Effective implementation of process safety management

K Naicker

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Supervisor: Prof PW Stoker

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Abstract

Title: Effective implementation of process safety management

Key Words: Process Safety Management, Safety Culture, Leadership Commitment, Employee Participation, Mechanical Integrity

Process Safety Management (PSM) is concerned with the safe handling of products, safe production of products and the safe operation of the process as confirmed by Thrower (2013). The Occupational Safety and Health Administration (OSHA) (2012) promulgated the PSM standard in 1992, which incorporated fourteen elements, to decrease the occurrence of process safety incidents.

Walt and Frank (2007) described the cracks in the implementation of PSM programs, emanating from major process safety incidents and compliance audits. This was confirmed by the decaying process safety performance observed in recent years. It was thus proposed that an analysis into the diverse process safety incident causes and its comparison against the implemented OSHA PSM program, would suggest its associated shortcomings.

The aim of the study was to determine the most effective approach to implement and sustain PSM in an organisation to prevent and manage the occurrence of major industrial catastrophes.

A semi-qualitative study was conducted through the employment of a survey questionnaire and published incident investigation reports. A total of fifty random process safety incidents were interpreted from published and accredited secondary literature. Most of the secondary literature was obtained from the Health and Safety Executive (HSE) and Centre for Chemical Process Safety (CCPS) databases.

From the study findings, Mechanical Integrity (MI) failures were found to significantly and consistently contribute to process safety incidents. Further analysis specifically concluded that equipment or control failure was the significant cause. Employee Participation (EP) was found to statistically correlate with the other elements. The researcher found that literature agreed with

the aforementioned findings and this study verified that the EP element was instrumental in the implementation of the other elements.

The researcher used literature to confirm that safety culture and leadership commitment was crucial to effective and sustainable PSM programs. The case study analysis validated this observation. Therefore the most effective approach to implement and sustain PSM was to adopt the DuPont, Centre for Chemical Process Safety (CCPS), Risk Based PSM framework or Energy Institute (EI) models. To conclude, this study was effective as all the objectives and the aim was achieved.

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List of Abbreviations

AIChE	American Institute of Chemical Engineers
API	American Petroleum Industry
CA	Compliance Audits
CAAA	Clean Air Act Amendments
CCPS	Centre for Chemical Process Safety
CSB	Chemical Safety Board
CTR	Contractors
DOM	Department of Manpower
EI	Energy Institute
EP	Employee Participation
EPA	Environmental Protection Agency
EPR	Emergency Planning and Response
EPSC	European Process Safety Centre
FER	Fires, Explosions and Releases
HSE	Health and Safety Executive
HSE-MS	Health, Safety and Environmental Management Systems
HSSE	Health, Security, Safety and the Environment
HWP	Hot Work Permit
II	Incident Investigation
KPI	Key Performance Indicators
KT	Kienbaum and TÜV SÜD
MAE	Major Accident Event
MI	Mechanical Integrity
MOC	Management of Change
NEP	National Emphasis Program
OGP	Association of Oil and Gas Producers

OHS	Occupational Health and Safety
OP	Operating Procedures
OSHA	Occupational Safety and Health Administration
PHA	Process Hazard Analysis
PQV	Program Quality Verification
PSI	Process Safety Information
PSM	Process Safety Management
PSSR	Pre Start-up Safety Review
SHE	Safety, Health and Environment
TR	Training
TS	Trade Secrets

Chapter 1: Introduction

1.1. Background

Several decades ago as early as the 1920s, in South Africa alone the Department of Manpower (DOM) reported figures on injuries and fatalities. Further in the 1950s and 1960s as a result of the industrial revolution on an international scale, a new generation of chemical plants were commissioned (Hawksley, 1984). This promoted economic growth and created new job opportunities.

Unfortunately this boom was largely concentrated on achieving significant economic gains rather than safer operations. These newer plants were operated at higher pressures and temperatures, with increased inventories of flammable or toxic chemicals. The consequence was an increase in the occurrence of safety, health and environmental (SHE) incidents as described by Hawksley (1984).

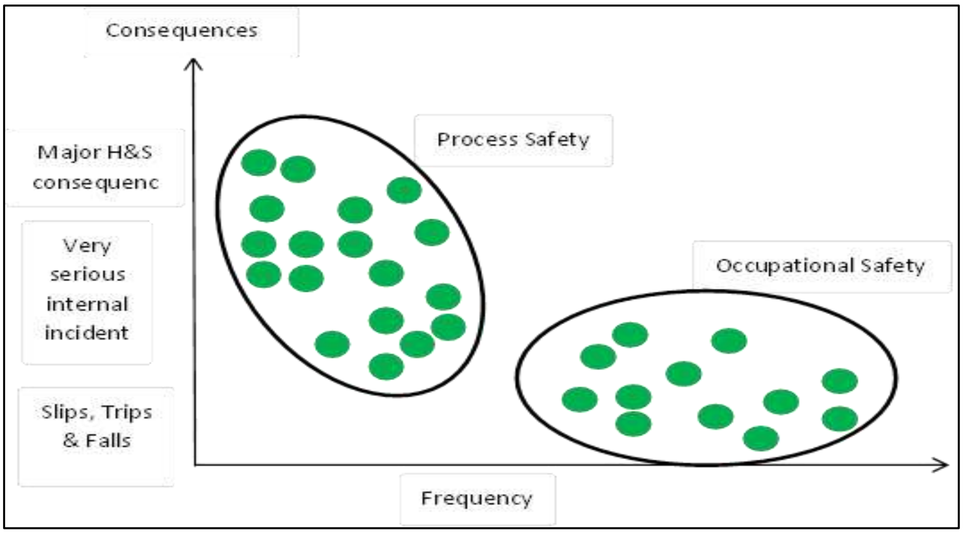

Figure 1 – Relationship between Process safety and occupational safety (ABB, 2013)

There are two main categories of safety incidents; namely process safety and occupational safety incidents. The above diagram, Figure 1, depicts the relationship between these two types of safety incidents. Occupational safety incidents consist of the more routine slips, trips and falls. These incidents are considered to be low severity and high probability incidents (ABB, 2013). ABB (2013) described process safety incidents as high severity and low probability major accidents resulting in fire, explosions and releases (FER). Therefore process safety incidents commonly resulted with SHE consequences.

Both occupational and process safety is equally important, with each requiring its own approach and management. Numerous good practices and guidance notes are available for occupational safety. However, process safety had not always received the attention it deserved, therefore the adoption of a new approach was necessitated (ABB, 2013).

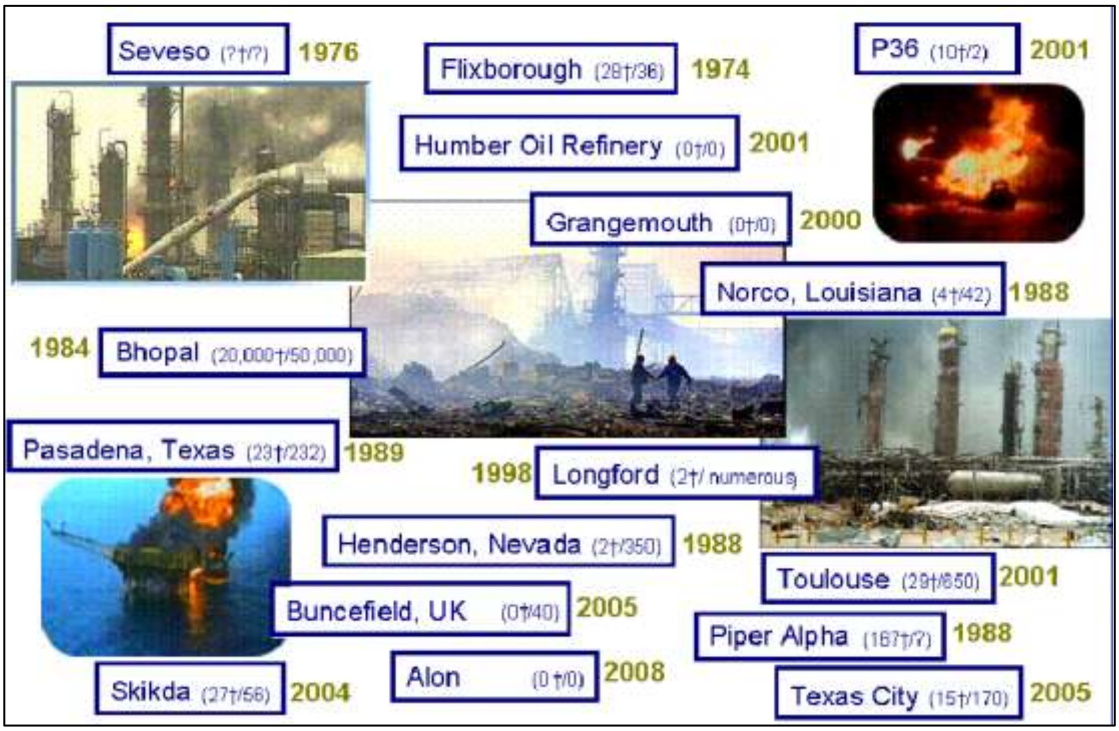

Figure 2 – Major incidents in the last decades (Schouwenaars, 2008)

Figure 2 illustrates an overview of the diverse major accidents in refinery and chemical sites across the world over the last thirty years. Taking Action on Risk (2012) further described some of these pivotal process safety incidents. As a result of this devastating trend, Process Safety Management (PSM) was conceived soon after the Bhopal incident. The American Institute of Chemical Engineers (AIChE) was tasked with the challenge, to lead this collaborative effort to eliminate catastrophic process incidents (AIChE, 2012).

Reviewing recent safety performance, the annual report published by the Health and Safety Executive (HSE) for the period of 2010 to 2011, noted 175 work related fatalities and over 200,000 reportable injuries (HSE, 2011a). The Chemical Safety Board (CSB, 2012) also described some of the more recent process safety incidents that occurred; an explosion in Yeosu at a chemical plant which killed seven employees, a release of toxic chlorine gas in Korea that hospitalized eleven employees and a fire in an underground mine in China that killed eleven employees.

Thus despite the fact that over twenty years had passed since the conception of PSM, process safety incidents, namely FERs, still remain very relevant in this industrial age.

1.2. Statement of the problem

A business's success is dependent on low operational costs which can allude to increased profit margins. These lower operational costs mostly manifested in managerial short-cuts, as previously indicated by Hawksley (1984) and Schouwenaars (2008) with the major industrial incidents. Therefore it was evident that this low perception of risk coupled with high risk appetite, resulted in the mismanagement of highly hazardous processes. This led to the occurrence of SHE incidents.

Consequently industry safety governance was promulgated mandating the implementation and management of PSM programs to prevent SHE incidents (AlChE, 2012). Walt and Frank (2007: 1) stated that, “Unfortunately, serious incident and audits all too frequently point to gaps in PSM implementation”. Non-conformances with respect to PSM element requirements resulted in severe penalties as illustrated in Table 1.

Table 1 – Cost of Non-Compliance (IRC, 2006)

Violation	Description	Fine
Other-than-Serious	A violation directly related to job safety and health, but likely not to cause death or serious physical harm.	Up to $7,000 per violation
Serious	A violation where there is substantial probability that death or serious physical harm and that the employer knew, or should have known, of the hazard.	Up to $7,000 per violation
Wilful	A violation involves an employer intentionally and knowingly committing or a violation that the employer commits with plain indifference to the law. The employer either knows what they are doing constitutes a violation, or is aware that a hazardous condition existed and made no reasonable effort to eliminate it.	Up to $70,000 per violation, with a minimum of $5,000 per violation
Repeated	A violation where OSHA finds a substantially similar violation during a re-inspection.	Up to $70,000 for each repeat
Failure to Abate	Employer failing to correct a previously cited violation beyond the prescribed abatement date.	Up to $7,000 per day

In this new industrial era, business's competitiveness and legislative compliance is respectively becoming increasingly more rife and stringent as detailed by the HSE (2012) and OHS (2012). This was confirmed by the Chemical Industries Association (2008: 2) who stated that, “The threat of legal action for non-compliance is a very real inducement, but the threat of serious injury or fatalities to staff, loss of production and income, damage to company's reputation, the potential for increased insurance premiums and the loss of valuable production assets are equally good reasons even though they may not involve the law directly”.

Harstad and Pitblado (2008) compiled safety incident data, primarily extracted from a few major internationally listed companies’ annual reports. Figure 3 below depicts the information gathered and it is evident from the populated graphs that from 1993, there had been a steady decline in the quantity of occupational incidents at these aforementioned process companies. Therefore the process safety incident performance of industries across the globe was observed to continually improve on a yearly basis. However the graph trend indicated declining process safety incident performance post 2005.

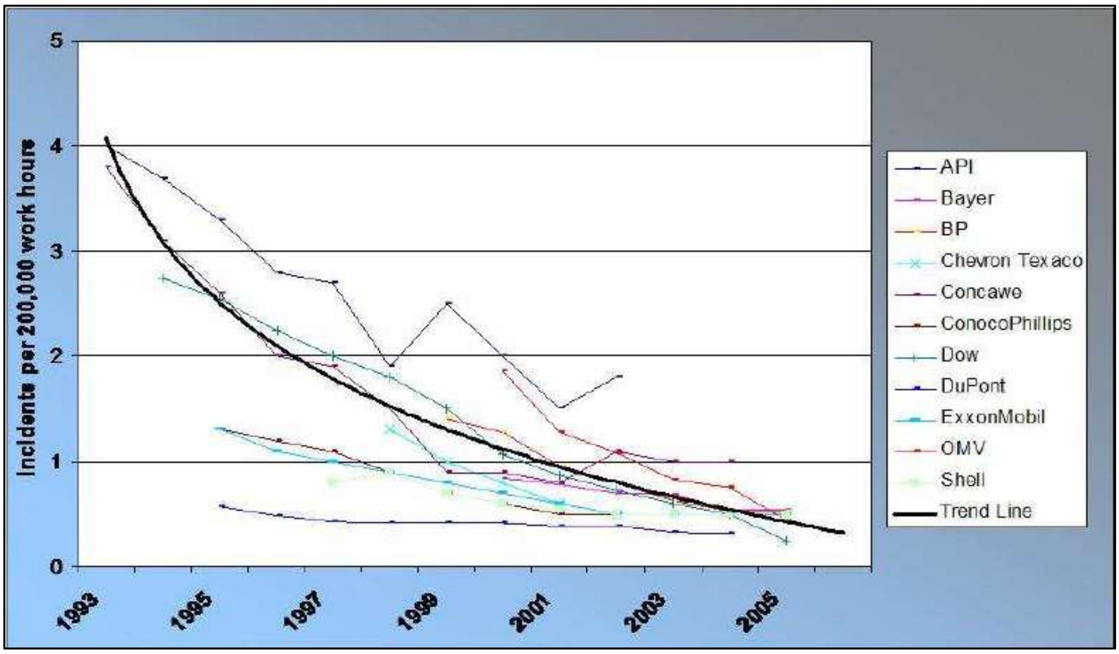

Figure 3- Major Process Industry Companies' Occupational Safety Performance

(Harstad & Pitblado, 2008)

DuPont’s published safety performance, as illustrated in Figure 4, verifies this trend observed by Harstad and Pitblado (2008). Significant reduction in the medium and high severity process incidents was observed until 2001, thereafter marginal decreases in process safety incident occurrence was noted. In some cases a sporadic increase in process safety incidents was observed. Obermiller (2008) presented the process safety performance statistics, compiled by the American Petroleum Industry (API), also agreed with DuPont’s process safety incident history.

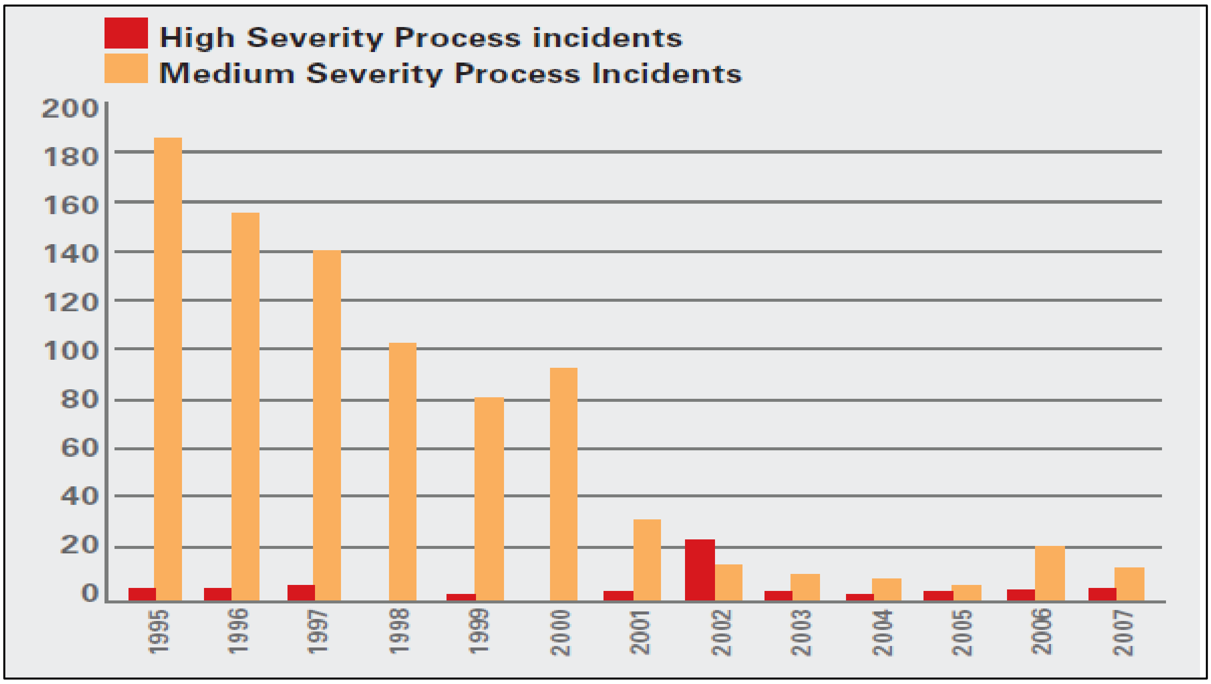

Figure 4–DuPont Process Safety incident history (DuPont, 2008)

It was clear from the aforementioned safety performance graphs, that since PSM was conceived, there was a reduction in the occurrence of process safety incidents. Despite the implementation of PSM by many process companies throughout the world, the minimal process safety performance observed in recent years posed numerous questions.

<u>This is the research problem</u>; essentially the PSM programs need to be optimised in order to further reduce the occurrence of process safety incidents.

It was thus proposed that an analysis into the diverse process incident causes and its comparison against the implemented PSM programs would suggest the shortcomings in existing programs.

1.3. Aims of the study

The aim of the study was to determine the most effective approach to implement and sustain PSM in an organisation, to prevent and manage the occurrence of major industrial catastrophes.

1.4. Objectives

The following research objectives were set for the study:

- To determine the PSM elements that significantly contributed to the occurrence of process safety incidents;
- To identify the PSM elements' failures that resulted in process safety incidents;
- To identify any relationships between the PSM elements in order to improve implementation effectiveness; and
- To perform case study analysis on three international companies' approach to PSM.

1.5. Outline of the Study

It was imperative to identify the gaps in the existing PSM programs in order to propose an effective PSM program. A semi-qualitative study was conducted through the employment of a survey questionnaire and published incident investigation reports. This study consisted of five chapters which are described below.

Chapter 1 introduces the reader to the background of PSM and its associated global performance in curbing process safety incidents. The research problem is also presented, along with the study's aim and objectives.

Chapter 2 deliberates over the different PSM models and its associated transformation over the years. These PSM models are also compared to the Occupational Safety and Health Administration (OSHA) PSM model, to assess their merits. Literature is consulted and summarised for the purpose of the study arguments. The investigated companies' profiles and their operational processes are discussed.

Chapter 3 discusses the methodology applied to gather the PSM incident causes and to identify the associated element failures.

The findings are presented and interpreted in Chapter 4. Literature is cited to confirm or contradict the findings raised.

The accomplishments with respect to the prescribed aims and objectives are concluded in Chapter 5. Further study recommendations are also stated. These recommendations are postulated to uplift the merits of this study alluding to more defined findings.

Chapter 2: Literature Survey

2.1. Introduction

The approach to the literature survey encompassed the identification and reviewing of works by acknowledged authorities on PSM and its associated programs. Numerous sources of literature was identified, however limited scholarly articles was surveyed.

The definition of PSM was investigated, as well as several implemented PSM programs throughout the world. This was conducted to understand the origins of the PSM programs and its associated transformation through the decades. These PSM programs were compared and further analysed to gauge their approach.

The implementation of PSM in three global chemical processing companies was studied. This was undertaken to determine the effectiveness of their respective implementations. Therefore the literature survey entailed the understanding of these companies' profiles and scale of operations.

2.2. Definition of PSM

There were numerous descriptions of PSM, PSM incidents and as to what a PSM program entailed. Many similarities in these definitions and underlying principles were observed as illustrated by the following examples.

DuPont (2008: 1), a global leader in PSM implementation and compliance, stated that, "Process Safety Management (PSM) is the application of programs, procedures, audits and evaluations to a manufacturing or industrial process to identify understand and control process hazard risks, creating systematic business improvements and safety standards".

The United States Chemical Manufacturers' Association (CMA, 1985) indicated that, "process safety is the control of hazards which are caused by maloperation or malfunction of the processes used to convert raw materials into finished products, which may lead to the unplanned release of hazardous material".

Shimada et al. (2009: 1) defined PSM as, "Process safety management (PSM) is a management system that is focused on prevention of, preparedness for, mitigation of, response to, and restoration from catastrophic releases of chemicals or energy from a process associated with a facility".

Kelly (2010: 2) described PSM as, "Process Safety Management is a comprehensive framework of activities for managing the integrity of a hazardous (chemical) operation. Its goal is to eliminate (prevent and mitigate) loss of containment incidents. Loss of containment events can lead to fire, explosion or toxic effects and may result in large numbers of casualties".

Kraus (2011) defined PSM as, "Whenever there are processes that employ temperature and pressure to change the molecular structure or create new products from chemicals, the possibility exists for fires, explosions or releases of flammable or toxic liquids, vapours, gases or process chemicals. The control of these undesired events requires a special science called process safety management. The terms process safety and process safety management are most commonly used to describe the protection of employees, the public and the environment from the consequences of undesirable major incidents involving flammable liquids and highly hazardous materials".

"The proactive and systematic identification, evaluation, and mitigation or prevention of chemical releases that could occur as a result of failures in process, procedures, or equipment", as stated by Toups (2003: 11).

There were common points in the PSM descriptions as follows:

- Maintaining the integrity of process equipment;
- Compilation and institutionalisation of safe operating procedures; and
- Identification of process risks and its respective prevention and mitigation.

Figure 5 below graphically explains the relationship of PSM in line with the above definitions.

Figure 5 – PSM Overview (Thrower, 2013)

In simple terms, PSM was therefore concluded to entail the safe handling of products, safe production of products and the safe operation of the process. This was achieved through the management of systems, compliance to legislation and maintaining a safety culture.

2.3. PSM Models

Since the first legislative implementation of PSM by OSHA (2000), there were numerous other authoritive bodies that developed PSM programs. The intent was to assist industry in combating the occurrence of process safety incidents. Therefore organisations devised and effected PSM procedures and standards tailored for the global industrial landscape. These different models and approaches was identified, reviewed and compared in this aspect of the literature survey.

2.3.1. OSHA

In 1992, OSHA (2000) promulgated the Process Safety Management of Highly Hazardous Chemicals standard in the United States of America. It contains the requirements for the management of hazards associated with processes that utilized highly hazardous chemicals to help assure safe work environments. This standard’s requirement included; hazard management of hazardous chemicals, comprehensive management program of technologies, procedures and practices.

There are fourteen elements apart of this PSM model, which covered diverse aspects, with respect to the management of an operational facility and process environment as illustrated in Figure 6. It involves (OSHA, 2000) the management and training of employees and service providers, conducting safety risk assessments, management of work and modifications conducted in the operational areas, maintenance of the plant equipment and incident management.

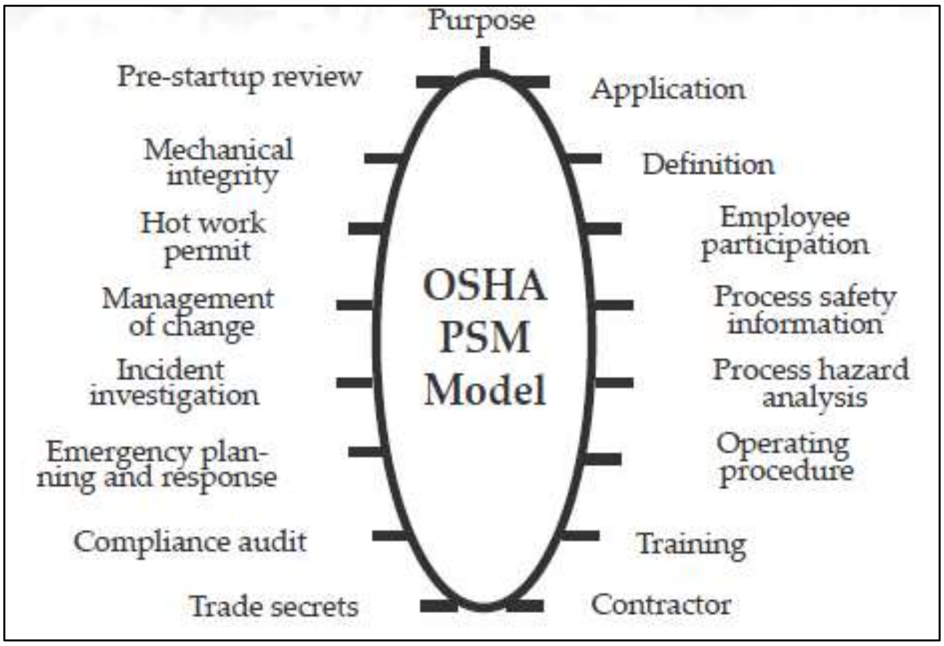

Figure 6 – OSHA Model (OSHA, 2012)

2.3.2. DuPont

DuPont (2008) pioneered the concepts and implementation of a PSM system in the 1960s. For over two hundred years, rigorous management of risk and process safety was at the foundation of their operating culture. By the late 1980s, OSHA and Environmental Protection Agency (EPA) recognised the benefits of the DuPont system and procured their services to develop the PSM regulations that currently govern industry (DuPont, 2008). DuPont consists of 175 operations in 70 countries (DuPont, 2008).

The DuPont PSM model is illustrated in Figure 7. At the cornerstone of this model, were the three fundamental aspects, namely; management, leadership and commitment. It is further segregated into three broad dimensions, consisting of their respective fourteen sub-elements reminiscent of the OSHA model.

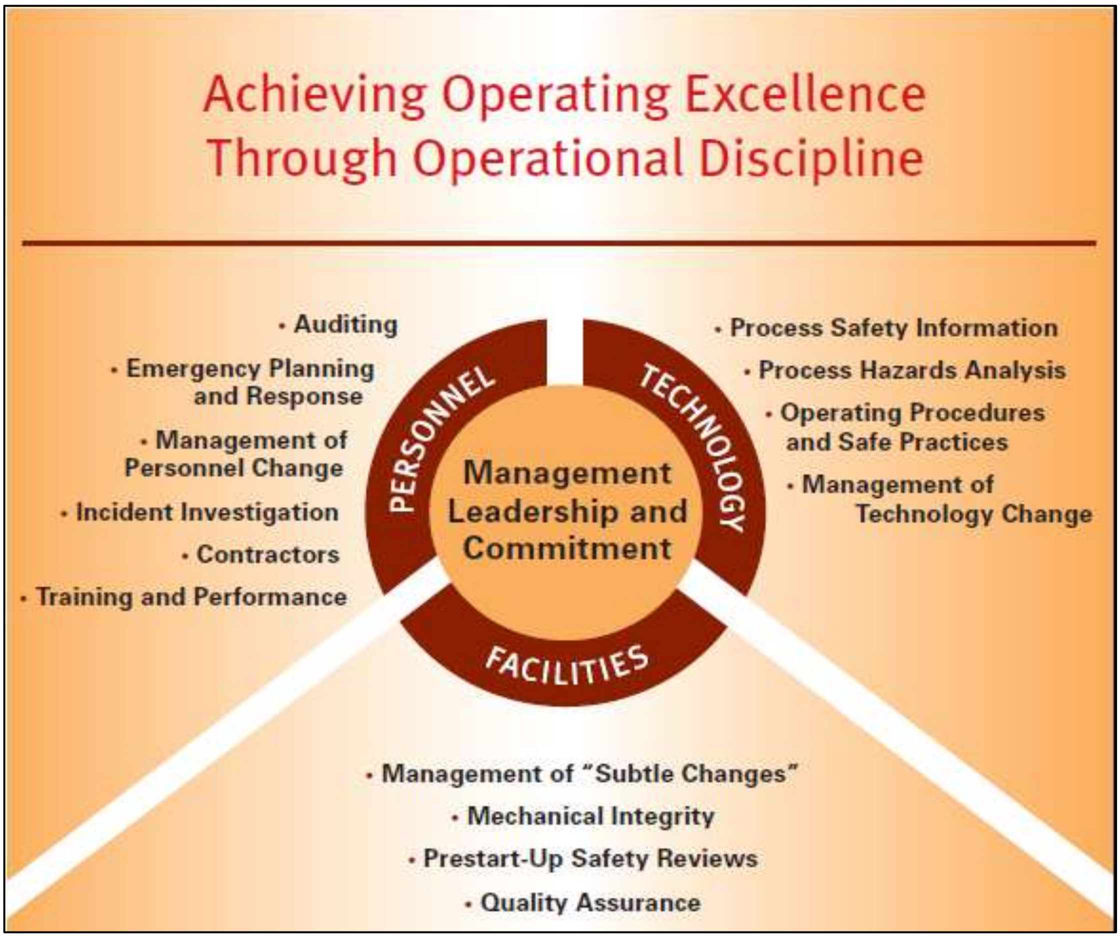

Figure 7 – DuPont PSM Model (DuPont, 2008)

This approach was consistent with a wide range of regulatory and professional guidelines in its comprehensive control of these three dimensions, namely (DuPont, 2008):

- **Facilities: To manufacture and handle hazardous materials**
  DuPont focused on a rigorous asset management program. This encompassed quality assurance, pre start-up safety reviews and on-going management of mechanical integrity.

- **Technology: Of the process**
  The periodic review and optimisation of technology ensured that the plant remained fit for operation. Process hazard analysis risk assessments assisted in managing the plant safely.

- **Personnel: Who operate, maintain, and support the process.**
  The level of personnel competence and experience was vital as the human element was interwoven through all the elements of PSM. Training of employees and compliance to developed operating procedures was necessary to assure safe operation of equipment.

It is evident that DuPont's PSM model closely resembled the OSHA model. The similarity of this model to the OSHA model can be attributed to the fact that DuPont assisted OSHA in developing its PSM model (DuPont, 2008).

2.3.3. SEMS

After the 2010 BP oil spillage tragedy, also known as the Deepwater Horizon, a review of safety management systems was undertaken. The outcome was the formulation of regulatory requirements in the form of a Safety & Environmental Management System (SEMS) for offshore facilities. Although SEMS was developed for off-shore application, the insights could be applied to onshore facilities.

There are fifteen elements in SEMS as depicted in Figure 8. This model also closely resembles the OSHA PSM model with the inclusion of the following elements; general provisions, records and documentation and safe work practices.

The Safe Work Practices and the Operating Procedure elements were deemed to respectively address the occupational task risks and the safe operation of the facility. The Records and Documentation, Safety and Environment Information and General Provisions were considered to fall under the OSHA Process Safety Information (PSI) element.

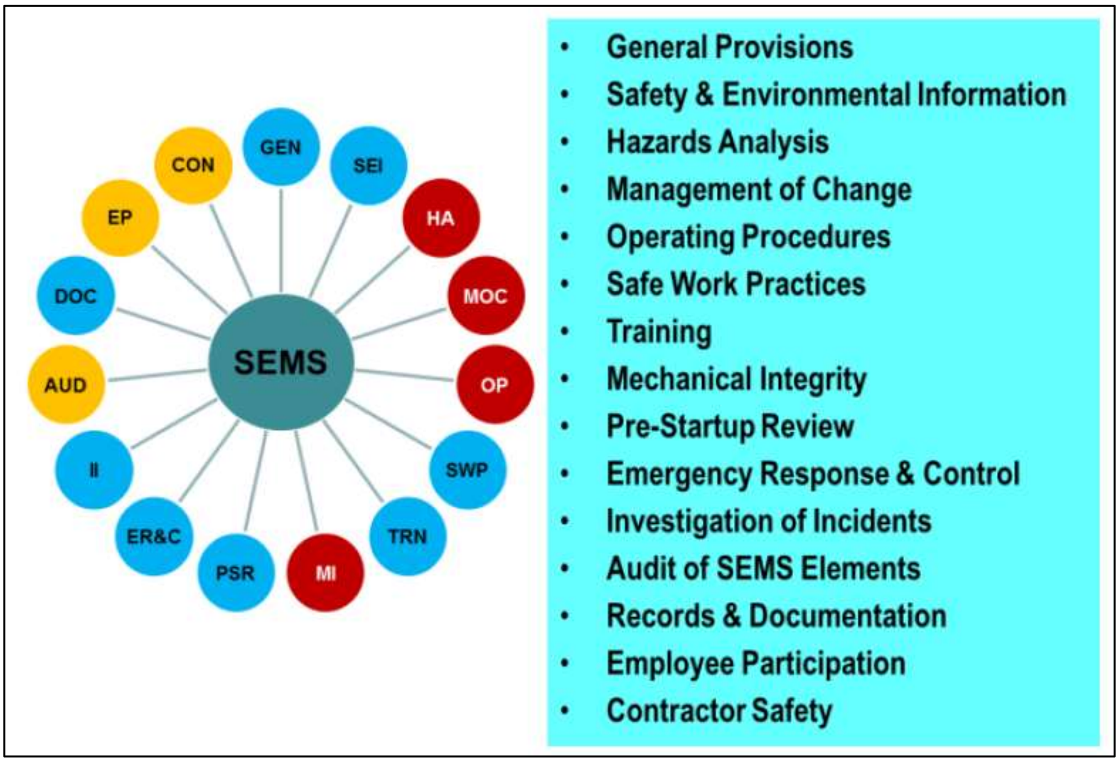

Figure 8 – Key SEMS Elements (Maher, 2011)

2.3.4. EPA Risk Based Process

Roughly four months after the OSHA publication, the Clean Air Act Amendments (CAAA) was enacted into law (EPA, 2011). The CAAA in partnership with the EPA required the promulgation, pursuant to the OSHA standard, of a chemical process safety standard to prevent the accidental release of chemicals that threatened employees and the public (EPA, 2011). This standard comprised a list of highly flammable hazardous chemicals inclusive of toxic, highly reactive, flammable and explosive substances.

This EPA model is similar to the SEMS model, as it is a risk based approach as depicted in Figure 9. It consists of twenty elements with five dimensions; Commit to Process Safety, Manage Risk, Understand Hazards and Risk, Manage Risk and Learn from Experience. It resembles the OSHA model with different terminology for some of the elements. This model also includes additional elements such as; Conduct of Operations, Stakeholder Outreach, Safe Work Practices, Compliance to Standards and Process Safety Competency and Management Review and Continuous Improvements.

Figure 9 – Risk Based PSM Framework (Bradshaw, 2012)

The additional elements were considered to focus on the compliance to procedures, training and competency of the facility employee. This alluded to the emphasis placed on the human involvement in PSM. This was strengthened through the Workforce Involvement, Stakeholder Outreach, Conduct of Operations and Contractor Management elements. Compliance and effectiveness of operations was ascertained through audits of standards and general audits.

2.3.5. CCPS

The chemical industry tasked AIChE leadership to commence and lead a collaborative effort to eliminate catastrophic process incidents. This undertaking incorporated the following objectives as described by AIChE (2012); to achieve the advancement of technology, management practices, serving as the foremost resource for information on process safety, support process safety in engineering and promoting process safety.

In 1985 the Centre for Chemical Process Safety (CCPS) was formed under the supervision of AIChE (2012). The CCPS published more than a dozen process safety guideline books and procedures within the first five years of inception (AIChE, 2012). Seventeen charter member companies and several other companies adopted and committed to the CCPS approaches to govern their processes.

The CCPS PSM model is illustrated in Figure 10 and contains twelve elements. This model places emphasis on the human aspect incorporating the Human Factor and Accountability elements. It is more simplified than the OSHA model, as it did not include the PSSR and Emergency Preparedness and Response elements. Yet again, the Trade Secrets element did not feature as a sole element, as was the case with the previous models.

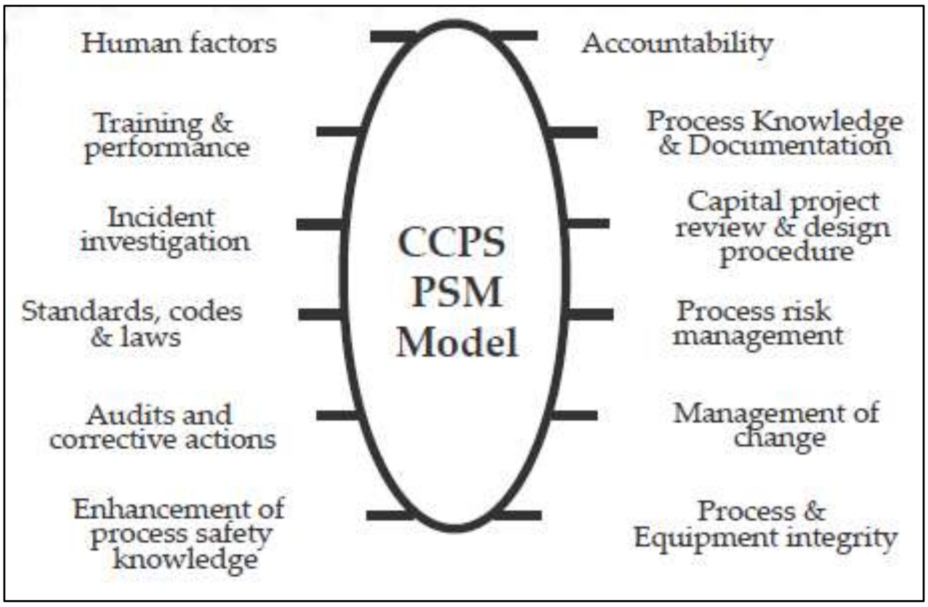

Figure 10 - CCPS Model (OSHA, 2012)

2.3.6. ABB Model

ABB's PSM model is based on a risk-based approach tailored to a company. There are three dimensions to their approach as illustrated in Figure 11 (ABB, 2012):

- Plant and equipment must be of an appropriate design standard / integrity and be adequately maintained;
- Systems / procedures must be fit for purpose and practicable; and
- People must be adequately competent and work within a positive cultural framework that encourages safe behaviour and a belief that any injury, harm or damage can be avoided.

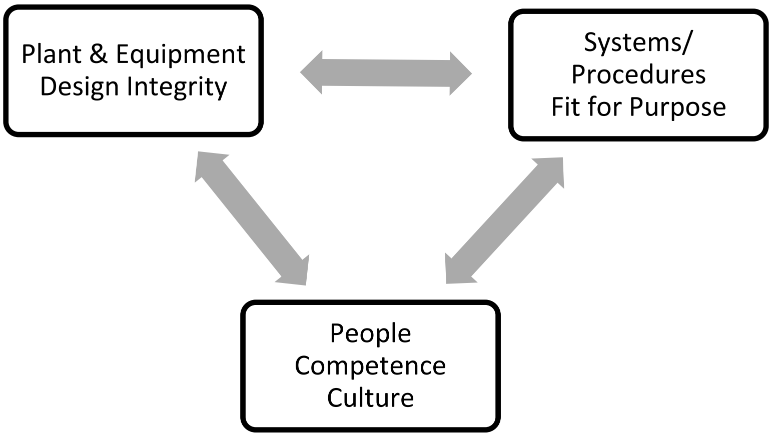

Figure 11 – ABB Approach (ABB, 2012)

Sustainable risk reductions are the foundations of this approach as depicted in Figure 12. This model is very different to the OSHA model and focuses more on a few OSHA PSM elements. These elements include the Process Hazard Analysis (PHA), Process Safety Information (PSI), Management of Change (MOC) and Mechanical Integrity (MI) elements. Recalling DuPont's model, ABB's model resembled this segregation approach into three dimensions. Both ABB and DuPont provided consultancy and compliance services, therefore their model resemblances were attributed to their comprehensive knowledge of PSM implementation and effectiveness in industry.

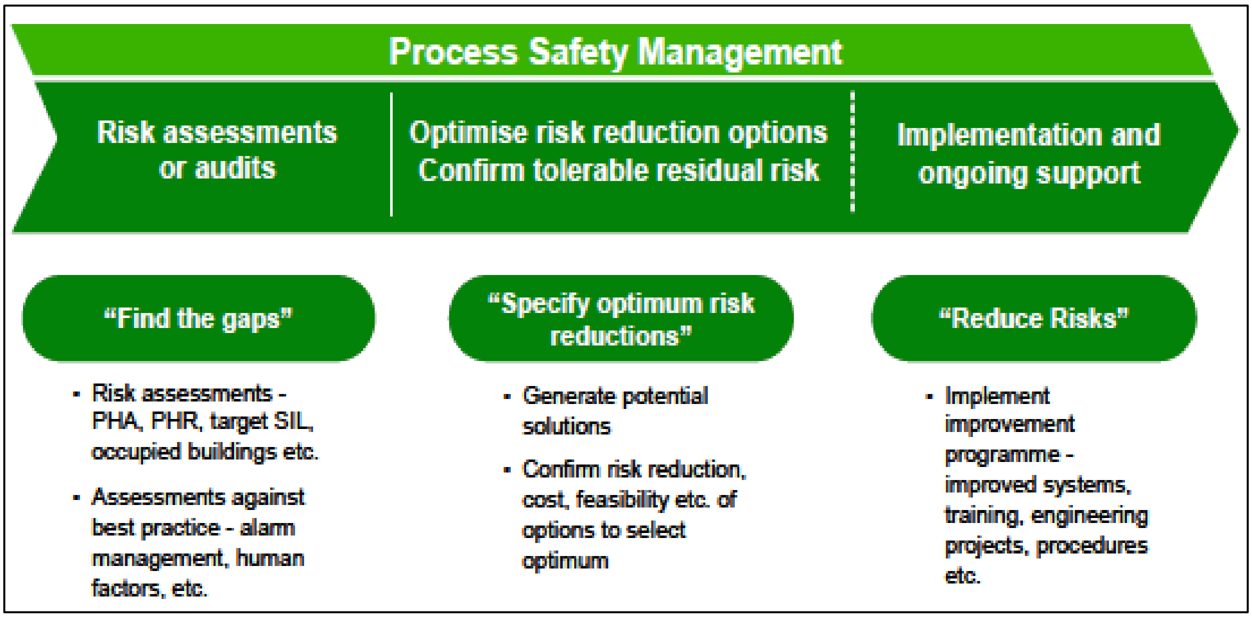

Figure 12 – ABB Approach (ABB, 2012)

2.3.7. Kienbaum and TÜV SÜD

Kienbaum and TÜV SÜD (KT) developed a Process Safety Excellence model as depicted in Figure 13. It consists of two legs, namely; Asset Safety Integrity and Process Safety Management. Again, this segregation into dimensions resembled the DuPont and ABB models. KT indicated that Process Safety Excellence assisted in the management of risks (Kienbaum & SÜD, 2013)

Figure 13–KT PSM Model (Kienbaum & SÜD, 2013)

Therefore this approach is similar to the ABB and SEMS models as it is also a risk based approach. Asset Safety Integrity entailed the safe operation, management and maintenance of the facility equipment. The PSM aspect is concerned with the management, skills, compliance and performance of the human involvement.

Essentially, KT had divided the OSHA PSM model and combined these elements, to form their new model which contained six elements. Each of these six elements contained another five sub-elements, which summated to thirty sub-elements as illustrated in Figure 14. This model is considered to encompass the most comprehensive list of elements from all the surveyed PSM models. However the intricacy of this model may result in its ineffective implementation in industry.

Figure 14–KT PSM Model (Kienbaum & SÜD, 2013)

2.3.8. Oil and Gas

The International Association of Oil and Gas Producers (OGP) is a global forum, tasked with identifying and sharing industrial best practices to ultimately operate safer. OGP (2013) was formed in 1974, to develop effective communications between the international regulators and upstream industry. OGP (2013) is composed of the world's leading industry associations, private, publicly traded and state owned oil and gas companies. The management committee is represented by BP PLC, Chevron Corporation, Exxon Mobil, ConocoPhilips, PetróleoBrasileiro SA, Shell International Exploration & Production BV, Statoil, Total and Schlumberger (OGP, 2013). The Managing Major Incident Risk Task Force of OGP (2013) published asset integrity guidance, to assist organisations to reduce major incident risks. It focuses on asset integrity management on both new and existing assets at every lifecycle stage.

OGP (2008: 3) defined asset integrity as, "…an outcome of good design, construction and operating practices. It is achieved when fatalities are structurally and mechanically sound and perform the processes and produce the products for which they were designed''. Therefore OGP's (2008) approach over the past two decades consisted of the development and implementation of a structured Health, Safety and Environmental Management Systems (HSE-MS). The asset integrity report, issued by OGP (2008), built on this and focused on the following aspects, namely; asset integrity risk management process, barriers, integrity throughout the asset lifecycle, human factors, competences, and monitoring and review. These aspects were further investigated and summarised as follows:

2.3.8.1. Asset integrity risk management process

In essence the Plan, Do, Check, Act methodology (OGP, 2008) was applied to identify the internal and external influences, conduct a risk assessment, treat the risk and monitor and periodically review the risk. The internal and external context consisted of applicable legislation to corporate risk management standards. The risk assessment revolved around communication and consultation, to conduct risk analysis and risk evaluation. Thereafter risk treatment considered all feasible options to minimise the residual risk to as low as reasonably practicable. Monitoring the assets while in operation allowed for an enhanced understanding of the risks and good practices. This facilitated improved risk management, as well as the incorporation of new knowledge (OGP, 2008).

2.3.8.2. Barriers

OGP (2008: 6) defined a barrier as, “a functional grouping of safeguards and controls selected to prevent the realisation of a hazard’’. Such barriers consisted of process procedures, plant equipment and the human element. Typical equipment barriers consisted of prevention, detection, control and mitigation and emergency response (OGP, 2008). Performance standards and emergency response was also prescribed as barriers due to their complexity, availability, reliability and functionality. OGP (2008) recommended the application of the Swiss Cheese and Bow Tie Models to assess and improve on barrier removal.

2.3.8.3. Integrity throughout the asset lifecycle

This facet considered the optimisation of early design choices which positively influenced asset integrity effectiveness and cost through the life of the facility (OGP, 2008).

Therefore this model resembled the KT model's two legged segregation, with the addition of the Barrier element to individually address risk management. The asset lifecycle element strongly involved the human aspect. This was a recurring theme in many of the PSM models.

2.3.9. Energy Institute

The Energy Institute (EI) is the leading chartered professional membership across the energy industry for both individuals and organisations. Its membership includes over 13,500 individuals and 300 companies in 100 countries (EI, 2010). As a Royal Charter organisation it focuses predominantly on promoting safe and environmentally responsible and efficient supply and use of energy in all applications and forms (EI, 2010).

The EI Process Safety Committee compiled a high level framework for PSM across the energy industry sectors. EI considered this as a simple and systematic approach applicable to both small and large energy sectors (EI, 2010). This approach highlighted key aspects in order to assure integrity of operations inclusive of maintenance, technical, operational and organisational and human factors. This framework consisted of three dimensions, namely PSM Focus Areas, PSM Elements and PSM Expectations. Each level was further explored and interpreted as follows (EI, 2010):

2.3.9.1. PSM Focus Areas

This set out the imperative high level components of the PSM framework. These focus areas were composed of the following (EI, 2010):

2.3.9.1.1. Process Safety Leadership

This area described how an organisation should define, communicate and implement the level of performance necessitated.

2.3.9.1.2. Risk Identification and Assessment

This area addressed how an organisation should identify and assess the risks to assure integrity of operations.

2.3.9.1.3. Risk Management

This area defined how an organisation should implement and manage the control measures identified in the previous focus area.

2.3.9.1.4. Review and Improvement

This focus area described how the organisation should measure, review and improve from compliance assessment on the EI framework.

2.3.9.2. PSM Elements and Expectations

Within each focus area were a variety of elements, which further divulged into the requirements to assure its integrity. These elements prescribed the expectations of the organisation and compliance thereof. EI (2012) described twenty elements inclusive of expectations which were incorporated into the focus areas.

Although this model contained elements from the OSHA model, it closely resembled the KT and EPA Risk Based models in terms of element comprehensiveness and intricacy. It further agreed with DuPont’s cornerstone dimensions in terms of its PSM focus areas.

To recap, since its inception the OSHA PSM model had evolved over the years, through the various new PSM models. This was attributed to the diverse incidents that shook the process safety arena. In summary, several strong themes were observed to emerge from these PSM models. These themes were described as follows:

- Constant maintenance and inspections to assure asset integrity;
- Workforce involvement entailed establishing the correct safety culture to eliminate human factor errors;
- Continuous population of comprehensive process safety information and its incorporation into operation procedures and risk analysis;
- Strong leadership with commitment to safety; and
- Rigorous identification and risk analysis. Thereafter the compilation, implementation and monitoring of preventative and mitigating control measures.

2.4. Comparison to OSHA Elements

As deliberated, the OSHA PSM model paved the road for the development of further PSM models. In this part of the literature survey, these PSM models were further investigated to determine their approach in relation to each OSHA PSM element. Before comparative studies were undertaken, the OSHA PSM model was thoroughly reviewed and summarised.

The CAAA required OSHA's process safety standard to govern the processing of highly hazardous chemicals, inclusive of; toxic, flammable, highly reactive and explosive substances. Further CAAA specified fourteen minimum fundamentals to be included in the OSHA standard which was described as follows (OSHA, 2012):

(1) Develop and maintain written safety information identifying workplace chemical and process hazards, equipment used in the processes, and technology used in the processes;

(2) Perform a workplace hazard assessment, including, as appropriate, identification of potential sources of accidental releases, identification of any previous release within the facility that had a potential for catastrophic consequences in the workplace, estimation of workplace effects of a range of releases, and estimation of the health and safety effects of such a range on employees;

(3) Consult with employees and their representatives on the development and conduct of hazard assessments and the development of chemical accident prevention plans and provide access to these and other records required under the standard;

(4) Establish a system to respond to the workplace hazard assessment findings, which shall address prevention, mitigation, and emergency responses;

(5) Periodically review the workplace hazard assessment and response system;

(6) Develop and implement written operating procedures for the chemical processes, including procedures for each operating phase, operating limitations, and safety and health considerations;

(7) Provide written safety and operating information for employees and employee training in operating procedures, by emphasizing hazards and safe practices that must be developed and made available;

(8) Ensure contractors and contract employees are provided with appropriate information and training;

(9) Train and educate employees and contractors in emergency response procedures in a manner as comprehensive and effective as that required by the regulations promulgated;

(10) Establish a quality assurance program to ensure that initial process-related equipment, maintenance materials, and spare parts are fabricated and installed consistent with design specifications;

(11) Establish maintenance systems for critical process-related equipment, including written procedures, employee training, appropriate inspections, and testing of such equipment to ensure on-going mechanical integrity;

(12) Conduct pre-start-up safety reviews of all newly installed or modified equipment;

(13) Establish and implement written procedures managing change to process chemicals, technology, equipment and facilities; and

(14) Investigate every incident that resulted in or could have resulted in a major accident in the workplace, with any findings to be reviewed by operating personnel and modifications made, if appropriate.

These guidelines were a collection of diverse practices that culminated toward PSM institutionalization. This minimum specification was incorporated into the PSM standard by deriving their respective element. Table 2 summarises these OSHA PSM elements with their associated prescriptions (OSHA, 2000):

Table 2 – Overview of the OSHA Elements (OSHA, 2012)

Element	Requirement
• Employee Participation (EP)	Required employee involvement in developing and executing a PSM program, particularly in the area of hazard evaluation.
• Process Safety Information (PSI)	Required the employer to compile information related to the nature of the chemical (or flammable) hazards involved, process technology, and process equipment.
• Process Hazard Analysis (PHA)	Required the employer to conduct a careful analysis of hazards involved with the process. Using one of several formal hazard analysis techniques, a team identified, evaluated, and recommended measures to eliminate, mitigate, or control hazards.
• Operating Procedures (OP)	Required the employer to develop and implement written operating procedures for the covered process over all phases of its operation including safe work practices.
• Training (TR)	Required employers to train all involved (including contractors) in operating the covered process on the hazards, operating procedures (normal & emergency), and safe work practices. The training was required for each person before they begin operating a covered process.
• Contractors (CTR)	For all contractors involved directly and in areas adjacent to covered processes, the employers need to evaluate the contractor's capabilities and safety history to assess their suitability for safe performance. In addition, all contractors expected to become involved in operating the covered process must receive training prior to their involvement in the operation.
• Pre Start-up Safety Review (PSSR)	Required that employers perform a detailed review of a new or modified (changed) system to insure the design is appropriate, construction adhered to design specifications, operating procedures was available, training was complete, process hazard analysis was completed, and all process safety information was current
• Mechanical Integrity (MI)	Required that employers develop and implement a methodical program for performing appropriate maintenance and equipment inspection/testing at proper frequencies to uncover equipment deficiencies before they fail.

Table 2 – Overview of the OSHA Elements (OSHA, 2012) (Continued)

Element	Requirement
• Hot Work Permit (HWP)	Required that employers develop a formal program to prevent fire and explosions from occurring while conducting hot work (welding, cutting, brazing, grinding, etc.) in and around the covered process.
• Management of Change (MOC)	Institute documented procedures aimed at insuring safe system operation as changes to the system occurred. The management of change process guided updates or development to process safety information, process hazard analyses, operating procedures, and training to insure all elements of the PSM program are current.
• Incident Investigation (II)	Required that employers investigated actual incidents or near-misses to understand the factors that contributed to the incident and to develop/resolve recommendations aimed at preventing their future occurrence. A formal incident investigation needed to begin with 48 hours of an incident.
• Emergency Planning and Response (EPR)	Required that employers conducted pre-planning for emergencies that may arise at the facility. At a minimum, the emergency planning needed to include notification procedures, escape routes, alarm systems and plant-wide training. More intensive efforts were required for situations where employees are expected to actively become involved in mitigating incidents.
• Compliance Audits (CA)	Involved critically evaluating a PSM program and the extent of its implementation at least every three years. The audit must certify the plant was in compliance with the standard or identify areas of non-compliance that the plant needed to address to bring the program back into compliance.
• Trade Secrets (TS)	This allowed employers to protect those aspects of their covered process considered a trade secret.

The above OSHA elements were used as the baseline PSM elements in terms of comparative studies. This was due to the fact that OSHA formalised and promulgated the first PSM system. Only the OGP and EI models were considered to be unique and acknowledged approaches. Therefore the following analysis described the differences between the OGP and EI PSM models against the OSHA PSM model. A summary of the expectations of each element was described.

2.4.1. Employee Participation (EP)

This OSHA element (OSHA, 2000) essentially required the participation and commitment from the employees and safety representatives in terms of the PSM programs. If employers do not comply and practice safe behaviours, then human errors can occur. Human error was a key factor in many major incidents (OGP, 2008), therefore the reduction of such errors forms apart of asset integrity. OGP (2008) highlighted the important aspects of human factors, which included; equipment design and controls layout, displays and alarms, work practices and procedures, work management and authorisation, task design and individual or team workload and process safety culture. These aspects were explained by OGP (2008) as follows:

2.4.1.1. Task design and individual or team workload

Human fatigue and overload alluded to human error. It was therefore required that tasks considered the employee’s capabilities, scope and duration to minimize fatigue and overload. Mandatory periodic rest for employees should be implemented to avoid effects or short and long term fatigue as well as high work load events such as shutdowns.

2.4.1.2. Process safety culture

The culture of safety in its entirety was required to address both process and occupational health and safety risks. Leadership played a pivotal role in ensuring participation from employees to simplify and improve the performance, availability and reliability of asset integrity barriers.

Similarly the EI presented three aspects that related to employee participation as follows (EI, 2010):

2.4.1.3. Leadership commitment and responsibility

Visible leadership commitment and accountability at all levels of the organisation will assure integrity of the operations. An organisation should define and adhere to process safety policies, targets and structure resources to achieve them.

2.4.1.4. Workforce involvement

High levels of health, safety, process safety and environmental performance required commitment from the entire workforce. Management was pivotal in ensuring alignment, involvement and empowerment of the whole workforce in the identification and management of hazards.

2.4.1.5. Process and operational status monitoring and handover

Comprehensive process and operational monitoring should be conducted, along with effective handover between working groups. This ensured safe operational continuity.

Therefore two common themes emerged from OGP and EI, namely; leadership commitment and safety culture. Table 3 summarises the EP requirements as described by EPA (1999):

Table 3 – EP Requirements (EPA, 1999)

• Write a plan.	Develop a written plan of action regarding how you will implement employee participation.
• Consult with employees.	Consult your employees and their representatives regarding conducting and developing PHAs and other elements of process safety management in the risk management program rule.
• Provide access to information.	Ensure that your employees and their representatives have access to PHAs and all other information required to be developed under the rule.

2.4.2. Process Safety Information (PSI)

PSI considered the process and equipment specifications to manage the plant in terms of maintenance and operability as follows (OSHA, 2000):

2.4.2.1. Process Chemical Hazards

The plant required a comprehensive acquisition of all the raw, intermediate and final materials, chemicals and products safety data sheets involved in the process.

2.4.2.2. Process Technology

The operability and process parameters needed to be well documented. This further included the safety operational limits, process schematics and troubleshooting procedures.

2.4.2.3. Process Equipment

Piping and instrument diagrams, mechanical flow diagrams, isometrics and equipment data sheets needed to be collected and documented for ease of reference and access. OGP (2008) built on OSHA's requirements and prescribed that sufficient process operating information, needed to be communicated to the process operator, to alert them of abnormal conditions. Therefore alarm management was included as well as the response time for action.

EI (2010) further described that applicable legislation needed to be comprehensively identified, fully understood and complied with, as it was a fundamental requirement. Also concise records and information was required to support safe operations. The longevity, accessibility and availability of such documentation must be instilled by an organisation. These models respectively increased the PSI requirements. Table 4 summarises the PSI requirements as described by EPA (1999):

Table 4 – PSI Requirements (EPA, 1999)

For chemicals, you must complete information on:	For process technology, you must provide:	For equipment in the process, you must include information on:
• Toxicity • Permissible exposure limits • Physical data • Reactivity • Corrosivity • Thermal & chemical stability • Hazardous effects of inadvertent mixing of materials that could foreseeably occur	• A block flow diagram or simplified process flow diagram • Information on process chemistry • Maximum intended inventory of the EPA-regulated chemical • Safe upper & lower limits for such items as temperature, pressure, flows, or composition • An evaluation of the consequences of deviation	• Materials of construction • Piping & instrument diagrams (P&IDs) • Electrical classification • Relief system design & design basis • Ventilation system design • Design codes & standards employed • Safety systems • Material and energy balances for processes built after June 21, 1999

2.4.3. Process Hazard Analysis (PHA)

The PHA element was emphasised as the most important element (OSHA, 2000), as it required the identification, analysis and mitigation of process risks. There are numerous hazard identification techniques that the diverse PSM models prescribe as depicted in Figure 15. Essentially each technique possesses merits in terms of identification and analysis of risk.

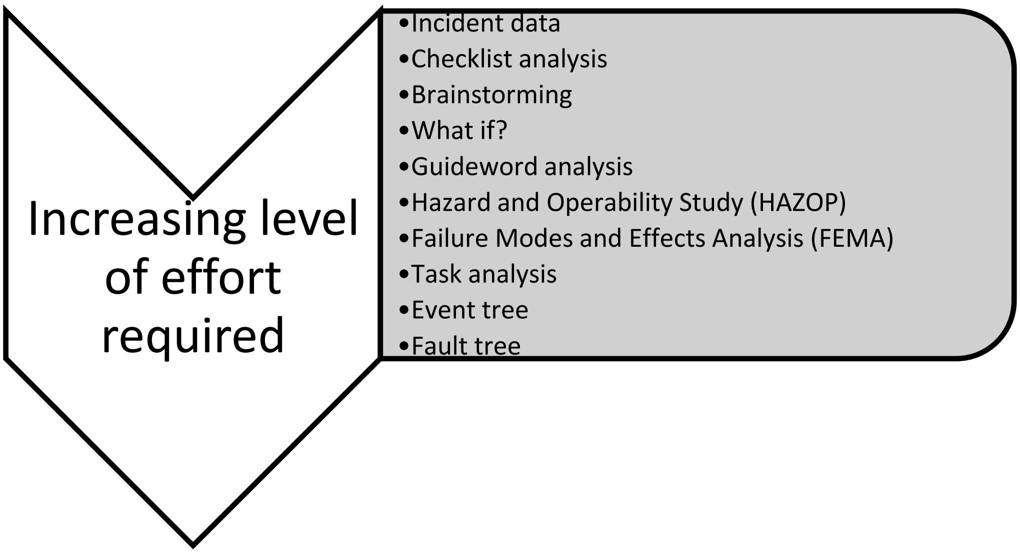

Figure 15 – Hazard Identification Techniques (WorkSafe, 2011)

Similarly OGP (2008) confirmed that an organisation must ensure that a comprehensive risk assessment process was implemented to manage arising operational risks. EI (2010) further recommended that the selected Key Performance Indicators (KPIs) should be aligned with the risk management process for the facility. Since there were numerous KPIs that an organisation can apply, much thought must be placed in the selection of the most value adding KPIs, for a specific industry based on its nature of operation. Therefore these models prescribed similar element requirements. Table 5 summarises the PHA requirements as described by EPA (1999):

Table 5 – PHA Requirements (EPA, 1999)

The PHA must cover::	Techniques must be one or more of:	Other requirements:
• Hazards of the process • Identification of previous, potentially catastrophic incidents • Engineering and administrative controls applicable to the hazards • Consequence of failure of controls • Siting • Human factors • Qualitative evaluation of health and safety impacts of control failure	• What If • Checklist • What If/Checklist • Hazard and Operability Study (HAZOP) • Failure Mode and Effects Analysis (FMEA) • Fault Tree Analysis • Appropriate equivalent methodology	• Analysis must be done by a team, one member of which has experience in the process, one member of which is knowledgeable in the PHA technique • A system must be developed for addressing the team's recommendations and documenting resolution and corrective actions taken • The PHA must be updated at least once every five years • PHAs and documentation of actions must be kept for the life of the process

2.4.4. Operating Procedures (OP)

The plant operating procedures prescribed the tasks to be conducted and should be technically accurate, easily interpretable and periodically reviewed (OSHA, 2000). Work practices and procedures was also a part of the OGP (2008) model and essentially all employers needed to clearly understand their roles and responsibilities. The procedures needed to be easily understood, concise and describe troubleshooting conditions. EI (2010) clarified the differences between operating procedures and work practices as follows:

2.4.4.1. Operating manuals and procedures

An organisation must establish safe operating parameters according to legislation and structure this operational philosophy into operating manuals and procedures.

2.4.4.2. Standards and practices

Robust standards and safe working practices enhance the health, safety, process safety and environmental performance. Therefore an organisation was to ensure that required work practices and standards to support maintenance, projects and operational activities are identified, developed and consistently applied.

Thus these models contained many overlapping requirements. Table 6 summarises the OP requirements as described by EPA (1999):

Table 6 – OP Requirements (EPA, 1999)

Steps for each operating phase	Operating limits	Safety & health considerations	Safety systems & their functions
• Initial startup • Normal operations • Temporary operations • Emergency shutdown • Emergency operations • Normal shutdown • Startup following a turnaround or emergency shutdown • Lockout/tagout • Confined space entry • Opening process equipment or piping • Entrance into the facility	• Consequences of deviations • Steps to avoid, correct deviations	• Chemical properties & hazards • Precautions for preventing chemical exposure • Control measures for exposure • QC for raw materials and chemical inventory • Special or unique hazards	• Address whatever is applicable

2.4.5. Training (TR)

This element defined the quality of necessary training programs, delivered to various disciplines of employees and contractors, inclusive of competency declarations (OSHA, 2000). Competent and proficient resources needed to be recruited and strategically placed in the diverse organisational positions, in order to effectively control the operation. Therefore EI (2010) described that employee selection; placement, competency and health assurance are key aspects when training employees.

Each position needed a defined range of skills, knowledge and personal attributes (OGP, 2008) which would enable that employee to successfully execute their tasks. The organisation may also specify training and proficient levels as deemed by formal qualifications. However an organisation will need to assure such training and verify proficiency. Periodic review of competence can include refresher training. Thus competent employees in diverse positions within the facility enabled the operation to perform effectively.

2.4.6. Contractors (CTR)

The effective selection and management of contractors was essential to reduce their risks from being introduced into a plant. The contractors needed to adopt the plant safety principles (OSHA, 2000). This was aligned with the EP, PHA and TR requirements. Establishing and maintaining stakeholders' confidence was important in order to maintain an organisation's license to operate (EI, 2010). Therefore an organisation was required to sustain good working relationships between stakeholders, in order to understand and address their concerns.

Operational interfaces of third parties, such as service providers, utilities or products needed to be identified, assessed and managed. The third parties that perform work within the operation need to adhere to the organisations safety requirements in a manner that was consistent and compatible. No clear requirements from OGP were observed. Therefore both the OSHA and EI models concluded that contractor management was vital to assure that an organisation's risk profile remained the same. Table 7 summarises the CTR requirements as described by EPA (1999):

Table 7 – CTR Requirements (EPA, 1999)

You must...	Your contractor must...
• **Check safety performance.** When selecting a contractor, you must obtain and evaluate information regarding the safety performance of the contractor.	• **Ensure training for its employees.** The contractor must train its employees to ensure that they perform their jobs safely and in accordance with your source's safety procedures.
• **Provide safety and hazards information.** You must inform the contractor of potential fire, explosion, or toxic release hazards; and of your emergency response activities as they relate to the contractor's work and the process.	• **Ensure its employees know process hazards and applicable emergency actions.** The contractor must assure that contract employees are aware of hazards and emergency procedures relating to the employees' work.
• **Ensure safe practices.** You must ensure that you have safe work practices to control the entrance, presence, and exit of contract employees in covered process areas.	• **Document training.** The contractor must prepare a record documenting and verifying adequate employee training.
• **Verify that the contractor acts responsibly.** You must verify that the contractor is fulfilling its responsibilities.	• **Ensure its employees are following your safety procedures.**
	• **Inform you of hazards.** The contractor must tell you of any unique hazards presented by its work or of any hazards it finds during performance.

2.4.7. Pre Start-up Safety Review (PSSR)

The commissioning of existing, modified or new equipment and plants posed risk to an operation. Therefore it was mandatory for a new plant or modification to be subjected to a risk study prior to it being commissioned. This PSSR was generally performed as a checklist to identify any potential failures during commissioning (OSHA, 2000). The EI (2010) accounted for operational readiness and process start-up, and prescribed the implementation of a systematic process to verify that the plant or equipment was safe to operate. Again no clear requirements from OGP were observed.

Thus EI and OSHA stances coincided with each other. Table 8 summarises the PSSR requirements as described by EPA (1999):

Table 8 – PSSR Requirements (EPA, 1999)

Design Specifications	Adequate Procedures	PHA/MOC	Training
• Confirm that new or modified construction and equipment meet design specifications.	• Ensure that procedures for safety, operating, maintenance, and emergencies are adequate and in place.	Perform a PHA and resolve or implement any recommendations for new process. Meet management of change requirements for modified process.	• Confirm that each employee involved in the process has been trained completely.

2.4.8. Hot Work Permit (HWP)

A form of work authorization must be issued for hot work operations conducted on or near a covered process. This permit had to document the fire prevention and protection requirements (OSHA, 2000). OGP (2008) defined work management and authorisation as:

- A permit to work system must be implemented for tasks that possessed the potential to impact the facility or employees; and
- Such permit systems should provide clear definitions and consistent application of isolation and integrity testing minimum standards for equipment in operation.

EI (2010) also prescribed a work control, permit to work and task risk management control system. The appropriate management of executed project or maintenance work assisted in the prevention of FER incidents with HSE consequences. Effective work control, permit to work and task risk management arrangements should be implemented and followed. It was evident that EI, OSHA and OGP's position on HWP was aligned. Table 9 summarises the HWP requirements as described by EPA (1999):

Table 9 – HWP Requirements (EPA, 1999)

• Issue a hot work permit.	You must issue this permit for hot work conducted on or near a covered process.
• Implement fire prevention and protection.	You must ensure that the fire prevention and protection requirements in 29 CFR 1910.252(a) are implemented before the hot work begins. The permit must document this.
• Indicate the appropriate dates.	The permit should indicate the dates authorized for hot work.
• Identify the work.	The permit must identify the object on which hot work is to be performed.
• Maintain the permit on file.	You must keep the permit on file until workers have completed the hot work operations.

2.4.9. Mechanical Integrity (MI)

This standard entailed the review of maintenance programs and schedules, on the equipment that store or process highly flammable or toxic products (OSHA, 2000). OGP (2008) indicated that changes to asset design, operating limits or maintenance aspects, should be subjected to a change control and reviewed by a competent technical authority. Further the instituting of metrics on equipment assisted in the evaluation of asset integrity performance against predefined goals. OGP (2008) described the lifecycle management of equipment as follows:

2.4.9.1. Acquisition

The asset integrity information must be included in the acquisition and absorbed by such costs.

2.4.9.2. Equipment design and controls layout

This focused on the arrangement of equipment in terms of ease of access. It also considered the labelling of controls, colour schemes and ease of activation of control systems.

2.4.9.3. Performance standard verification

The operational facility itself should be subjected to direct assessment at frequent intervals. This entailed the inspection of physical conditions to check for evidence of deterioration in equipment through to emergency equipment.

2.4.9.4. Decommissioning, dismantling and removal

This was a crucial stage, as the normal operational barriers may be compromised or eliminated. Therefore process materials from equipment and the site must be removed for safety.

EI (2010) stated that necessary inspection and maintenance requirements must be identified and executed to sustain safe operations. Legislative requirements and maintenance philosophies needed to be identified and adhered to. Safety critical equipment and devices assisted in preventing FER incidents with HSE consequences. Such devices and equipment needed to be identified, monitored and maintained for operation.

Therefore these models prescribed similar element requirements. Table 10 summarises MI as described by EPA (1999):

Table 10 – MI Requirements (EPA, 1999)

Written procedures	Training	Inspection & testing	Equipment deficiencies	Quality assurance
• Establish & implement written procedures to maintain the integrity of process equipment.	• Train process maintenance employees in an overview of the process and its hazards. • Make sure this training covers the procedures applicable to safe job performance.	• Inspect & test process equipment. • Use recognized and generally accepted good engineering practices. • Follow a schedule that matches the manufacturer's recommendations or more frequently if prior operating experience indicates is necessary. • Document each inspection & test with: Date, inspector name, equipment identifier, test or inspection performed, results.	• Correct equipment deficiencies before further use of process equipment or whenever necessary to ensure safety.	• Establish a QA program for new construction & equipment, newly installed equipment, maintenance materials, and spare parts & equipment.

2.4.10. Management of Change

This aspect detailed the procedures for managing changes to processes. The anticipated changes to a process must be thoroughly evaluated in order to comprehensively assess the impact on the business and employee safety and health (OSHA, 2000). EI (2010) also agreed with this approach as any change that can impact the organisation, needed to undergo a risk assessment to ensure that it supported the organisation.

OGP (2008) practiced inherently reliable concepts as this would avoid the management of difficult asset integrity concerns. While the asset design was being populated, the asset integrity barriers for maintenance needed to be developed in parallel. Poor detailed design may considerably reduce asset integrity by making barriers ineffective.

Complete documentation was needed to describe the asset design, operating and maintenance strategies which alluded to the importance of PSI. The finalisation of all procedures that comprised operating, maintenance and testing was mandated. Further competent personnel must be recruited and trained as described in the TR element. This training must incorporate functional performance testing of equipment. Therefore OSHA, EI and OGP were deemed to align their approach. Table 11 summarises MOC as described by EPA (1999):

Table 11 – MOC Requirements (EPA, 1999)

MOC procedures must address:	Employees affected by the change must:	Update process safety information if:	Update operating procedures if:
• Technical basis for the change • Impact on safety and health • Modifications to operating procedures • Necessary time period for the change • Authorization requirements for proposed change	• Be informed of the change before startup • Trained in the change before startup	• A change covered by MOC procedures results in a change in any PSI required under EPA's rule (see § 67.65)	• A change covered by MOC procedures results in a change in any operating procedure required under EPA's rule (see § 67.69)

2.4.11. Incident Investigation

OSHA (2000) stated that all incidents needed to undergo a thorough investigation to identify the sequence of events and causes. This enabled the determination and application of effective corrective measures.

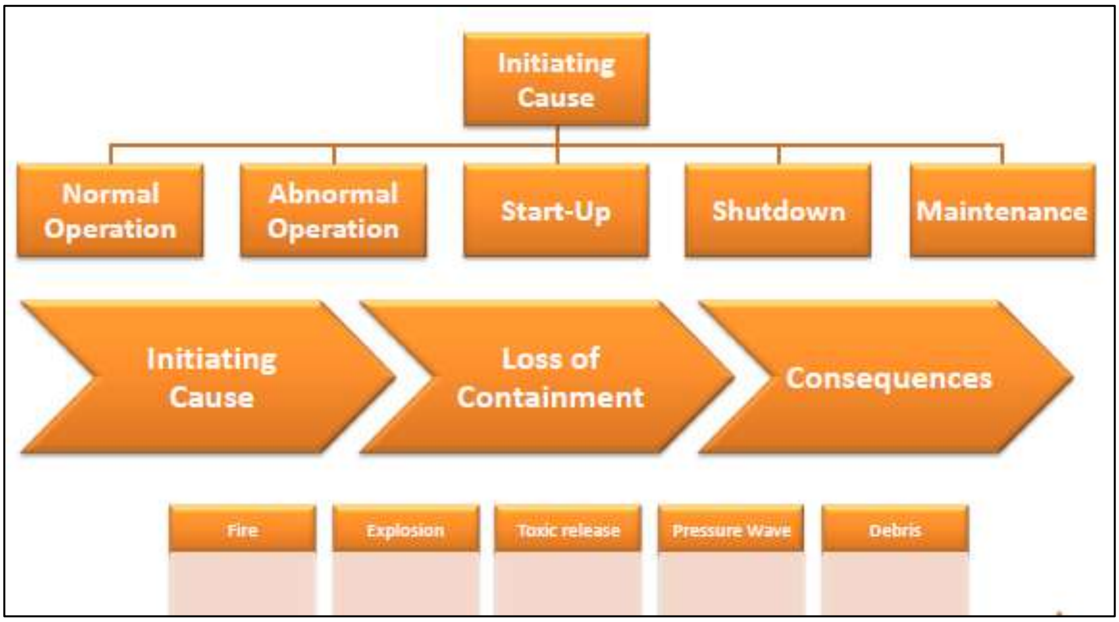

Figure 16 – Causes of Incidents (Thrower, 2013)

OGP (2008) was aligned with this approach and required that all incidents be tracked and assessed, even minor incidents. They further prescribed both lagging and leading indicators. Figure 16 illustrates an example of an incident investigation process as well as the three facets of an incident, namely; initiating cause, loss of containment and consequences. EI (2010) described the communication and inclusion of learning's in OPs and PHAs. Thus alignment between OSHA, OGP and EI was again observed. Table 12 summarises II as described by EPA (1999):

Table 12 – II Requirements (EPA, 1999)

• Initiate an investigation promptly.	Begin investigating no later than 48 hours following the incident.
• Establish a knowledgeable investigation team.	Establish an investigation team to gather the facts, analyze the event, and develop the how and why of what went wrong. At least one team member must have knowledge of the process involved. Consider adding other workers in the process area where the incident occurred. Their knowledge will be significant and should give you the fullest insight into the incident.
• Summarize the investigation in a report.	Among other things, the report must identify the factors contributing to the incident. Remember that identifying the root cause may be more important than identifying the initiating event. The report must also include any recommendations for corrective actions. Remember that the purpose of the report is to help management take corrective action.
• Address the team's findings and recommendations.	Establish a system to address promptly and resolve the incident report findings and recommendations; document resolutions and corrective actions.
• Review the report with your staff and contractors.	You must share the report - its findings and recommendations - with affected workers whose job tasks are relevant to the incident.
• Retain the report.	Keep incident investigation reports for five years.

2.4.12. Emergency Planning and Response (EPR)

Unfortunately despite the best planning, the occurrence of an incident was still probable. Therefore it was necessary that emergency pre-planning and training of employees was undertaken. This ensured prompt reaction from all stakeholders to control the emergency (OSHA, 2000).

Likewise EI (2010) prescribed that in the event of an emergency, the organisation must be appropriately prepared to contain the consequences thereof. Emergency equipment, response plans and training formed a part of this preparedness. OGP (2008) confirmed this approach.

2.4.13. Compliance Audits

OSHA (2000) prescribed periodic compliance audits to verify the effectiveness of PSM implementation and adherence. These audits needed to be conducted by competent and experienced personnel, so that areas of improvement was identified and remedied. Similarly EI (2010) stated that periodic internal and external review and audit of PSM framework compliance was essential to ensure sustained performance in the prevention of FER incidents with HSE consequences.

OGP (2008) required management to manage and review asset integrity performance to assure sustained performance. This activity considered the findings from all the aforementioned elements, inclusive of good industry practices and incident lessons. Management could then conclude informed decisions to improve the overall asset integrity. The risk profile of an asset dictated the type and occurrence of an audit. The asset integrity management system elements were essentially reviewed to gauge the implementation and effectiveness. Further improvement areas could be identified to maintain performance. Therefore all these models prescribed similar element requirements.

2.4.14. Trade Secrets

OSHA (2000) stated that all employers needed to make information available, namely PSI. The information extended from OP to EPR, essentially covering all the elements. However, confidentiality agreements and access control can be imposed so that such imperative information was not disclosed to other parties. It was concluded that only the OSHA PSM model prescribed this requirement in the form of an element.

In conclusion, comparative studies were conducted on the OSHA PSM model against the OGP and EI models. Many similarities were observed with respect to each element and model. Alignment between the models' element prerequisites was attributed to the good practices industry adopted to prevent process safety incidents.

2.5. Manufacturing Industry Overview

The study extracted the cause information from incidents that occurred in industry. These process safety incidents occurred in many diverse industries, which manufactured products in large quantities. Essentially these industries processed raw materials into more valuable products. The study comprised of five industries and overviews of these industries are presented below.

2.5.1. Metallurgical Industry

This industry was concerned with the refining, alloying and fabrication of metals (EPA, 2009). It was classified as a heavy manufacturing industry due to the capital intensity and large scale of operations (BLS, 2013). Steel and iron was predominantly processed due to its requirement as raw material in the production of further valuable products.

2.5.2. Chemical Industry

This industry had evolved over the decades due to the increased demand for economic activity (Chartered Technofunctional Institute, 2012). It was divided into three categories, namely; heavy chemicals, pharmaceuticals and petrochemicals (Wetfeet , 2012). Heavy Chemicals processed mineral deposits or by-products and involved mining activities. Pharmaceuticals involved the manufacturing of drugs and medicines. Petrochemicals involved the processing of chemicals attained from fuel sources. Incidents that occurred on oil rigs and ships that transported crude oil, was grouped a part of this industry.

2.5.3. Food Processing Industry

This industry entailed the processing of raw materials into food products, food preservation and food packaging. Similarly the food products can be used as raw material to produce another high valuable product. An example of this was the use of refined sugar in baking to produce cakes. It was classified as a light manufacturing industry as it involved consumer products (Zahie, n.d.).

2.5.4. Agricultural

This massive industry was responsible for providing mankind with sustenance (MSU, 2013). It mainly consisted of growing food crops and raising livestock, however field crops such as tobacco and cotton was also included. This industry also contained support functions, namely; pest management and animal husbandry. Therefore fertilizer and pesticide products were grouped a part of this industry.

2.5.5. Nuclear

This industry generated electricity and was considered to be an alternate source of energy. In this application, Uranium, a natural mined metal, undergoes fission which splits its nuclei thereby releasing energy in the form of heat (Nuclear Energy , 2011). This excessive heat was then absorbed by water, which was then converted into steam. The steam would drive turbines which in turn drive generators to produce electricity. Stringent legislation had been implemented for nuclear operations as it was a high risk facility. This form of energy was considerable cheaper than the coal derived energy source.

These identified manufacturing industries unfortunately had process safety incidents which occurred whilst in operation. Their respective process safety incidents were surveyed to obtain all causes of the incident. The examination of diverse industry incidents assisted in a broad understanding of PSM effectiveness. However the practical application and sustainability of PSM implementation required investigation. Therefore case studies were conducted, in order to understand the effectiveness of PSM in industry. The succeeding chapter presented an overview on the selected companies for the case study.

2.6. Case Studies: Company Profiles

The institutionalization of PSM in industry was key in understanding the diverse approaches to PSM implementation and sustainability. Therefore case studies were conducted on three international companies with high risk operations. The chemical industry was selected with emphasis placed on the Petrochemical division. The following Petrochemical companies were investigated; Sasol, Shell and British Petroleum (BP). An overview of these companies' profiles and scale of operations was presented below:

2.6.1. Sasol

Sasol is an integrated chemical and energy company with global operations. They employ over 34 000 people that work in 38 countries (Sasol, 2012), which allude to the enormity of the company. Sasol (2012) stated that safety was a top priority and a core valve. They committed to achieve a safety goal of zero harm thereby eliminating incidents, minimising risk and promoting operational performance excellence (Sasol, 2012). Sasol procured the services of DuPont, to ascertain its PSM compliance.

2.6.2. British Petroleum (BP)

BP is also one the world's leading oil and gas companies, with operations in over 80 countries that employ over 85,900 people (BP, 2013a). The history of BP extended far back as 1908 (BP, 2013a). BP currently possess a stake in 16 refineries which roughly produce 2,354 thousand barrels per day (BP, 2013a).

2.6.3. Shell

Shell is a global group which is composed of energy and petrochemical companies. They employ about 87,000 people in more than 70 countries (Shell, 2012b). Shell's objective is to assist and meet the energy demands of society in a manner that is economically, environmentally and socially responsible (Shell, 2012b).

Shell and BP employ more resources and managed more global operations in comparison to Sasol. Their operations were significantly larger, almost double in comparison to Sasol. However these companies' mission statements contain much resemblance.

In summary, Chapter 2 had covered vast amounts of literature depicting the numerous PSM models and pitting them against the OSHA model. The industries that formed a part of the study were also discussed. Similarly, a concise overview of the case study company profiles was presented.

Upon concluding the literature study on the PSM model and its individual elements, the development of an empirical investigation was undertaken. The information gathered from the literature study, was utilized to generate the empirical design. It was also applied in the analysis of the study findings. The next chapter presents the concept and merits of the empirical investigation approach and survey questionnaire.

Chapter 3: Empirical Investigation

3.1. Introduction

In this chapter, the approach utilized to gather and analyse the data in the study is described. A semi-qualitative research methodology was conducted and its specific elements are discussed.

3.2. Data Gathering

The author is employed at a Petrochemical company during the compilation of this dissertation, therefore the author had the opportunity to analyse the implementation of PSM at his employer. However an analysis of PSM on this one company would return an analysis solely based on said company. Further, research into this one company's incident causes would reveal challenges in terms of the PSM program only within this company. The research problem was on a global scale; hence an analysis on an individual company will not adequately address the problem.

To objectively identify gaps in the PSM program, interpretation of global process safety incidents would provide a concise and effective analysis. Numerous process safety incident reports were published throughout the years from diverse process industries. Such reports were public knowledge, in an effort to share lessons learnt and prevent similar incidents from occurring. Therefore information on incident causes was readily available.

Process safety incidents do not discriminate and occurred in diverse countries, from third world to first world as indicated by Schouwenaars (2008). Therefore the PSM landscape was randomly selected across the globe and across process industries. The study population comprised of fifty global manufacturing and processing industries over a span of forty years. The reviewed incidents were randomly selected from both small and large scale operations to effectively gauge PSM implementations on a broader scope.

3.3. Survey Development

Research into random past incidents and their causes was the predominant avenue of data collection. Incident causes were initially segmented into the following categories, namely; direct causes, root causes and contributing causes. However due to the unavailability of abundant comprehensive incident reports as discussed in Chapter 4, only cause and no cause categories were incorporated into the survey questionnaire. These incidents were thoroughly investigated and their identified causes were definitive. Therefore an aspect of this study was considered to be quantitative.

A set of constructs is defined to enable the numerical analysis of the obtained data. The survey questionnaire was devised on the foundation of the OSHA PSM model. Thus two constructs, namely incident information and PSM elements was developed employing the literature study information in Chapter 2.

Incident Information was gathered to understand the study population. Upon conclusion of the research into the OSHA PSM elements and their associated requirements, sub-element questions were populated. These key sub-element questions essentially alluded to the challenges within a particular element. Therefore this aspect of the study was considered to be qualitative. Since the overall study was qualitatively based, this study was fundamentally considered to be a semi-qualitative study.

3.3.1. Survey Validation

Major, significant, moderate and minor PSM process incidents, as described in chapter 1 and other incidents, were reviewed to gather the generic causes. The study comprised of both off-shore and on-shore incidents.

This data was reviewed and interpreted according to the survey questionnaire. The initial survey questionnaire was also reviewed by an independent statistician, whom provided valuable insights in terms of strengthening the validity of the survey.

As previously discussed, numerous lessons to prevent the re-occurrence of process safety incidents were published and readily available. Therefore the identified causes were identified and verified from credible sources. These literature references were depicted in Appendix C – Incident Information, Table 24.

3.3.2. Survey Questionnaire

The intent of this survey questionnaire, as illustrated in Appendix A, Table 22 was to examine diverse process incidents and to obtain the commonly identified causes. These causes were interpreted against the OSHA PSM elements as previously discussed. The imperative PSM elements were determined based on their contribution to the incident occurrence.

This empirical investigation discussed and concluded on the employed research methodology. This approach entailed the surveying of a hundred incident reports. However only fifty incidents were utilized in the study and the remaining fifty incident reports were used for cause verification purposes. The next chapter presents the findings obtained from this study. These findings are discussed and verified against literature.

Chapter 4: Findings and Discussion

4.1. Introduction

The previous chapter provided insights into how the empirical investigation was conducted through the application of the survey. In this section the findings from the investigation are presented and explained. The study population is presented to illustrate the landscape of process safety incidents. Thereafter the observed element distribution is illustrated, along with the statistical methodologies and findings. Literature is cited to determine the merits of these findings.

4.2. The Study Population

A total of fifty random process safety incidents were interpreted as published in accredited secondary literature. Most of the secondary literature was obtained from the HSE and CCPS databases. A summary of these incidents is depicted in Appendix C, Table 24. Process safety incidents were selected at random dating back from 1974 through to 2012 as depicted in Figure 17. About 42% and 58% of the observed incidents respectively occurred pre-implementation and post implementation of the OSHA standard.

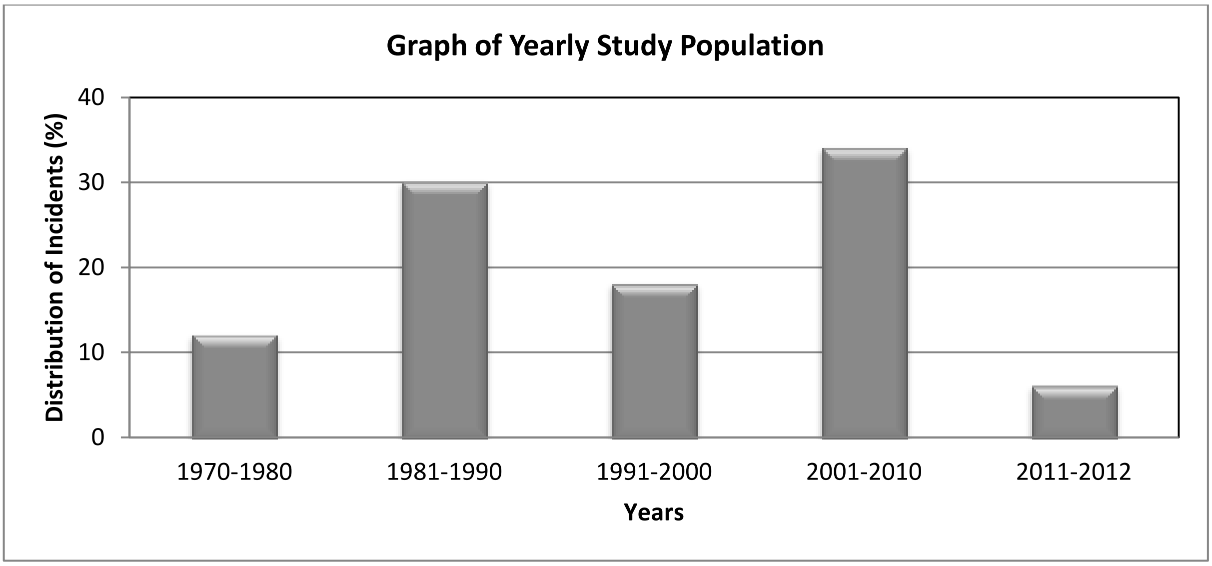

Figure 17 – Graph of Incident yearly frequency

The observed study population consists of incidents spanning the globe as illustrated in Figure 18. The study incidents occur mostly in America and Europe. This was attributed to the Seveso Directive and OSHA legislation, which required the publication and sharing of process safety incident investigations.

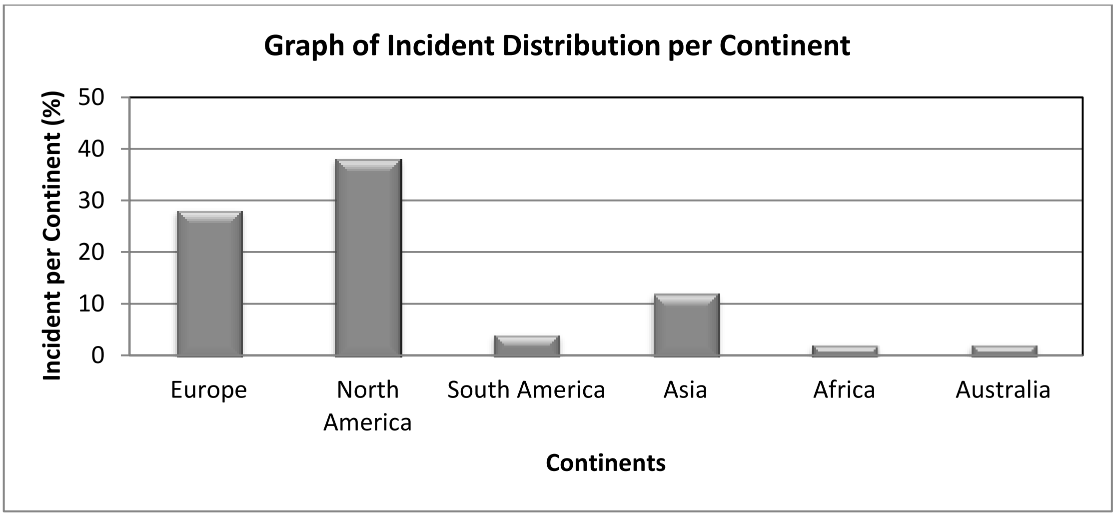

Figure 18 – Graph of Incident Distribution per Continent

The process safety incidents are classified according to Appendix B Table 23, as described by Overton (2008). A good distribution of incident severity should allude to attaining an enhanced insight, into diverse incident causation of diverse proportions. However the observed incident distribution consisted mainly of 90% Level 1, 8% Level 2, 2% Level 3 and no Level 4 incidents. This was due to the limitations in the secondary literature that was available. These incidents were also classified according to their respective type, namely FER. About 88% fire and explosion incidents were observed according to the distribution.

The observed industry distribution included 84% chemical industry incidents. The study methodology was therefore strengthened by adopting the OSHA PSM model, as most of the incidents resulted in North America in the chemical industry post implementation of the OSHA standard.

4.3. Overall OSHA PSM Element Effectiveness

The PSM element causes' distribution is illustrated in Figure 19. The three elements which resulted in a cause occurrence above 40% are CTR, MI and EPR elements with respective frequencies of 44%, 84% and 50%.

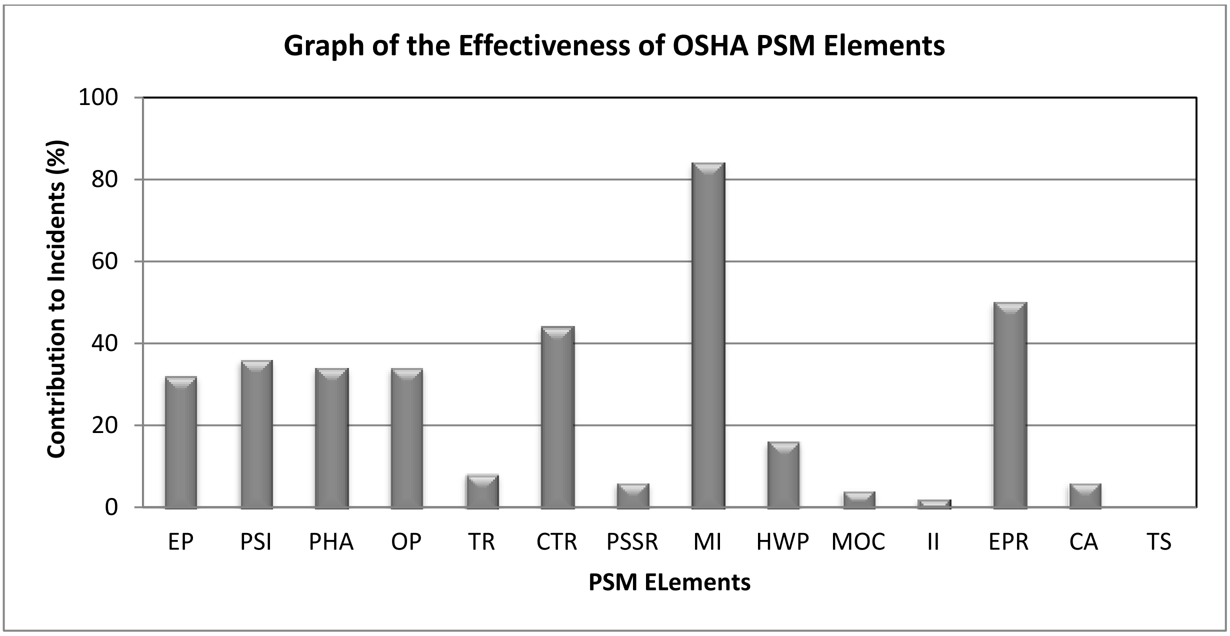

Figure 19 – Element frequencies

The first four PSM elements; EP, PSI, PHA and OP, had a frequency distribution between 30% and 40%. The HWP element had a frequency distribution of 16% and the remaining PSM elements had frequency distribution below 10%. The TS element did not feature as related to a process safety incident cause. Bickford (2013:21) stated that, "Most Process Safety Incidents are the result of multiple failures, not single failure". The aforementioned distribution agreed with Bickford (2013).

As discussed in Chapter 2, OSHA promulgated the PSM standard in 1992 and in 1994 they issued an instruction which described the compliance requirements. A part of this instruction included OSHA conducting a limited quantity of Program Quality Verification (PQV) inspections due to the resource constraint (OSHA, 2011). Unfortunately only a handful of PQV inspections were performed by OSHA on an annual basis (OSHA, 2011).

In order to address this gap, in 2009 OSHA implemented the pilot National Emphasis Program (NEP) for chemical facilities. This new approach to inspections, catered for a greater quantity of inspections while employing effective use of OSHA resources. Therefore the NEP initiative expanded and was considered to be the most significant PSM enforcement engagement since the inception of the standard (Barab, 2012).

OSHA issued citations to companies for their respective PSM element non-conformances. There were citations issued to 173 pilot inspections, with the majority of violations in the General Industry sector, and PSM contributed to 60% of the total violations (Lay, 2012). These NEP citations are accounted against each element as tabulated in Table 13.

Table 13 – OSHA's NEP Citations (Barab, 2012)

Chem NEP Citations by PSM Element

Element	Description	% of PSM Citations
j	Mechanical Integrity	23.2%
d	Process Safety Information	20.9%
e	Process Hazard Analysis	15.8%
f	Operating Procedures	14.0%
l	Management of Change	5.5%
o	Compliance Audits	4.5%
g	Training	3.8%
h	Contractors	3.4%
c	Employee participation	2.8%
m	Incident Investigation	2.6%
n	Emergency Planning & Response	1.8%
i	Pre-startup Review	1.1%

Significant citations were issued for the following elements; MI, PSI, PHA and OP as displayed above. Only MI is in agreement with the study finding as depicted in Figure 19. The remaining elements, to a degree, agreed with this NEP analysis, however it was deemed to be inconclusive. From the NEP, the CTR and EPR elements was insignificant, therefore this contradicted the study findings.

4.4. Pre and Post OSHA element performance

An analysis into the effectiveness of the implemented OSHA PSM elements was investigated against the pre-implementation phase. Figure 20 indicates the incident cause distribution with respect to each PSM element, in terms of pre and post OSHA implementation. As depicted, the MI element featured significantly both pre and post OSHA implementation. However CTR and EPR element failures decreased by as much as 21% post OSHA implementation. This performance was in line with the hypothesis as the implementation of the OSHA PSM standard was intended to drive down the occurrence of process safety incidents. The remaining elements' performance did not feature significantly, hence these were deemed negligible.

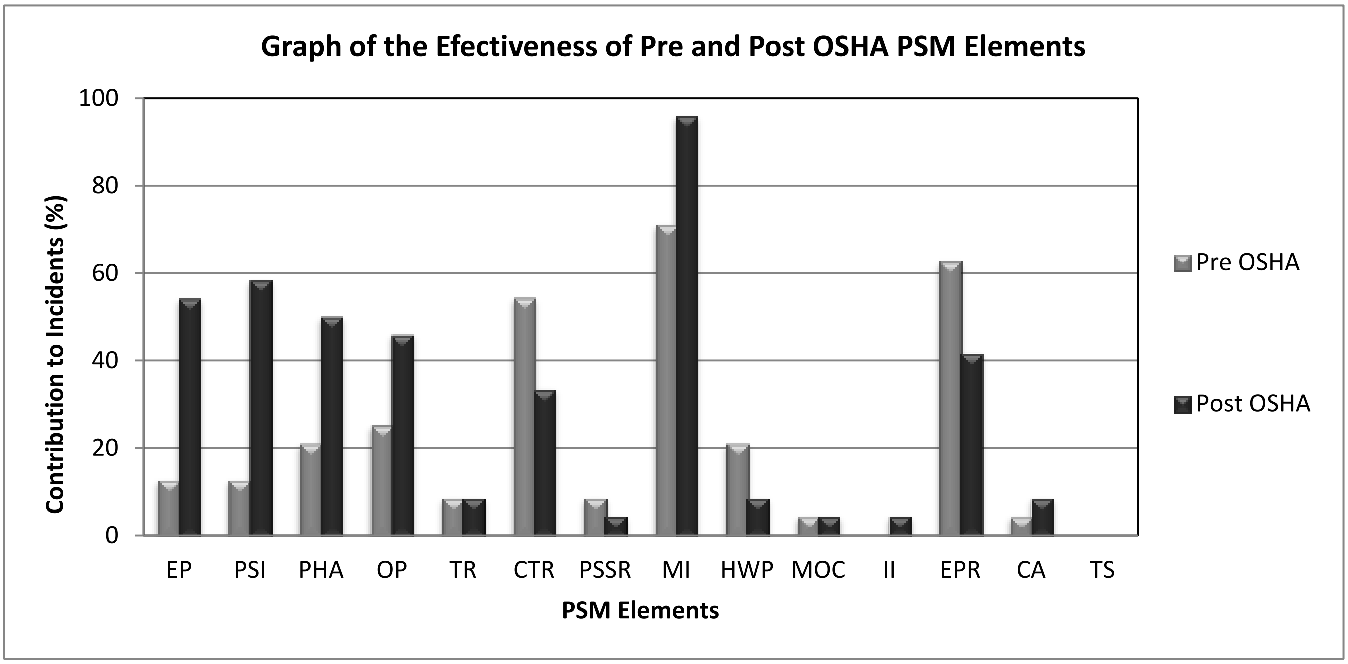

Figure 20 – Element performance after implementation

PSM focus areas, based on specific elements, were identified and reviewed from literature. This focus placed on such elements, implied declining performance which required urgent attention.

NOPSA (2009) adopted four focus areas for 2009/2010, which was related to the OSHA PSM elements; Process Safety Leadership in MAE prevention (EP), Asset Integrity (MI), Contractor Management (CTR) and Emergency Response (EPR). Whereas the 2010 Global Congress on Process Safety (Bickford, 2013) indicated the top ranking causes for loss of containment which were related to the OSHA PSM elements as follows:

• Design concerns	- PSI
• Preventive maintenance and reliability	- MI
• Procedures and training	- OP and TR
• Operating discipline	- EP

The CCPS Vision 2020 was an initiative intended to improve process safety performance through this decade (McCavit et al., 2013). It comprised of a roadmap to the year 2020, which mandated the characteristics that companies will require in order to achieve great process safety performance. This initiative was twofold, as it also focused on the roles of four societal themes, namely; the government, public, industry and labour sectors. For the purposes of this discussion, the former aspect of this initiative was investigated. There are five characteristics identified for companies to develop and sustain as illustrated in Figure 21.

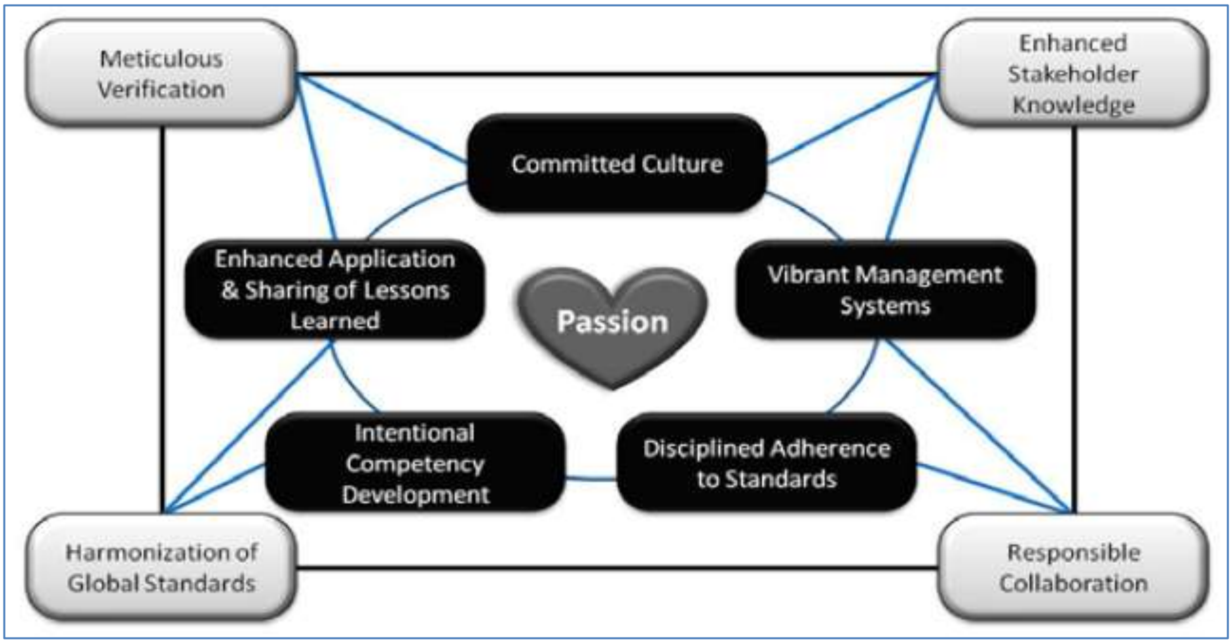

Figure 21 – Interrelationship of characteristics (McCavit et al., 2013)

As depicted, the central theme of this CCPS Vision 2020 approach was passion, which translated into a combination of functions working in synergy to achieve great process safety performance. These five characteristics described by McCavit et al. (2013) were summarised and related to the OSHA PSM model as interpreted from Chapter 2:

- **Committed Culture**

It comprised consistent visible leadership involvement from senior management. Such direction and commitment to engaged workforces, resulted in perfect execution of tasks. This characteristic was considered to be similar to the OSHA EP element.

- **Vibrant Management Systems**

This required the structured implementation of systems which clearly explained the expectations of management. These fit-for-purpose systems provided the foundation for the implementation of process safety element management. This characteristic was considered to be similar to the OSHA OP element.

- **Disciplined Adherence to Standards**

It entailed the rigorous compliance of both new and existing equipment installations. All equipment was necessitated to have minimum compliance standards and implemented systems to maintain safe operability. This characteristic was considered to be similar to the OSHA MI element.

- **International Competency Development**

Employees involved in or who contributed to the safe operation of the process, were required to be fully capable in executing their functions. This characteristic was considered to resemble the OSHA TR element.

- **Enhanced Application of Lessons Learned**

Incident learning from within a company as well as from external companies was pivotal, to ensure the non-occurrence of such an incident. This characteristic was considered to be similar to the OSHA II element.

Another initiative spear headed by CCPS, was to align PSM metrics globally in an effort to drive consistency and improvement (Overton, 2008). There were respectively three lagging indicators proposed, which involved; the counting and categorisation, industry normalisation incident rate and industry normalisation severity rate of process safety incidents. Thus these metrics were positioned at the II OSHA element. The six leading indicators proposed were considered to align to the MI, MOC, TR (Operator Competency) and EP (Safety Culture) OSHA PSM elements. The remaining two leading indicators could not be related to OSHA PSM elements, therefore they were excluded. These indicators were the Action items follow-up and Challenges to the Safety System.

The MI element failures increased by 25% post OSHA implementation. Literature agreed with the study findings, as only the MI element was observed to be a focus area a part of all the literature reviewed. The CTR and EPR finding was only confirmed by NOPSA (2009), therefore these elements' contributions were considered inconclusive. Further, EP and TR emerged from literature, as common focus areas.

There was also a significant increase in incident occurrence for the first four PSM elements by as much as 46%. These observed results are in agreement with the NEP major citations on MI, PSI, PHA and OP. Therefore literature, to a degree, verified these findings.

A further analysis was conducted in five yearly intervals, post implementation of the OSHA PSM standard. This was undertaken to determine any trends in terms of element effectiveness. Figure 22 depicted below, illustrates the cause distribution per element over the aforementioned intervals.

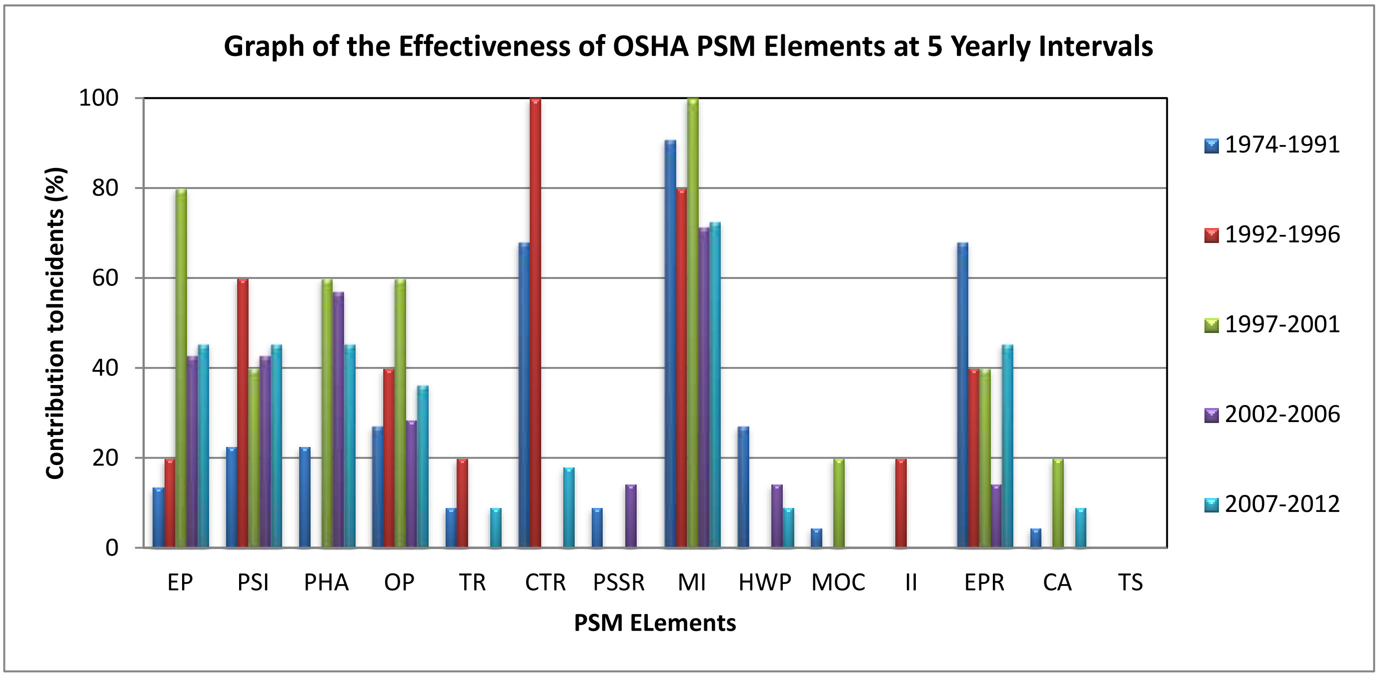

Figure 22 – Element performance in 5 yearly intervals

Only the MI element consistently featured significantly over the five year intervals. This analysis revealed that, to a degree, the effectiveness of this element was increasing. This finding was deemed to contradict literature. The remaining elements' trends were considered insignificant, which was in line with Figure 20 and the previous discussion.

Once a PSM program was developed and integrally implemented into a facility, continuous maintenance of the system was required to ensure its sustainability. Table 14 was compiled by the IRC (2006) to guide management toward sustainable PSM. It indicates the activities within each element that required on-going support (IRC, 2006).

Table 14 – Sustaining PSM Implementation (IRC, 2006)

PSM Element	On-going Requirement	Frequency
(c) Employee Participation	Employees involved	Continuous
(e) Process Hazard Analysis	Update and re-validate	5 yrs
(f) Operating Procedures	Certified current	1 yr
(g) Training	Refresher training	3 yrs
(h) Contractors	Evaluate contractor performance	Periodically[1]
(j) Mechanical Integrity	Inspections and tests	Periodically[2]
(l) Management of Change	Update program during plant changes	As-needed
(m) Incident Investigation	Investigate and develop recommendations	As-needed
(o) Compliance Audit	Audit PSM program	3 yrs

Due to resource, competency and time constraints, the following hypothesis was considered; the higher the frequency of the activity, the less likely it was effectively maintained. Based on this hypothesis, it was clear from the above table that EP, CTR and MI required the most frequent attention. Therefore literature further verified the EP and MI element focus areas as previously deliberated. CTR was not confirmed by the aforementioned literature.

In summary, from the study findings, only the MI element was discovered to correlate well with literature. Peon (2008:4) defined MI as, “MI means the process of ensuring that process equipment is fabricated from the proper materials of construction and properly installed, maintained and replaced to prevent catastrophic failures and accidental releases”.

The MI study distribution is indicated by Figure 23. In this study MI incorporated mechanical, electrical and instrumentation functions. The largest contribution to incident causes arose from equipment or control failure.

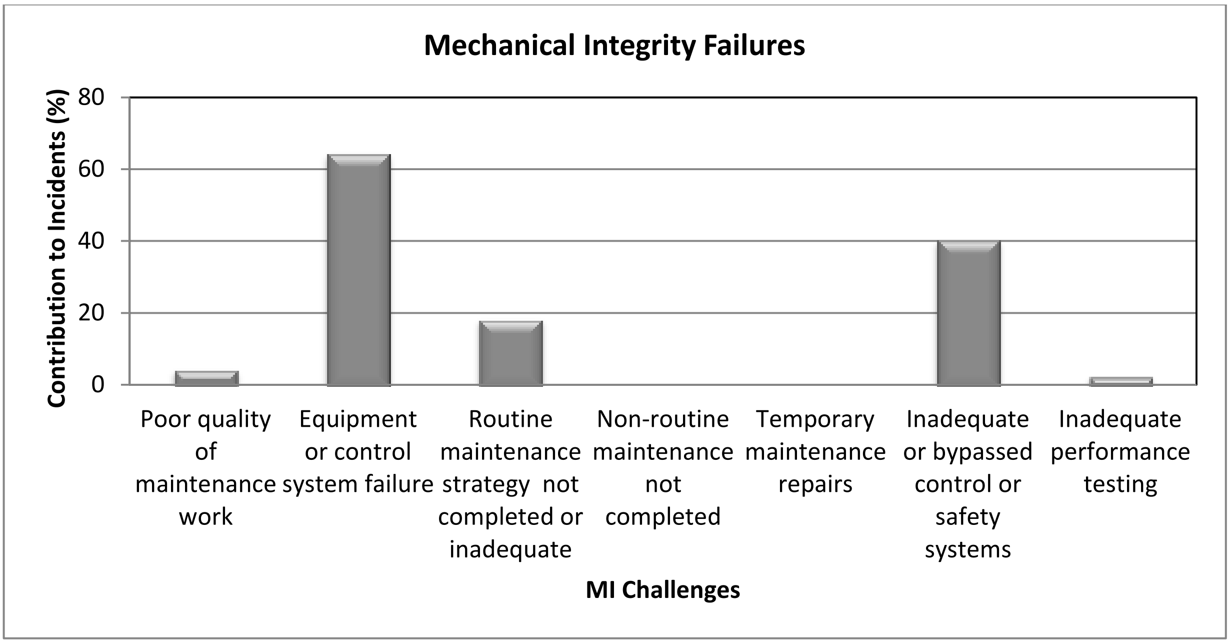

Figure 23 – Mechanical Integrity Failures

Figure 24 illustrates DuPont’s model for the construction of a MI system. The OGP (2008) model for asset integrity discussed in Chapter 2, verified this approach. These models agreed with the study findings as it contained aspects that addressed equipment and control failures. Continuous inspections and tests coupled with critical spares were important to ensure that equipment was always operated safely with increased reliability and availability (Peon, 2008). This would prevent the occurrence of FER incidents with HSE consequences.

DuPont's model focused on the sustainability of the MI element, ensuring that the maintenance executor was competent, trained and guided by procedures to execute a task (Peon, 2008). Quality assurance was also included to ensure a second independent evaluation of the work. Lax et al (2013) confirmed that numerous good practices incorporated the EP, TR and MI elements. However this was not emphasised in the study.

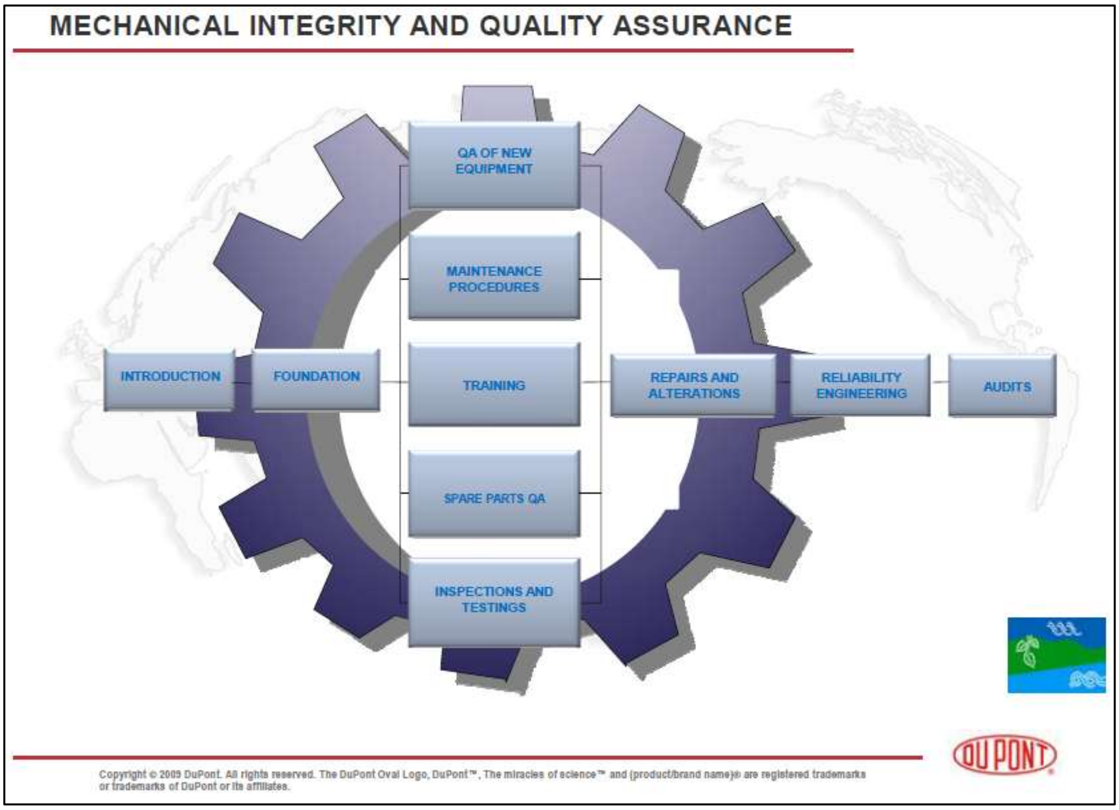

Figure 24 – DuPont's Mechanical Integrity and Quality Assurance Model (Peon, 2008)

4.5. Statistical Analysis

A statistical analysis was conducted on the observed data to identify any relationships between each of the PSM elements. The incident cause reports as attained through secondary literature, was not adequately formulated in terms of direct, root and contributing causes. The majority of these reports indicated the general causes. Due to this limitation, an in-depth cause analysis could not be undertaken. Thus the observed cause data was more indicative of a true and false data base. The observed data consisted of summarised counts of qualitative data which was divided into the element groups, therefore it was categorical data.

There was no premise for the characteristic structure between the PSM elements. The observed data was deemed to be ordinal, as it consisted of discrete items which belonged to a common category ranked by the year of occurrence. The observed data was classified as descriptive (Trochim, 2006), thus non-parametric statistics was conducted. These statistics do not depend and assume that the data had any characteristic structure; however they do assume that the data was measured at the nominal or ordinal level. Descriptive statistics was applied in order to describe the relationships between the PSM elements.

4.5.1. Element Correlations

The Spearman's rho correlation was utilized, as it is a non-parametric measure of statistical dependence between two variables. It was assumed that the underlying elements' relationship was monotonic. The hypothesis tested was that each PSM element correlated to another PSM element. Spearman's rho returned values between -1 and +1, which respectively represented negative and positive correlations (White & Korotayev, 2004). Therefore the following scale was adopted for Spearman's rho:

- 0.50 to 1.00 = Strong positive relationship
- 0.01 to 0.50 = Weak positive relationship
- -0.01 to -0.50 = Strong negative relationship
- -0.50 to -1.00 = Weak negative relationship

Two tailed significance was applied to test the null hypothesis that there was no relation between the PSM elements. This probability test consisted of the two significance levels, namely; 5% and 1% level of significance (White & Korotayev, 2004). Therefore the following scale was adopted for the significance level:

- 0.00 to 0.01 = Highly significant
- 0.01 to 0.03 = Moderately significant
- 0.03 to 0.05 = Significant
- 0.05 to 1.00 = Not significant

All fourteen elements were analysed against each other, in order to identify any statistical correlations. Six correlations are concluded as illustrated in Table 15. Three of the correlations, (Correlations 2, 4 and 6), had weak positive relationships while the remaining three correlations, (Correlations 1, 3 and 5), had weak negative relationships.

Table 15 – Spearman's rho Correlations

Correlation Number	Element 1	Element 2	Correlation Coefficient	Two Tailed Significance
1	HWP	PSI	-0.319*	0.024
2	EP	OP	0.320*	0.023
3	EPR	PSI	-0.322*	0.022
4	PSSR	PSI	0.330*	0.019
5	CTR	EP	-0.352*	0.012
6	EP	CA	0.401*	0.004

Correlation 6, between the EP and CA element, indicated a highly significant positive relationship. The remaining correlations indicated moderately significant relationships. From correlation 1 and 3, increased PSI related to improved identification and mitigation of risks. Therefore this led to improved execution of HWP and EPR as described in Chapter 2. Similarly in correlation 5, a positive relationship was expected, as effective EP resulted in enhanced management of CTR. Therefore these weak correlations, 1, 3 and 5, inversely correlated with literature.

Similarly as discussed in Chapter 2, correlations 2 and 6 agreed with literature, as the engagement of EP translated into improved execution of OP and CA. Further, the Baker Panel report issued after the Texas City Incident (Chilworth, 2010) indicated that although systems and procedures were imperative, it didn't solely constituent to effective PSM. Similarly properly documented PSI assisted a team to comprehensively complete a PSSR as detected in correlation 4. These positive correlations were also confirmed by literature.

The PSI element respectively correlated to the HWP, EPR and PSSR elements, however no correlation was observed between these individual elements. Similarly for the EP element, no correlations were found between OP, CTR and CA elements. This observation was attributed to the respective dependency relationships on the EP and PSI elements.

4.5.2. Element Cross Tabulation

Cross tabulation analysis was used to analyse the categorical data. This was conducted to determine the dependent or independent relationships between the PSM elements. The Pearson Chi-Square statistic (White & Korotayev, 2004) was applied to test the statistical significance of the null hypothesis, that there was no relation between the PSM elements. The relationship was considered significantly dependent, if the probability lied between 0 and 0.05. Therefore the following scale was adopted:

- 0.00 to 0.01 = Highly significant
- 0.01 to 0.05 = Moderately significant
- 0.05 to 1.00 = Not significant

There were two measures of association for Chi-Square application, namely; Phi and Cramer's V. They were used to determine the strength and direction of the relationships between the two elements. However symmetrical relationships were applied, as it was uncertain as to which PSM element was dependant or independent. Phi and Cramer's V was respectively applicable to only 2 categories and more than 2 categories. Phi and Cramer's V vary from 0 to 1, and the higher this value, the greater the strength of the association (White & Korotayev, 2004). Therefore the following scale was adopted:

- 0.00 - 0.30 = no relationship to weak relationship
- 0.31 - 0.70 = moderate relationship
- 0.71 - 1.0 = strong relationship

4.5.2.1. PSM Elements

This analysis concluded that only two strong relationships exist as depicted in Table 16. The Phi and Cramer's V values don't agree for Correlation 2. Since Cramer's V is more suited for our data, its value was accepted. Therefore both correlations were highly significant and possessed moderate relationships.

Table 16 – Cross Tabulation

Correlation Number	Element 1	Element 2	Value	Asymptote Two Tailed Significance	Phi	Cramer's V
2	EP	OP	30.464	0	0.781	0.552
6	EP	CA	10.740	0.005	0.463	0.463

The cross tabulation correlations 2 and 6 reaffirmed and built on the Spearman's rho correlations. As previously discussed, these correlations agreed with literature. Again no relationships were observed between the CA and OP elements, which endorsed its respective dependence on the EP element.

4.5.2.2. Pre and Post OSHA PSM Implementation Comparison

A statistical analysis was conducted to determine if any relationship existed per PSM element against pre and post implementation of the OSHA standard. Three PSM elements are identified with relationships as shown in Table 17.

Table 17 – OSHA Implementation Comparison

PSM Element	Asymptote Two Tailed Significance	Phi	Cramer's V
EP	0.040	0.358	0.358
CTR	0.009	0.481	0.481
EPR	0.009	0.480	0.480

Both CTR and EPR were highly significant correlations with moderate relationships. EP was moderately significant with a moderate relationship. The Phi and Cramer's V values for all three elements were also equal.

The observed distribution as indicated in Figure 20 confirms the CTR and EPR elements' relationship. MI was also prominent in this distribution, however no relation was observed in the cross tabulation. In accordance with the NOPSA, Global Congress on Process Safety, CCPS Vision 2020 and Metric Alignment Initiative review, only EP was considered to agree in literature. However CTR was found to be inclusive of EP (McCavit et al., 2013). Therefore EP and CTR relationships were confirmed by literature.

4.5.2.3. Five Yearly OSHA PSM Comparison

Another statistical analysis was conducted to determine if any relationship existed per PSM element, at its respective five yearly intervals, post implementation of the OSHA standard. Only the CTR element features in this statistical analysis, as a highly significant and strong relationship as shown Table 18.

Table 18 – Five Yearly Comparisons

PSM Element	Asymptote Two Tailed Significance	Phi	Cramer's V
CTR	0.003	0.769	0.444

Figure 22 illustrates that the EP, PSI, PHA, OP, CTR, MI and EPR possess a strong distribution. The CTR relationship was attributed to increased focus or enhanced management. NOPSA (2009) agreed with this relationship, as CTR was a focus area.

4.5.2.4. Element Dependencies

It is evident from the aforementioned statistical analysis, that significant relationships were observed with the EP and PSI elements. These element dependencies, as indicated in Table 15, are discussed and interpreted against literature. Therefore EP correlated with the OP, CTR and CA elements. While PSI correlated with the PSSR, HWP and EPR elements. Bickford (2013) alluded to a relationship between the EP and MI elements. However this dependency between EP and MI was not observed.

Similarly, Perez (2011) described the importance of the plant engineers' role in PSM. Plant engineers were required to facilitate and/or participate in the PSM elements, such as PHA, MI and MOC. In order to effectively complete this, these plant engineers needed to be trained and competent. Therefore crucial missing links was that PSI related to EP and TR. However it was the human that identified and populated the PSI and executed the PSSR and HWP element tasks.

Soczek (2010: 2) stated that, "It is important to note that successful implementation of PSM alone cannot guarantee success in eliminating major incidents and achieving a culture of safety. Actions of people are critically important". Thus these aforementioned elements were concluded to also depend on the EP element. Consequently, more emphasis was placed to identify the constraints of the EP element.

The EP element was considered to embody human factors. As discussed by Bridges and Tew (2010), process safety was concerned over controlling risk of errors and failures. Related to this risk, was the risk of human error. Human factors played a crucial role in process safety as it was the foundation of each element. Knegtering (2002) confirmed the interrelations of the PSM elements.

Bridges and Tew (2010) further stated that human factors were instrumental in nearly all of the major accidents over the past thirty years. Figure 25 illustrates the different management systems that involved the control of human errors. It illustrated the implementation level relationship of; OP to Procedures and Training, CTR was related to Behavioural Habit Control and CA related to Audits and Performance Measurement.

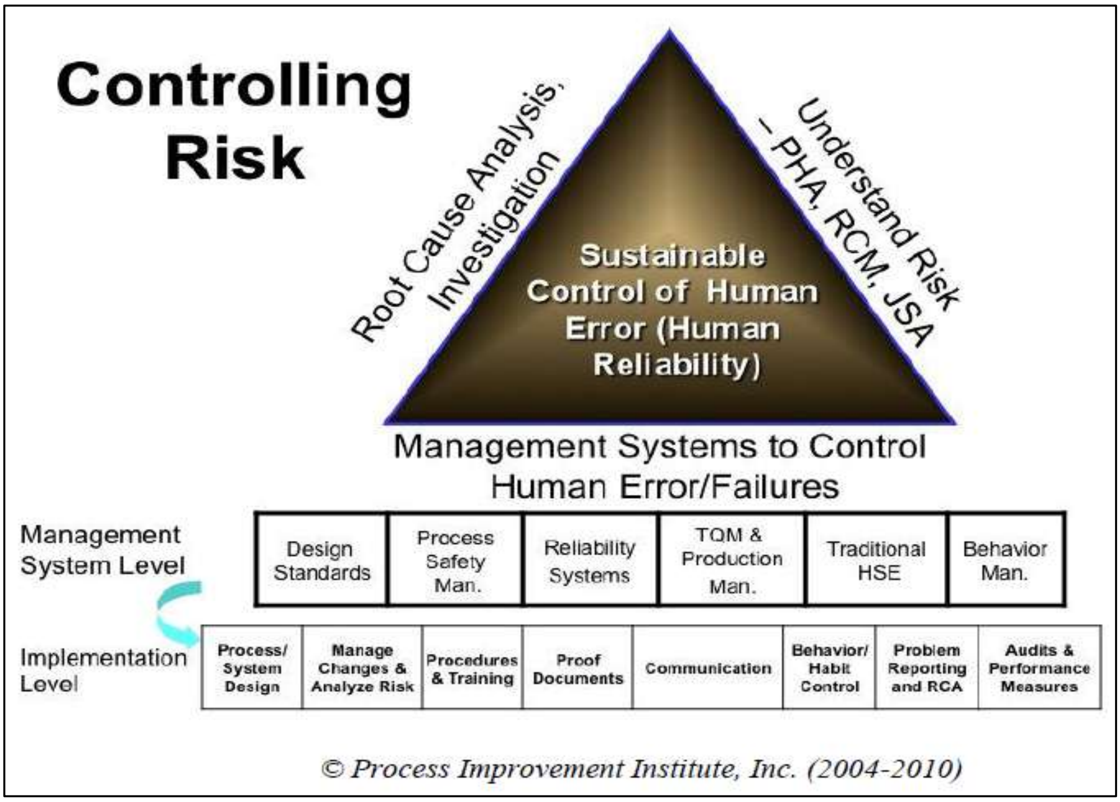

Figure 25 – Controlling Human Factor Errors (Bridges & Tew, 2010)

Therefore the author used literature to confirm the dependency of EP in relation to OP, CTR and CA. Bridges and Tew (2010) specified that a PSM model should incorporate a dedicated human factor element, as this placed emphasis on its importance. In Chapter 2, many newer PSM models were observed to include a human factor element. Therefore the Risk Based PSM framework model was best suited to this approach.

Literature was investigated to determine the cause for the EP element failure. The EPSC (2012) published insights into the importance of the cultural aspects of PSM. Investigations into disasters were attributed by the action or inaction of the people operating the system (EPSC, 2012).

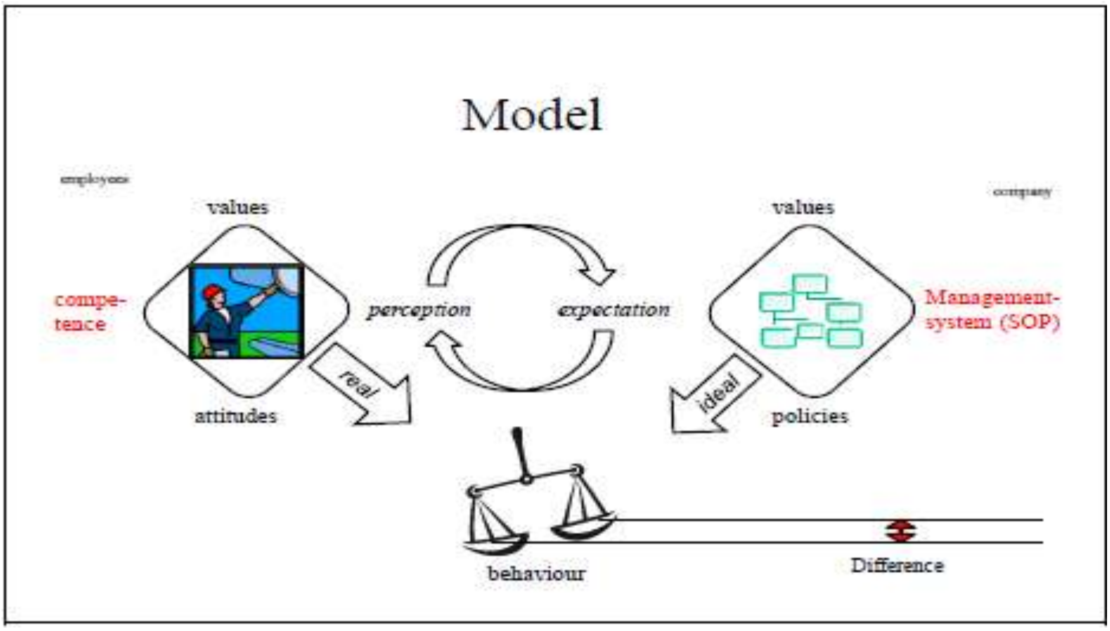

Figure 26 – Behavioural Model (EPSC, 2012)

The above model, Figure 26, depicts the misconception that recruiting competent employees will result in adherence to the management systems. This agreed with the study, as no relationship between OP and TR was observed. Essentially, this model indicated that there are gaps that can emerge in the way in which a workforce behaved and how the managers and the business expected the workforce to conduct itself (EPSC, 2012).

These gaps are classified into five parameters of safety culture (EPSC, 2012) as illustrated in Table 19. Therefore the challenge to align all employees toward a uniform safety culture arose due to the diverse backgrounds of the employees, in terms of social and educational background. EPSC (2012) stated there was a direct relationship between recruiting a new employee and instilling a positive safety culture, as after time that worker adopted the safe working behaviours.

Table 19 – Five parameters of safety culture (EPSC, 2012)

No	Parameter	Employee	Transparency	Company's Influence	Company
1	Value	Diversity Knowledge of company values	No	Low High	Uniformity Consistent set of values for all employees
2	Attitude	Diversity Knowledge of company's policies	No	Low High	Uniformity Policies defined for all employees
3	Perception	Diversity depending on values and attitudes but already streamlined by behavior	(Yes)	Medium	"Gaussian distribution" Influenced by supervisors as part of their job description Leadership Support by training
4	Competencies	Individual (newcomer) to more or less specific knowledge depending on job description	Yes	High	Management task: "the right competence at the right place" Leadership Support by training and instructions
5	Behaviour	Restricted by standards (SOP) as part of a safety management system	Yes	High	"Gaussian distribution" Management task: identification and wording of the standards Information, instruction of employees about new or changed standards Leadership through the whole organization Audits, follow-up

In summary, EP was concluded to form the foundation of an effective PSM program. However a safety culture was imperative to ensure that EP was entrenched in a company. As illustrated in Figure 27**,** Den Bakker (2012) defines the journey to PSM with the commencement of a pathological and reactive level. Thereafter this transitioned into a calculative level in which efforts resulted in the adherence to minimum requirements. This was considered as the implementation phase. However in order to sustain the program, proactive and generative levels were deemed essential to achieve desired PSM performance.

Elke (n.d: 2) stated that, "Management commitment, process safety information and hazard identification are the core elements in a successful safety management program. However, an effective Process Safety Management Program requires a systematic evaluation of the whole process". Therefore the PSM performance could decline, if the system was not diligently monitored and tracked. Consequently, Den Bakker (2012) described that a PSM system required explicit sustainability to assure it was effectively embedded in leadership, people, process, structures and culture. Canso (2008) also agreed with the importance of safety culture.

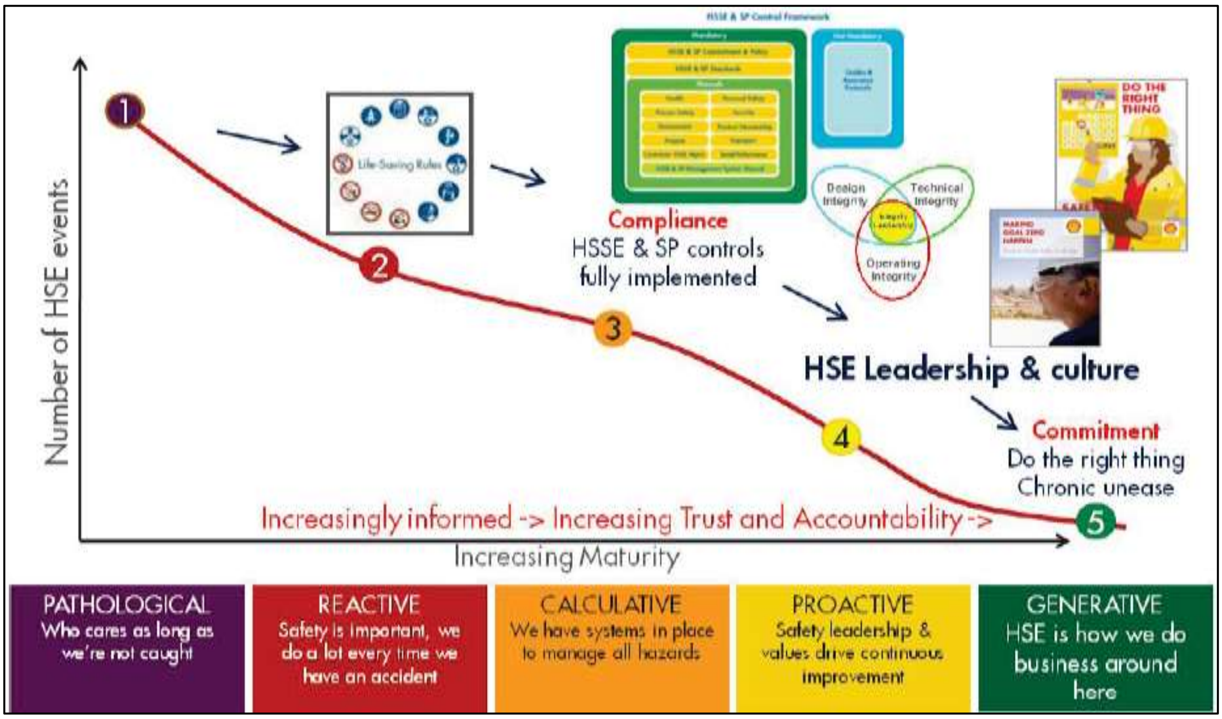

Figure 27 – Journey to PSM implementation (Den Bakker, 2012)

Soczek (2010: 4) also stated that, "When implementing PSM, the challenge is not to change the local culture, but to implement PSM within the existing environment". Walt and Frank (2007) indicated that PSM implementation was more probably to succeed, if a sound safety culture was institutionalised in employees at all levels within an organisation. Bob Hansen, the COE of DOW Corrning (OECD, 2012: 12) stated, "Creating a culture where all employees expect the unexpected and strive for error-free work is absolutely essential for success in process safety. This kind of culture is possible only through demonstrated leadership at all levels of the organisation". Therefore these statements alluded to the importance of a safety culture which was sustained through leadership committed to safety.

Although process safety tasks may be delegated, ultimate accountability and responsibility remained with senior leadership. Figure 28 derived by OECD (2012), depicts the essential elements apart of process safety for corporate governance. Therefore the foundation for this model was strong senior leadership, as it was central to an organisation, and leadership in turn influenced employee behaviour and safety (OECD, 2012).

Figure 28 – Essential PSM Elements (OECD, 2012)

Arising from legislation, an organisation's management was held legally accountable for process safety incident impacts (DuPont, 2008). McGrady (2013) indicated that nearly all safety incidents arose from poor management. DuPont (2008) confirmed that major process incidents, resulted from failures in management systems and control. MacDonald (n.d) also confirmed the merits of Process Safety Leadership which was vital to a PSM program. Therefore fundamental to EP was a strong safety culture which was sustained by committed leadership.

4.6. Limitations

Unfortunately abundant and comprehensive process safety incident investigative cause reports were not freely available in literature. These causes were also seldom classified into direct, root and contributing causes. Therefore many of the investigative reports stated all causes with no distinction between the levels of causation.

Generally only major process safety incidents, namely Level 1 incidents, were investigated at depth and reports published with the aforementioned cause categories. The other process safety incidents with severity levels of 2, 3 and 4, could have been thoroughly investigated, however these reports were not published and available for public access.

Near miss incidents were generally not published or investigated in sufficient detail. Further past incident investigative reports were not available or published at depths as compared to more recent incident investigative reports.

4.7. Case Study Findings

The identification of major industrial role players that employed PSM, assisted in gauging how established companies selected their most effective implementation. Therefore these case studies served as a means to validate the previously discussed findings. The petroleum industry was investigated and the following companies were selected; Sasol, Shell and British Petroleum (BP). These companies were found to openly publish their PSM implementation programs as well as statistics indicating their safety performance.

4.7.1. Sasol

PSM was implemented in each of their ventures. Sasol focused on highlighting two PSM elements in their annual reports, namely; PHA and Incident Management. They stated that PHA studies were undertaken and that all significant safety incidents are reported and thoroughly investigated (Sasol, 2012).

External safety compliance audits were a part of Sasol's strategy to identify gaps and improve PSM effectiveness. DuPont conducted such a PSM audit on Sasol in 2005. Only selected South

African operational facilities were a part of this audit scope. DuPont’s PSM model as described in Chapter 2, was used to evaluate Sasol’s OSHA derived PSM program (DuPont, 2005).

DuPont (2005) recognised the management teams of Sasol for their commitment and safety culture in improving safety performance on the different sites. They discovered that PSM was implemented to varying degrees amongst Sasol’s operational facilities. Therefore DuPont (2005) prescribed sustained efforts and periodic internal compliance audits. DuPont (2005) identified areas of improvement in Sasol’s developed best practices, namely; zero tolerance, hazard identification, internal/ external resource competence.

Sasol’s Chief Executive Officer (CEO) attributed the company’s long term success on the safety behaviours from their employees (Sasol, 2012). However the 2012 safety performance indicated a decline in the quantity of significant Fires, Explosions and Releases (FER), to 42 compared with 52 in 2011 (Sasol, 2012). In 2010 this figure stood at 60 which was directly on Sasol’s target, however the succeeding years depicted Sasol not achieving their respective targets of 50 and 35 in 2011 and 2012 (Sasol, 2012). Therefore marginal improvements were noted in the safety performance of Sasol over the last 2 years. Thus Sasol’s CEO assured commitment to excel on this performance (Sasol, 2012).

4.7.2. British Petroleum (BP)

BP stated that they were serious about the welfare of their staff and strived to create and maintain safe and healthy working environments (BP, 2013b). BP committed to prevent, mitigate and ensure preparedness to respond to incidents across all operations. The foundations of BP’s risk and safety management approaches was based on the learning derived from the Texas City refinery explosion in 2005, Deepwater Horizon oil spill in 2010, other incident investigation, audits and risk reviews (BP, 2013b).

BP also focused on the application of the processes and practices by the employees, as it ensured the strength of the safety culture and workforce capability. Therefore Leadership and Culture was one of the imperatives for BP’s operational leaders to excel as safety leaders. This included developmental programmes on operating management system, process safety and risk and safety leadership for all leaders (BP, 2013b). There were three different types of programmes, namely; Operations Academy, Managing Operations and Operating Essentials ranging respectively from Senior level leaders to Mid-level leaders and Frontline leaders.

BP measured a number of process safety metrics, however reported API tier 1 and tier 2 process safety events. BP (2013c) described the tier 1 events as, “the losses from primary containment, from a process of greatest consequence causing harm to a member of the workforce or costly damage to equipment, or exceeding defined quantities’’. This was considered as level 1 and 2 process safety incidents. Similarly BP (2013c) described the tier 2 events as, the “losses of primary containment, from a process, of lesser consequence’’. This was considered as level 3 and 4 process safety incidents.

In 2012, BP reported 43 tier 1 process safety events as compared to a more consistent 74 events reported in 2010 and 2011 (BP, 2013c). There were 154 tier 2 safety events reported for 2012 (BP, 2013c). This was the first year that BP reported tier 2 events externally; therefore no prior company history was available.

4.7.3. Shell

Shell (2010) believed that given the nature of the risks associated with their operation, safety and integrity of their assets was of paramount to them. This company simplified process safety as essentially being composed of; ensuring facilities are well designed, safely operated, properly inspected and properly maintained. Shell also strived to prevent safety incidents to employees, facilities, neighbours and the environment (Shell, 2010).

Since 2006, Shell invested $6 Billion in a PSM programme to improve the safety of their facilities (Shell, 2012a). Regular training was a key aspect of this programme for employees, whom managed and operated their facilities. Further Shell invested about $1 Billion in the safety and reliability of the refineries, chemical plant and distribution facilities (Shell, 2012a).

Table 20 – HSSE PSM Framework (Den Bakker, 2012)

Risk Management	1- Hazard identification
	2- Risks management
	3- Competence
	4- Fitness to Work
	5- Contractor HSE management
	6- Supervision
	7- Statement of Fitness
Design & Construction	8- Technical Integrity Establishment
	9- Design and Engineering standards (DEM1)
	10-Process Safety Basic Requirements (DEM2)
	11- Critical documentation
	12- Process Safety Reviews
Operations, inspection and maintenance	13- Classified areas
	14- Operational limits
	15- Technical Integrity inspection
	16-Maintenance
	17-Permit to Work
Process Safety Culture	18- Asset manager
	19-Business Management Review
	20- Location Management Review
	21- Hazard knowledge
	22- Leadership demonstration

A Health, Security, Safety and the Environment (HSSE) framework was initiated by Shell in 2009 (Shell, 2010). It included all past standards and manuals and was a mandatory source for rules covering process safety. This framework is composed of 22 elements as depicted in Table 20. Shell (2010) further devised 4 pillars of integrity, which encompassed process safety management. They include Design Integrity, Technical Integrity, Operating Integrity and Leadership Integrity as illustrated in Figure 29.

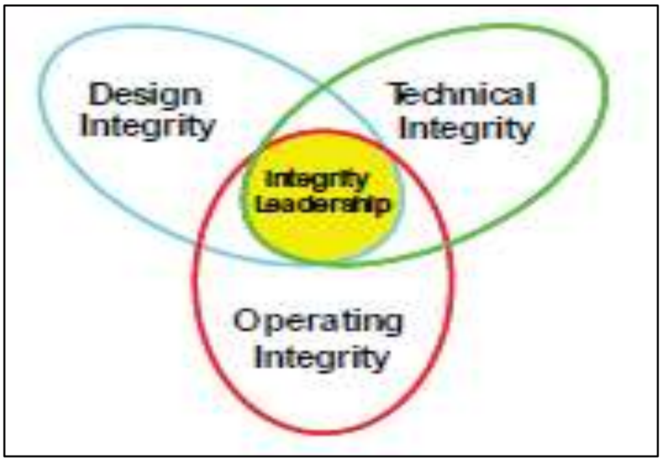

Figure 29 – Shell's PSM Overview (Den Bakker, 2012)

Design integrity involved the compilation of more than 350 design and engineering practices (Shell, 2010). Asset integrity was achieved by maintaining the hardware and operating them within operational barriers. Shell continued to invest, with the commencement of a $5 Billion program in the upstream business to improve equipment. This program contained detailed maintenance and integrity initiatives which focused on the technical integrity of their facilities.

Open, transparent and clear communication with staff, operating procedures, asset monitoring protocols and the cohesive involvement from staff and management were the principles of this approach. Integrity of Leadership entailed that each Shell manager was accountable for PSM. They were tasked with demonstrating visible and felt leadership in the field (Shell, 2010). Another aspect was that managers adhered to commissioning a plant following a detailed set of safety criteria, with employees adhering to all procedures.

Similar to BP, Shell reported process safety incidents as per API tier 1. In 2012, Shell reported 91 tier 1 incidents and this is an improvement compared to 2011 (Shell, 2012b). Oil spillages were also reported and tracked apart of performance measurements. Shell's (2012) incident rate performance improved, with a decrease in spillages by over 3,900 tonnes in 2012 as compared to 2011.

In summary, all the case study companies employed the OSHA's PSM model with a few renditions of other elements and models described in Chapter 2. Sasol adopted the OSHA PSM model, while Shell and BP implemented a mixture of the DuPont, CCPS, Risk Based PSM framework and EI models. These models were also in agreement with the OCED model's toward process safety for corporate governance. However BP's incident rate performance could not be ascertained and Sasol was not performing as per their fixed targets. Therefore Shell's reduction in incident rates alluded to an effective PSM program.

Neely (2013) described the PSM standard as a performance standard and not a specification standard. Therefore it's a facility function and not just a safety function. It was evident that the case study companies adopted this philosophy, with emphasis placed on leadership commitment and safety culture. Since PSM was a facility function, it thus required a dedicated task team. Neely (2013) described the roles and responsibilities of a PSM committee, which was composed and managed by senior leadership. The intent of the committee was to sustain the PSM program and its associated effectiveness. However it was unclear if these case study companies mandated a PSM committee and its respective effectiveness thereof.

It was evident that a PSM system was a network that ran deep into a facility's management and operation functions. Figure 30, depicts how PSM was intertwined into an operational plant. The case study companies achieved exactly this, by incorporating PSM seamlessly into the daily plant activities.

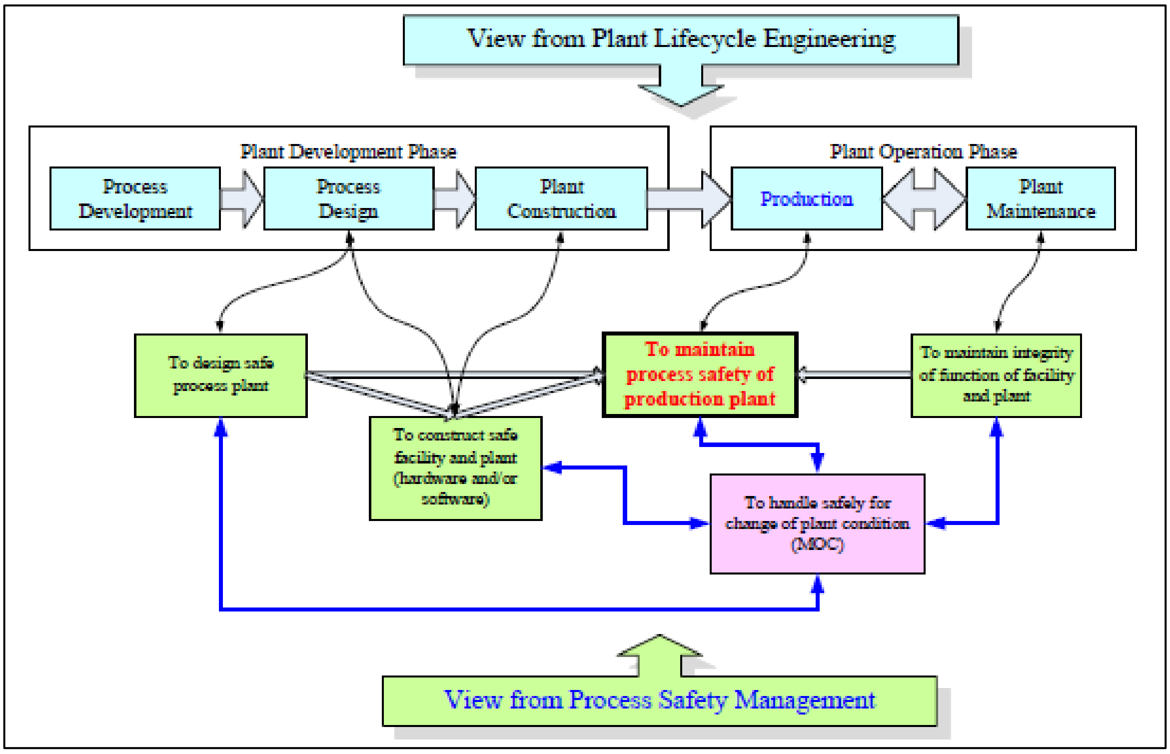

Figure 30 – Plant lifecycle and PSM Overview (Neely, 2013)

Chemical Industries Association (2008: 6),stated that, "More recently we have seen in the Baker Report and the HSE's "leading from the top" programme an increased emphasis on people behaviours and the organisational culture aspects of PSM. This completed the triumvirate of equipment, systems, and people elements of effective PSM". In support of this leadership committee, courses are offered to coach senior management in the art of process safety leadership (NSA, n.d.).

Nuclear safety was considered to encompass the most stringent and comprehensive legislation as well as proof of compliance. Thus a PSM program in the nuclear industry was far more effective or detailed as compared to OSHA's PSM program applicable to the chemical industry. A comparison into the two industries' respective PSM programs was investigated.

In the nuclear industry, Safety Assessment Principles (SAPS) applied to the assessment of nuclear facility abilities to demonstrate high standards of nuclear safety and radioactive waste management (HSE, 2006). There are eight fundamental principles, which served as the foundation for nuclear facility safety as depicted in Table 21. Therefore these fundamentals, to a degree, related to CAAA specifications derived for the OSHA standard, as discussed in Chapter 2.

Table 21 – Nuclear Safety Fundamentals (HSE, 2006)

Fundamental principles	Responsibility for safety	FP.1
The prime responsibility for safety must rest with the person or organisation responsible for the facilities and activities that give rise to radiation risks.		

Fundamental principles	Leadership and management for safety	FP.2
Effective leadership and management for safety must be established and sustained in organisations concerned with, and facilities and activities that give rise to, radiation risks.		

Fundamental principles	Optimisation of protection	FP.3
Protection must be optimized to provide the highest level of safety that is reasonably practicable.		

Fundamental principles	Safety assessment	FP.4
The dutyholder must demonstrate effective understanding of the hazards and their control for a nuclear site or facility through a comprehensive and systematic process of safety assessment.		

Fundamental principles	Limitation of risks to individuals	FP.5
Measures for controlling radiation risks must ensure that no individual bears an unacceptable risk of harm.		

Fundamental principles	Prevention of accidents	FP.6
All reasonably practicable steps must be taken to prevent and mitigate nuclear or radiation accidents.		

Fundamental principles	Emergency preparedness and response	FP.7
Arrangements must be made for emergency preparedness and response in case of nuclear or radiation incidents.		

Fundamental principles	Protection of present and future generations	FP.8
People, present and future, must be protected against radiation risks.		

There were two fundamental principles which stood out, namely; FP.1 Responsibility for Safety and FP.2 Leadership and Management for Safety. The first two fundamentals placed emphasis on the safety culture and leadership commitment as previously discussed in the statistical analysis. INSAG (1991: 1) defined a safety culture as, “that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues received the attention warranted by their significance”.

Therefore these two fundamentals alluded to the importance of the EP element. HSE (2011) confirmed the importance of EP, by requesting enhanced commitment from leadership. Further the common themes from the PSM models survey in Chapter 2, agreed with the imperativeness of a safety culture and leadership aspects. Therefore literature verified the requirement of a safety culture and leadership commitment in a PSM model.

At the core of these case study companies’ PSM model, was the inclusion of a safety culture and leadership commitment. This validated the statistical analysis, whereby EP was found to be central to a PSM program. The EP and CTR elements involved the human aspect. Therefore an EP and CTR element dependency was devised and proposed as illustrated in Figure 31.

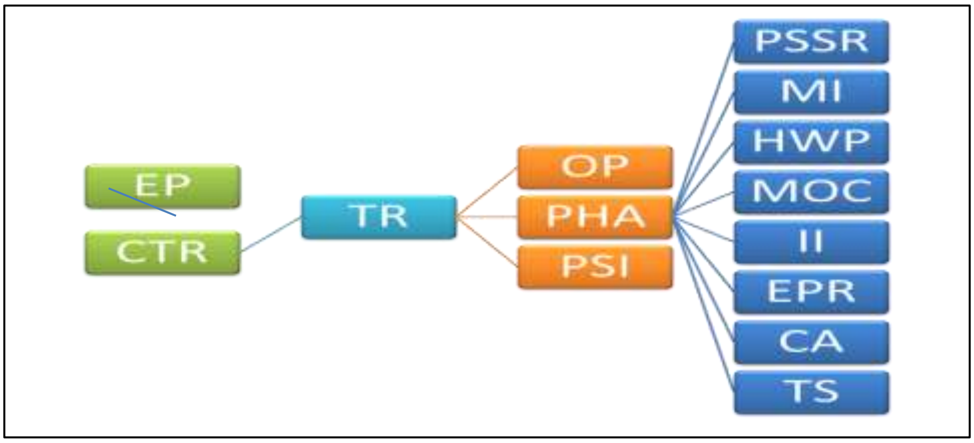

Figure 31 – PSM element dependency

This element dependency culminated from all the study findings and reviewed literature. The next chapter concluded on the findings as previously conversed. The study’s goals and associated effectiveness was discussed. Recommendations from this study were also prescribed.

Chapter 5: Conclusions and Recommendations

5.1. Introduction

In this chapter the conclusions are presented based on the objectives and aim as set out in Chapter 1. This was conducted employing the study findings attained and their associated comparison and verification to literature. Further study recommendations are proposed based on the study limitations and conclusions as discussed. These recommendations are postulated to uplift the merits of this study alluding to more defined findings.

5.2. Objectives

There were four objectives set forth for this study as follows:

1. To determine the PSM elements that significantly contributed to the occurrence of process safety incidents
2. To identify the PSM elements' failures that resulted in process safety incidents
3. To identify any relationships between the PSM elements in order to improve implementation effectiveness
4. To perform case study analysis on three international companies' approach to PSM

NOPSA, Global Congress on Process Safety, NEP, CCPS Vision 2020 and the Metric alignment initiative placed focus on the following overlapping OSHA elements, namely; MI, TR, EP and the II. However only the MI element was concluded to arise as a significant focus area as verified by literature. Therefore objective 1 was achieved as MI was found to significantly and consistently contribute to process safety incidents. Similarly objective 2 was completed, as further analysis into MI concluded that equipment or control failure was the significant cause. Techniques to improve the MI element were described by Peon (2008) and OGP (2008).

Objective 3 was also achieved, as literature was found to verify the dependency of OP, CTR and CA to EP and of PSSR, HWP and EPR to PSI. PSI was also deemed dependant on EP, which was not evident in the study, however was confirmed by literature. Two strong themes emerged from the literature, namely; safety culture and leadership commitment. These themes involved a key PSM element, which was the EP element. Therefore EP was confirmed to be foundation of a PSM program.

The case studies validated the findings from objective 3. An effective PSM program was observed by Shell and BP, as they incorporated the aforementioned themes into their PSM model. Therefore objective 4 was also achieved.

5.3. Aim

The aim of this study was to determine the most effective approach to implement and sustain PSM in an organisation to prevent and manage the occurrence of major industrial catastrophes. As previously deliberated, the statistical analysis verified by literature, indicated that the EP element was the foundation for the other elements. Literature also confirmed that the safety culture and leadership commitment aspects were imperative in order to achieve an effective and sustainable PSM program. This was validated by the case study analysis. The following PSM models from Chapter 2 were observed to contain these aspects, namely; DuPont, CCPS, Risk Based PSM framework and EI models.

These models were quite comprehensive and also incorporated the OSHA's PSM model. The TS element was confirmed as an insignificant element as it was included in PSI. As previously discussed in Chapter 4, the strength of the study methodology by employing the OSHA PSM model was confirmed. Therefore an effective approach was considered to employ OSHA's thirteen elements, with the exception of TS, and incorporation of the safety culture and leadership commitment aspects. Thus the most effective approach to implement and sustain PSM was to adopt the DuPont, CCPS, Risk Based PSM framework or EI models. To conclude, this study was effective as all the objectives and the aim was achieved.

5.4. Recommendation to improve this study

A safety culture and leadership commitment was concluded to be fundamental in an effective and sustainable PSM program. The DuPont, CCPS, Risk Based PSM framework and EI models were determined to best incorporate these fundamentals. Therefore the recommendation was to determine how these fundamental aspects can be entrenched into an organisation. Further, a new PSM program could be proposed, incorporating these fundamental aspects that would achieve an effective and sustainable PSM program.

5.5. Recommendations for further research

This study population was casted over a broad network of industries. The intention was to find common element constraints and relationships applicable to a wide group of industries. This would assure a uniform “one way” approach to sustainable PSM.

As deliberated in Chapter 4, there were many limitations to this study. The recommendation to improve the strength of this study; is to analyse incidents post millennium with particularly focus on incidents post 2005. Due to restrained competence and knowledge of PSM pre millennium, comprehensive cause analysis was not adequately defined. Divulging into cause analysis depths, namely; direct causes, root causes and contributing causes would uplift the detail and findings of this study.

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Appendix A – Survey Questionnaire

Table 22 – Survey Questionnaire

Incident Information		
Description of Incident		
Continent		
Year		
Consequence		
Industry		
Incident Classification		
Cause Analysis	***Cause***	***No Cause***
PSM Elements		
Employee Participation (EP)		
Senior Management Participation		
First Line Management Participation		
Floor level Participation		
Management Inspections		
Poor safety culture		
Process Safety Information (PSI)		
Codes and Standards not Identified		
Inadequate design		
Risks not identified		
Poor records of plant Drawings		
Poor records of plant equipment data		
Process Hazard Analysis (PHA)		
Risks not identified		
Ineffective Control Measures		
Poor risk perception		
Control measures not implemented		
Operating Procedures (OP)		
Deviation from procedures		
Procedures not updated		
Risks not included in the SOP		
Training (TR)		
Employees not trained		

Table 22 – Survey Questionnaire(Continued)

Inadequate training		
Inadequate experience		
Contractors (CTR)		
Personnel not aware of Hazards		
Inadequate training		
Inadequate experience		
Pre Start-up Safety Review (PSSR)		
Inspection of maintenance		
Poor quality of Maintenance		
Deviations from SOP start-Up		
Senior operating management not present during start-up		
Mechanical Integrity (MI)		
Poor quality of maintenance work		
Inferior or defective equipment used		
Routine maintenance not Completed		
Non-routine maintenance not completed		
Temporary maintenance Repairs		
Hot Work Program (HWP)		
Inadequate safe making of Equipment		
Inadequate monitoring of process environment		
Hazards not identified		
Deviation of control Measures		
Management of Change (MOC)		
No personnel change Procedure		
No project change Procedure		
Risks not identified		

Table 22 – Survey Questionnaire (Continued)

Temporary modifications		
Control measures not Adequate		
Incident Investigation (II)		
Past incident not Investigated		
Corrective actions not Implemented		
Inadequate depth of Investigation		
Poor investigative Techniques		
Not all causes identified		
Emergency Planning and Response (EPR)		
Equipment non-functional		
Personnel not trained		
Scenario not included in plan		
Personnel not prepared for response		
Compliance Audits (CA)		
Management inspection not done		
Disciplinary inspections not done		
Poor quality of assessment execution		
Non-comprehensive assessments		
Trade Secrets (TS)		
Confidential information not known		
Selective information shared		

Appendix B – Discussion Information

Table 23 – CCPS Incident Severity Categories (Overton,2008)

Table 2: Process Safety Incidents & Severity Categories				
Severity Level (Note 4)	**Safety/ Human Health (Note 5)**	**Fire or Explosion (Including overpressure)**	**Potential Chemical Impact (Note 3)**	**Community/ Environment Impact (Note 5)**
NA	Does not meet or exceed Level 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 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 – see Note 2A	Short-term remediation to address acute environmental impact. No long term cost or company oversight. Examples would include spill clean-up, soil and vegetation removal.
3 (**3 points** used in severity rate calculations for each of the attributes which apply to the incident)	Lost time Injury to employee or contractors associated with a process safety event.	Resulting in $100,000 to $1MM of direct cost	Chemical release outside of containment but retained on company property OR flammable release without potential for vapour cloud explosives – See Note 2B	Minor off-site impact with precautionary shelter-in-place OR Environmental remediation required with cost less than $1MM. No other regulatory oversight required. OR 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 vapour cloud entering a building or potential explosion site (congested/ confined area) with potential for damage or casualties if ignited – see Note 2C	Shelter-in-place or community evacuation OR Environmental remediation required and cost in between $1MM – 2.5MM. State government investigation and oversight of process. OR Regional media coverage or brief 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 – see Note 2D	National media coverage over multiple days OR Environmental remediation required and cost in excess of $2.5MM. Federal government investigation and oversight of process. OR Other significant community impact.

Appendix C – Incident Information

Table 24 – Incident Report Summary

No.	Description of Incident	Continent	Year	Consequence	Industry Classification	Incident Classification	Reference	Validated By
1	A cyclohexane vapour cloud explosion occurred when a bypassed system ruptured	Europe	1974	Explosion and Fire	Chemical	1	(ARIA, 2008)	(HSE, 1975)
2	A vapour cloud explosion occurred when a vapour was released from a depropaniser	Europe	1975	Explosion and Fire	Chemical	1	(Van Wingerden et al., 1995)	(HSE, 1996b)
3	Dioxin was released after a disc ruptured	Europe	1976	Release	Agricultural	1	(Kobayashi & Tamura, n.d.)	(HSE, 1996d)
4	Propane was released after a pipeline failed	North America	1976	Release	Chemical	1	(ERCB, 1980)	(HSE, 1980)
5	Small amounts of radioactive gases and iodine was released after a partial nuclear meltdown	North America	1979	Release	Nuclear	1	(Almanac of Policy Issues, 2002)	(Fact Sheets, 2010)
6	A fire on the platform resulted from released oil and gas	North America	1979	Release	Chemical	1	(ERCO, 1982)	(Ixtoc Oil Spill, n.d.)
7	An explosion occurred when the water supply to the hexane still condenser was interrupted	Europe	1981	Explosion and Fire	Chemical	3	(HM, 1982)	(HSE, 1982)
8	An explosion and fire resulted from water short-circuiting the power to the platform control panel	North America	1982	Explosion and Fire	Chemical	1	(NASA, 2011)	(OGP, 2012)
9	Released Liquefied Petroleum Gas ignited from a ruptured pipeline	North America	1984	Explosion and Fire	Chemical	1	(Paulin & Santman, n.d.)	(HSE, 1996e)
10	Methyl Isocyanate was released after a relief valve on a storage tank lifted	Asia	1984	Release	Agricultural	1	(Dutta, 2002)	(Kalelkar & Little, 1988)
11	An explosion occurred after flammable vapours were released from a hair line crack	North America	1984	Explosion and Fire	Chemical	1	(Beitler, 2008)	(Groves, 2006)
12	A warehouse fire resulted in chemicals being released into the River Rhine.	Europe	1986	Release	Chemical	1	(Edelparke, 2010)	(BBC, 2012a)
13	A nuclear meltdown occurred from loss of control during a test.	Europe	1986	Explosion and Fire	Nuclear	1	(Ecodefence, 2011)	(World Nuclear Association, 2013)
14	A vapour cloud explosion resulted from the release of the Hydrocracker Unit's flammable liquid	Europe	1987	Explosion and Fire	Chemical	2	(SEPA, 2003)	(HSE, 1989)
15	A hydrocarbon gas explosion resulted from a corroded catalytic cracker pipe	North America	1988	Explosion and Fire	Chemical	1	(Hoffman, 2013)	(Seghers, 2013)
16	An explosion and fire occurred on a platform	Europe	1988	Explosion and Fire	Chemical	1	(CCPS, 2005)	(Pate-Cornell, 1993)
17	An explosion occurred at an ammonium perchlorate plant that produced rocket fuel	North America	1988	Explosion and Fire	Chemical	1	(Mniszewski, 1995)	(NASA, 2012)

Table 24 – Incident Report Summary (Continued)

No.	Description of Incident	Continent	Year	Consequence	Industry Classification	Incident Classification	Reference	Validated By
18	Improper mixing of chemicals at a metal plant resulted in a release of toxic vapours	North America	1988	Explosion and Fire	Metallurgical	1	(Walter, 2002)	(Kinney & Mosley, 1990)
19	A flammable vapour cloud explosion resulted at a polyethylene plant	North America	1989	Explosion and Fire	Chemical	1	(Yates, 1989)	(HSE, 1996f)
20	A tank explosion resulted from a flammable space within a waste water storage tank	North America	1990	Explosion and Fire	Chemical	1	(Oil & Gas Journal, 1991)	(OSHA, 2010)
21	An explosion resulted from a runaway reaction at a fluoroaromatics plant	Europe	1990	Explosion and Fire	Chemical	2	(ICIS, 1991)	(HSE, 1996c)
22	A release occurred at a phosgene plant	Europe	1991	Release	Chemical	1	(Speller, 2009)	(HSE, 1993)
23	An explosion occurred from a tank that was heat penetrated	Asia	1992	Explosion and Fire	Chemical	1	(Kobayashi, n.d.)	(HSE, n.d. c)
24	An explosion occurred on a pipe that accumulated flammable vapours	North America	1992	Explosion and Fire	Chemical	1	(Dugal, 1999)	(Stargardter & Garcia, n.d.)
25	A reactor fire resulted from a released highly flammable solution	Europe	1994	Explosion and Fire	Chemical	2	(Ralph, n.d.)	(HSE, 1996g)
26	A fire occurred at a warehouse that stored polypropylene	Europe	1995	Explosion and Fire	Chemical	1	(Wisemann, n.d.)	(HSE, 1996a)
27	An explosion occurred at a road tanker which contained sodium chlorite and epichlorohydrin	Europe	1996	Explosion and Fire	Chemical	1	(Legal Watch, 2004)	(HSE, 1999)
28	An explosion occurred from ignited light gases released from a pipe	North America	1997	Explosion and Fire	Chemical	2	(CSHIB, 2001)	(EPA, 1998)
29	An explosion at the absorber occurred when a pump went offline	Australia	1998	Explosion and Fire	Chemical	1	(Hopkins, 2000)	(KMS, n.d.)
30	An explosion occurred at a plastic plant	North America	2000	Explosion and Fire	Chemical	1	(AcuSafe, 2002)	(White, 2000)
31	A Liquefied Petroleum Gas vapour cloud explosion resulted from a pipe failure	Europe	2001	Explosion and Fire	Chemical	1	(HSE, n.d. b)	(HSE, 2005)
32	An explosion at a warehouse that stored ammonium nitrate granulates	Europe	2001	Explosion and Fire	Chemical	1	(ARIA, 2007)	(Bravo, n.d.)
33	An explosion occurred at a fine powder plant	North America	2003	Explosion and Fire	Chemical	1	(CSHIB, 2005)	(CSB, 2004)
34	An explosion occurred from drilling into a pressurised natural gas and hydrogen sulfide field	Asia	2003	Explosion and Fire	Chemical	1	(China Labour Bulletin, 2003)	(Goodman, 2003)
35	An explosion occurred from ignited gas released from a pressurised petroleum gas pipe	Europe	2004	Explosion and Fire	Chemical	1	(Watterson & Taylor, 2007)	(Explosions Hazards Ltd, 2011)
36	A vapour cloud explosion occurred at a liquefaction plant	Africa	2004	Explosion and Fire	Chemical	1	(BAPE, 2004)	(Poten, 2004)
37	An explosion occurred when flammable product was released	North America	2005	Explosion and Fire	Chemical	1	(Mogford, 2005)	(CSHIB, 2007)
38	A hydrocarbon vapour cloud explosion occurred at the Buncefield plant	Europe	2005	Explosion and Fire	Chemical	1	(Hackitt, 2008)	(COMAH, n.d.)

Table 24 – Incident Report Summary (Continued)

No.	Description of Incident	Continent	Year	Consequence	Industry Classification	Incident Classification	Reference	Validated By
39	An explosion occurred at a flammable solvents plant	North America	2006	Explosion and Fire	Chemical	1	(CSHIB, 2008)	(Globe, 2006)
40	Liquid steel was released when a ladle that separated from an iron rail	Asia	2007	Release	Metallurgical	1	(Jianhong, 2007)	(Uaphawou, 2008)
41	An explosion occurred when propane was released during a tank transfer	North America	2008	Explosion and Fire	Chemical	1	(CBC, 2013)	(PennWell Public Safety, 2013)
42	A dust explosion occurred at a sugar plant	North America	2008	Explosion and Fire	Food	1	(CSHIB, 2009)	(O'Connor & Harkins, 2011)
43	An explosion occurred from a leak on a pipeline	Asia	2009	Explosion and Fire	Chemical	1	(Mishra et al., 2012)	(Vindhani, n.d.)
44	An explosion occurred from a tank fuel gauge failure	South America	2009	Explosion and Fire	Chemical	1	(FEMA, 2009)	(Waichman, 2009)
45	A methane vapour cloud explosion occurred at a well	North America	2010	Explosion and Fire	Chemical	1	(OSC, 2011)	(Durando, 2009)
46	Caustic sludge was released from an alumina plant	Europe	2010	Release	Chemical	1	(Javor & Hargitai, 2011)	(Burns, 2010)
47	An explosion occurred at a power plant	North America	2010	Explosion and Fire	Chemical	1	(CNN, 2010)	(CSHIB, 2010)
48	An earthquake resulted in a nuclear incident	Asia	2011	Explosion and Fire	Nuclear	1	(NAIIC, 2012)	(Akiyama, 2012)
49	An explosion occurred at a refinery storage tank	Europe	2011	Explosion and Fire	Chemical	1	(BBC, 2012b)	(HSE, n.d. a)
50	A vapour cloud explosion resulted from released olefins	South America	2012	Explosion and Fire	Chemical	1	(Rueda, 2012)	(Moya, 2013)