury or Illness Incident/Drilling Depth Capacity:

$$\text{Total Injury or Illness Rate} = \frac{\text{Total Recordable Incidents} \times 10{,}000\text{ Feet}}{\text{Total Drilling Depth Capacity}} \tag{13}$$

Total Injury or Illness Incident/Operating Days:

$$\text{Total Injury or Illness Rate} = \frac{\text{Total Recordable Incidents} \times 100\text{ Days}}{\text{Total Operating Days}} \tag{14}$$

Total Injury or Illness Incident/Drilling Depth:

$$\text{Total Injury or Illness Rate} = \frac{\text{Total Recordable Incidents}}{\text{Total Drilling Depth}} \tag{15}$$

5. RESULTS AND DISCUSSION

In this section, quantitative and qualitative assessments will be used to compare normalized incident rates generated by different process lagging metrics. To address the difficulty in interpreting data sets caused by confusing patterns and unwanted bias, quantitative analysis was selected for the analysis. This method allows the user to modify variables of interest in mathematical form and makes a comparison of results. In addition, those proposed metrics which are eligible after quantitative analysis would be revalidated by essential characteristics of good metrics.

5.1 Quantitative Basis

In this section, normalized incident rates were plotted in time-series graphs, which depict changes over a relatively long period of years. Here, the safety performance evaluation results were presented by displaying a series of data sets in plots to aid in identifying and visualizing any improvement (or retrogress). In order to keep a consistent graphic construction, the x-axis was divided into equal intervals to represent time scale. Similarly, the y-axis was used to show the variable of interest (such as incident ratio numbers).

First of all, process safety metrics proposed for integrated oil and gas industries would be tested. A case study has been demonstrated by using ExxonMobil’s data. Process safety incident rate profiles have been generated through suitable metrics. Here Equation 3, 4 (author’s contribution) and 1 (CCPS metric) were the selected metrics for evaluating and comparing the input denominators (crude oil production volume, oil and gas equivalent production volumes and hours worked, respectively). Then the selected metrics are tested using the ExxonMobil's data set (shown in Table 3) to generate three incident profiles, for validating the proposed metrics as depicted in Equation 1, 3 and 4. Table 3 summarizes the number of process safety incidents (operational oil spills) and three process incident rates derived from different metrics:

Table 3 ExxonMobil's Performance Data

Process safety incident number (number of oil spills)				
Year	2002	2003	2004	2005
	567	465	474	370
Year	2006	2007	2008	2009
	295	252	211	241
Year	2010			
	210			
Process safety incident rate/Crude oil production (per 300,000 barrels)				
Year	2002	2003	2004	2005
	0.187	0.152	0.152	0.121
Year	2006	2007	2008	2009
	0.090	0.079	0.072	0.083
Year	2010			
	0.071			

Table 3 Continued

Process safety incident rate/Oil and gas production (per 500,000 BOE)				
Year	2002	2003	2004	2005
	0.183	0.152	0.154	0.125
Year	2006	2007	2008	2009
	0.095	0.083	0.074	0.084
Year	2010			
	0.065			
Process safety incident rate/Hours worked (per 200,000 hours)				
Year	2002	2003	2004	2005
	0.616	0.528	0.551	0.440
Year	2006	2007	2008	2009
	0.360	0.311	0.264	0.298
Year	2010			
	0.250			

Fig. 5 shows the generated incident rate profiles that have been normalized by the three different metrics. The two profiles generated by proposed process metrics seem to overlap with each other, but they significantly differ from time-based profile, which will bring the difficulty to compare these profiles visually. A hypothesis could be given here: have standard factors or denominators been properly chosen for metrics? However, using the same Equation 1, 3 and 4 for another company's data, an opposite example has been displayed in Fig. 6. Applying same three metrics for BP's data, all profiles generated by process metrics are very close to each other. Therefore, those two examples reject the hypothesis mentioned above. In order to eliminate any fluctuations (as seen from the PSI/HW trend in Fig. 5) arising from using different standard factors, a statistical method known as 'unitization' was developed for this purpose.

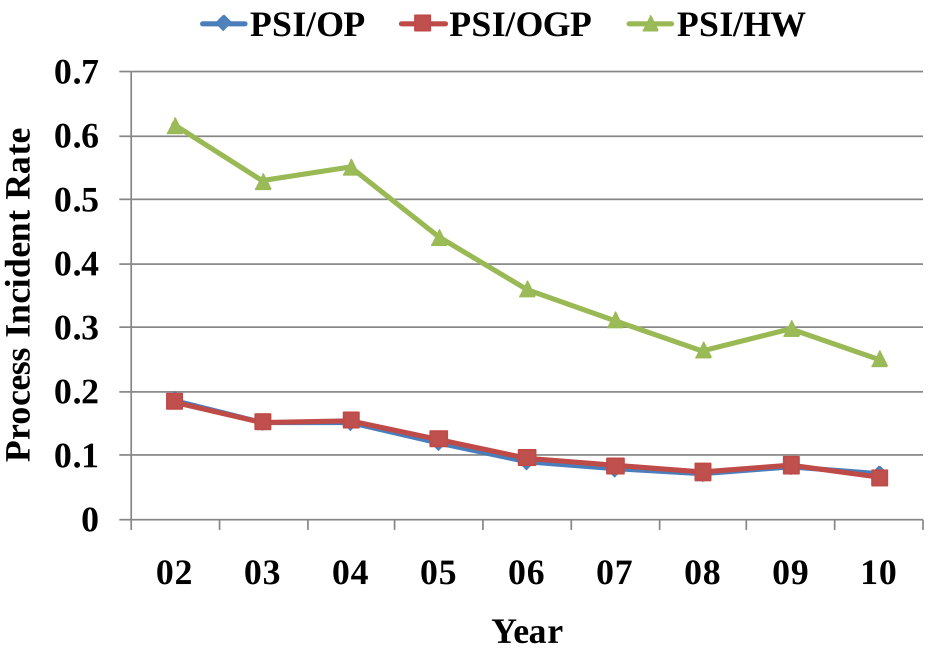

Fig. 5. Process Safety Incident Profiles by Different Metrics (ExxonMobil Data)

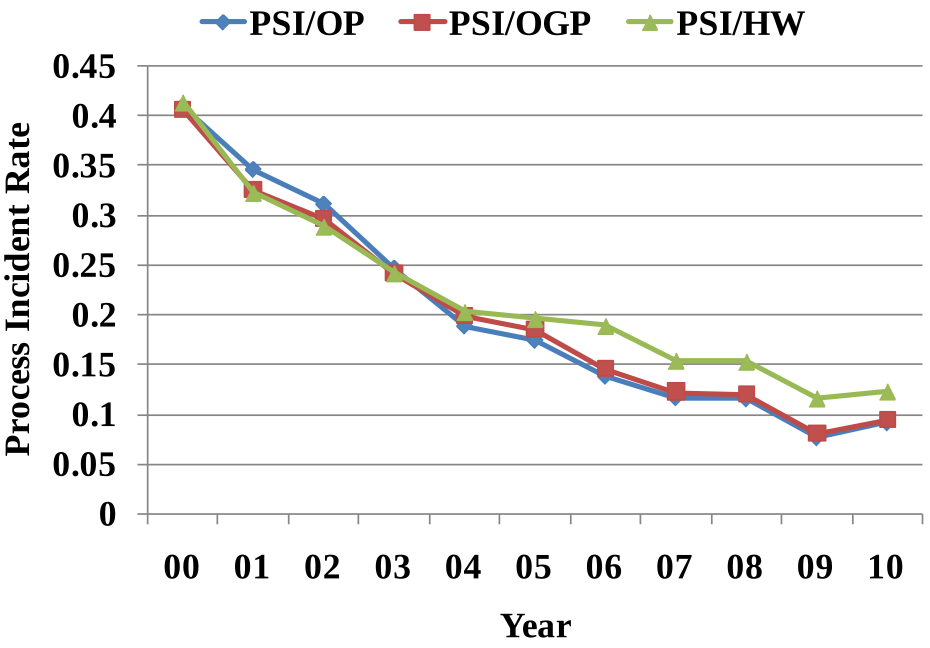

Fig. 6. Process Safety Incident Profiles by Different Metrics (BP Data)

5.1.1 Unitization of incident rates

The challenge presented in normalized incident rates is their profiles would be influenced by different standard factors or denominators. Once original incident profiles cannot be shown in the same scale, it would be very difficult for analyzing their similarity visually. Only based on visual judgment, the true relationship between trends can be hardly concluded. Thus, introducing any method to solve this problem is very critical for subsequent analysis. Unitization is the method to transfer incident rates from different ranges into a unified one. After the unitization process, all data sets can be scattered in the range of 0 to 1. This dimensionless method translates any absolute value to a certain relative value.

When every point in the normalized incident rate curve is unified, each point is converted to a relative value based on the distribution of total population, generating a new unified incident profile. By doing this, biased visual judgment could be avoided.

Unitization has been widely used in unifying data sets. This unified curve can be generated using the following Equation 16:

$$Y_U = \frac{Y_i - Y_{\min}}{Y_{\max} - Y_{\min}} \tag{16}$$

where, Y_U stands for the unified value of incident rates, Y_i stands for the incident rate in certain year, Y_{max} and Y_{min} stand for the maximum and minimum incident rates, respectively, over the time period under study of available data.

Using Equation 16 for linear unitization of the results obtained in Fig. 5, the unitized incident rates corresponding to each process safety incident profile were obtained and displayed in Table 4 and Fig. 7. As seen in Fig. 7, the green curve is the process incident profile normalized by time-based metric (CCPS approach), the blue curve indicates the unitized process safety incident rate normalized by oil production, and the red curve represents the unitized process safety incident rate normalized by oil and gas equivalent production. It can be inferred from Fig. 7 that the unitized incidents generated from proposed metrics are in a close agreement with the time-based metric introduced by CCPS.

Table 4 Unitized Process Safety Incident Rate (ExxonMobil Data)

Unitized process safety incident rate/Crude oil production (per 300,000barrels)				
Year	2002	2003	2004	2005
	1.000	0.699	0.695	0.427
Year	2006	2007	2008	2009
	0.166	0.069	0.007	0.102
Year	2010			
	0			
Unitized process safety incident rate/Oil and gas production (per 500,000BOE)				
Year	2002	2003	2004	2005
	1.000	0.733	0.754	0.506
Year	2006	2007	2008	2009
	0.259	0.151	0.076	0.163
Year	2010			
	0			
Unitized process safety incident rate/Hours worked (per 200,000 hours)				
Year	2002	2003	2004	2005
	1.000	0.760	0.822	0.520
Year	2006	2007	2008	2009
	0.300	0.167	0.038	0.130
Year	2010			
	0			

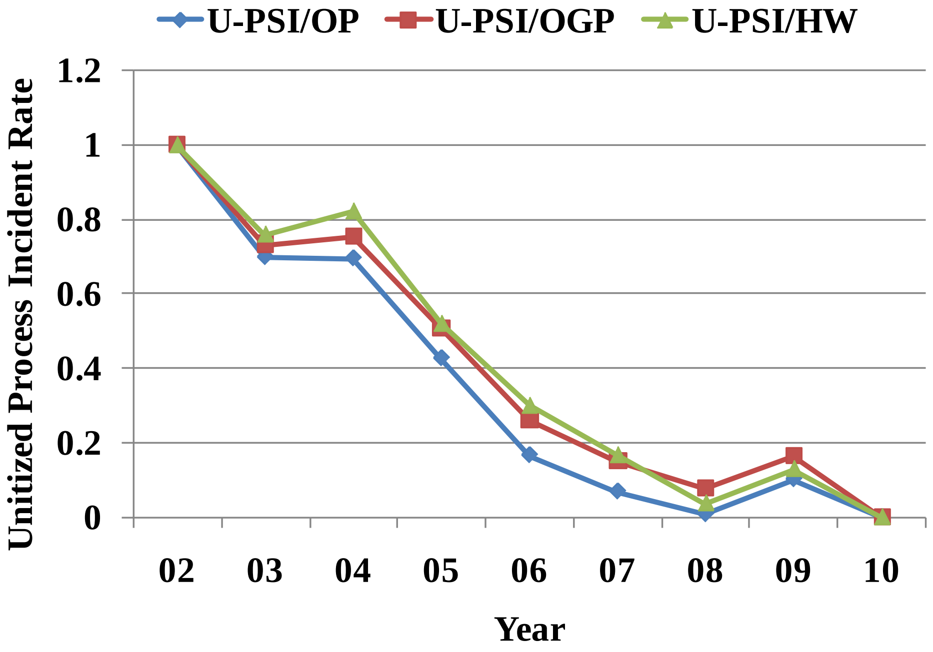

Fig. 7. Process Safety Incident Rate after Unitization

5.1.2 Linear regression

In this section, linear regression has been applied as a key indication to validate and compare the similarity of proposed and existing metrics. Trend line and coefficient determination value have been used in understanding the information that is delivered by incident profiles.

5.1.2.1 Trend line

Trend line is a useful statistical method to aid the interpretation of incident data. Comparing the similarity of a trend line for every metric enables the user to make and justify any tendency of the data. It is also possible to construct a mathematical model to describe the behavior of the observed data. By using a trend line, the user could distinguish any tendency from the proposed metrics as compared to the time-based metric. If the incident profiles generated from the proposed metrics closely match the profile resulting from the time-based metric, then the proposed metrics could be used to evaluate the performance of surveyed data. It could be inferred that the tested metrics would function properly similar to the accepted time-based metric.

The detailed steps to interpret the trend line quantitatively can be found elsewhere (Cacha, 1997). A brief description is provided here, with the focus of applying the trend line to the unified incident rate profiles as shown in Table 5.

Step 1: Use X variable to represent the year distribution. By arranging the year distribution from the lowest value to the highest value (from years 2002 to 2010) and picking the middle one (year 2006) as the median, the user can assign 0 for this center point. The remaining data sets in X variable (years) are presented in either ascending or descending sequences, starting from the center point by the interval value of 1. The next move is labeling incident rates as Y variable for each corresponding X value. The fourth column in Table 5 is the product of X and Y values, while the fifth column is the square value of X. Table 5 shows the results generated from the unitized process safety incident rates described above (divided by crude oil production-per 300,000 barrels) for the ExxonMobil case study.

Table 5 Calculations for Constructing a Trend Line

Year	**X**	**Y**	**XY**	**X^2**
2002	-4	1	-4	16
2003	-3	0.699	-2.097	9
2004	-2	0.695	-1.39	4
2005	-1	0.427	-0.427	1
2006	0	0.166	0	0
2007	1	0.069	0.069	1
2008	2	0.007	0.014	4
2009	3	0.102	0.306	9
20010	4	0	0	16
Sum		3.165	-7.525	60

Step 2: Use a linear regression model to explain the correlation between X and Y using the regression model: $Y = a + bX$. Because there is only one independent variable X in the model, it is considered as a simple linear regression model. In the regression models, the independent variables are also referred to as repressors or predictor variables. The slope and intercept values for the linear model can be generated using Eqns. 17 and 18. Y is the incident rate for a particular year, X is the value assigned to this year. From Table 5, the user can find slope and interception, respectively.

$$a = \frac{\sum_{j=1}^{n} Y_j}{N} \tag{17}$$

$$b = \frac{\sum_{i=1,\, j=1}^{n} X_i Y_j}{\sum_{i=1}^{n} (X_i)^2} \tag{18}$$

where, X_i is the assigned value for the annual distribution, Y_i is the incident rate for a particular year. N is the number of the samples.

Step 3: The fitted linear trend line can be constructed using the following Equation: $Y = -0.125X + 0.352$

As seen in Fig. 8, all trend lines are almost parallel to each other, which results in a similar slope value (around -0.13) for all cases. This corresponds to the incident rate profiles, which linearly decrease over time. The rapid decrease of the incident rate profiles might indicate the improvement made in the process safety performance. Moreover, the parallel trend lines also indicate that the alternative denominators (*i.e.*, oil production, oil and gas equivalent production) proposed in this study can be used alternatively to evaluate the annual safety performance (instead of the work hours denominator).

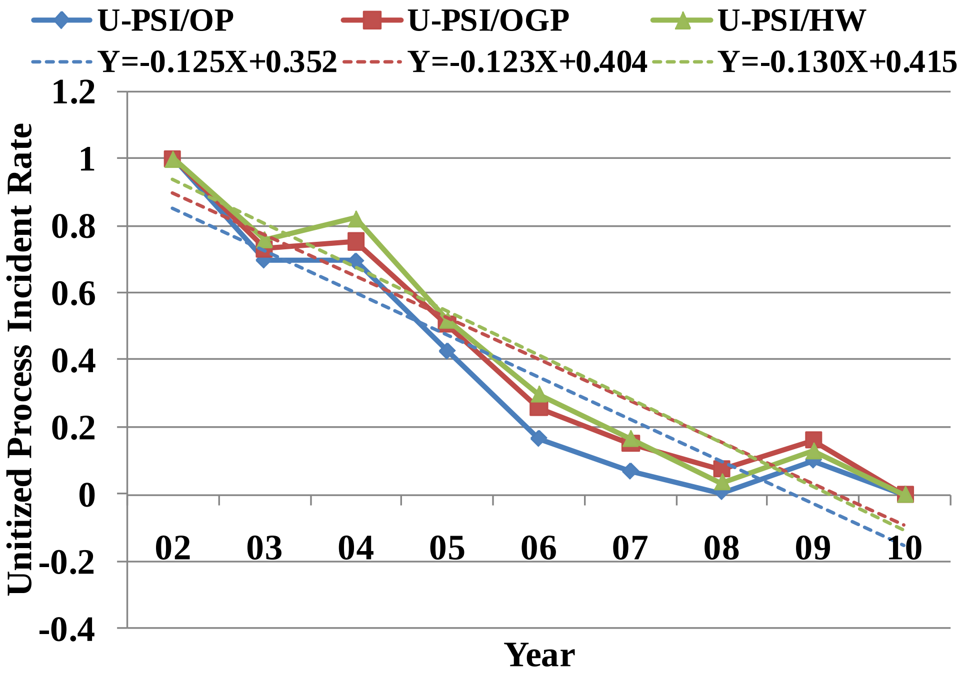

Fig. 8. Trend Lines for Unitized Process Safety Incident Profiles

5.1.2.2 Coefficient of determination value-R^2

In order to observe the variances of fitted values and observed values, the coefficient of determination for generalized linear models was used in the analysis of trend line. From a statistics point of view, a coefficient of determination measures how well future outcomes are likely to be predicted by the model or the amount of variability in the data sets. In this study, a simple linear model has been selected to evaluate the trend lines. Thus, the coefficient of determination-R^2 (ranges from 0 to 1) is the correlation coefficient between the outcome and predicted values. The Equation 19 is used to find the coefficient:

$$R^2 = \frac{(\sum_{i=1,j=1}^{n} (X_i - \overline{X})(Y_j - \overline{Y}))^2}{\sum_{i=1}^{n} (X_i - \overline{X})^2 \sum_{j=1}^{n} (Y_j - \overline{Y})^2} \tag{19}$$

where, X_i is the assigned value for the annual distribution, Y_i is the incident rate for a particular year, and N is the number of data sets. Table 6 shows the calculated R^2 value for the linear regression of trend lines in Fig. 8.

Table 6 Coefficient Determination Value for Unitized Trend Line

Unitized Process safety incident rate / Crude oil production (per 300,000 barrels)	
Coefficient Determination-R^2	Coefficient Determination-R^2
Unitized Process safety incident rate / Oil and gas production (per 500,000 BOE)	
Coefficient Determination-R^2	Coefficient Determination-R^2
Unitized Process safety incident rate / Hours worked (per 200,000 hours)	
Coefficient Determination-R^2	Coefficient Determination-R^2

As seen in Table 6, the calculated R^2 value for all three trend lines is around 0.9. When an R^2 value is very close to 1, it indicates that the regression line is able to predict the trend of a whole population perfectly. Although a significant agreement between the actual values and predicted values from the linear model cannot decide which denominator is better, high R^2 values imply that these trend lines are deemed credible to evaluate the distribution of surveyed data.

Metrics (crude oil production, oil and gas equivalent production as denominators) applied to the ExxonMobil data sets have shown their feasibility to be used as alternative lagging metrics. A transverse comparison of trend line slope value has been conducted for selected oil and gas companies, as shown in Fig. 9. Fig. 9 shows that the slope values employing crude oil production or oil and gas equivalent production have the same trend, similar to the time-based metric, in evaluating the process safety performance. Thus, these two lagging metrics are valid to be used for integrated oil and gas companies.

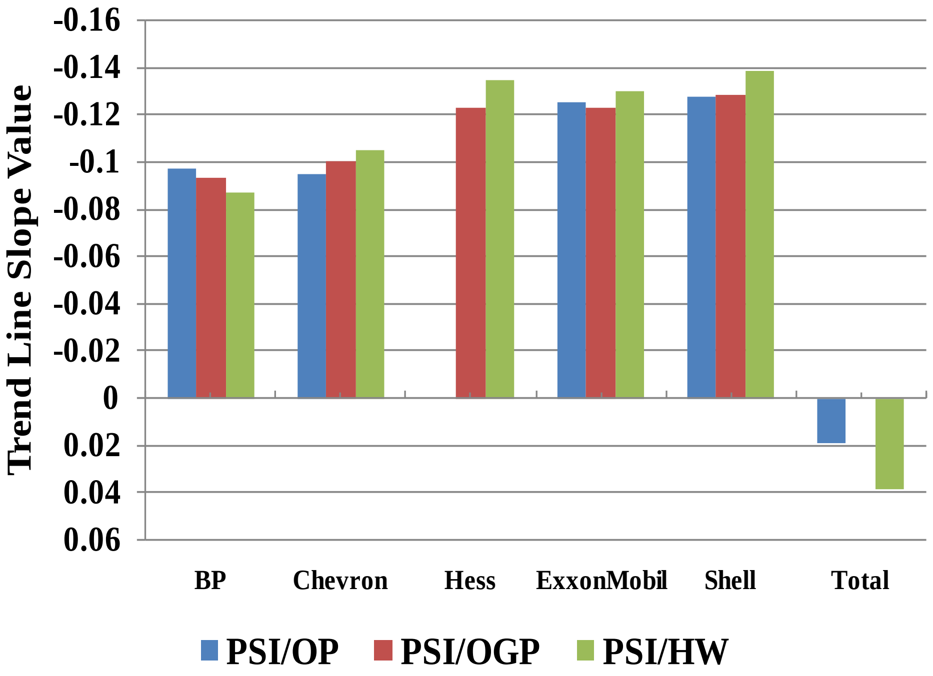

Fig. 9. Slope Value Comparisons for Integrated Oil and Gas Metrics

5.1.3 Metrics testing

5.1.3.1 Crude oil production, oil and gas equivalent production

In summary, following the quantitative assessment of the existing and proposed lagging metrics, metrics utilizing oil production and oil and gas equivalent production have been validated as credible denominators in addition to work hours denominator. Unitized incident profiles neglect the differentiation among various lagging metrics by generating a dimensionless scale for trend line comparison. High coefficient determination value implies the credibility of a trend line. From the case study and transverse comparison for integrated oil and gas category, the slopes of the three unified incident profiles are quite similar, following a parallel pattern which indicates the potential of using process related parameters as the lagging metric for evaluating the safety performance as alternative methods to the existing time-based metric commonly used by process industries.

The next step is to test some potential process related metrics using the actual surveyed data.

5.1.3.2 Total energy consumption

The next step is to test some potential process related metrics using the actual surveyed data. Fig. 10 shows process safety incident rate profiles generated from other process related metrics using total energy consumption and hours worked as denominators. The red curve represents the unitized process safety incident rate derived from work hours denominator, and the blue curve describes the unitized process safety incident rate divided by the energy consumption denominator. The trend lines of these two profiles are quite identical, with the slope values for both trend lines are fairly close to each other. Although they do not exhibit a high linear regression coefficient, the gap between the two profiles is quite small. Again, more cases would be brought in to observe the metric's repeatability.

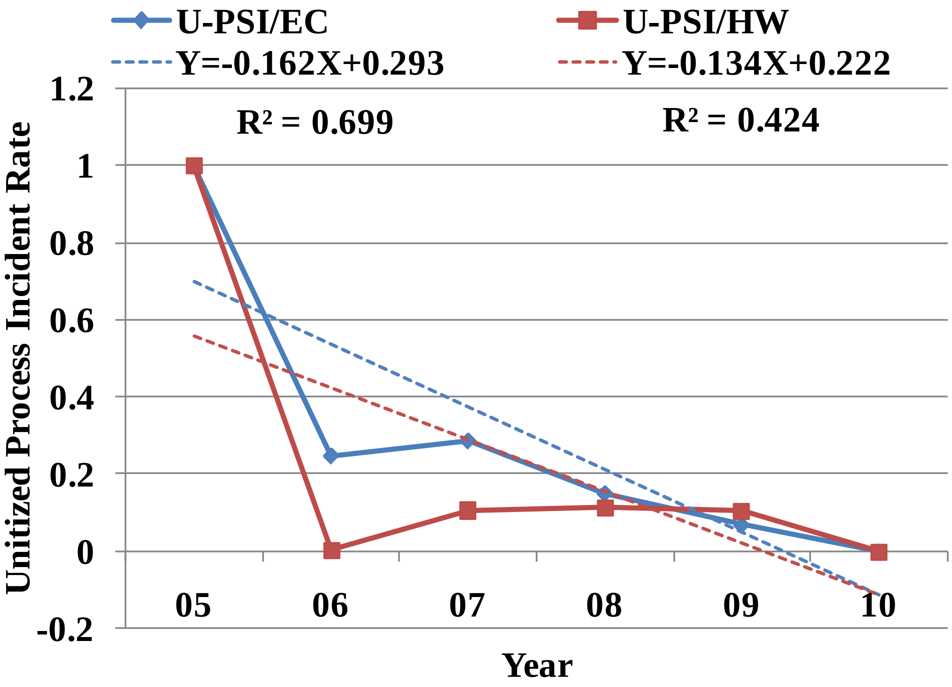

Fig. 10. Unitized Process Safety Incident Profiles by Different Metrics (Hess Data)

Fig. 11 shows the comparison of trend line slope values of several surveyed companies. The slope value for each metric exhibits a similar pattern with little difference to that observed in Hess and Dow Canada data sets (less than 10% difference). Despite the difficulty in obtaining various company data and projecting comparative slope values, energy consumption remains another independent variable which should be considered as a potential denominator, similar to the work hours, for evaluating process safety performance.

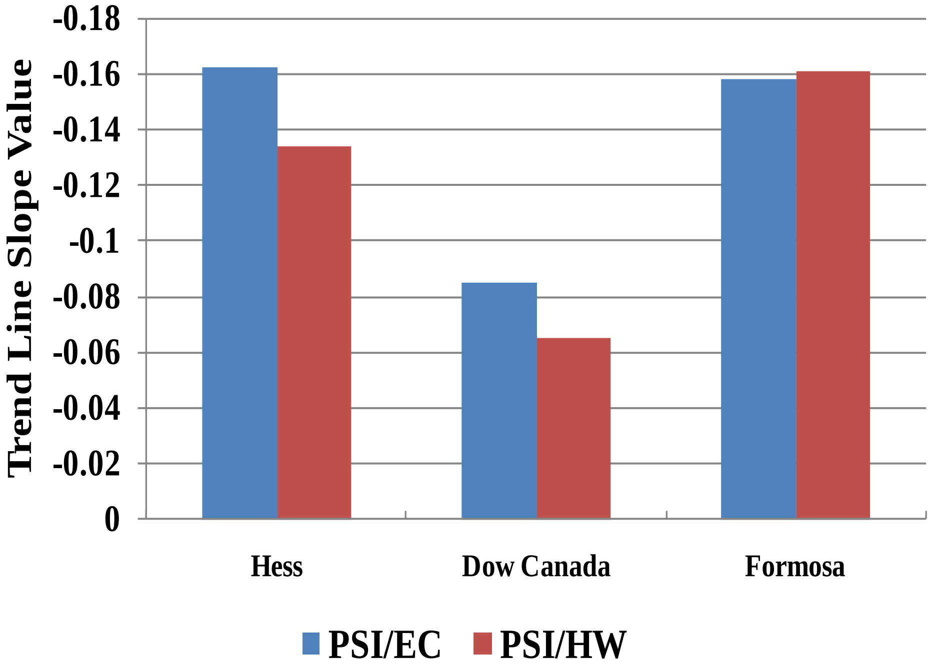

Fig. 11. Slope Value Comparisons for Energy Consumption Metric

5.1.3.3 Financial indicators

Fig. 12 shows the process safety incident rate profiles generated from metrics utilizing net income, net sales and hours worked as denominators. The green curve represent the unitized process safety incident rate derived from the time-based denominator, while the blue curve represents the unitized process safety incident rate divided by net income denominator, and the red curve is normalized by the net sales denominator. As seen in Fig. 12, trend lines generated with work hours and net sales denominators indicate a parallel pattern, while the trend line generated with net income denominator shows a dramatic difference in both slope and coefficient determination values. This means a metric employing a net sales denominator exhibit the same behavior as a time-based metric, which depicts the improvement in process safety performance; while the other metric using the net income denominator is not valid. Dupont's data sets present an example where the net income is a not an appropriate denominator to use since it differs from other two denominators significantly.

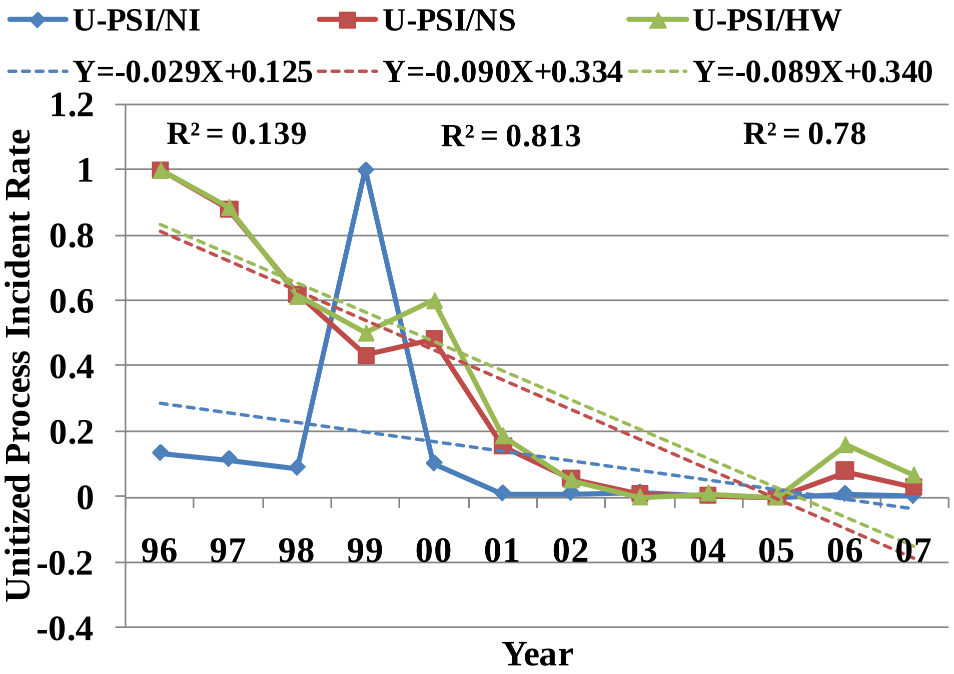

Fig. 12. Unitized Process Safety Incident Profiles by Different Metrics (Dupont Data)

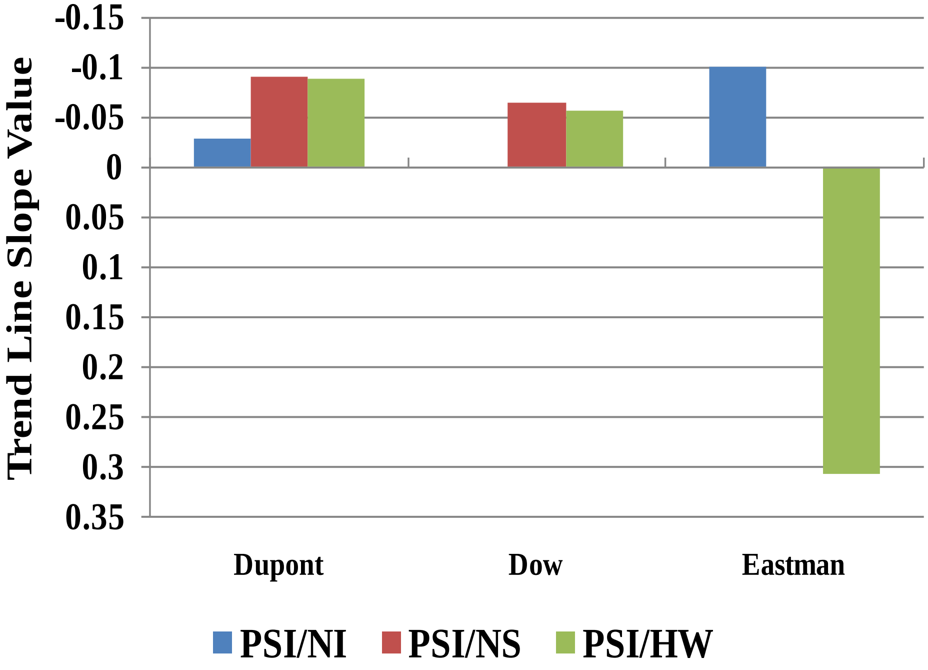

Fig. 13. Slope Value Comparisons for Financial Metrics

The comparison for financial indicators as potential lagging metrics has been conducted for chemical companies. From the trend line perspectives, net sales have the potential to become a denominator, like the work hours denominator, for all chemical industries. It can be concluded from Fig. 13 that the metric utilizing net sale denominator provides a similar trend, as time-based metric, in evaluating the process safety performance. However, the metric using the net income denominator has not reached author’s expectation.

5.1.3.4 Chemical production

Fig. 14 shows the process safety incident rate profiles generated from metrics using chemical production volume and hours worked as denominators. The blue curve represents the unitized process safety incident rate derived from time-based denominator, and the red curve represents the unitized process safety incident rate divided by total chemical products volume. The trend lines of the two profiles are quite similar, with the slope values for both trend lines are fairly close to each other. Although they are not showing high correlation, the gap between the two profiles is quite small. Future studies should focus on evaluating this lagging metric with more comprehensive industrial data to validate its suitability for evaluating the safety performance of the process industries.

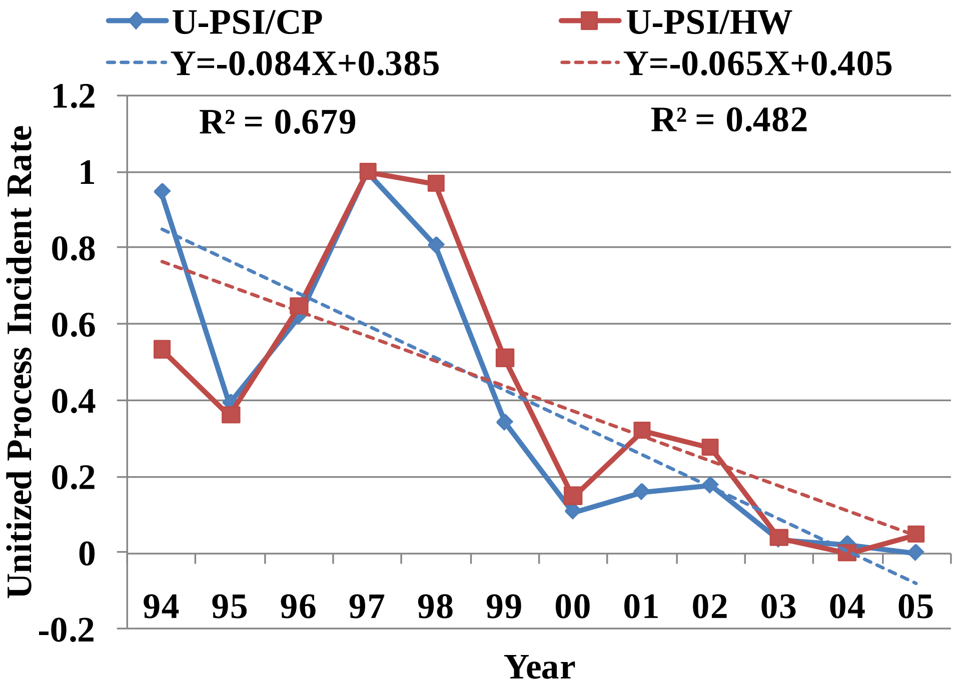

Fig. 14. Unitized Process Safety Incident Profiles by Different Metrics (Dow Canada Data)

Fig. 15 compares the slope values for different chemical companies to prove the hypothesis that chemical production volume is a potential denominator for process industries. Trend line slope values for incident rate profiles normalized by chemical production and hours worked are relatively close to each other. It could be concluded that the chemical production volume lagging metric can, in addition to the acceptable time-based metric, help management in assessing process safety performance.

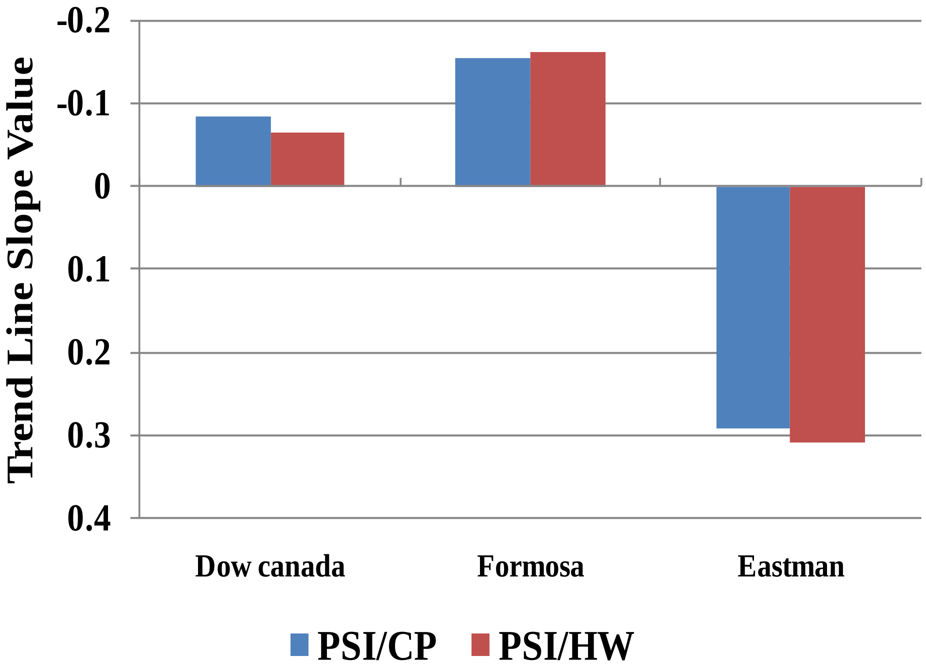

Fig. 15. Slope Value Comparisons for Chemical Production Metric

5.1.3.5 Drilling depth capacity, operating days and drilling length

Fig. 16 shows the incident rate profiles of drilling contractor. Currently, the drilling contractors/industries have also emphasized the personal safety metrics reporting, while process safety incidents record has not been found for drilling industries. However, several potential process-related denominators could be captured to evaluate the safety performance of drilling industries, as shown in Fig. 16. Here, the numerator is assumed to be total recordable incidents. Total recordable incident profiles were generated from different lagging metrics utilizing various denominators such as: drilling depth capacity, operating days and hours worked. The green curve shows the incident profile derived from time-based metric, the blue curve illustrates the unitized total recordable incident rate normalized by total drilling depth capacity, while the red curve represents the unitized total recordable incident rate divided by operating days. In all cases, all trend lines present a parallel pattern, the slope and coefficient determination values are almost identical (around 0.8). The slope values are also relatively close as seen in Fig. 17. This means drilling depth capacity and operating days lagging metrics follow a similar tendency as time-based metric. Parker Drilling and Noble Corporation’s data sets give a good example of drilling contractor safety performance. The proposed lagging metrics seem to be reasonable and effective.

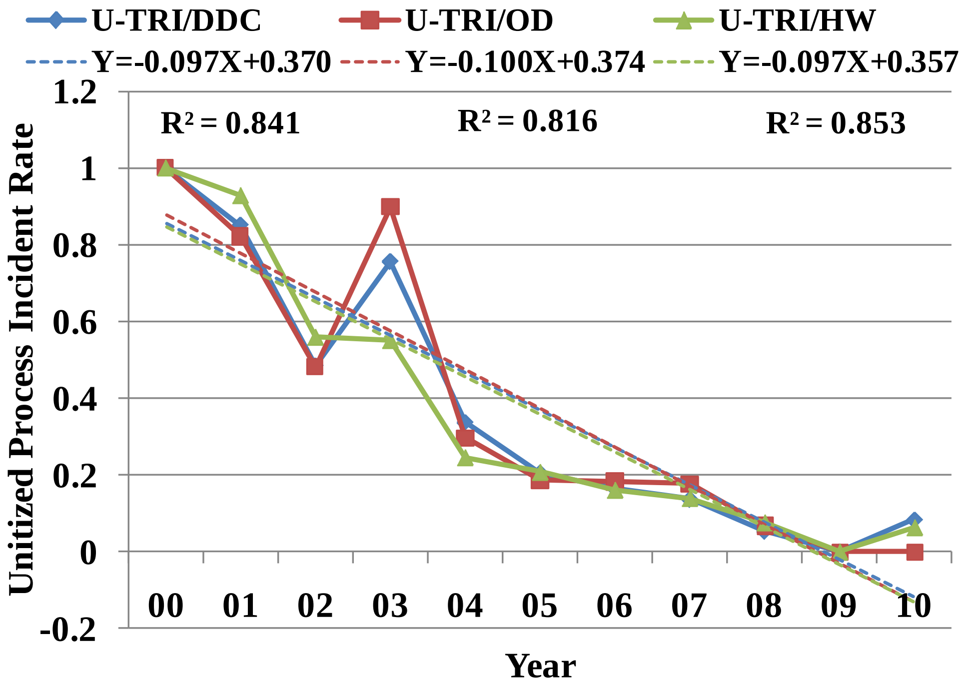

Fig. 16. Unitized Process Safety Incident Profiles by Different Metrics (Parker Drilling data)

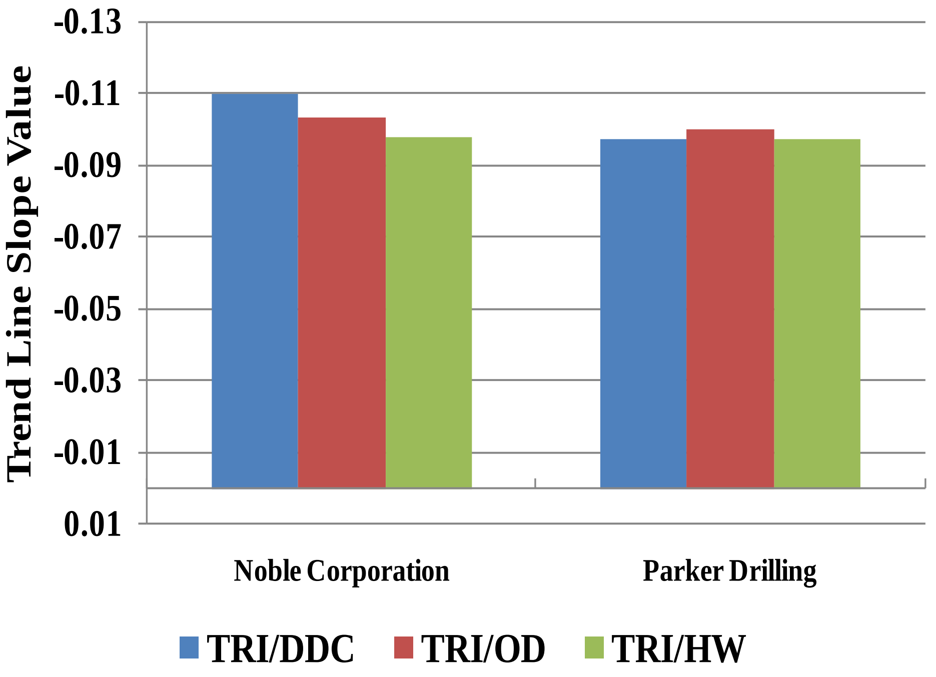

Fig. 17. Slope Value Comparisons for Drilling Related Metrics

Fig. 18 depicts lost workday profiles generated from metrics using total drilling depth and hours worked as denominators. The red curve represents the unitized lost workday case rate derived from time-based denominator, and the blue curve describes the unitized incident rate divided by drilling depth. The trend lines from the two profiles have significant differences, resulting in different slope and R^2 values. Woodside data sets give an example showing that drilling length is not an appropriate lagging metric to be used in evaluating the safety performance since it varies significantly as compared to the time-based metric.

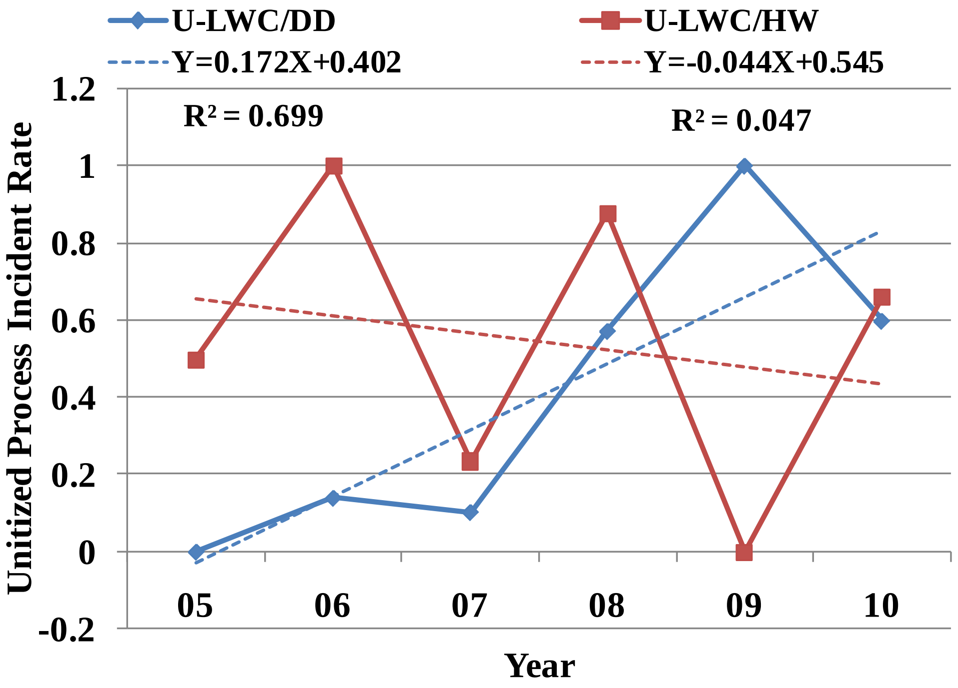

Fig. 18. Unitized Process Safety Incident Profiles by Different Metrics (Woodside data)

5.2 Qualitative Basis

From a qualitative assessment point of view, CCPS's Guidelines for Process Safety Metrics (CCPS, 2009) (Safety 2009) has provided certain criteria to develop an effective and credible process safety metrics evaluation. Some of the CCPS criteria are modified to fit the scope of this study, while the quantitative results provide justification of metrics selection and validation.

5.2.1 Characteristics of good metrics

5.2.1.1 Reliability and repeatability

The requirement of metrics is that they can be used repeatedly at different time periods, and broad applicability in meeting industry needs. Most denominators proposed in this study have shown results in the same range by using various industrial data sets. Benchmarking between the accepted time-based metric and the proposed process metrics validates the reliability of proposed lagging metrics. In terms of repeatability, it has been shown that results from the proposed metrics have been reiterated to a number of surveyed industries. The proposed process-related metrics have been tested with available data from companies of different categories. From the slope value comparison of trend lines, it can be concluded that specified lagging metrics could be used universally in their corresponding industries.

5.2.1.2 Consistency and independence

In this research, the unit and definition of each individual denominator is consistent throughout the four distinguished groups of companies (integrated oil and gas, exploration and production, chemicals, and drilling contractors). The total amount of oil and gas production, direct energy consumption, and drilling depth capacity are the critical denominators for evaluating process safety performance. For illustration, barrels, and barrels of oil equivalent are examples of standard units that have been used broadly. Similarly, units such as per cubic feet of production have been used for natural gas, per ton for chemical products, and per trillion Joule for energy consumption. The advantage of keeping denominator's consistent will enable benchmarking across organizations. Moreover, the selection of potential denominators was developed in this work based on real industrial publications. Independence is another important factor to decide the selection of denominators. Some denominators have a relatively stable and consistent record, while some are not. For example, the net income and annual drilling depth are susceptible to market fluctuation. They would be easily impacted by uncertain factors that make the data sets change dramatically over a time period. Those denominators do not produce good metrics compared with the production volume metric which has a high demand and gives a consistent record.

5.2.1.3 Process behavior related

Integrating the process related information in the lagging metric is another key element for developing a robust process safety metric. Process output variables have been used as denominators, which clearly distinguish process lagging metrics from personal injury metrics. Denominators that correlated with process outputs or behaviors have been considered in this study, such as various production volume, energy consumption, total drilling depth capacity, and operating days. On the contrary, the financial denominators should be avoided in evaluating the safety performance. Trial results presented in previous section suggested process related metrics give better outcomes when analyzing industrial data.

5.2.1.4 Comparability and adequacy

Another function of lagging metrics is to give internal or external comparisons across organization or industries. Good metrics should be able to be compared with other similar metrics to give a consensus conclusion. From this study, quantitative results such as trend line and coefficient determination values give the visualization outcomes when comparing the proposed lagging metrics with the existing time-based metric. In addition, results show that selected lagging metrics are potential denominators to be used for different companies within the group classification. In this study, most results are generated based on industrial data from the public sources. Results using the long-interval data sets demonstrate the importance of monitoring and evaluating the denominators. Large population data sets make statistical analyses more reliable for measuring performance changes.

5.2.1.5 Operability for audience

Metrics should meet the specific need of the target audience and can be captured easily. For instance, production volume is the most interesting indicator for upper management. Thus, there is no difficulty in obtaining these data since it has already been recorded monthly or even daily. Proposed denominators are regular indicators and accessible to any audience. Another point is that those lagging metrics suggested in this study can be obtained and calculated easily. They follow the similar form of CCPS’s defined time-based lagging metric. The normalized form is developed to be user-friendly for operators and EHS management team.

6. SUMMARY

The analysis of lagging metrics has been performed using quantitative assessment (statistical unitization, trend line comparison, coefficient of determination from linear regression) and qualitative evaluation. The results shown in this study demonstrate that lagging metrics can be developed using identified process related denominators in additional to work hours. Quantitative assessment enables the analysis of incident rate profiles mathematically by avoiding biased visual judgments. Qualitative evaluation stating only the good features of the metrics could result in an impartial decision in selecting the lagging metrics. Normalized incident rate profiles were found to be effective in describing process safety performance. Several conclusions can be drawn from this research:

- Grouping the surveyed companies into four business categories served as a reference to select corresponding data sets and lagging metrics. The safety performance data (such as number of process incidents, production volume, energy consumption, etc) were acquired from company publications. They have been integrated into the database according to the four categories.

- Normalized lagging metrics were derived in accordance to each identified process-based category. The differences in the scope of work in each category have been taken into consideration to generate customized lagging metrics.

- Statistical unitization has been applied to the original incident rate profiles, which were normalized by the proposed metrics, to give better insight for quantitative assessment. Unitized incident rate profiles neglect the differentiation among various lagging metrics by building the dimensionless scale for trend line comparison. High coefficient of determination describes the credibility of the trend line.

- Trend analysis provided an overall understanding of process safety incidents within the four industry categories and served as the key indicators to determine the reliability of metrics. The slope value for unified incident rate profiles can be seen from the trend line model. The parallel patterns shown by most profiles demonstrate the potential of using process related metrics, in addition to the time based metric, as alternatives to evaluate the safety performance in process industries.

- Process lagging metrics eligible for quantitative assessment have been screened based on characteristics of good process metrics to ensure their appropriateness.

In summary, metrics using crude oil production, oil and gas equivalent production for the integrated oil and gas group; total energy consumption, chemical production for chemical industry; operating days, and drilling depth capacity for drilling contractors have been validated as the potential denominators, in additional to the commonly used hours worked. Particularly, metrics from their own categories contain more specified process information; this trait enables more precise evaluation in describing process safety performance.

7. FUTURE WORK

The study of process safety performance metrics is an emerging topic advocated by the process industries. Future effort should focus on gathering process deficiency information (such as reliability, etc) in a categorized database. The database should be continuously updated and expanded to provide data sets needed for comprehensive analysis and has the potential to serve academic or industrial needs. Users can expand this database by adding more information in additional columns, especially, when process safety incidents per CCPS definition have been reported. The next step is to use the extended data sets to complement the existing proposed metrics, giving more accurate description. The next step is to identify other potential lagging metrics from the database for other industrial groups.

REFERENCES

Allars, K. (2007). *BP Texas City incident-Baker review.* http://www.hse.gov.uk/leadership/bakerreport.pdf

API. (2010). *ANSI/API Recommended Practice 754, Process Safety Performance Indicators for the Refining and Petrochemical Industries*, First Edition.

Baker, J. A. (2007). *The Report of the BP U.S. Refineries Independent Safety Review Panel.*http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/SP/STAGING/local_assets/assets/pdfs/Baker_panel_report.pdf

BP. (2011). *2011 Sustainability Review.* http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/e_s_assets/e_s_assets_2010/downloads_pdfs/bp_sustainability_review_2011.pdf

Cacha, C. A. (1997). *Research Design and Statistics for the Safety and Health Professional.* New York: Van Nostrand Reinhold.

CCPS. (2007). *Guidelines for Risk Based Process Safety*. New York: American Institute of Chemical Engineers.

CCPS. (2009). *Guidelines for Process Safety Metrics.* New York: American Institute of Chemical Engineers.

CCPS. (2011) *Process Safety Leading and Lagging Metrics-You Don't Improve What You Don't Measure.* New York: American Institute of Chemical Engineers. http://www.aiche.org/uploadedFiles/CCPS/Metrics/CCPS_metrics%205.16.08.pdf

Crowl, D. A., & Louvar, J. F. (2011). *Chemical Process Safety-Fundamentals with Applications,* 3rd Edition. Boston: Prentice Hall.

CSB. (2005). *Investigation Report No. 2005-04-I-TX, "Refinery Exploration and Fire", BP, Texas City*. http://www.csb.gov/assets/document/CSBFinalReportBP.pdf

Dow Canada. (2006). *The Dow Canada 2006 Public Report.* http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_00af/0901b803800af5fd.pdf?filepath=facilities/pdfs/noreg/722-00080.pdf&fromPage=GetDoc

Dupont. (2011). *Sustainability Progress Report.* http://www2.dupont.com/inclusive-innovations/en-us/sites/default/files/2011_DuPont_GRI_Report.pdf

EIA. (2011). *Ranking of U.S. Refineries.* http://www.eia.gov/neic/rankings/refineries.htm

EPRI. (2001). *Final Report on Leading Indicators of Human Performance.* http://esh-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=1603

ExxonMobil. (2010). *Corporate Citizenship Report.* http://ir.exxonmobil.com/phoenix.zhtml?c=115024&p=irol-reportsCitizenship

Fawcett, H. H., & Wood, W. S. (1982). *Safety and Accident Prevention in Chemical Operations.* New York: Wiley.

Groeneweg, J. (2006). *The future of behavior management.* Health and Safety Culture Management for the Oil and Gas Industry. Conference, Amsterdam, The Netherlands.

Hale, A. (2009). Why safety performance indicators? *Safety Science,* 47(4), 479-480.

Heinrich, H. W. (1931). *Industrial Accident Prevention.* New York: McGraw-Hill.

Hess. (2010). *Corporate Sustainability Report.* http://www.hess.com/reports/sustainability/US/2010/default.pdf

Hollnagel, E., Woods, D. D., Leveson, N. (2006). *Resilience Engineering: concepts and precepts*. Williston: Ashgate Publishing, Ltd.

HSE. (2006). *Step-By-Step Guide to Developing Process Safety Performance Indicators.* http://www.oecd.org/dataoecd/6/57/41269710.pdf

Johnston, D. (1996). *Refining Report Complexity index indicates refinery capability, value.* http://www.ogj.com/articles/print/volume-94/issue-12/in-this-issue/general-interest/refining-report-complexity-index-indicates-refinery-capability-value.html

Kletz, T. A. (1993). Accident data-The need for a new look at the sort of data that are collected and analyzed. *Safety Science,* 16(3-4), 407-415.

Morrison, D. T., Fecke, M., & Martens, J. (2011). Migrating an incident reporting system to a CCPS process safety metrics model. *Journal of Loss Prevention in the Process Industries,* 24(6), 819-826.

Parker Drilling. (2010). *Parker Drilling 2010 Annual Report.* http://parkerdrilling.investorroom.com/index.php?s=120

Reason, J.T. (1990). The Contribution of Latent Human Failures to the Breakdown of Complex Systems. *Philosophical Transactions of the Royal Society (London),* Series B (327): 475-484.

Reason, J. T. (1997). *Managing the Risks of Organizational Accidents*. London: Ashgate Publishing Company.

Woodside. (2010). *Annual Report 2010*. http://www.woodside.com.au/Investors-Media/AnnualReports/Documents/Woodside%20Interactive%20Annual%20Report%202010.pdf

APPENDIX A

PROCESS SAFETY INCIDENT SEVERITY

A severity level and point will be assigned for each consequence category for each process safety incident by using the criteria (CCPS, 2011) shown in Table 7.

Table 7 Process Safety Incidents & Severity Categories

Severity Level	Safety/Human Health	Fire or Explosion (including overpressure)	Potential Chemical Impact	Community/Environment Impact
N/A	Does not meet or exceed Level 4 threshold	Does not meet or exceed Level 4 threshold	Does not meet or exceed Level 4 threshold	Does not meet or exceed Level 4 threshold
4 (1 point used in severity rate calculations for each of the attributes which apply to the incident)	Injury requiring treatment beyond first aid to employee or contractors (or equivalent) associated with a process safety incident (In USA, incidents meeting the definitions of an OSHA recordable injury)	Resulting in $25,000 to $100,000 of direct cost	Chemical released within secondary containment or contained within the unit	Short-term remediation to address acute environmental impact. No long term cost or company oversight. Examples would include spill cleanup, soil and vegetation removal.
3 (3 points used in severity rate calculations for each of the attributes which apply to the	Lost time injury to employee or contractors associated with a process safety event	Resulting in $100,000 to 1MM of direct cost.	Chemical release outside of containment but retained on company property OR flammable release without potential for vapor cloud explosives	Minor off-site impact with precautionary shelter-in-place OR Environmental remediation required with cost less than $1MM. No other regulatory oversight required. OR

incident)				Local media coverage
2 (9 points used in severity rate calculations 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 off site 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	Shelter-in-place or community evacuation OR Environmental remediation required and cost in between $1MM - $2.5 MM. State government investigation and oversight of process. OR Regional media coverage or brief national media coverage.
1 (27 points used in severity rate calculations 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	National media coverage over multiple days OR Environmental remediation required and cost in excess of $2.5 MM. Federal government investigation and oversight of process. OR other significant community impact

APPENDIX B

INTEGRATED OIL AND GAS GROUP DATA AND CALCULATIONS

BP

Number of Employees				
Year	2000	2001	2002	2003
	107,200	110,150	115,250	103,700
Year	2004	2005	2006	2007
	102,900	96,200	97,000	98,100
Year	2008	2009	2010	
	92,000	80,300	79,700	
Total Hours Worked (Million hours-workforce)				
Year	2000	2001	2002	2003
	464	503	528	527
Year	2004	2005	2006	2007
	571	555	443	445
Year	2008	2009	2010	
	440	408	429	
Fatality (Employee)				
Year	2000	2001	2002	2003
	10	5	3	5
Year	2004	2005	2006	2007
	4	1	0	3
Year	2008	2009	2010	
	2	0	0	
Fatality (Contractor)				
Year	2000	2001	2002	2003
	13	11	10	15
Year	2004	2005	2006	2007
	7	26	7	4
Year	2008	2009	2010	
	3	18	14	
Recordable Injury Case (Workforce)				
Year	2000	2001	2002	2003
	2726	2392	2012	1604
Year	2004	2005	2006	2007

	1513	1471	1067	1060
Year	2008	2009	2010	
	951	665	1284	
Day Away From Work Case (Workforce)				
Year	2000	2001	2002	2003
	450	327	272	239
Year	2004	2005	2006	2007
	230	305	188	167
Year	2008	2009	2010	
	175	134	408	
Fatal Accident Rate (FAR-per 10^8 hours)				
Year	2000	2001	2002	2003
	4.96	3.18	2.46	3.80
Year	2004	2005	2006	2007
	1.93	4.86	1.58	1.57
Year	2008	2009	2010	
	1.14	4.41	3.26	
Recordable Incident Frequency (RIF per 200,000 hours worked-workforce)				
Year	2000	2001	2002	2003
	1.26	0.95	0.77	0.61
Year	2004	2005	2006	2007
	0.53	0.53	0.48	0.48
Year	2008	2009	2010	
	0.43	0.34	0.61	
Day Away From Work Frequency (DAFWF per 200,000 hours worked-workforce)				
Year	2000	2001	2002	2003
	0.21	0.13	0.1	0.09
Year	2004	2005	2006	2007
	0.08	0.11	0.085	0.075
Year	2008	2009	2010	
	0.08	0.069	0.193	
Oil Spill (Loss of primary containment >1 barrel)				
Year	2000	2001	2002	2003
	958	810	761	635
Year	2004	2005	2006	2007
	578	541	417	340

Year	2008	2009	2010	
	335	234	261	
Crude Oil Production (Thousand Barrels per day)				
Year	2000	2001	2002	2003
	1,928	1,931	2,018	2,121
Year	2004	2005	2006	2007
	2,531	2,562	2,498	2,414
Year	2008	2009	2010	
	2,401	2,535	2,374	
Net Natural Gas Production (Million cubic feet per day)				
Year	2000	2001	2002	2003
	7,609	8,632	8,707	8,613
Year	2004	2005	2006	2007
	8,503	8,424	8,536	8,143
Year	2008	2009	2010	
	8,334	8,485	8,401	
Net Hydrocarbons Production (Thousand Barrel of oil equivalent per day)				
Year	2000	2001	2002	2003
	3,240	3,419	3,519	3,606
Year	2004	2005	2006	2007
	3,997	4,014	3,926	3,818
Year	2008	2009	2010	
	3,838	3,998	3,822	
Refinery Throughput (Thousand Barrel per day)				
Year	2000	2001	2002	2003
	2,928	2,611	2,774	2,723
Year	2004	2005	2006	2007
	2,607	2,399	2,198	2,127
Year	2008	2009	2010	
	2,155	2,287	2,426	
Petrochemical Production (Thousand tons per year)				
Year	2000	2001	2002	2003
	9,588	9,699	11,166	12,392
Year	2004	2005	2006	2007
	13,358	14,076	14,426	14,320
Year	2008	2009	2010	
	12,835	12,660	15,594	

CHEVRON

Number of Employees				
Year	2000	2001	2002	2003
	57,327	55,763	53,014	50,582
Year	2004	2005	2006	2007
	47,265	53,440	55,882	59,162
Year	2008	2009	2010	
	61,675	59,963	58,267	
Total Hours Worked (Thousand hours-employee)				
Year	2000	2001	2002	2003
	114,654	111,526	106,028	101,164
Year	2004	2005	2006	2007
	94,530	106,880	111,764	118,324
Year	2008	2009	2010	
	123,350	119,926	116,534	
Fatality (Employee)				
Year	2000	2001	2002	2003
	4	2	1	0
Year	2004	2005	2006	2007
	2	2	1	3
Year	2008	2009	2010	
	0	0	0	
Fatality (Contractor)				
Year	2000	2001	2002	2003
	14	21	15	12
Year	2004	2005	2006	2007
	15	4	11	14
Year	2008	2009	2010	
	5	9	5	
Total Recordable Incident Rate (TRIR per 200,000 hours worked-employee)				
Year	2000	2001	2002	2003
	0.82	0.72	0.68	0.6
Year	2004	2005	2006	2007
	0.46	0.38	0.34	0.4
Year	2008	2009	2010	
	0.31	0.32	0.22	

Lost-Time Incident Rate (LTIR per 200,000 hours worked-employee)				
Year	2000	2001	2002	2003
	0.4	0.34	0.252	0.252
Year	2004	2005	2006	2007
	0.214	0.168	0.082	0.096
Year	2008	2009	2010	
	0.066	0.066	0.034	
Oil Spill (Oil, chemicals and drilling fluid spill>1 barrel)				
Year	2000	2001	2002	2003
	1553	1428	1502	1145
Year	2004	2005	2006	2007
	986	846	803	826
Year	2008	2009	2010	
	760	798	639	
Net Oil and Liquid Production (Thousand Barrels per day)				
Year	2000	2001	2002	2003
	1,997	1,959	1,897	1,808
Year	2004	2005	2006	2007
	1,710	1,669	1,732	1,756
Year	2008	2009	2010	
	1,649	1,846	1,923	
Net Natural Gas Production (Million cubic feet per day)				
Year	2000	2001	2002	2003
	4,466	4,417	4,376	4,292
Year	2004	2005	2006	2007
	3,958	4,233	4,956	5,019
Year	2008	2009	2010	
	5,125	4,989	5,040	
Net Oil and gas equivalent production (Thousand Barrel of oil equivalent per day)				
Year	2000	2001	2002	2003
	2,741	2,695	2,626	2,637
Year	2004	2005	2006	2007
	2,509	2,517	2,667	2,619
Year	2008	2009	2010	
	2,530	2,704	2,763	
Refinery Throughput (Thousand Barrel per day)				

Year	2000	2001	2002	2003
	6,675	6,256	5,854	5,729
Year	2004	2005	2006	2007
	5,866	5,608	5,610	5,317
Year	2008	2009	2010	
	5,287	5,132	5,007	
Refinery capacity (Thousand Barrel per day)				
Year	2000	2001	2002	2003
	2,472	2,079	1,991	1,958
Year	2004	2005	2006	2007
	2,212	1,989	1,833	1,858
Year	2008	2009	2010	
	1,878	1,894	2,160	

CONOCOPHILLIPS

Number of Employees				
Year	2003	2004	2005	2006
	N/A	N/A	N/A	38,400
Year	2007	2008	2009	2010
	32,600	33,800	30,015	29,705
Total Hours Worked (Thousand hours-employee)				
Year	2003	2004	2005	2006
	N/A	N/A	N/A	76,800
Year	2007	2008	2009	2010
	65,200	67,600	60,030	59,410
Total Recordable Incident Rate (TRIR per 200,000 hours worked-employee)				
Year	2003	2004	2005	2006
	N/A	N/A	N/A	0.68
Year	2007	2008	2009	2010
	0.62	0.52	0.4	0.31
Crude Oil Production (Thousand barrel per day)				
Year	2003	2004	2005	2006
	934	905	907	972
Year	2007	2008	2009	2010
	854	806	968	913
Natural Gas Production (Millions of cubic feet per day)				
Year	2003	2004	2005	2006
	3,522	3,317	3,270	4,970
Year	2007	2008	2009	2010
	5,087	4,847	4,877	4,606
Total Oil and gas production (Thousand barrel of oil equivalent per day)				
Year	2003	2004	2005	2006
	1,541	1,477	1,471	1,829
Year	2007	2008	2009	2010
	1,731	1,642	1,809	1,707
Refinery Crude Oil Processed (Thousand barrel per day)				
Year	2003	2004	2005	2006
	2,488	2,455	2,420	2,616
Year	2007	2008	2009	2010
	2,560	2,416	2,226	2,156

EXXONMOBIL

Number of Employees				
Year	2002	2003	2004	2005
	92,000	88,000	86,000	84,000
Year	2006	2007	2008	2009
	82,000	81,000	80,000	81,000
Year	2010			
	84,000			
Total Hours Worked (Million hours-Employee)				
Year	2002	2003	2004	2005
	184	176	172	168
Year	2006	2007	2008	2009
	164	162	160	162
Year	2010			
	168			
Fatality (Employee)				
Year	2002	2003	2004	2005
	3	4	0	3
Year	2006	2007	2008	2009
	3	0	0	4
Year	2010			
	0			
Fatality (Contractor)				
Year	2002	2003	2004	2005
	7	19	6	5
Year	2006	2007	2008	2009
	7	8	5	4
Year	2010			
	3			
Total Recordable Incident Rate (TRIR per 200,000 hours worked-employee)				
Year	2002	2003	2004	2005
	0.54	0.41	0.39	0.39
Year	2006	2007	2008	2009
	0.33	0.33	0.37	0.31
Year	2010			
	0.23			

Lost-Time Incident Rate (LTIR per 200,000 hours worked-employee)				
Year	2002	2003	2004	2005
	0.083	0.07	0.044	0.069
Year	2006	2007	2008	2009
	0.049	0.031	0.053	0.042
Year	2010			
	0.043			
Oil Spill (Oil, chemicals and drilling fluid spill>1 barrel)				
Year	2002	2003	2004	2005
	567	465	474	370
Year	2006	2007	2008	2009
	295	252	211	241
Year	2010			
	210			
Total Liquid Production (Thousand Barrels per day)				
Year	2002	2003	2004	2005
	2,496	2,516	2,571	2,523
Year	2006	2007	2008	2009
	2,681	2,616	2,405	2,387
Year	2010			
	2,422			
Natural Gas Production (Million cubic feet per day)				
Year	2002	2003	2004	2005
	10,452	10,119	9,864	9,251
Year	2006	2007	2008	2009
	9,334	9,384	9,095	9,237
Year	2010			
	12,148			
Net Oil and gas equivalent production (Thousand Barrel of oil equivalent per day)				
Year	2002	2003	2004	2005
	4,238	4,203	4,215	4,065
Year	2006	2007	2008	2009
	4,237	4,180	3,921	3,932
Year	2010			
	4,447			
Refinery Throughput (Thousand Barrel per day)				

Year	2002	2003	2004	2005
	5,400	5,500	5,700	5,700
Year	2006	2007	2008	2009
	5,600	5,600	5,400	5,400
Year	2010			
	5,300			
Chemical Production (Thousand Metric tons per year)				
Year	2002	2003	2004	2005
	26,600	26,600	27,800	26,800
Year	2006	2007	2008	2009
	27,400	27,500	25,000	24,800
Year	2010			
	25,900			

HESS CORPORATION

Number of Employees				
Year	2004	2005	2006	2007
	11,301	11,975	12,921	12,071
Year	2008	2009	2010	
	12,432	12,229	12,587	
Fatality (Employee)				
Year	2004	2005	2006	2007
	2	0	0	0
Year	2008	2009	2010	
	0	0	1	
Total Hours Worked (Thousand hours-employee and contractor)				
Year	2004	2005	2006	2007
	32,650	37,660	51,200	46,900
Year	2008	2009	2010	
	47,400	44,500	47,700	
Total Recordable Incident Rate (TRIR per 200,000 hours worked-workforce)				
Year	2004	2005	2006	2007
	2.17	1.57	1.04	0.93
Year	2008	2009	2010	
	0.88	0.64	0.62	
Lost-Time Incident Rate (LTIR per 200,000 hours worked-workforce)				
Year	2004	2005	2006	2007
	N/A	N/A	0.41	0.28
Year	2008	2009	2010	
	0.26	0.22	0.17	
Oil Spill (Oil spill>1 barrel)				
Year	2004	2005	2006	2007
	192	270	115	129
Year	2008	2009	2010	
	132	122	106	
Gross Operated Hydrocarbon Production/Throughput (Thousand barrel of oil equivalent per day)				
Year	2004	2005	2006	2007
	1,170	1,210	1,120	1,392
Year	2008	2009	2010	

	1,333	1,392	1,345	
Net Hydrocarbon Production/Throughput (Thousand barrel of oil equivalent per day)				
Year	2004	2005	2006	2007
	342	335	359	377
Year	2008	2009	2010	
	381	408	418	
Direct Energy Usage (Trillion-joules)				
Year	2004	2005	2006	2007
	N/A	37,450	32,600	34,700
Year	2008	2009	2010	
	43,295	46,126	45,904	

SHELL

Number of Employees				
Year	2001	2002	2003	2004
	96,000	N/A	112,371	112,000
Year	2005	2006	2007	2008
	109,000	108,000	104,000	102,000
Year	2009	2010		
	101,000	97,000		
Total Hours Worked (Thousands hours-workforce)				
Year	2001	2002	2003	2004
	686,275	750,000	737,705	673,913
Year	2005	2006	2007	2008
	680,000	660,714	677,419	764,706
Year	2009	2010		
	869,565	750,000		
Fatality (Workforce)				
Year	2001	2002	2003	2004
	35	51	45	31
Year	2005	2006	2007	2008
	34	37	21	26
Year	2009	2010		
	20	12		
Operational Oil Spill				
Year	2001	2002	2003	2004
	N/A	784	678	711
Year	2005	2006	2007	2008
	560	465	392	275
Year	2009	2010		
	264	193		
Lost Time Injury Rate (LTIR per million hours worked-workforce)				
Year	2001	2002	2003	2004
	1.3	1.1	1.1	1.1
Year	2005	2006	2007	2008
	1	0.8	0.7	0.6
Year	2009	2010		
	0.4	0.3		

Total Recordable Injury Rate (TRIR per million hours worked-workforce)				
Year	2001	2002	2003	2004
	2.9	2.5	2.6	2.6
Year	2005	2006	2007	2008
	2.5	2.1	1.9	1.8
Year	2009	2010		
	1.4	1.2		
Oil and Liquids Production (Thousand barrel per day)				
Year	2001	2002	2003	2004
	2,211	2,359	2,333	2,173
Year	2005	2006	2007	2008
	1,998	1,948	1,818	1,786
Year	2009	2010		
	1,665	1,723		
Oil and gas equivalent production (Thousand barrel of oil equivalent per day)				
Year	2001	2002	2003	2004
	3,746	3,960	3,905	3,772
Year	2005	2006	2007	2008
	3,518	3,473	3,315	3,248
Year	2009	2010		
	3,142	3,314		

TOTAL

Number of Employees				
Year	2001	2002	2003	2004
	122,025	121,469	110,783	111,401
Year	2005	2006	2007	2008
	112,877	95,070	96,442	96,959
Year	2009	2010		
	96,387	92,855		
Total Hours Worked (Million hours-workforce)				
Year	2001	2002	2003	2004
	N/A	N/A	N/A	397
Year	2005	2006	2007	2008
	423	429	432	446
Year	2009	2010		
	455	466		
Fatality (Workforce)				
Year	2001	2002	2003	2004
	41	14	11	16
Year	2005	2006	2007	2008
	22	18	15	8
Year	2009	2010		
	21	17		
Oil Spill (Loss of primary containment >1 barrel)				
Year	2001	2002	2003	2004
	215	165	286	350
Year	2005	2006	2007	2008
	489	708	766	464
Year	2009	2010		
	458	399		
Lost Time Injury Rate (LTIR per million hours worked-workforce)				
Year	2001	2002	2003	2004
	7.5	5.9	5	3.9
Year	2005	2006	2007	2008
	3.6	3	2.4	2.1
Year	2009	2010		
	1.9	1.6		

Total Recordable Injury Rate (TRIR per million hours worked-workforce)				
Year	2001	2002	2003	2004
	15.4	11.8	9.5	7.4
Year	2005	2006	2007	2008
	6.3	5.1	4.2	3.6
Year	2009	2010		
	3.1	2.6		
Oil and Liquids Production (Thousand barrel per day)				
Year	2001	2002	2003	2004
	1,497	1,635	1,714	1,741
Year	2005	2006	2007	2008
	1,665	1,550	1,550	1,479
Year	2009	2010		
	1,433	1,404		
Natural Gas Production (Millions of cubic feet per day)				
Year	2001	2002	2003	2004
	4,061	4,532	4,786	4,894
Year	2005	2006	2007	2008
	4,780	4,674	4,875	5,000
Year	2009	2010		
	4,920	5,648		
Oil and gas equivalent production (Thousand barrel of oil equivalent per day)				
Year	2001	2002	2003	2004
	2,197	2,416	2,539	2,585
Year	2005	2006	2007	2008
	2,489	2,356	2,391	2,341
Year	2009	2010		
	2,281	2,378		
Refined Product Capacity (Thousand barrel per day)				
Year	2001	2002	2003	2004
	2,580	2,660	2,696	2,692
Year	2005	2006	2007	2008
	2,708	2,700	2,598	2,604
Year	2009	2010		
	2,594	2,363		

APPENDIX C

EXPLORATION AND PRODUCTION GROUP DATA AND CALCULATIONS

TALISMAN

Number in Workforce (employees and contractors)				
Year	2003	2004	2005	2006
	2428	3253	3818	4404
Year	2007	2008	2009	2010
	4764	5360	4806	4600
Total Hours Worked (Thousand hours-workforce)				
Year	2003	2004	2005	2006
	4,856	6,506	7,636	8,808
Year	2007	2008	2009	2010
	9,528	1,072	9,612	9,200
Lost-time Incident Frequency (LTIF per million hours worked-workforce)				
Year	2003	2004	2005	2006
	3.7	2.55	1.8	1.95
Year	2007	2008	2009	2010
	1.65	1.83	1.08	0.88
Production Volume (Thousand Barrel of oil equivalent per day)				
Year	2003	2004	2005	2006
	445	398	434	452
Year	2007	2008	2009	2010
	423.7	432	425	417

WOODSIDE

Number in Workforce (employees and contractors)				
Year	2003	2004	2005	2006
	2,133	2,150	2,025	1,996
Year	2007	2008	2009	2010
	2,019	2,000	2,100	3,650
Year	2011			
	3,856			
Total Hours Worked (Workforce)				
Year	2003	2004	2005	2006
	15,308,604	12,890,836	23,811,758	29,599,071
Year	2007	2008	2009	2010
	32,168,510	37,774,249	59,952,906	29,599,071
Year	2011			
	29,258,318			
Lost Workday Incident				
Year	2003	2004	2005	2006
	27	15	21	32
Year	2007	2008	2009	2010
	25	39	41	28
Year	2011			
	20			
Total Recordable Incident				
Year	2003	2004	2005	2006
	95	69	90	153
Year	2007	2008	2009	2010
	155	187	229	177
Year	2011			
	140			
Lost Workday Frequency (LWF per million hours worked-workforce)				
Year	2003	2004	2005	2006
	1.8	1.2	0.9	1.1
Year	2007	2008	2009	2010
	0.79	1.03	0.68	0.95
Year	2011			
	0.68			

Total Recordable Frequency(TRF per million hours worked-workforce)				
Year	2003	2004	2005	2006
	6.2	5.4	3.8	5.1
Year	2007	2008	2009	2010
	4.82	4.95	3.82	5.98
Year	2011			
	4.78			
Production Volume (Million Barrel of oil equivalent per year)				
Year	2003	2004	2005	2006
	60.7	56.2	67.9	70.6
Year	2007	2008	2009	2010
	70.6	81.3	80.9	72.7
Year	2011			
	64.6			
Drilling Depth (Meters)				
Year	2005	2006	2007	2008
	93238	107197	89554	74198
Year	2009	2010		
	54623	51908		

APPENDIX D

CHEMICALS GROUP DATA AND CALCULATIONS

DOW CHEMICAL

Number of Employees				
Year	1995	1996	1997	1998
	39,500	40,300	42,900	39,000
Year	1999	2000	2001	2002
	39,200	53,300	52,700	50,000
Year	2003	2004	2005	2006
	46,400	43,200	42,400	42,600
Year	2007	2008	2009	2010
	45,900	46,100	52,200	49,500
Total Hours Worked (Million hours-employee)				
Year	1995	1996	1997	1998
	79	80.6	85.8	78
Year	1999	2000	2001	2002
	78.4	106.6	105.4	100
Year	2003	2004	2005	2006
	92.8	86.4	84.8	85.2
Year	2007	2008	2009	2010
	91.8	92.2	104.4	99
Injury and Illness Rate (IRR per 200,000 hours worked-employee)				
Year	1995	1996	1997	1998
	2.22	1.71	1.74	1.4
Year	1999	2000	2001	2002
	1.24	1.08	0.86	0.74
Year	2003	2004	2005	2006
	0.6	0.51	0.52	0.48
Year	2007	2008	2009	2010
	0.38	0.4	0.29	0.32
Loss of Primary Containment (LOPC-new portfolio per CCPS after 2005)				
Year	1995	1996	1997	1998
	2405	2257	2217	2046
Year	1999	2000	2001	2002
	1798	1729	1533	1393

Year	2003	2004	2005	2006
	997	791	1320	1105
Year	2007	2008	2009	2010
	920	768	461	355
Process Safety Incident (PSI-new portfolio per CCPS after 2005)				
Year	1995	1996	1997	1998
	143	138	137	110
Year	1999	2000	2001	2002
	84	74	81	77
Year	2003	2004	2005	2006
	65	52	90	58
Year	2007	2008	2009	2010
	69	74	44	45
Annual Net Sales (Million dollar)				
Year	1995	1996	1997	1998
	20,200	20,503	20,018	25,396
Year	1999	2000	2001	2002
	26,131	29,727	27,988	27,545
Year	2003	2004	2005	2006
	32,536	40,063	46,186	49,009
Year	2007	2008	2009	2010
	53,375	57,361	44,875	53,674

DOW CANADA

Number of Employees				
Year	1994	1995	1996	1997
	2,289	1,998	2,000	1,883
Year	1998	2009	2000	2001
	1,644	1,565	1,628	1,647
Year	2002	2003	2004	2005
	1,880	1,732	1,492	1,343
Injury and Illness Rate (IRR per 200,000 hours worked-employee)				
Year	1994	1995	1996	1997
	3.5	1.71	1.2	2.17
Year	1998	2009	2000	2001
	1.8	1.11	1.15	1.31
Year	2002	2003	2004	2005
	0.99	0.79	0.57	0.71
Leak, Breaks and Spills				
Year	1994	1995	1996	1997
	97	72	93	112
Year	1998	2009	2000	2001
	96	65	46	57
Year	2002	2003	2004	2005
	62	42	34	33
Dow’s Process Safety Incident				
Year	1994	1995	1996	1997
	N/A	1	2	5
Year	1998	2009	2000	2001
	3	4	2	1
Year	2002	2003	2004	2005
	3	0	3	3
Production Volume (Million kilograms)				
Year	1994	1995	1996	1997
	5851	7811	7592	6483
Year	1998	2009	2000	2001
	6525	7625	8485	9347
Year	2002	2003	2004	2005
	9797	9457	7945	8302

Direct Energy Usage (Trillion-joules)				
Year	1994	1995	1996	1997
	31,594	333,53	32,567	31,961
Year	1998	2009	2000	2001
	30,602	33,169	33,770	45,520
Year	2002	2003	2004	2005
	42,029	39,435	32,653	33,291

DUPONT

Number of Employees				
Year	1996	1997	1998	1999
	97,000	98,000	101,000	94,000
Year	2000	2001	2002	2003
	93,000	79,000	79,000	81,000
Year	2004	2005	2006	2007
	60,000	60,000	59,000	60,000
Year	2008	2009	2010	
	60,000	58,000	60,000	
Total Hours Worked (Million hours-employee)				
Year	1996	1997	1998	1999
	194	196	202	188
Year	2000	2001	2002	2003
	186	158	158	162
Year	2004	2005	2006	2007
	120	120	118	120
Year	2008	2009	2010	
	120	116	120	
Process Safety Incident per CCPS				
Year	1996	1997	1998	1999
	155	140	103	80
Year	2000	2001	2002	2003
	93	30	14	8
Year	2004	2005	2006	2007
	7	6	20	12
Annual Net Sales (Million dollar)				
Year	1996	1997	1998	1999
	23,644	24,088	24,767	26,918
Year	2000	2001	2002	2003
	28,268	24,726	24,006	26,996
Year	2004	2005	2006	2007
	27,340	26,639	27,421	29,378
Year	2008	2009	2010	
	30,529	26,109	31,505	
Annual Net Income (Million dollar)				

Year	1996	1997	1998	1999
	2991	3108	2913	219
Year	2000	2001	2002	2003
	2314	4328	1841	1002
Year	2004	2005	2006	2007
	1780	2053	3148	2988
Year	2008	2009	2010	
	2007	1755	3031	

EASTMAN

Number of Employees				
Year	2007	2008	2009	2010
	10,500	10,500	10,000	10,000
Occupational Injury and Illness Rate (OII per 200,000 hours worked-employee)				
Year	2007	2008	2009	2010
	0.8	0.75	0.6	0.79
Day Away from Work Rate (DAFWR per 200,000 hours worked-employee)				
Year	2007	2008	2009	2010
	0.08	0.16	0.11	0.11
Process Safety Incident per CCPS				
Year	2007	2008	2009	2010
	5	5	8	7
Production Volume (Million kilograms)				
Year	2007	2008	2009	2010
	4,994	4,823	4,714	4,809
Net Earnings (Million dollar)				
Year	2007	2008	2009	2010
	300	346	136	438
Annual Net Sales (Million dollar)				
Year	2007	2008	2009	2010
	5,513	5,936	4,396	5,482

FORMOSA

Number of Employees				
Year	2004	2005	2006	2007
	2,133	2,150	2,025	1,996
Year	2008	2009	2010	
	2,019	2,000	2,100	
Total Hours Worked (Thousand hours-employee)				
Year	2004	2005	2006	2007
	4,266	4,300	4,05	3,992
Year	2008	2009	2010	
	4,038	4,000	4,200	
Lost Workday Incident Rate (LWIR per 200,000 hours worked-employee)				
Year	2004	2005	2006	2007
	0.37	0.86	0.58	0.42
Year	2008	2009	2010	
	0.23	0	0.4	
Total Recordable Incident Rate (TRIR per 200,000 hours worked-employee)				
Year	2004	2005	2006	2007
	1.12	1.73	0.76	0.75
Year	2008	2009	2010	
	0.78	0.43	0.79	
Process Safety Incident Rate (PSIR per 200,000 hours worked-employee)				
Year	2004	2005	2006	2007
	0.2	0.3	0.2	0.3
Year	2008	2009	2010	
	0.03	0.03	0.03	
Process Safety Severity Rate (PSSR per 200,000 hours worked-employee)				
Year	2004	2005	2006	2007
	6.04	3.81	0.21	0.43
Year	2008	2009	2010	
	0.08	0.08	0.06	
Production Volume (Thousand Tons)				
Year	2004	2005	2006	2007
	4,600	4,400	4,600	4,750
Year	2008	2009	2010	
	4,300	4,400	5,100	

Energy Usage (Billion-joules)				
Year	2004	2005	2006	2007
	31,280	30,800	29,900	28,975
Year	2008	2009	2010	
	26,660	28,160	31,620	

HUNTSMAN

Total Recordable Incident Rate (TRIR per 200,000 hours worked-employee)				
Year	2004	2005	2006	2007
	N/A	0.82	0.85	0.74
Year	2008	2009		
	0.61	0.49		
Process Safety Incident Number				
Year	2004	2005	2006	2007
	31	30	48	42
Year	2008	2009		
	36	17		
Energy Usage (Trillion-joules)				
Year	2004	2005	2006	2007
	150,000	140,000	120,000	70,000
Year	2008	2009		
	56,000	50,000		

APPENDIX E

DRILLING CONTRACTOR GROUP DATA AND CALCULATIONS

NOBLE CORPORATION

Number in Workforce (Employees and contractors)				
Year	2004	2005	2006	2007
	5,300	5,567	6,336	6,600
Year	2008	2009	2010	
	6,000	5,700	5,900	
Total Hours Worked				
Year	2004	2005	2006	2007
	11,008,012	11,833,656	12,696,413	13,426,878
Year	2008	2009	2010	
	12,000,000	11,400,000	11,800,000	
Total Recordable Incident Rate (TRIR per 200,000 hours worked)				
Year	2004	2005	2006	2007
	0.74	1.17	0.77	0.89
Year	2008	2009	2010	
	0.64	0.43	0.6	
Lost Time Incident Rate (LTIR per 200,000 hours worked)				
Year	2004	2005	2006	2007
	0.11	0.25	0.03	0.12
Year	2008	2009	2010	
	0.11	0.05	0.1	
Operating Days (Under contractual terms)				
Year	2004	2005	2006	2007
	16426	19603	19287	19395
Year	2008	2009	2010	
	18904	17893	17700	
Total Drilling Depth Capacity (Feet)				
Year	2004	2005	2006	2007
	1,352,300	1,537,250	1,543,050	1,518,425
Year	2008	2009	2010	
	1,496,900	1,383,650	1,597,950	
Recordable Case/ Operating Days (Per 100 days)				
Year	2004	2005	2006	2007

	0.25	0.35	0.25	0.31
Year	2008	2009	2010	
	0.20	0.14	0.20	
Recordable Case/ Drilling Depth Capacity (Per 10,000 feet)				
Year	2004	2005	2006	2007
	0.30	0.45	0.32	0.39
Year	2008	2009	2010	
	0.26	0.18	0.22	
Lost-Time Case/ Operating Days (Per 100 days)				
Year	2004	2005	2006	2007
	0.037	0.076	0.010	0.041
Year	2008	2009	2010	
	0.035	0.016	0.033	
Lost-Time Case/ Drilling Depth Capacity (Per 10,000 feet)				
Year	2004	2005	2006	2007
	0.045	0.096	0.012	0.053
Year	2008	2009	2010	
	0.044	0.021	0.037	

PARKER DRILLING

Number in Workforce (Employees and contractors)				
Year	2000	2001	2002	2003
	3,542	3,654	2,898	2,920
Year	2004	2005	2006	2007
	3,014	3,040	2,628	3,087
Year	2008	2009	2010	
	2,766	2,011	2,372	
Total Hours Worked (Thousand hours-workforce)				
Year	2000	2001	2002	2003
	7,084	7,308	5,796	5,840
Year	2004	2005	2006	2007
	6,028	6,080	5,256	6,174
Year	2008	2009	2010	
	5,532	4,022	4,744	
Total Recordable Incident Rate (TRIR per 200,000 hours worked)				
Year	2000	2001	2002	2003
	2.84	2.67	1.8	1.78
Year	2004	2005	2006	2007
	1.06	0.97	0.86	0.81
Year	2008	2009	2010	
	0.66	0.48	0.63	
Operating Days (Under contractual terms)				
Year	2000	2001	2002	2003
	14235	16297	13267	8050
Year	2004	2005	2006	2007
	11317	13692	10602	11915
Year	2008	2009	2010	
	12716	9402	14527	
Total Drilling Depth Capacity (Feet)				
Year	2000	2001	2002	2003
	755,265	838,455	694,205	491,750
Year	2004	2005	2006	2007
	545,800	675,580	575,140	693,960
Year	2008	2009	2010	
	683,890	466,430	498,280	

Recordable Case/ Operating Days (Per 100 days)				
Year	2000	2001	2002	2003
	0.71	0.60	0.39	0.65
Year	2004	2005	2006	2007
	0.28	0.22	0.21	0.21
Year	2008	2009	2010	
	0.14	0.10	0.10	
Recordable Case/ Drilling Depth Capacity (Per 10,000 feet)				
Year	2000	2001	2002	2003
	1.33	1.16	0.75	1.06
Year	2004	2005	2006	2007
	0.58	0.43	0.39	0.36
Year	2008	2009	2010	
	0.27	0.21	0.30	

VITA

Mengtian Wang received his Bachelor of Engineering degree in Safety from Zhejiang University of Technology at Hangzhou in 2010. He joined the Mary Kay O’Connor Process Safety Center at Texas A&M University to pursue a Master of Science degree in Safety Engineering, under the guidance of Dr. M. Sam Mannan.

Mengtian Wang may be reached at Mary Kay O'Connor Process Safety Center, the Department of Chemical Engineering, Texas A&M University, 417 Jack E Brown Engineering Building, College Station, Texas 77843-3122. His email is chewmt0229@gmail.com.