Title

Linking asset management implementation to process safety performance and SHE risks.

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Masters of Science in Engineering (Industrial Engineering)

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DECLARATION

I, Jealous Chitima, (Student number: 1285596) herewith submit the research report, in partial fulfilment of the requirements for the degree of Masters of Science in Engineering.

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ABSTRACT

The purpose of this research was to identify how hazardous chemical process operations present a unique challenge to decision makers on how to manage assets, while concurrently considering how effective asset management (AM) effects process safety (PS) performance. The study was conducted at a division of an integrated hazardous chemical company in South Africa

The study was conducted in two stages. The first stage was to develop a theoretical framework for asset management and process safety management (PSM) capability assessment from literature. This was done by reviewing the concept of asset management and the life cycle of assets and process safety management concepts in a hazardous chemical operations. The result was the identification of the stages of an asset in its life cycle and the PSM concepts

The second stage of the study was to assess the link between the asset management life cycle standards and the PSM elements to gain a better understanding of the relationship between AM and PSM. The researcher utilised information from the published papers that are in the public domain and some information available from a South African chemical operation. Additionally, the researcher used some data from the data base of a hazardous chemical operations company that tracked the chemical process plants' asset management practices prior to and after the implementation of an asset management driven project. The researcher analysed process safety performance data prior to the AM project program initiation and process safety performance for a period of five years, post AM program. The AM project was executed over a period of two years. The process involved the analysis of records of the root cause analyses of process safety incidents, management actions taken, technical audits on the maturity level of AM life cycle standards prior to and post execution of the AM program and similarly compared the performance of PSM through the recorded number of incidents and the severity of process safety incidents from the hazardous chemical company. The researcher further, conducted interviews to assist in the identification of key assessment areas. The general results indicate that there could be a relationship between the asset life cycle stages and process safety management elements.
The theoretical framework from the research papers and the results of the survey were used to affirm the status quo and identify gaps or overlaps, which exist in the

linkage of asset management life cycle and process safety performance to determine what could be improved on the current relationship between asset management and process safety performance.

Recommendations are given on what could be done to better understand improvements needed to integrate or minimise duplication of roles and duties in the management of assets and process safety in hazardous chemical operation companies.

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LIST OF ABBREVIATIONS

AI	Asset Integrity
AM	Asset Management
AIM	Asset Integrity Management
ALARP	As Low as Reasonably Practicable
BM	Business Management
BSI	British Standard Institution
CA	Compliance Audits
CCPS	Centre for Chemical Process Safety
CI	Continuous Improvement
CIEAM	The Cooperative Research Centre for Integrated Engineering Asset Management
CMMS	Computerised Maintenance Management System
DI	Design Integrity
EM	Engineering Management
EMS	Emergency Management Services
EPSC	European Process Safety Centre
FEL	Front End Loading
FER-SR	Fire Explosion and Release Severity Rate
FMEA	Failure Mode and Effects Analysis
HAZOP	Hazard and Operability Study
IAM	Institute of Asset Management
II	Incident Investigation
IM	Information Management
ISO	International Standards Organisation
KP3	Key Programme 3 (Asset Integrity Programme)
LCC	Life Cycle Cost
MIC	Methyl iso-cyanate
MISS	Maintenance Integrity Safety System
MOC	Management of Change
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
NCR	Non-conformance Reports
OEM	Original Equipment Manufacturer
OI	Operational Integrity

OS	Occupational Safety
OSHA	Occupational Safety and Health Act
PAS	Publicly Available Specification
PEFs	Process equipment failures
PHA	Process Hazard Analysis
P & ID	Piping and Instrumentation Diagram
PSCE	Process Safety Critical Equipment
PS	Process Safety
PSI	Process Safety Information
PSM	Process Safety Management
PSSR	Pre Start-up Safety Review
PtW	Permit to Work
QCP	Quality Control Plans
SCE	Safety Critical Equipment
SHE	Safety, Health and Environment
SME	Subject Matter Expert
SPM	Service Provider Management
SOPs	Standard Operating Procedures
TCO	Total Cost of Ownership
TI	Technical Integrity
TNA	Training needs analysis

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1 INTRODUCTION

1.1 Background

Hazardous chemical operations present a unique challenge to decision makers on how to manage assets, while concurrently considering how to manage process safety effectively. The integration with or the absence of asset management programs from process safety management influences process safety performance in hazardous chemical process operations. The integration with or the separation of asset management from process safety management has an effect on the performance safety, health and environment, (SHE) which could result in positive SHE risk reduction or escalation respectively.

1.1.1 Engineering Assets

Engineering assets referred to in this document as assets, have acquired powerful strategic and sensitive business and social roles in the modern day socio-economic, political and technological set up. Traditionally, 'asset management' implies financial assets (Chandima and Markeset, 2012). Emerging asset management focuses solely on physical assets, (production, process, manufacturing facilities, plants, infrastructure, support systems et al.), being dedicated to the development, application of engineering and managerial solutions to make physical assets safe, productive, cost-effective, efficient and environmentally-friendly (El-Akruti, et al, 2013).

Asset management encompasses the planning process, design, the acquisition, operations, maintenance, improvement and the disposal of assets, (plants). Chandima and Markeset (2012, p145-146), summarise asset management as, "… the acquisition, exploitation, maintenance, modification and disposal of critical assets and properties which is vital to the sustainable performance of most asset-intensive businesses. When the industrial operations become more asset-intensive then the corresponding business performance is more tied to the availability, maintenance, and deployment of assets".

Ramasamy and Yusof (2015), describe an asset as an entity from which the asset owner can derive an economic benefit in future accounting period by holding on and utilising the entity over a period of time. The Institute of Asset Management defines asset management as a set of systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditure over their life cycles for the purpose of achieving its organisational strategic plan (BSI PAS 55-1: 2008, Asset Management, 2008). In the same context Ratnayake (2012a) describes an asset as any physical core possession or the custody of any elements of significant value to the organisation, which provides and services requirements for the organization.

“The term ‘asset management’ (AM) has been adopted as the label for the integrated, whole life, risk-based management of industrial assets” (Ratnayake 2012a, p4). According to Ratnayake (2012a), “AM principally evolved during the late 1980s in the North Sea oil and gas industry, as a result of increased survival pressure, due to the regulatory changes subsequent to the Piper Alpha disaster and the crash in oil prices. However, the term AM had long been used in the financial sector within the area of maximising the value of an investment portfolio. The term ‘AIM’ is used to indicate a complete and fully integrated company strategy directed towards optimising efficiency and thus maximising the profit and return from operating assets” (Ratnayake 2012a, p4).

The role of asset management is a strategic, systematic, organisation-wide and a multi-disciplinary approach throughout the life cycle of assets to achieve sustainable value for companies. Traditionally companies have created relatively “small” support groups that are entrusted with asset management, which are normally placed in support services or functional departments. This generally makes the asset management department personnel work as advisers or consultants to the decision makers, rather than being decision makers themselves.

1.1.2 Safety

Safety is a word whose meaning has changed throughout history and seems to come from the old French word ‘sauf’, which comes from the Latin word salvus. ‘Sauf” means ‘uninjured’ or ‘unharmed’, while the meaning of salvus in Latin is uninjured, healthy, or safe. The modern day meaning of being safe is ‘not being exposed to danger’, ‘free from risk’, originated in the 16th century (Hollnagel, 2014). Hollnagel (2014) further states that safety means the absence of unwanted outcomes such as incidents or accidents resulting in a condition of being safe from harm. A more detailed generic definition could be that safety is the system characteristic or quality that is necessary and sufficient to ensure that the number of events that could be harmful to workers, the public, or the environment is acceptably low (Hollnagel, 2014).

Safety management is aimed at creating and maintaining a work environment that is safe for all stakeholders (employees, communities, customers, equipment, environment et al). Safety can be further broken down into two broad areas, namely Occupational Safety and Process Safety. This paper will focus on process safety as applicable in chemical process plants.

Process safety management is a discipline for managing the integrity of hazardous operating systems and processes using good engineering and operating principles.

Campbell et al. (2014), defined process safety management as a disciplined framework for managing the integrity of hazardous operating systems and processes by applying good design principles, engineering and operating practices. Campbell et al., (2014, p8) further elaborate on process safety management, stating that it deals with "….the prevention and control of incidents that have the potential to release hazardous materials or energy. Such incidents can cause toxic effects, fire or explosion and could ultimately result in serious injuries, property damage, lost production and environmental effect."

Khan et al (2015) summarise process safety as the common global language used to communicate the strategies of hazard identification and analysis, risk assessment and evaluation, safety measures, and safe critical decision making. Process safety differs from occupational safety as it solely focuses on preventing and mitigating major process accidents such as fires, explosions, and toxic releases, whereas occupational safety focuses on workplace hazards such as trips, slips, and falls.

Hazardous chemical process operations need to leverage asset management with process safety management to manage risk. A process is a set of interrelated or interacting activities which transforms inputs into outputs.

This study suggests that, this approach can be done through a focused structured approach and a better integration of asset management and process safety management functions.

1.2 Problem Statement

Many hazardous chemical operations in South Africa manage the two concepts of asset management and process safety separately. Integrating the two concepts and organisationally structuring the resources could result in the improvement of process safety, health and environmental performance and have SHE associated risk reduction. The possibility of such an integration in South Africa has not been broadly explored.

1.3 The Purpose Statement

The purpose of this research is to establish the link between asset management application and process safety performance, to determine the outcome with the view of proposing possible enhanced integration of asset management and process safety management.

1.4 Motivation

It is expected that the integration of the AM and PSM can improve the process safety performance, which has a direct effect on the safety performance in particular and the safety, health and environment performance of the organisation in general. The safety performance improvement could result in SHE risk reduction for the South African hazardous chemical operations. It is necessary to explore the AM and PSM processes to understand where they overlap and share business processes and systems. From the outcome it is expected that valuable insight will be gained that might lead to some hazardous chemical operations reviewing how they implement asset management and process safety principles.

1.5 Research Question

This research revolves around the central research question on the relationship between asset management and process safety performance:

- What is the link between asset management and process safety performance?

1.6 Research Objectives

The objectives of this research project are:

1. To assess the relationship between focused implementation of asset management systems and the outcomes of process safety performance in a hazardous chemical operations company;

2. To determine improvements needed to integrate the current asset management models with process safety management principles in a South African hazardous chemical process operations company;

3. To develop a conceptual framework for an integrated asset and process safety management standards; and

4. To make recommendation on areas of improvement to the asset management model utilisation in the process safety management in a hazardous chemical operations organisation.

1.7 Assumptions

A number of assumptions were considered by the researcher before embarking on the research project. The assumptions were listed as follows: the hazardous chemical organisation would grant limited permission to the researcher for the use of the available information on an anonymous basis; the researcher would conduct an interview survey with the interview participants on a face-to-face, one on one basis; the proposed interview participants would be selected from the current and former experts from the asset management and process safety management departments' personnel; there is vast information available on asset management and process safety management; not all proposed participants would take part in the interview study; the research information on linking asset management to process safety would be readily available.

1.8 Delimitations

The delimitations to the study included the following: limited time to conduct the research; inadequate resources to support the research; the research is limited to one hazardous chemical process organisation, hence the sample used in this research study might not represent the full picture of the hazardous chemical industry in its entirety; the available data are limited to a period of about five years only. The ability to have the level of interaction with the targeted process safety and the asset management personnel is contingent on the researcher's employment tenure at the company.

1.9 Report Structure

The rest of the research report is divided into five chapters namely:

1. Literature review which aims to provide a view on asset management and process safety principles in a hazardous chemical operations using the existing literature. The purpose of this chapter is to provide an overview and literature review on asset management and process safety principles. The chapter comprises the review of the available research on asset management and process safety covering definitions of both asset management and process safety, what they are and how they are currently applied in the hazardous chemical organisations.
2. Research methodology provides an oversight of how the researcher approached the research project. The chapter outlines how the researcher identified the participants, utilised data collection instruments, what criteria for data validation was applied and the description of data analysis instruments utilised.
3. Results and analysis explore the outcome of the research based on the information given by the interview participants and the available collected data with regards to asset management and process safety management over a period under review from the hazardous chemical organisation. In this chapter the conversion of the collected information is processed into themes and the collected data is compiled into tables, histograms, pie charts and audit reports summary. The results were analysed to have an outcome from the research.
4. Discussion chapter deliberates the main findings of the research vis-à-vis the central research question and objectives as stated in the introduction and the existing literature on asset management and process safety management as discussed in the literature review.
5. Conclusion links the research outcome to the research question and explores if the research question was answered or not, and whether the research objectives were met.

2 LITERATURE REVIEW

The literature review aims to provide a view on the knowledge areas of both asset management and process safety management and how the link between these two knowledge areas are fundamental to process safety performance improvement and reducing SHE risks for a chemical process organisation.

2.1 Pre-view

The diagram on Figure 1, gives an overview of the literature review.

Asset Management
(Stand-alone system)

- Asset management policy, objectives, strategy and standards
- Asset acquisition
- Employee Training
- Asset management systems
- Asset implementation
- Asset integrity
- Start-up of assets
- Asset maintenance
- Continuous improvement
- Asset renewal/ disposal

Process Safety Management
(Stand-alone system)

- Employee participation
- Process safety information
- Process hazard analysis
- Standard operating procedures
- Employee & training competency
- Service provider management
- Pre-start up safety review
- Mechanical integrity safety system
- Permit to work
- Management of change
- Incident investigation
- Emergency management system
- Compliance audits
- Trade secrets

Linked Asset Management and Process Safety Management System

- **Asset and PSM policies, objectives, strategies and standards**
  - Asset management and SHE policies; asset management and SHE plans; contingency and SHE planning; design standards; SHE planning;
- **Asset Acquisition**
  - Asset life cycle; Outsourcing of assets; asset management; employee participation; communication and consultation; PHA; PSI; service provider management; trade secrets; set up operating standards; tools facilities.
- **Asset Management Systems**
  - Work management processes; life cycle activities; communication and consultation; PSI; MOC; asset documentation system; trade secrets; design standards and specifications; set up operating standards; employee training.
- **Asset Implementation**
  - Tools facilities and equipment; life cycle activities; tools facilities and equipment; PHA; PSI; SOP; service provider management; employee participation; design standards and specifications; OEM standards;
- **Start-up of Assets**
  - Work management processes; SOP, PSSR; OEM standards; EMS; risk management; MOC; tools facilities and equipment; employee training.
- **Asset Maintenance**
  - Employee & training competency; SOP; employee participation; service provider management; permit to work; MISS; EMS; incident investigation; PSSR; trade secrets; work management processes; asset management strategies; COPs; risk management; asset documentation system; MOC;
- **Continuous Improvement**
  - Permit to work; management of change; incident investigation; EMS; compliance audits; service provider management; review design and operating standards; review maintenance standards; asset related failures;
- **Asset Renewal/ Disposal**
  - PtW; MOC; EMS; audits; records; service provider management; risk review.

Figure 1: An overview of asset management and process safety managed separately and what could happen if AM and PSM were to be integrated (Source: author).

2.2 Asset Management

Asset management encompasses the planning process, design, the acquisition, operations, maintenance, improvement and the disposal of assets (Chandima and Markeset, 2012). Koronios et al (2007, p2) borrowing from The Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM), define asset management as the process of organising, planning and controlling the acquisition, use, care, refurbishment, and/or disposal of physical assets to optimise their service delivery potential and to minimise the related risks and costs over their entire life through the use of intangible assets such as knowledge based decision-making applications and business processes. In this definition, physical (or engineering) assets, such as buildings, roads, machinery and hardware, are distinguished from intangible assets such as knowledge, software, intellectual property, and financial assets.

According to Schuman and Brent (2005), asset management can best be described as a strategic, integrated set of comprehensive processes (financial, management, engineering, operating and maintenance) to enable a lifetime effectiveness, utilisation and return from physical assets (production, operating equipment and structures).

2.2.1 Asset Management Policy, Objectives, Strategy and Standards

Asset management needs to be part of an organisational strategy that must be driven at the topmost of any organisation for it to be effectively implemented and embedded (Asset management operations handbook, 2013). A dynamic but implementable strategy must be developed, which must be translated into a policy, with clear direction.

Below is a typical extract of an asset management framework model.

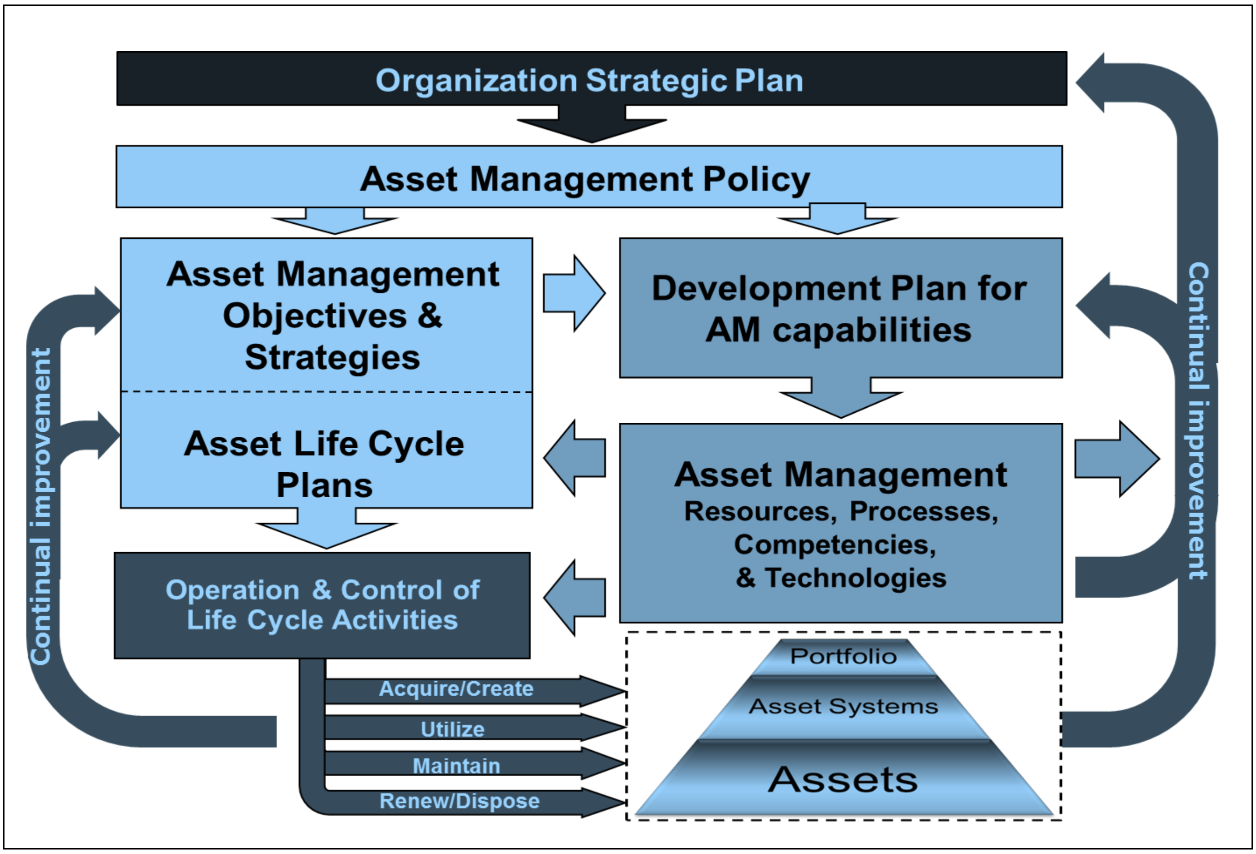

Figure 2: A typical strategic plan for asset management, (Source: Asset management operations handbook of a hazardous chemical operations company in South Africa, 2013)

Figure 2 portrays a typical strategic plan for asset management and indicates processes that could be followed in asset management. There are two inter-related actions, which are the asset management objectives and strategy setting on one hand and asset life cycle planning on the other. These actions should be put in place before an asset such as a pump is acquired. Once the planning is approved the four phases of the asset management life cycle namely: acquire; operate; maintain; and dispose are initiated. Schuman and Brent (2005) state that the asset management process should be managed through asset management policy, strategy, objectives setting, planning, feasibility study, design, procurement, installation, operation, maintenance, continuous improvement and disposal to gain better value and have a competitive advantage for any chemical process operation from an assets such as a pump.

Schuman and Brent (2005, p568) state that "in practice, with specific reference to the process industry, the management responsibility changes hands from one phase to the next. A research and development or a technical department will take full responsibility for the acquisition phase and will hand over to an operations department for the utilisation phase."

According to BSI PAS 55-1 (2008) a business or organisation consists of five assets, namely: human assets; information assets; intangible assets; financial assets and physical assets. Physical assets form the core of the assets, which is the focus of BSI PAS 55-1 (2008) and covers the life cycle of assets that are core to the organisation's purpose, such as oil and gas installations, manufacturing, utility plants, process plants, among others and divides the asset management into four layers with corporate management at the apex of the layers (see figure 3). The bottom layer which is broad is sub-divided into a further four areas: create or acquire assets; utilise assets; maintain and renew or dispose assets.

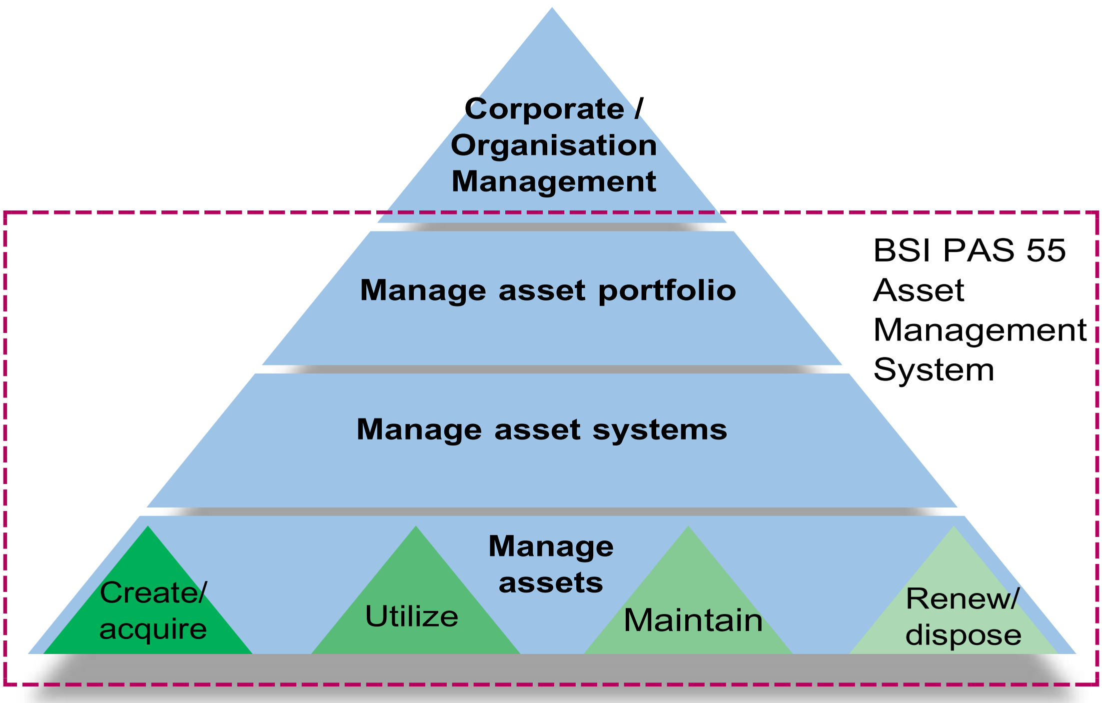

Figure 3: Levels of assets and their management (Source: BSI PAS 55-1:2008)

An integrated framework for asset management should divide the asset management process into twelve functional areas namely: strategic planning; risk planning; asset ownership; budgeting and costing; condition monitoring; data management; human resources; tactical planning; asset usage life cycle; performance measures; information systems; and financial management (CIEAM, 2009).
Koronios et al (2016), indicate that the twelve functional areas can be further grouped into three interrelated sub-groups, as namely: 1. business management: strategic planning, risk planning, asset ownership, budgeting and costing and financial

management; 2. engineering management: condition monitoring, tactical planning, asset usage life cycle and performance measures; and 3. information management: data management, human resources and information systems. This is illustrated in Figure 4.

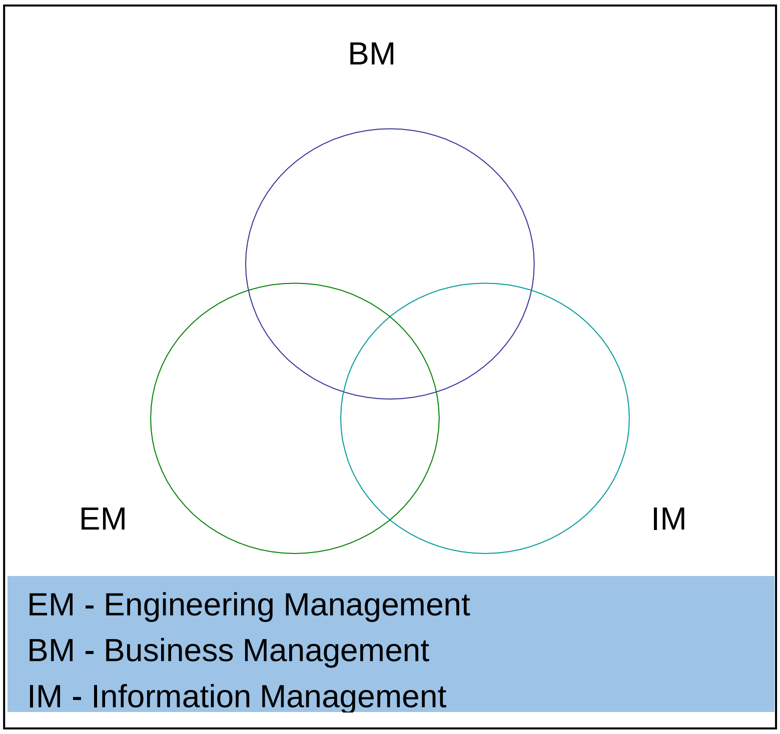

Figure 4: Integrated Engineering Asset Management (IEAM) Diagram, (Source: Koronios et al. 2016)

There are a number of activities that need to be defined and detailed under each functional area of business management, engineering management and information management. El-Akruti et al (2013) mention that each AM related solution has to be defined and examined according to the sequence of the phenomenon represented by a number of elements. “This involves identifying the strategy event, defining the asset solution and its provision, determining the asset performance and outcomes related to the strategy” El-Akruti et al (2013, p4).

Schuman and Brent (2005) list the following as critical processes in asset management namely: the development of an asset, process plant or production facility is initiated by a need identification; the asset, process plant or production facility requires maintenance and support during its operational lifetime for the asset to fulfil the identified need; an asset life cycle management approach has to be applied in order to reduce the asset’s operating, maintenance costs, productivity optimisation of the process plant, maintenance and continuous improvement should be implemented simultaneously. They continue to say that an asset effectiveness starting from reliability, availability up to maintainability are of equal importance to the functional requirements of an asset throughput, product quality, return on capital, schedule compliance among others. It is of critical importance that the afore-mentioned requirements should be clearly defined during the conceptual phase of an asset acquisition.

These fundamental concepts are part of an effective asset management strategy which enables chemical process plants to have a sustainable competitive advantage.

It is critical to explore why asset management is important in a hazardous chemical process operations, such as fertiliser and pesticide manufacturing. Asset management assists organisations in reducing operational cost; base asset capital cost; health effect, safety and legal risks, while minimising the environmental effect and improving the asset operating performance; regulatory compliance, socio economic effect and organisational reputation (Schuman and Brent, 2005).

The Institute of Asset Management's Competencies Framework (2008) lists five key activities that must be performed after developing an asset management policy and strategy. These activities are asset planning; delivering on the asset management plans; developing people; managing risk and managing asset information. These are illustrated in Figure 5.

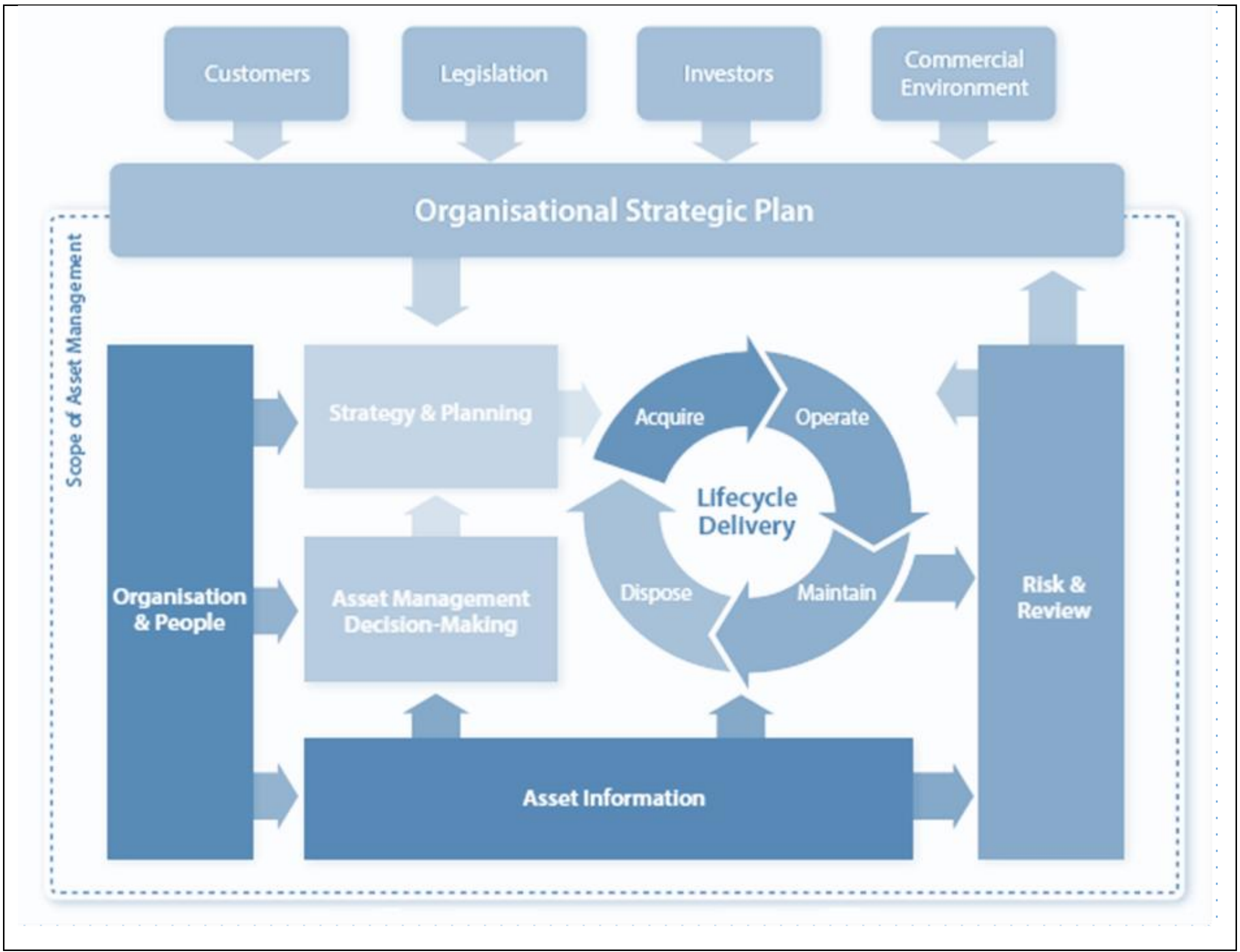

Figure 5: The IAM Conceptual Model (Source: The Institute of Asset Management, 2008)

The BSI PAS 55-1 (2008) sets the standards for asset management utilising the "plan, do, check and act, model". It breaks down the four stages into seven sub-processes namely: general requirements; asset management policies; asset management strategy, objectives and plans; asset management enablers and controllers; implementation of asset management plans; performance assessment and improvement; and management review (p xiiii).

Figure 6 illustrates the life cycle of an asset according to the BSI PAS 55-1 (2008), where asset management is integrated with other management systems. The life cycle of an asset starts in the "plan" phase and ends in the "act" phase.

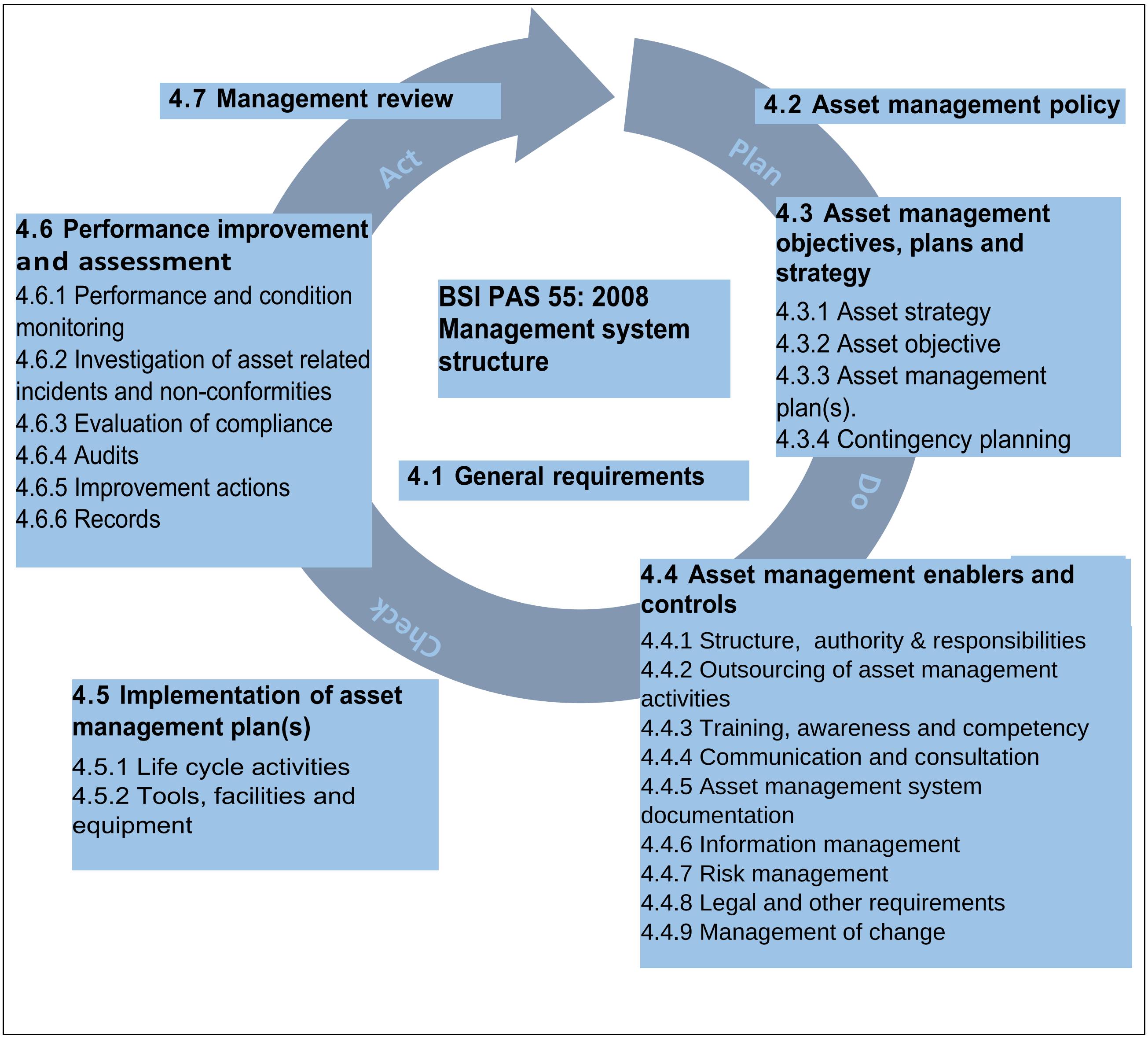

Figure 6: Structure of BSI PAS 55-1: 2008 (Source: BSI PAS 55:2008)

2.2.2 Asset Acquisition

The acquisition of assets covers everything that involves planning, designing and procurement of an asset (Davis 2018, p11) and the creation, improvement, refurbishment or enhancement design, modification, procurement, construction and commissioning (BSI PAS 55, 2008). The identification need for assets begins during the initial investigation stage of a project in the chemical process industry. Schuman and Brent (2005) indicate that the focus during this project stage is on investigating and evaluating the process requirements with little detail on the actual assets, if any. The asset requirements are specified in broad terms, e.g. a refinery, capable of producing a specific fuel product, volume, within the legal compliance.

2.2.3 Asset Management Systems

To ensure asset management effectiveness and for it to be measurable a number of systems need to be defined and the BSI PAS 55-1 (2008) refers to them as asset management enablers and controls. BSI PAS 55-1 (2008) describes the enablers and controls in detail in BSI PAS 55 (2008, p10-14). The enablers and controls are listed as follows: "structure, authority and responsibilities; outsourcing of asset management activities; training awareness and competency; communication participation and consultation; asset management system documentation; information management; risk management; legal and other requirements and management of change". According to Figure 6, these form part of the "DO" on the asset management life cycle.

2.2.4 Asset Implementation

The construction phase of an asset should be integrated with the operations phase and process safety management in a hazardous chemical process operations. Maintenance and process safety should be integrated to ensure a smooth transition from construction to operation. Schuman and Brent (2005) state that the construction and production of the process facility takes place during the execution stage of the project management. The operations and maintenance personnel become fully involved as the process plant nears completion, whereby they are trained at this stage to ensure competency. It is important for operating personnel, to complete training before the critical start-up. The pre-commissioning and commissioning periods of a process plant provide valuable training opportunities that should be fully exploited (Schuman and Brent, 2005).

Chemical process plants need to implement, maintain the processes and procedures for the asset implementation, which covers the procurement, utilisation, maintenance and disposal. During plant construction, the actual accessibility needs to be evaluated, although it might be late at this stage in the project for major changes, recommendations should be considered if necessary (Schuman and Brent, 2005).

Training forms a critical part of asset implementation, operation, maintenance and disposal as indicated in figure 6; thus, training covers the whole life cycle of asset management. Employee training is an organised way which allows organisations to provide development and enhance quality competence to both new and existing employees. Training is viewed as a systematic approach of learning and development that improves the individual, group and organisation (Nda and Fard, 2013). Asset implementation would not be complete without training.

2.2.5 Asset Integrity

Asset integrity management (AIM) is important in the life cycle of an asset and it must be built in and assured during the asset construction, implementation and maintenance of the asset. “Asset integrity (AI) can be defined as the ability of an asset to perform its required function effectively and efficiently whilst protecting health, safety and the environment. Asset integrity management is the means of ensuring that the people, systems, processes and resources that deliver integrity are in place, in use and will perform when required over the whole lifecycle of the asset” (Health and Safety Executive 2007, p5). The objectives of asset integrity include: the compliance to national regulations, company policies and standards; adaptation to the industry requirements and international standards and regulations; staying safely fit for purpose under all operational circumstances; ensuring that all assets safely operate reliably and efficiently within design parameters; ensuring that all suitable checks, processes and reviews are in place to safeguard the asset; ensuring that the asset design, construction, installation, operation and maintenance are at a risk level tolerable to the ALARP concept; protection of company brand and reputation; achieving planned production forecast to retain and gain markets, while complying with the operating and maintenance philosophies (Health and Safety Executive, 2007).

In hazardous chemical process plants and in the oil and gas industries “the AI level depends on the ability to maintain the pressure containing envelope to hold the hydrocarbons inside the pipes and vessels without causing accidental leaks that can lead to catastrophic failures” (Ratnayake and Markeset 2012, p4). Chemical process plants inherently undergo integrity degradation during their operational life (Ratnayake, 2012b).

Industrial assets inherently undergo integrity degradation during their operational life as illustrated on Figure 7. The figure suggests that maintenance and modifications upgrade the level of integrity to a certain threshold or above level. The challenge is how to sustain and continuously improve the assets’ integrity over time without the asset integrity falling down below the threshold level as specified by the regulatory authorities. Figure 7 clearly illustrates possible AI scenarios that can arise over the operational life of a chemical process asset.

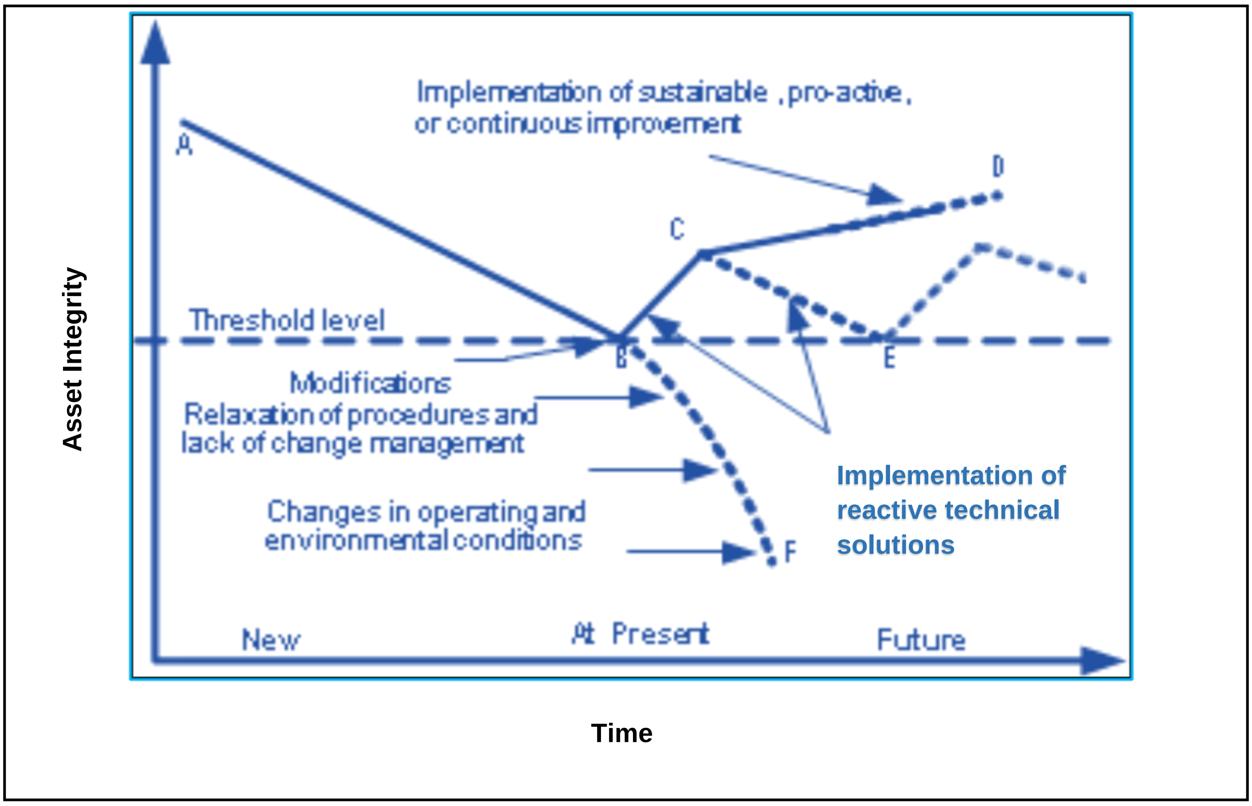

Figure 7: Possible declination of integrity, reactive technical solutions, and sustainable continuous improvement, (Source: Ratnayake, 2012a).

Ramasamy and Yusof (2015) assert that asset integrity can be divided into design integrity, technical integrity and operation integrity as illustrated in Figure 8.

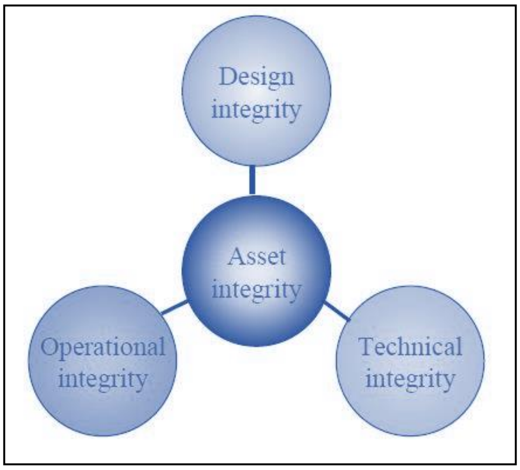

Figure 8: Sub-groups of asset integrity (Source: Mohamed, et al, 2012)

Baby, et al (2008) state that design integrity provides assurance that facilities are designed in accordance to governing standards and meet specified operating requirements without compromising on safety, accessibility, operability and maintainability. Asset integrity evolves from the design phase and the integrity management plan must be implemented as per asset management strategy systems defined by the asset management life cycle of the organisation or the chemical process plant.

Technical integrity is the development of a design that is carried out by competent personnel, who were assessed and found to be competent in accordance with recognised, sound practices and procedures with adequate provision for reviews and audits to ensure the design intent is unimpaired in any way that could cause undue risk or harm to people and damage to the environment, (Ramasamy and Yusof, 2015). Asset technical integrity is a condition where the technical state of assets includes all related operations and business processes as one process to ensure that there will be no (zero) harm to people, property and the environment.

Ramasamy and Yusof (2015) emphasise that operational integrity addresses operating within an asset’s operating envelope, as defined by technical barriers; appropriate knowledge, required experience, adequate manning, competence manpower; and reliable data for decision making are essential to operate the plant as intended throughout asset lifecycle. Hazardous chemical process plants have to manage assets to prevent any process safety incidents by managing the asset governance and integrity.

Ratnayake (2012a) recommends that maintenance considerations should begin simultaneously with equipment procurement and construction while evaluating the spare parts requirements. They further emphasise the need to conduct risk studies that encompass the whole asset life cycle. In the asset implementation the risk studies should include cost-risk studies to assist in deciding on whether and how many expensive, slow moving spares should be kept. Ratnayake (2012a) prefers that spare parts identified as critical be on site prior to start-up to prevent long process plant downtime, due to non-availability of spare parts. Standardisation and interchangeability of spare parts should be considered to minimise the stock quantities that are kept in the warehouse.

Ratnayake (2012a) states that special tasks for the future maintenance on the equipment should be identified and any special purpose tools identified, procured or constructed during this stage to ensure that established assets can be maintained after start-up as per OEMs' specifications. In addition to maintenance and operational personnel training, operational documentation systems, such as standard operating procedures, codes of practice, management of change processes, training manuals, competence evaluation processes, et al, need to be developed and completed at this stage.

According to Schuman and Brent (2005) in the oil and gas or chemical process industry, the tender bids are usually requested, evaluated at this stage. The asset establishment bids are issued based on the life cycle cost (LCC) and total cost (TCO) of ownership, instead of basing the bids on initial capital layout only. This trend at times extends to either asset maintenance outsourcing or to a full outsourcing of the operations and the maintenance of the chemical process plant to a third party. It is in the interest of the contracted parts supplier to supply parts that have lowest LCC.

Schuman and Brent (2005) are of the view that outsourcing compels the suppliers to supply and install more reliable equipment and parts which could result in less down time, unplanned maintenance production losses and better asset integrity. It is therefore important that maintenance contracts are thoroughly evaluated at this stage.
Towards the end of the construction phase, the operating and maintenance personnel become involved with plant checkouts. It is of importance for process reliability and equipment maintainability that highly competent personnel are utilised to perform the plant check outs and inspections. Schuman and Brent (2005) emphasise that during the inspections, conformance to process and maintainability requirements should be confirmed and approved; the end of job documentation such as operating manuals, maintenance manuals, code data books, P & IDs, as-built drawings must be available at commissioning; and the plant reliability strategies should be completed, signed off and the computer maintenance management systems (CMMS) must be populated, tested and ready for start-up, at the end of this stage.

2.2.6 Start-up of Assets

The utilisation of an asset is in most cases the longest period of an asset life in the asset life cycle (Shuman and Brent, 2005). According to Shuman and Brent (2005, p578), "Operating the plant within the design parameters, supports process reliability during system utilisation". The operating parameters are defined in the design stages of the project development. The construction and commissioning of the plant is an equally complex undertaking, requiring a large number of a variety of resources and good resource planning and deficiency management.

Manning and Martyna (2004) emphasise that chemical process plants are complex and due to their complexity in construction and commissioning these projects often have start-up delays and present a number of problems for the owner or operator. Manning and Martyna (2004) further underscore that chemical process plant commissioning is often incomplete, due to poorly documented processes, inconsistent procedures, and inefficient project scheduling. Apart from poor documentation, personnel safety is compromised and is at risk if procedures are not followed. The complexity and the sheer size of hazardous chemical process plants in oil and gas can easily lead to inconsistencies in procedures and practices, since different technical personnel could proceed with poor coordination and lack of clear guidelines. Manning and Martyna (2004) highlight the importance of quality control in construction and commissioning, hard-copy verification of work completed is inconsistently provided. At times, typical project construction and commissioning may not include independent auditing procedures and sometimes verification procedures do not exist at all. Manning and Martyna (2004) further stress that the lack of documentation might result in chemical process plant start-up which could result in poor quality product, serious process safety incidents, premature plant breakdown that could result either a financial loss, negatively affect the health of personnel, the community and the environment; and without a clearly documented and controlled verification procedure, an insurance claim may fail, when based only on the assertion that steps were taken to ensure that the plant was set up properly prior to start-up, in the event of an incident or accident that might need to raise an insurance claim.

Generally, hazardous chemical plant owners and operators want documented assurances to ensure that all the equipment is installed correctly and tested. If there are any non-conformances found these must be documented and accountable personnel identified with sign-off accountabilities (Manning and Martyna, 2004).

According to BSI PAS 55-1 (2008) the “Check” stage involves life cycle activities, tools, facilities and equipment. This stage assesses asset commissioning and maintenance activities. Poor asset construction, asset start-up and maintenance might affect asset integrity, which could affect the hazardous chemical process plant’s operational and process safety performance, measured in fire, explosions, explosions severity index.

2.2.7 Asset Maintenance

Dekker (1996) defines maintenance as the combination of all technical and associated administrative actions intended to retain an item or system in or restore it to a state in which it can perform its required function. The maintenance objectives can be summarised under four headings (Dekker, 1996): ensuring system function (availability, efficiency and product quality); ensuring system life (asset management); ensuring safety; ensuring human well-being. Moubray (1997), defines asset maintenance as the insurance that physical assets continue to do what their users and owners want them to do. On the other hand, the BSI PAS 55-1 (2008) identifies tasks in maintenance to include inspection, condition monitoring, functional testing, repair, refurbishment, and/or life extension of assets and replacement of individual assets is considered as part of the maintenance of asset systems.

The structures and diversity of the maintenance management systems found in hazardous chemical process plants are complex. This complicates the performance measurements as the definitions for corrective maintenance backlog, overdue maintenance, corrective maintenance and safety critical maintenance often lack clarity. The complexity makes it difficult for maintenance managers to absolutely understand the maintenance tasks at hand and the maintenance performance which could lead to poor management prioritisation. When the inspection and verification tasks are added, the levels of complexity increase enormously. Besides the complexity, the variance in definitions across the chemical process industry makes it more complicated to produce clearly detailed performance indicators.

The Health and Safety Executive (2007) states that management prioritisation is more difficult with the companies' needs to balance maintenance requirements and upgrade proposals due to severe bed space or resource constraints. In addition, poor performance in maintenance systems could be further exacerbated by an incompetent workforce, with little or no experience. Hazardous chemical plant operations notably are under pressure competing for a few human resources that are available on the labour market over recent years.

Dekker (1996) indicates that the maintenance objective for production equipment is to ensure the production system function, with maintenance providing the right (but not maximum) reliability, availability, efficiency and capability (i.e. producing at the right quality) of production systems. In principle an economic value to the maintenance results can be accorded with a cost balance done as well (Dekker, 1996). Norms to define failure and benefits of maintenance have to be set and they are generally difficulty to quantify with reference to hazardous chemical process plant operations. Process safety plays a huge role in case failures e.g. reactor failure, ammonium tank failure can have drastic consequences, to the safety and health of employees, the surrounding communities and the environmental effect. Hence testing and inspection activities constitute an important part of the maintenance work.

A number of activities and tasks ensure that assets are maintained according to standard and to retain their integrity. The BSI PAS 55-1 (2008) specifies these as follows: performance assessments and condition monitoring; investigation of asset related failures, incidents and non-conformities; evaluation of compliance and audits. The utilisation of effective management processes and systems ensures that maintenance work is identified and planned in time and with clear task description for the maintenance planners and supervisors to know what needs be done. If a well-defined priority system exists, it should ensure that critical tasks are prioritised, which eliminates time wastage and ensures efficient resource utilisation. To better the maintenance, predictive maintenance tools (The BSI PAS 55, 2008) should be used, and scheduled condition-based maintenance tasks must be monitored, executed and in cases of deviations, immediate corrective actions must be taken.

2.2.8 Continuous Improvement

Continuous improvement (CI) is one of the most widely discussed topics in process industries, business and academic circles. Cochran (2003, p1) defines continuous improvement as “the incremental process of becoming a smarter, stronger and more successful organisation”. Cochran (2003) elaborates that continuous improvement involves the understanding of the set standards, the current performance of the current resources, machinery, equipment, human, systems and the anticipated future performance. Cochran (2003) states that chemical process plants such as fertiliser and petro-chemical plants are designed for a specific lifetime, however in practice the chemical process plants’ life is often extended beyond the design life span and some plant components wear out and fail at different rates and get replaced from time to time. The whole chemical process plant does not need to be replaced during its life cycle. Utilisation of asset management principles assist decision makers on whether to renew or dispose of an asset towards the end of its life. A number of considerations should be considered, such as: economic cost; production interruption; availability of spare parts; and health, safety and environmental effect (Cochran, 2003).

For chemical process plants, the continuous improvement programs plants vary with the level of maturity on the application of the AM methodologies. The Institute of Asset Management (2015)(IAM) generally groups these levels of maturity into 6 categories as follows: innocent; this is when the organisation is unconsciously unaware of the need for asset management and there are no plans to put it in place; aware is where asset management is identified as need and there is an intention to set up and implement it by the organisation; developing, is where the requirements are consistently achieved in a systematic manner and credible resourced plans are in place, by the organisation; competent; is where requirements set out in ISO 55001 are systematically and consistently met; optimising; is where asset management is systematically and consistently utilised in practice as set out in the organisation's objectives; excellent; is where an organisation achieves maximum value from asset management using leading practices, in line with the organisation's objectives.

Continuous improvement programs are initiated to improve plant performance, maintenance, human capacity, asset life, LCC, integrity, to mention a few (Schuman and Brent, 2005).

2.2.9 Asset Disposal

Despite all interventions there will be a time when a chemical process plant must be disposed of e.g. after the end of its operational life. Disposal of chemical process plants occurs when they reach the end of their production lives or have fallen below what is considered financially viable in the business models of larger oil companies and the levels of integrity are low based inspection and corrosion prevention with a significant refurbishment effort required (Health and Safety Executive, 2007).
Whenever the chemical process plant disposal need arises, it should be done in a safe, healthy and environmentally compliant to the statutory laws, the company's environmental policy, in a responsible and socially acceptable manner after the end of its operational life.

2.3 Process Safety Management

Process safety management (PSM) is a disciplined framework for managing the integrity of hazardous operating systems and processes and processes by applying good design principles, engineering and operating practices according to Campbell et al (2014). Khan et al (2015) define process safety as a language used to communicate the strategies of hazard identification and analysis, risk assessment and evaluation, safety measures, and safe critical decision making globally. In the petrochemical industry process safety is an integral part of the business processes rather than an add on to the processes. Process safety for the purpose of this study is different from occupational safety because its sole focus is on prevention and mitigation of major chemical process incidents namely; fire, explosions and toxic releases, whereas on the other hand the study takes the view that occupational safety's focus is on the workplace hazards such as body injuries, trips, slips, and falls. Campbell et al (2014, p8) clarify that process safety management deals with "….the prevention and control of incidents that have the potential to release hazardous materials or energy. Such incidents can cause toxic effects, fire or explosion and could ultimately result in serious injuries, property damage, lost production and environmental effect." Klein and Vaughen (2017) elaborates further that process safety management is a system that focuses on prevention of, preparedness for, mitigation of, response to and restoration from catastrophic releases of chemicals or energy from a process associated with a hazardous chemical processing facility. PSM is credited in the hazardous chemical process industries for the prevention and reduction of major accident risks and for an improved safety performance over the past years by eliminating and minimising catastrophic events which could have resulted in loss of life, negative environmental effect and an increase in SHE risks. Examples of major and catastrophic incidents that have taken place are given further below.

Leveson and Stephanopoulos (2014) argue that process safety is not part of the mission or reason for the existence of any hazardous chemical process plant. Rather, a hazardous chemical process plants' mission, reason for existence is to produce chemicals and generate income by meeting market demand. The creation of a safe environment by minimising and elimination of exposure to bystanders and the surrounding environment to destructive effects of unleashed toxins and/or shock waves is actually a constraint, on how a hazardous chemical process plant can achieve its mission. A constraint in this instance implies to the limitations on the behavioural degree of freedom of the system components (Leveson and Stephanopoulos, 2014). This observation and statement have far reaching ramifications on how process safety should be viewed, applied and how safe processes should be designed and operated.

This assertion is based on the observation that incidents occur when the process safety-imposed constraints are ignored, violated or unknown and these constraints are imposed on the operational state of a hazardous chemical process plant system. This gives a view that process safety is a problem that must be addressed within the scope of an operating hazardous chemical process plant system.

It is quite critical to understand and differentiate process safety from reliability since "… process safety is different from Reliability Engineering" (Leveson and Stephanopoulos, 2014, p6) although the two might overlap or share principles and systems. Leveson and Stephanopoulos (2014) explain that process safety management thinking is that process safety performance is improved by increasing the reliability of the individual system components, assuming that if components do not fail, then incidents will not occur. However, a high-reliability chemical process, i.e. a process with highly reliable engineered components (vessels, piping, connectors, pumps, sensors, control valves, control algorithms, etc.) is not necessarily a safer process because, dysfunctional interactions among the process components or operations personnel can lead to unsafe operations while all components are perfectly functioning as intended.

Khan et al (2015) note that a number of research organisations and research programs have been established to advance process safety and its industrial applications. Major and catastrophic incidents such as the Bhopal accident in India, 1984; the Seveso accident in Italy, 1976; and the Flixborough accident in the UK, 1974 have resulted in regulatory and legislative responses from various authorities. In addition, there has been an establishment of a number of organisations that focus on the health and safety in the workplace, such as the European Process Safety Centre (EPSC) and the Centre for Chemical Process Safety to develop guidelines, standards, methodologies and safe work practices for chemical process industries.

Figure 9 portrays process safety methodology, which utilises the "Plan, Do, Monitor and Review" initiated from process safety management knowledge base. The methodology follows five stages in the cycle namely: 1) build the PSM foundation knowledge base; 2) risk-based planning, (risk-based PS planning); 3) risk based PSM; 4) risk-based PS monitoring and assurance; 5) and risk-based PS review.

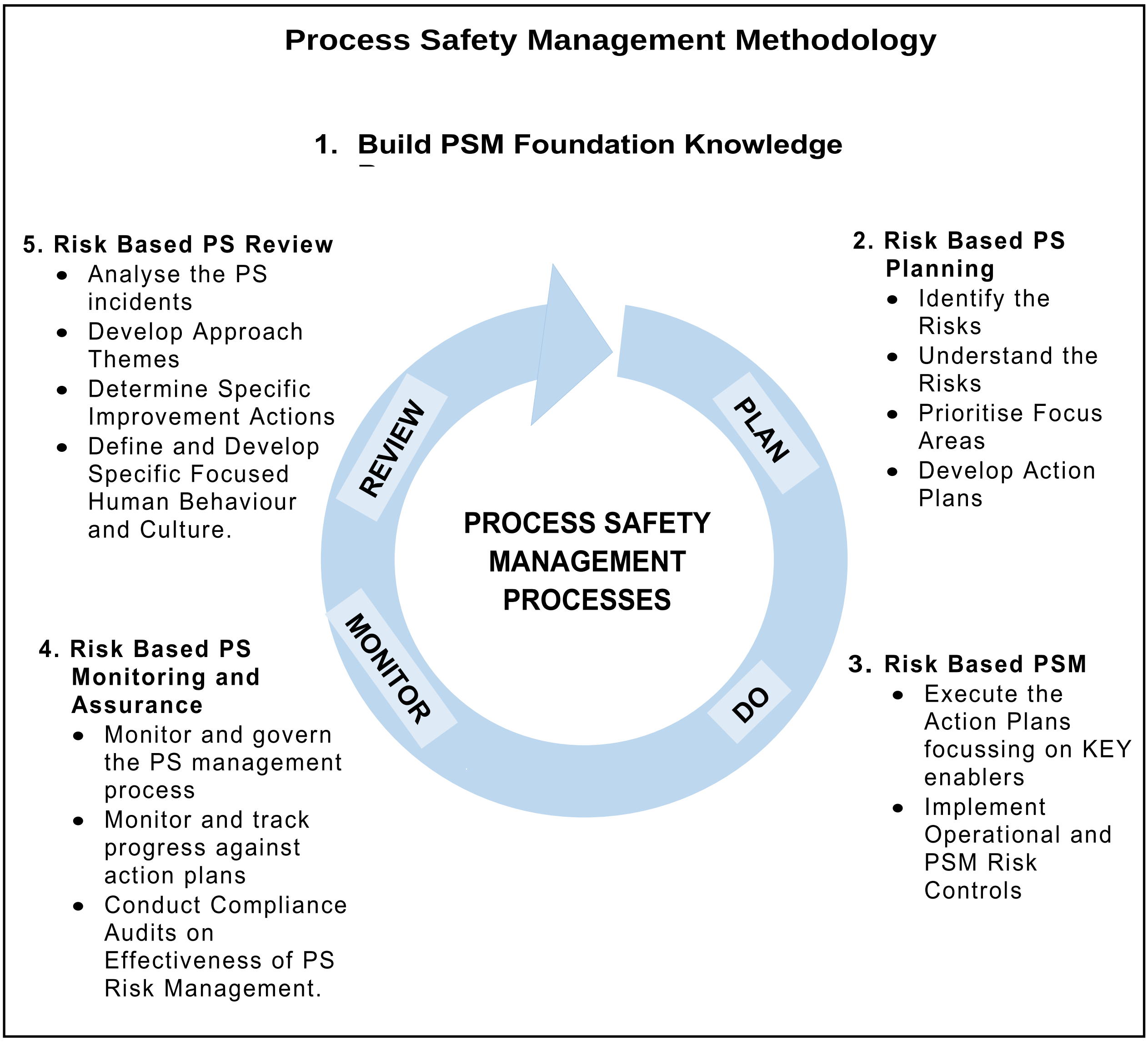

Figure 9: A typical process safety management cycle, (A modified risk management diagram sourced from asset management operations handbook of a hazardous chemical operations company in South Africa, 2013)

Process safety management consists of a number of systems that are generally summarised as the, "...14 elements of risk-based process safety" (Centre for Chemical Process Safety, 1995, p4). The 14 process safety elements remain at the centre of PSM although there are new developments that have expanded the PSM elements to 20 elements (Hoboken: AICHE Centre for Chemical Process Safety, Guidelines for Risk Based Process Safety, 2007).This research report focuses on the basic 14 PSM elements detailed below in the management of process safety.

2.3.1 Employee Participation

Human factors and management play a key role in PSM. According to the United States of America (US) Occupational Safety and Health Act (OSHA), (2000) one of the most important requirements is the employee participation where employees, including production and maintenance staff should be involved in every aspect of the PSM programs at the respective workplace. The employee participation defines and outlines how an organisation should involve and continuously engage with its employees, by setting the minimum requirements for employee programs. Martinez-Corcoles, et al (2012) indicate that motivating organisational members to participate in safety systems and initiatives is a major concern. Managers and leaders have specific influence on the safety behaviour in the workplace. Managers and supervisors should document what roles employees play, their involvement in the development of the programs, training and continued participation in the process for an organisation to achieve effective employee participation. Fernández-Muñiz, et al (2009) urge that there should be incentives for employee participation in health and safety activities, aimed at promoting safe behaviour and involving personnel in decision-making processes, through a punishment and rewards system as well as by consulting them about their wellbeing in the workplace.

2.3.2 Process Safety Information

Process safety information is a standard set of technical information that is utilised in the procurement, construction, operations and maintenance of a chemical process plant (Centre for Chemical Process Safety, 1995).

Process safety information includes information on the hazards of highly hazardous chemicals used or produced by the process, information on the technology of the process, and information on the equipment in the process. The Occupational, Health and Safety Act (2000) states that the process information of hazardous chemical plants consists of toxicity, permissible exposure limits, physical data and corrosiveness data, while the technical information of the process' technology includes block flow diagrams, process flow diagrams, mechanical flow diagrams, piping and instrumentation diagrams; process chemistry, maximum intended inventory, among others (Occupational, Health and Safety Act, 2000).

The Occupational, Health and Safety Act (2000) indicates that the compilation of written process safety information helps the employer and the employees involved in operating the process plants to identify and understand the hazards posed by processes involving highly hazardous chemicals. Written process safety information should be completed under the same schedule as a process hazard analysis study. In cases where the original technical information does not exist, the technical information shall be developed in conjunction with the process hazard analysis study. The technical information of the equipment in the process should include: materials of construction; piping and instrumentation diagrams; electrical classification; pressure and temperature relief system design and design basis; ventilation system design; required design codes and standards; material and energy balances for processes; and safety systems (e.g., interlocks, fire and gas detection, or suppression systems)(Einolf and Menghini, 1999).

2.3.3 Process Hazard Analysis

Khan et al (2015) state that process safety assessment has several essential steps that need to be taken to identify hazards. Though there are a number of important steps, there are three steps that are considered key namely; hazard identification, risk assessment and risk management in process safety management. Hazard identification, looks at what can go wrong and identifies as many process hazards as possible (Khan et al, 2015). Risk is a combination of measurement of the incident’s severity and its occurrence frequency. Risk management involves actions that are put in place to eliminate the risk or minimise the impact of the risk should it occur (Khan et al, 2015).

An established and widely used qualitative hazard identification method is the Hazard and Operability Analysis (HAZOP). The HAZOP is a widely accepted method used to identify and evaluate process hazards as well as to identify operability problems (Centre for Chemical Process Safety, 1995). The initial development of HAZOP primarily focused on continuous manufacturing process operations, with limitations when it was applied to batch process (Mushtaq and Chung, 2001). A standard HAZOP analysis is a manual, repetitive and time-consuming process. A HAZOP is further limited to assess hazards generated, due to variation of process variables and is not able to take into consideration the interaction of human, management and organisational factors of certain hazards (Mushtaq and Chung, 2001).

The Occupational, Health and Safety Act (2000) states that the process hazard analysis should be done in a thorough, orderly, systematic approach for identifying, evaluating and controlling the hazards of hazardous chemical processes, utilising an appropriate methodology according to the complexity of the chemical process. The methodologies may include any of the following: what-if checklist; hazard and operability study; failure mode and effects analysis; layer of protection analysis; and fault tree analysis. Irrespective of methodology that is used, the process hazard analysis should ensure that the chemical process hazards, the identification of any past incident that had a potential for catastrophic consequences, engineering and administrative controls applicable to the chemical hazards, the detection methodologies that provide early warning of hazardous chemical releases are addressed.

It is recommended that process hazard analyses are performed by a team with expertise in engineering and process operations (Occupational, Health and Safety Act 2000). In addition the team should comprise of at least one experienced employee, with the knowledge of the chemical process being evaluated and an experienced employee with the knowledge of the specific analysis methodology being used. Further, any actions taken should be documented with written schedules for action completion, including communication of the actions to the operating, maintenance and other employees whose work tasks involves interactions with the hazardous chemical processes (Occupational, Health and Safety Act, 2000).

Once the compilation of the initial process hazard analysis is completed, the process hazard analysis should be updated and revalidated, at most every five years (Occupational, Health and Safety Act, 2000).

2.3.4 Standard Operating Procedures

A standard operating procedure (SOP) is a set of step-by-step instructions compiled by an organization to help workers carry out complex routine operations (United States of America Environmental Protection Agency, 2007) (US EPA).

The United States of America Environmental Protection Agency (2007) defines a Standard Operating Procedure as a set of written instructions that document repetitive set of activities that are followed by an organisation. The compilation and application of SOPs forms part of an integral quality system that provides individuals or groups the information required to perform tasks properly, while enabling standards compliance and consistency in the quality and integrity of a product (United States of America Environmental Protection Agency (2007).

Amare (2012) states that an SOP describes a set of steps that a person or group of people must perform to complete a job by removing variation, a process document that details the way an operator should perform a given function.

SOPs detail the regularly recurring work processes that should be followed by an organisation. SOPs document how the tasks should be performed to enable consistent conformance to technical and quality system requirements and to support data quality. Amare (2012) emphasises that SOPs can be organisation-wide to site-specific activities that describe and assist that particular organisation or site to maintain a standard outcome, such as quality control and ensure regulatory compliance. In addition, employees should be trained in the use of SOPs and SOPs should be drafted by competent people. Halim and Mannan (2018) identified failure due to lack of proper enforcement of safety rules and SOPs as the cause of an explosion at West Fertilizer Company in West, Texas, in April 2013.

The use of SOPs should be reviewed and re-enforced by management, especially the direct supervisor, otherwise they become redundant (Halim and Mannan, 2018). Current copies of the SOPs should be readily accessible for reference in the work areas of the individuals performing the activities and tasks, either in hard copy or electronic format. If SOPs are not readily available the employees will not utilise them, rendering them redundant or of little value (Halim and Mannan, 2018).

Amare (2012) notes that the use of SOPs minimise variation and promote quality through consistent implementation of a process or procedure within the organisation. SOPs could be valuable for reconstructing project activities when no other references are available and are frequently used as checklists by inspectors during compliance auditing procedures. The benefits of a valid SOPs are reduced work effort, improved safety performance, comparability, credibility and legal defensibility (Halim and Mannan, 2018). SOPs play an important role, even when published methods are supplied and utilised (Amare, 2012). In hazardous chemical process operations the utilisation of SOPs cannot be over emphasised.

The Occupational, Health and Safety Act (2000) requires that an employer develops and implements a number of written standard operating procedures, consistent with the process safety information, that provide clear instructions for the employees to safely conduct activities involved in each process. The SOPs should address the following areas as a minimum compliance (Occupational, Health and Safety Act, 2000):

2.3.4.1 Steps for each operating phase:

The operating phases are as follows: the initial startup; normal and temporary operations; emergency shutdown, including the conditions under which emergency shutdown is required, and the assignment of the shutdown responsibility to qualified operators to ensure a safe emergency shutdown; emergency operations; normal shutdown; and a startup after a turnaround maintenance, or an emergency shutdown.

2.3.4.2 Operating limits:

The operating limits should include the consequences of deviations from the standard operating procedures and the corrective steps.

2.3.4.3 Safety and health considerations:

The safety and health considerations should include the properties of and the hazards presented by the chemicals that are used in the chemical processes; precautions to prevent the employees from chemical and fire exposure, such as engineering and administrative controls and personal protective equipment; control measures in case of physical contact or airborne exposure to the employees; control measures for the hazardous chemical inventory levels; and safety systems (e.g., interlocks, detection or gas and fire suppression systems) and their functions.

The review of SOPs should include changes in process chemicals, technology, equipment and facilities and the accuracy must be certified annually.

2.3.5 Employee Training and Competency

Safety training is the instruction and coaching of workers regarding the risks and dangers related to industry activities (Occupational, Health and Safety Act, 2000).

Sacks et al (2013) note that the construction workers’ ability to identify and assess risks is acquired through training and experience and is among the key factors that determine their behaviour and thus their safety. Sacks et al (2013) states that some researchers question the effectiveness of conventional safety training after using the empirical methods to evaluate the effectiveness of training in improving safety and yet a regression analysis of the safety strategies and the site safety records of construction companies identified safety training as one of the four most effective components of a safety program.

The PSM element focuses on the compliance requirement of the employer of a hazardous chemical process plant, that requires the employer to provide refresher training every three years as a minimum to each employee that is involved in operating or maintaining the hazardous chemical process equipment and the development of a process that informs employees and management on process safety concerns, safety hazards and any improvement. This element requires that employers develop a methodology to verify the employees' understanding of the training on the hazardous chemical process, a process for employees to submit concerns, notification of safety hazards and how to identify process safety non-conformances (Occupational, Health and Safety Act, 2000).

Santos-Reyes et al (2002) find that most post-incident investigations reveal the lack of competency in executing certain process safety tasks to have contributed to the disastrous events that occur; the incompetency may have been that of a frontline operator, or of an engineer who designed the system or it could be the decision maker at the top level of management. The Control of Major Accident Hazards (COMAH), (2015) defines competence as the ability to undertake responsibilities and to perform activities and tasks to a relevant standard, necessary to ensure process safety and prevent major incidents. Competence is a combination of three elements namely: knowledge; skills; and experience, of which skills and knowledge are acquired through training and coaching (The Control of Major Accident Hazards, 2015).

2.3.6 Service Provider Management

The Occupational, Health and Safety Act (2000) states that process safety management is applicable to service providers' personnel performing any maintenance work (repairs, turnaround, major renovation, speciality work et al) on or near a hazardous chemical process plant. PSM excludes service providers' personnel that provide incidental services that do not influence process safety, such as janitorial, food and drink, laundry, delivery, or other supply services.

The Occupational, Health and Safety Act (2000) permits many categories of contract labour to operate the facility or do particular aspects of jobs for short periods when the need arises, such as in turnaround operations or have specialised knowledge or skill set. There are special provisions for service providers and their employees, but with emphasis that they do not endanger themselves or those working nearby. According Occupational, Health and Safety Act (2000) there are a number of employer and sub-contractor requirements that should be fulfilled which are as follows:

2.3.6.1 Employer responsibilities

Informing the contract employers of known potential fire, explosion, or toxic release hazards related to the service provider's work and the hazardous chemical processes; the emergency action plan; the safe work practices to control the presence, entrance, and exit of contract employers and contract employees in hazardous chemical process plants; evaluation of the performance of contract employers periodically; and the records of contract employees' injury and illness log related to the service provider's work.

2.3.6.2 Contract employer responsibilities

Ensuring that the contract employees are trained to perform tasks safely; are aware of any potential fire, explosion, or toxic release hazards related to any given task and applicable the emergency action plans; document each contract employee's training records.

2.3.7 Pre-Start-up Safety Review

The Centre for Chemical Process Safety (1995) recommends that a safety review takes place before any hazardous chemical is introduced into a hazardous chemical process. PSM requires the performance of a pre start-up safety review (PSSR) for new and significantly modified process chemical plants, if they necessitate a change in the process safety information. The pre-startup safety review should verify that the construction and equipment are in accordance with the design specifications; safety, operating, maintenance and emergency procedures are adequate and in place; a process hazard analysis was performed and recommendations were implemented before start-up and the modifications comply with the management of change requirements; and operational employees were trained (Occupational, Health and Safety Act, 2000).

2.3.8 Maintenance Integrity Safety System

The Health and Safety Executive, (2007) defines asset integrity management as the means of ensuring that the people, systems, processes and resources that deliver integrity are in place, in use and will perform according to standard when required to, over the whole lifecycle of the asset. Essential for the integrity of any installation are the process safety-critical equipment (PSCEs). These are equipment in an installation and process plant (including computer programs) whose purpose is to prevent, control or mitigate major incident hazards (MIHs) and their failure could result in a major accident.

The Health and Safety Executive (2007) states that the maintenance integrity safety system (MISS) primarily focuses on the maintenance management of PSCEs, i.e. the management systems and processes which should ensure that PSCEs should be available when required. MISS includes several elements, covering the physical asset state, the actual number of PSCEs in the system. An effective PSCE maintenance system should include some of the following processes and checks: system custodian; a maintenance management system; reporting to senior management process; specific indicators of maintenance effectiveness; communications between process operations and maintenance; defined life repairs; supervision (i.e. confirmation that maintenance tasks have been completed according to the instructions on the work orders, time spent on the plant by supervisors etc.); measuring compliance with performance standards; corrective maintenance; records of breakdowns; mean time to repair (MTTR); mean time to failure (MTTF); backlogs and backlog management system; deferrals and deferral and rescheduling process, among others ((Health and Safety Executive, 2007).

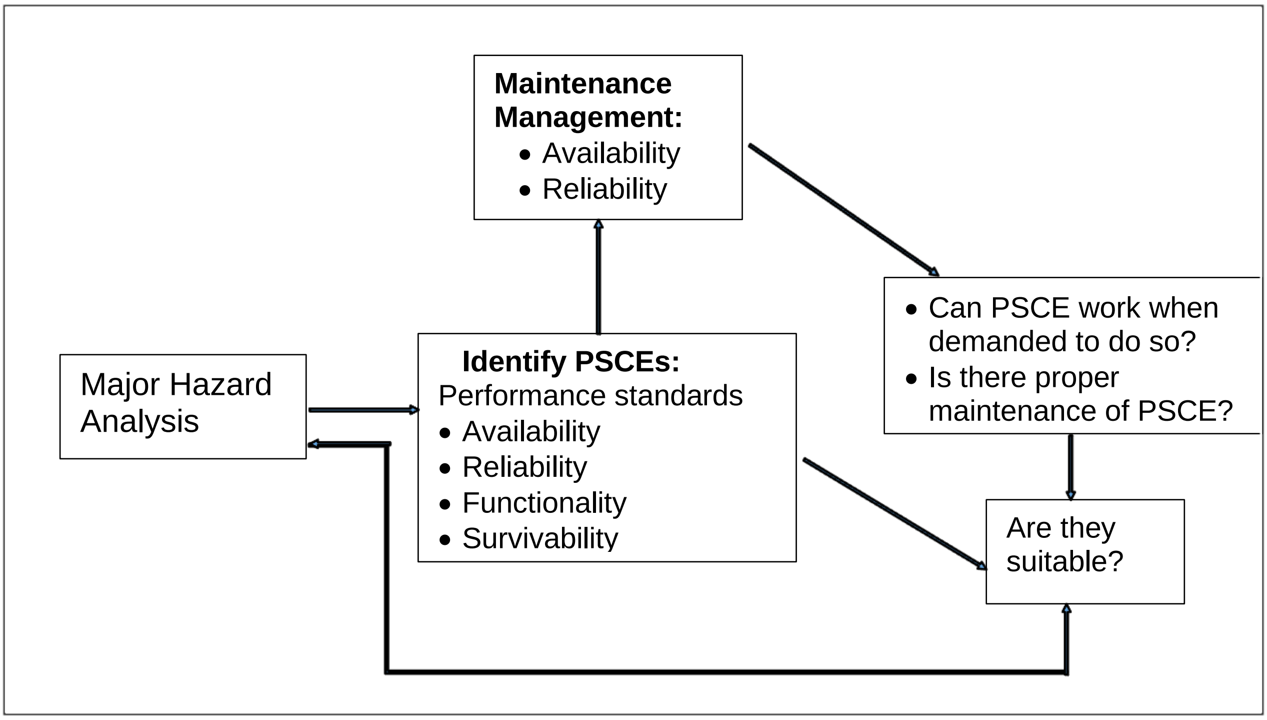

Figure 10: A modified diagram of the relationship between major hazards, PSCE development and maintenance management. (Source: Health and Safety Executive, 2007)

The process safety critical equipment in a hazardous chemical process plant includes: pressure vessels and storage tanks; piping systems including valves and other piping components; relief and vent devices and systems; emergency shutdown systems; controls (including monitoring devices and sensors, alarms, and interlocks); pumps; rotating equipment; heat exchanger; electrical generation and distribution equipment; un-interruptible power supplies; emergency power supply equipment; and fire protection equipment (OHSA 2000).

2.3.9 Permit to Work

Hazardous chemical process plants impose risks by their nature to the plant operations, personnel, communities and the environment. To ensure that there is control on how work activities are managed there must be a system to manage these activities and minimise risks. This process is a permit to work or hot work permit. A permit to work (PTW) is a formal written system to control certain types of work which are identified as potentially hazardous (Occupational, Health and Safety Act, 2000)

According to the Occupational, Health and Safety Act (2000) , process safety management's permit to work standard focuses on managing high risk work, commonly known as "hot work". A hot work permit is issued for hot work operations conducted on or near any chemical process equipment. The hot work permit ensures that the fire prevention and protection requirements as stipulated in the Occupational, Health and Safety Act (2000) regulations [1910.252(a)] are implemented prior to any hot work task. The hot work permit documentation indicates the authorisation date for the hot work activities, the identity and the location of the equipment. The hot work permit must be kept in a file until the completion of the hot work activities. Jahangiri (2015) notes that the permit to work (PTW) is a means of safety system to coordinate different work activities. However, it may be susceptible to human error. The most important identified errors were; inadequate isolation of process equipment, inadequate labelling of equipment and delay in starting the work after issue of the work permit, improper gas testing, inadequate site preparation measures etc. As such a permit to work is only one of the ways of mitigating risk on work activities (Jahangiri, 2015).

2.3.10 Management of Change

The management of change (MOC) is one of elements that is managed through process safety management. An MOC system is a process for evaluating and controlling modifications to facility design, operation, organization, or activities prior to implementation, to make certain that no new hazards are introduced and that the risk of existing hazards to employees, the public, or the environment is not unnecessarily increased (Schreiber, 2008).

The MOC standard stipulates the guidelines on how to manage changes safely in the hazardous chemical processes. The guidelines must pertain to any change (except for “replacements in kind”) to process chemicals, technology, equipment, and any change to facilities that affect a chemical process plant (Occupational, Health and Safety Act, 2000).

Halim and Mannan (2018) note that when a system requires or undergoes a change, it needs precise estimation of the safety, health and environmental risk arising from the process change through an MOC. A competent team is needed for this task to make correct decisions and ensure that all changes to the process are properly reviewed and adequate measures are taken when there are changes in the process. In the eventuality of an incident occurrence, the organisation can fulfill legal requirements and regulatory obligations in case an incident occurs (Halim and Mannan, 2018)

Halim and Mannan (2018) state that the Flixborough incident in the UK, 1974, prompted a number of regulatory and legislative responses from various authorities, which resulted in the introduction of the MOC process.

The Occupational, Health and Safety Act (2000) requires that changes to a chemical process (e.g. equipment, process variables and technology) should be evaluated thoroughly in detail to assess the effect on employee's safety and health, equipment and environment. The employees who operate and maintain a hazardous chemical process plant who could be affected by the changes must be informed and trained on the implemented change prior to start-up.

2.3.11 Incident Investigation

Mohammadfam, et al (2013) indicates that process equipment failures are one of the most important causes of process safety incidents. When incidents occur, they must be investigated to establish what could have gone wrong, a root cause established and corrective action should be found, implemented, documented and lessons learnt must be shared with all relevant personnel. The process equipment deviations from their design intents or desired operating conditions may lead to the catastrophic consequences. The application of process safety principles has received significant attention, but equipment related incidents continue to occur (Stricoff, 2012).

Mohammadfam, et al (2013) recognise that to investigate and prevent the process equipment failures (PEFs) there must be some resources, such as personnel with PEFs domain knowledge, tools, PEFs data on equipment designs and failure. All PEFs related incidents should be investigated to determine the basic causes of the failures and the incidents or any other associated facts.

The Occupational, Health and Safety Act (2000) states that process safety incidents involve the escape of toxic substances, or the release of flammable material which may or may not result in fire or explosions. Process safety incidents either damage or have the potential to damage the chemical process plant and to generate multiple fatalities.

Hopkins (2007) notes that process safety incidents occur when all safety barriers fail exposing the target to harm. The diagram below, Figure 11, shows what is referred to as a Swiss cheese model (Hopkins, 2007) which outlines an organisation's defence system against failure which are modelled as a series of barriers, represented as slices of cheese. The cheese slices have holes which represent weaknesses in individual parts of the system, continuously varying in size and position across the slices. The Swiss cheese model of accident causation is used in risk analysis and risk management in several industries including the hazardous chemical process; oil and gas; the aviation safety; and engineering industries among others.

Figure 11 shows how various control barriers fail to control hazards resulting in incident occurrence.

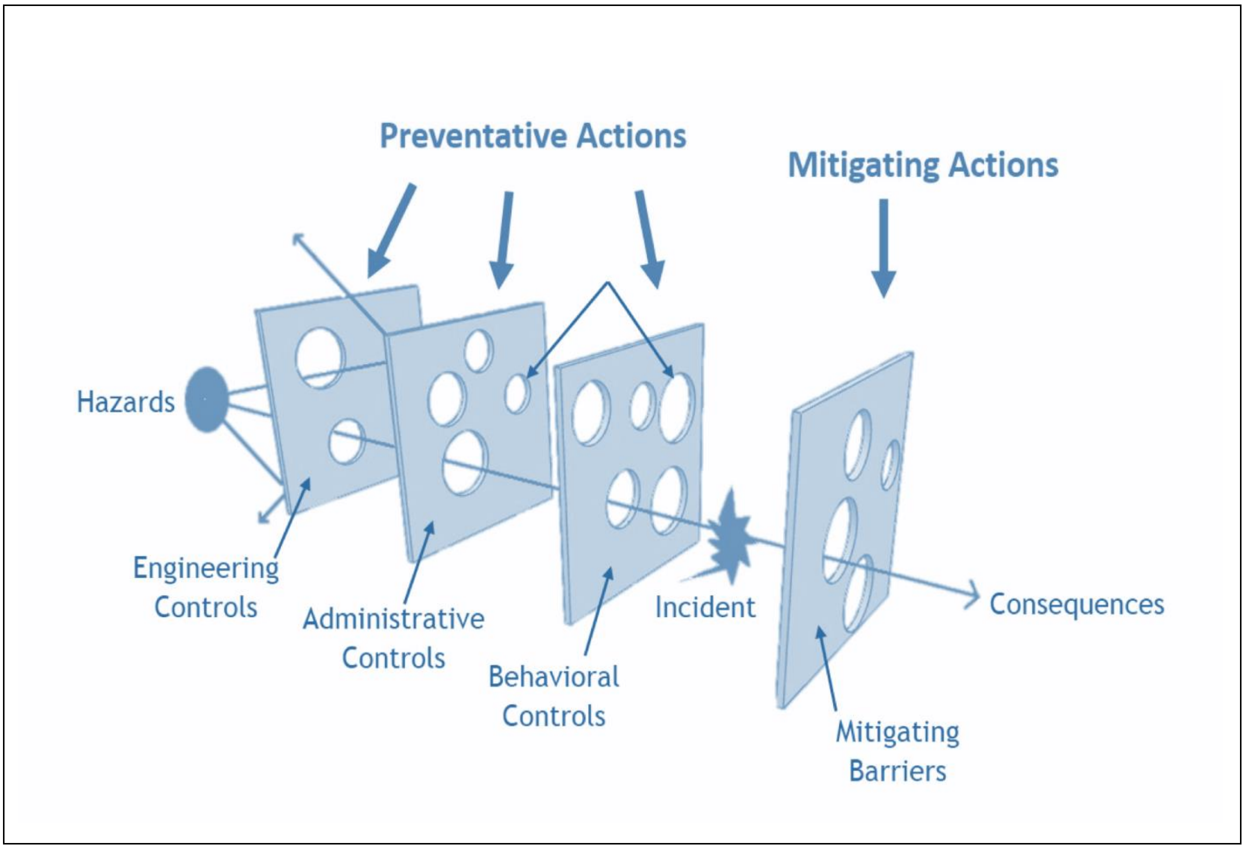

Figure 11: A modified diagram showing barriers to hazards and their failure.
(Source: Hopkins, 2007)

The Occupational, Health and Safety Act (2000) requires that the outcome of an incident investigation provide an incident investigation report that includes the following: the process safety incident's date; the commencement date of the investigation; the process safety incident description; the contributing factors to the process safety incident; and the findings and the recommendations from the process safety investigation to prevent recurrence.

There should be a system established to address and resolve the process safety incident's investigation findings and recommendations quickly. The resolutions and corrective actions from the process safety investigation should be documented and safely stored (Occupational, Health and Safety Act, 2000)

2.3.12 Emergency Management System

Nicholas (1997) notes that any hazardous chemical plant operation has systems in place to prevent failure, but at one point or another equipment or process failure may occur. Should failure occur there must be a mitigation to minimise the negative effect on the health and safety of employees, customers, suppliers, communities and the environment. This mitigation is called an emergency management system. Nicholas (1997) describes emergency responses as those that seek to reduce the seriousness of injuries, property damage, and environmental damage resulting from chemical process accidents.

Nicholas (1997) states further that an emergency management system consists of two subsystems, namely administrative and human processes and a hard subsystem. The administrative and human subsystems include staff training, operation and maintenance of equipment, emergency plans and on the other hand, a hard subsystem consists of physical components, such as passive fire protection, detection, alarm and suppression, evacuation system, smoke and gas detection and control, and emergency lighting.

The Occupational, Health and Safety Act (2000) states that an emergency management system is a mitigation's coordination to address any process safety emergency event in a chemical process plant and it emphasises on the necessity of emergency pre-planning and training of employees to make them aware of different emergency scenarios that could happen in a chemical process plant to enable the employees to safely execute the mitigation actions.

Any set of emergency action plans should include the entire chemical process plant, various scenarios that could arise and the emergency procedures to manage even minor releases of hazardous chemicals, explosions or fire (Occupational, Health and Safety Act, 2000).

2.3.13 Compliance Audits

The compliance audits for PSM are similar to those in asset management, they must be conducted periodically for process safety to assess the effectiveness of the process safety management system. Santos-Reyes and Beard (2002) indicate that audits and audit reports on process operations, process safety incidents and identified problem areas provide important information for the adaptation of work instructions, maintenance and operating procedures, which in turn may lead to adaptation of company policies on safety and standards. In addition, audits of high-profile destructive incidents, or a series of reported events may help regulatory authorities to tighten regulations by improving the standards or new legislation. Santos-Reyes and Beard (2002) are of the view that audit programs for process safety management system elements need to be planned, established, implemented and maintained by the organisation, once determined by the risk assessments results and the results from previous audits.

The BSI PAS 55-1 (2008) states that audit processes and procedures should be set, implemented and maintained to address the following: the responsibilities, competencies and planning requirements for audit execution, results reports and records; audit criteria determination, scope and methods based on business significance and risks. The auditor selection and the conduct of audits need to be objective and impartial. Audits should be conducted by independent personnel from those with direct responsibility and operational interests.

The Occupational, Health and Safety Act (2000) indicates that the compliance audit standard should verify that the process safety management in a chemical process plant is effective through the evaluation of process safety system compliance against the PSM standards periodically. The compliance audit should be conducted by at least one person with auditing knowledge and an audit report should highlight the gaps and weaknesses in the system.

2.3.14 Trade Secrets

Trade secrets come from the law that seeks to protect company trade information, but there has been some debate on what a trade secret is about with no clear agreement (e.g. do trade secrets protect the company or do trade secrets limit employees' ability to perform?) (Majid et al, 2016). According to Majid et al (2016) the answer remains unclear in most engagements and view trade secrets as one of the 14 elements of the

Occupational Safety and Health Act (2000), PSM standard which has little explanation or guidance on how to comply with this element, unlike the other 13 PSM elements. The Occupational, Health and Safety Act (2000) recognises the ambiguity of the trade secrets definition and that it causes disagreements. To eliminate unclear lines, the Occupational, Health and Safety Act (2000) states that “until recently, some companies attempted to protect proprietary information by keeping process details from their employees, hence to prevent this scenario and enhance worker safety, the trade secrets element gives employees the right to know processes that may affect their health and safety”.

2.4 Technical Elements

The process safety elements are important to effectively manage process safety in a hazardous chemical plant. The PSM 14 elements can be grouped into two, namely technical and non-technical elements. There are five technical elements from the 14 PSM elements, which are (OHSA, 2000): process hazard analysis; process safety information; pre start-up safety review; management of change; and maintenance integrity safety system. The effectiveness of the technical elements will enable the hazardous chemical plant to address the critical risks on a Pareto principle (80/20 principle).

In a typical hazardous chemical organisation in South Africa, the maintenance integrity safety system and effectiveness are the maintenance department’s focus area, which ensures the integrity of assets (equipment) in operation through focussed preventative maintenance strategies and implementation. The improvement solutions by the maintenance department could minimise or eliminate asset failure that could result in process safety incidents.

The Centre for Chemical Process Safety (2014) defines a process safety incident as an incident that results in either: a fire; an explosion; an episodic, unintended release of a hazardous chemical from primary containment; an excursion of pressure energy that causes harm; or any combination of the above and all cases, chemicals and a chemical process are involved in a process safety incident. Process safety management assists in risk reduction by prevention or elimination of the above listed process safety incident consequences. The occurrence of any of the listed consequences increases the hazardous chemical organisation’s risk exposure. “The process safety incidents could result in serious injuries or fatalities, asset damage, environmental effect and production loss, such as the 1984 Bhopal, India incident at Union Carbide. A toxic release and an explosion of methyl iso-cyanate occurred resulting in over 2000 people being killed", the Centre for Chemical Process Safety (2014, p5).

In terms of consequences, process safety incidents are of such a nature that could include the following SHE and non-SHE risks to the hazardous chemical process organisations: reduction in profit and bankruptcy; loss of life; health complications; total closure of the hazardous chemical facility by the authorities; environmental damage and reputational damage. They are therefore to be avoided at all cost as possible.

2.5 The Integrated AM and PSM Training

The first step in designing a training and development program is to conduct a needs assessment. Miller and Osinski (2002) emphasise that the training assessment begins with a "need" which can be identified in several ways but, it is generally described as a gap between what is currently in place and what is needed now and in the future. Gaps can include discrepancies or differences between what the organisation expects to happen and what actually happens; current and desired job performance; and existing and desired competencies and skills (Miller and Osinski, 2002). Additionally, a needs assessment can be used to assist with work team competencies and performance (Miller and Osinski, 2002); problem solving or productivity (Miller and Osinski, 2002); asset performance (Miller and Osinski, 2002); and preparation for responses to future changes in the organisation or job duties (Miller and Osinski, 2002).

According to Goldstein (1993) one of the most important steps in training development is conducting a training needs analysis with the first step focusing on the process of deciding who and what should be trained. Goldstein (1993) further elaborates that training needs analysis consists of five steps namely: determination of training needs; the need assessment; data collection; data analysis; and feedback. This is conducted to determine where training is needed, what needs to be taught, and who needs to be trained. There are several outcomes that include learning objectives specifications, which shape the training design, delivery and set the criteria development.

Miller and Osinski (2002) state that the results obtained from the needs assessment assists the training department or people in setting up the training objectives by answering two basic questions: who, needs training and what kind of training is needed? In certain cases, training is not the solution, as some performance gaps can be minimised or eliminated through other management solutions such as communicating clear expectations, providing supportive work environment, consequence management, removing obstacles and checking job fit (Miller and Osinski, 2002)

When the needs assessment is completed and the integrated AM and PSM training objectives are clearly identified, the design phase of the training and development should be initiated focusing on the selection of the internal or external resources to facilitate the design and the development of the training (Miller and Osinski, 2002). At this stage a team of AM and PSM specialists, operational personnel and management representative should select and design the program content (Miller and Osinski, 2002); the techniques to be used to facilitate learning (Miller and Osinski, 2002), that should include the content, lectures, role playing and simulation; the appropriate setting (Miller and Osinski, 2002), such as on the job training and classroom training; the materials to be utilised in delivering the training (Miller and Osinski, 2002) including work books, videos, slides, etc.; identify and train instructors (Miller and Osinski, 2002) if the needs analysis identified internal trainers. The cost of training and budget (Miller and Osinski, 2002) should be determined, and the senior management must be engaged to approve for implementation.

The integrated AM and PSM training design phase should be followed by training implementation, which involves the following: participant identification (Goldstein, 1993) invitations and confirmation; scheduling of classes, facilities, scheduling of instructors to present the training; materials preparation and delivery to the scheduled locations; and the presentation of the training (Goldstein, 1993)

Miller and Osinski (2002) indicate that the final phase in the training and development program is evaluation of the program to determine if the training objectives were met. The evaluation process includes determining participant reaction to the training program, what the participants learnt and how well the participants transfer the training back on the job. The information collected from the training evaluation is utilised to continuously improve future training. It is important to note that the training needs assessment, training objectives, design, implementation and evaluation is a continuous process for the organisation.

In line with the literature reviewed thus far, this study considers the practical implications and suggests that the AM and PSM training needs analysis should look at the employees involved in asset management life cycle and the 4-stage risk based PSM cycle in the hazardous chemical process plant. The employees who should be trained could include the personnel that acquire, implement, operate, maintain and dispose of the assets. This would involve setting up of teams comprising subject matter experts from AM, PSM and operations personnel.

In addition, the training should be developed in a 3-tier system, focusing on management personnel training giving a high overview of an integrated AM and PSM; a second tier focusing on the AM and PSM specialists, engineering and projects personnel; and the third tier focusing on maintenance personnel, operators and administrators.

Further investigation will need to be carried out by the training personnel to determine the training methods and tools. The AM and PSM training methods that could be explored to determine targeted training audience best fit may include one to many in classroom training, online training, simulation training and on job practical training.

Following the suggestion provided, the integrated AM and PSM training is expected to result with the following outcomes: a focussed structured approach to an integrated AM and PSM training; a continuous competency improvement tool; and an embedded and integrated AM and PSM competency.

2.6 Staffing of Process Safety Departments in South Africa

"The operations and maintenance departments are the core of process safety management program in any facility," (Centre for Chemical Process Safety, 1995, p11). The maintenance activities of the hazardous chemical process equipment are important for the safe operation and contribute to the compliance with the process safety management by ensuring mechanical integrity of process equipment (Centre for Chemical Process Safety, 1995)

Gormley et al (2016) find that process safety departments in South African hazardous chemical operations are staffed by chemical engineers in a number of cases and yet a number of failures are mechanical integrity related. According to Gormley et al (2016) the trend of documented maintenance (mechanical, electrical, instrumentation and control) failure incidents contribute about two thirds of all process safety incidents recorded in hazardous chemical industries world-wide. The South African hazardous chemical operations are no exception to the worldwide trend and yet staff the process safety department with chemical engineers and rarely include other engineering disciplines (Gormley et al, 2016).

In a written document for the international risk management engineers representing insurance underwriting companies for large hazardous chemical industries, Gormley et al (2016) raise concerns with regard to the PSM departments staffing in South Africa. There is an emphasis on the clear role classification; the main role of chemical engineers is to do process design, run the chemical process operations and to trouble shoot chemical processes. Gormley et al (2016) emphasises that chemical engineers are not knowledgeable in plant maintenance. Maintenance engineering is a discipline and profession of applying engineering concepts for the optimisation of equipment, procedures, budgets to achieve better maintainability, reliability, availability and the safety of any process plant (Kauer, et al, 2004). The disciplines that are mainly involved in chemical process plant’s maintenance are mechanical, electrical, instrumentation and control, and metallurgical engineers. Maintenance which is a subject of asset management and process safety are linked as lack of maintenance could result in a chemical process plant failure (equipment breakdown, pipe leaks, pipe bursts, pump failure and leaks under normal operating conditions) due to chemical process plant integrity deterioration. Staffing the PSM with other engineering disciplines would help with the diversification of knowledge and competency to uplift process safety performance (Gormley et al, 2016).

This study proposes that the integration of the asset management with process safety management plays a vital role in improving process safety performance, through process safety incidents elimination or mitigation, improvement of safety performance and hence assisting in the SHE risks reduction in hazardous chemical process operation in South Africa.

2.7 Summary of Key Points from the Literature on AM and PSM Linkages

Asset management and process safety management share many characteristics. The life cycle of AM stages focusses on similar elements that are on the risk-based process safety management. The two management methodologies have focus areas that are common on policies, objectives and standards.

Asset management emphasises on the systematic acquisition of assets, tools and setting up of operating standards, while PSM emphasises on the risk analyses of the asset acquisition through PSI, PHA, setting up standard norms and conformance to ensure risk elimination or minimisation.

AM systems involve work management processes, life cycle activities, setting up of operating standards, communication and risk awareness and PSM emphasises AM life cycle support through PHA, process safety information management, patents protection through trade secrets, clear management of change standards and setting up of SOPs.

AM implementation stage elements involve tools, facilities and equipment, life cycle activities and OEM standards, PSM supports AM with SOPs, life cycle risk analysis by utilising PHAs and ensuring that accurate information is supplied with the asset on acquisition by PSI management.

PSM links AM on the start-up of assets life cycle stage through SOPs, pre-start up safety reviews, emergency management services, risk management and management of change elements.

Asset maintenance links AM and PSM further by sharing of employee and training competency, SOPs, employee participation and engagement, permits to work system, maintenance integrity safety system and risk management processes.

Asset continuous improvement and disposal renewal link the two management methodologies through design and risk reviews done during design, hazard and operability studies, review of maintenance studies and compliance audits in the fourth stage of AM life cycle.

2.8 Conclusion of the Literature Review

The researcher concludes the literature review by proposing a model that links the two management concepts as depicted on Figure 12. The diagram on Figure 12 depicts the integration of asset management model by linking it to the process safety management model, as adapted by the researcher. The researcher links each AM life cycle stage to similar elements focus of process safety management.

The asset life cycle is as follows: Define (plan and design the process); optimise (select and install an asset); manage (operate and manage an asset); and engineering (evaluate and improve or discard an asset).

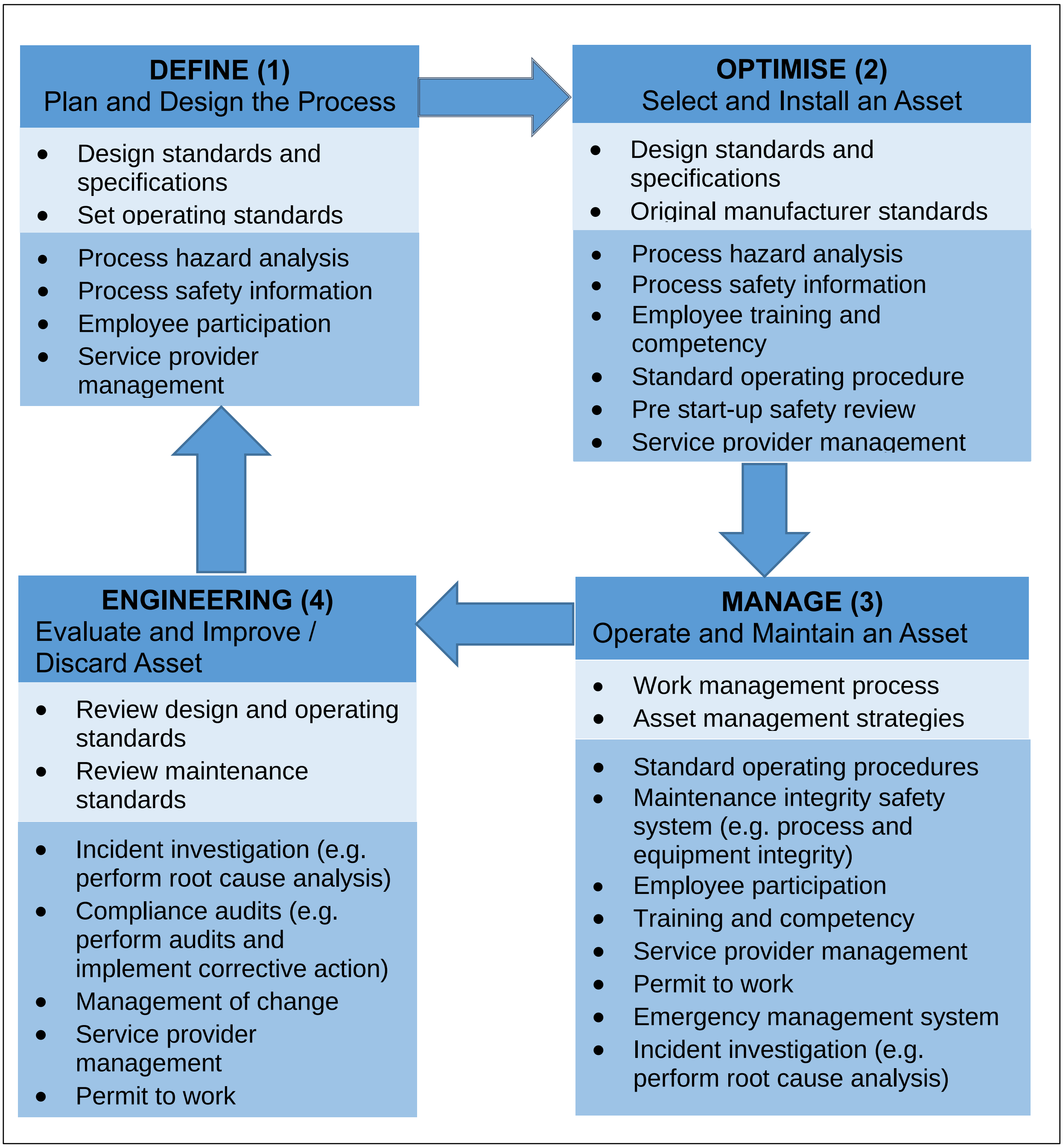

Figure 12: Adapted from the Asset Management integrated with Process Safety Management Diagram (Source: Asset management operations handbook of a hazardous chemical operations company in South Africa, 2013)

\- (The deeper shaded hue) has been added by the author.

3 RESEARCH METHODOLOGY

A qualitative approach was used for this research because there was need to capture the opinion of participants knowledgeable in the industry regarding ways of addressing the issue of how asset management could be used to enhance the process safety management performance. Questions of "how", including opinions are best researched using qualitative rather than quantitative approach (Leedy and Ormrod, 2010). The research design involves the use of primary data (from interviews) and secondary data (from existing data that are currently available from a hazardous chemical processing company in South Africa, as part of the secondary data that links an integrated approach to asset management with process safety management and the effect on process safety performance. The secondary data were collected for a period of 5 years from 2012 to 2017).

Interviews were conducted to collect the primary data. This was done by asking participants questions, which determined what the people involved in asset management and process safety management perceive about the research concepts and the implementation thereof. The participants were asked if there were any gaps in the current models and what the gaps were that could be improved, based on the proposed research objectives (A copy of the proposed interview questionnaire is provided in the Appendix).

The secondary data were extracted from the South African company's existing data base. The time frame was based on a period after the hazardous chemical company developed and implemented a new asset management framework. The new asset management framework implementation was tracked down against the process safety performance.

3.1 Participants

The participants for the interviews were selected and grouped by disciplines such as maintenance, operations and support services to obtain views from different speciality areas. The individuals were selected based on their seniority (e.g. senior managers, middle managers) and the number of years of experience (at least 5 years). The total number of participants were subjected to the principle of saturation as described further below.

According to Underwood (2010) the type of qualitative study chosen is also one of the most important factors to consider when choosing sample size and the types of questions being studied have an equally important factor as the sample size chosen for these various methods. Some of the more common methods include in-depth interviews, focus groups, and ethnographic research typically used in qualitative market research. One of the most important principles to keep in mind is the principle of saturation. The objective of qualitative research (as compared to quantitative research) is to lessen discovery failure; in quantitative research, the objective is to reduce estimation error. The principle of saturation comes in, with saturation, when the collection of new data does not give the researcher any new additional insights into the issue being investigated. Qualitative research seeks to uncover diverse opinions from the participants, and one person's opinion is enough to generate a code. There is a point of diminishing return with larger samples; more data does not necessarily lead to more information, it simply leads to the same information being repeated, (saturation). The goal, therefore, is to have a large enough number of participants in a qualitative study that allows to uncover a range of opinions, but to cut the participants number where it gets to a saturation point.

Underwood (2010) recommends a specific number based on studies that have been done in academia on this very issue. The number of participants can vary with 30 being an ideal sample size, but some samples can have as little as 10 total participants can still yield extremely fruitful and applicable results.

The research interview targeted a minimum of 20 people, but only 14 agreed to be interviewed. The participants were selected from organisational leadership, senior managers, managers, specialists and frontline supervisors from various disciplines by convenience sampling. The participants were forwarded the interview questionnaire prior to the interview to enable them to prepare for the interviews. The disciplines included reliability, maintenance, operations and process safety personnel. The sampling was based on the following conditions: employed in AM or PSM department; a minimum of 5 years' experience in either one or both departments; completed internship and / or training. The age and gender of participants was not taken into consideration. The population was drawn from a South African hazardous chemical operations company.

3.2 Instrumentation

Since the research is qualitative, it was based on subjective judgment taken as the research proceeded and the utilisation of data and information available from the South African hazardous chemical process organisation. There was lack of reliable guidance on estimating the number of participants before starting the research, with a range of suggestions given. The instrument for collecting primary data was through interviews and existing data from the data bank.

3.2.1 Interview study

The interview questionnaire was drafted exploring the link between asset management and process safety management. The questions explored the current organisational set up and beliefs in the organisation on asset management; process safety management; process safety performance; the current organisational structure; skills staffing; and personnel training. Additionally, the questionnaire further probed on how to improve the link between asset management and process safety management and develop an optimal organisational structures hazardous chemical process operations.

3.2.2 Data from the South African hazardous chemical process company

3.2.2.1 Data Tables, Pie Charts and Graphs

The researcher was granted limited permission to access to some of the data from the hazardous chemical organisation over a five-year period. These data were utilised to compile tables, pie charts, and a histogram. The data were collected over a period of 5 years from year 2012 to year 2016.

3.2.2.2 Audit Reports

The researcher had permission to access some of the reports that are attached to the research report and analysed the reports against asset management business processes and standards.

3.3 Data Analyses

Qualitative data refers to non-numeric information such as interview transcripts, notes, video and audio recordings, images and text documents. Dudovskiy (2018) states that qualitative data analysis can be divided into the following five categories: content analysis, which is a process of categorising verbal or behavioural data to classify, summarise and tabulate the data; narrative analysis, involves the reformulation of stories presented by respondents taking into account context of each case and different experiences of each respondent; discourse analysis**,** an analysis of naturally occurring talk and all types of written text; framework analysis**,** is the more advanced method consisting of several stages such as familiarisation, identifying a thematic framework, coding, charting, mapping and interpretation; and the grounded theory, starts with an analysis of a single case to formulate a theory, then examines additional cases to see if they contribute to the theory.

Data was collected from targeted groups of people about their opinions, behaviour or knowledge. This researcher used a combination of both content analysis and narrative analysis in analysing the collected data.

3.3.1 The Research Data Analyses

The collected data were analysed in following three steps.

3.3.1.1 Developing and Applying Codes.

Dudovskiy (2018) notes that coding can be explained as categorisation of data. A ‘code’ can be a word or a short phrase that represents a theme or an idea. All codes need to be assigned meaningful titles. A wide range of none quantifiable elements that can include events, behaviour, activities, meanings among others, can be coded. Dudovskiy (2018) states that, coding can be done in any of the following three ways: open coding (the initial organisation of raw data to try to make sense of it); axial coding (interconnecting and linking the categories of codes); and selective coding (formulating the story through connecting the categories) (Dudovskiy, 2018).

3.3.1.2 Identifying themes, patterns and relationships**.**

Dudovskiy (2018) argues that, unlike quantitative methods, in qualitative data analysis there are no universally applicable techniques that can be applied to generate findings. Analytical and critical thinking skills of researcher plays significant role in data analysis in qualitative studies. Therefore, no qualitative study can be repeated to generate the same results.

Dudovskiy (2018) argues further stating that nevertheless, there is a set of techniques that you can use to identify common themes, patterns and relationships within responses of sample group members in relation to codes that have been specified in the previous stage. The most popular and effective methods of qualitative data interpretation which is used in this research, include the following: word and phrase repetition – scanning primary data for words and phrases commonly used by respondents, words and phrases used with unusual emotions; primary and secondary data comparison – comparing the findings of interview/focus group/observation/any other qualitative data collection method with the findings of literature review and discussing differences among them; and search for missing information – discussing aspects of the issues that were not mentioned by respondents, despite the researchers' expectation to have them mentioned (Dudovskiy, 2018)

Themes and patterns were drawn from the interview studies, available data and audit reports

3.4 Ethical Issues

There were ethical issues that necessitate declaration with The School for Mechanical, Industrial and Aeronautical Engineering. An application for ethics clearance was made to the School Ethics Committee before commencing the research. The research complied with the requirements for ethics as specified by the University of the Witwatersrand Research Committee. The clearance was done under Clearance Number: **MIAEC 074/19**

4 RESULTS AND ANALYSIS

Dudovskiy (2018) states that this stage links research findings to the research aim and objectives. When compiling data analyses one can use quotations from the transcript in to highlight major themes within findings and possible contradictions.

4.1 Research Results

The research results are broken down in to 3 categories namely: interview study; data and audit results.

4.1.1 Interview Study Results

Interview studies were conducted where individuals were asked questions and filled in answers to the questions. It was later found out that some of the questions were leading and the question raising concerns were reviewed, modified and sent to the same participants who were interviewed during the first time. The returned answers were summarised through a combination of “open coding” and “selective coding” as displayed on the Table 1.

Table 1 depicts the questions that were sent to the interview participants, a word collection of the returned answers, developed codes and the outcome objective extract by the researcher.

Table 1: A summary of the findings from the interviews conducted.

Question	Word Collection	Developed Code	Objective Extract
1. What do you understand about process safety management?	• Identification and management of processes; • Prevent/reduce incident frequency; • Prevent FER incidents; • Risk management; • Reduce incidents; • Prevent unwanted release.	Process safety incident prevention or process safety incident severity reduction.	The participants interviewed seemed to understand that process safety management is about process safety incident prevention or process safety

			incident severity reduction.
2. What is your understanding of Asset Management?	• Plan, do, review and improve; • Availability and integrity life cycle for equipment; • Systematic approach to equipment governance; • Equipment life cycle; • Establishment and governance of management systems; • Managing current or new assets.	Plan, do, review and improve.	The utilisation of the plan, do, review and improve methodology is reasonably understood and should be applied with other asset management specific systems and governance throughout the life cycle of an asset. A few number of participants did not link the plan, do, review and improve methodology into the 4 stages of the asset life cycle.
3. Is there any relationship between asset management and process safety management and explain your thinking?	• Plan, do, review and improve; • Stay within and operate the asset according to set parameters; • Yes; • Overlapping indicators and similar objective; • Avoid incidents and failures;	Yes, business sustainability, asset integrity and prevention or minimising equipment failure.	A majority of the participants seemed to think that there is relationship between AM and PSM. The people interviewed understood the principles of good or bad asset management and

	• Good asset management.		how this could be related to PS performance.
4. In your own experience in the organisation, do you think AM and PSM are properly understood currently and why?	• Not well enough; • Sub-processes within these frameworks are understood; • Room for improvement; • Doubt that the value is understood and if executed fully even if it is understood.	Not understood.	According to the participants interviewed a number of them seem to think that AM and PSM are not "fully" understood in the hazardous chemical process organisation.
5. How do you think the staffing in process safety management should be done?	• Experience and plant exposure in operations and maintenance is a must; • Mixture of engineering disciplines; • Internal and external recruitment; • Spread over a wide range of engineering disciplines; • Allow out of box thinking.	Plant operations exposure and a multi-discipline approach.	The participants interviewed felt that PSM should be staffed by personnel with exposure to the plant operations and maintenance, with a multi-disciplinary engineering personnel approach. Some participants related to on job training with vast experience, while the qualifications should meet minimum entry

			level and related how experience could not be substituted by qualifications only.
6. Do you think the process safety management department is correctly and optimally staffed and why?	• No; • The number of people in the PSM department when compared to the Occupational safety department doesn't relate well; • Employs only one engineering discipline; • Is a challenge when interpretation of other engineering disciplines; • This weakens the department; • Not sure; • Few resources were competent on PSM in the plant; • Short of well balanced and competent team; • Shows lack of PSM understanding at senior management level.	The PSM department could be optimally staffed.	The collated information ranges from not sure, to the PSM department is not correctly staffed. Many respondents are of the view that the PSM department lacks the engineering diversity (engineering discipline spread) that is needed to make it an effective and well knowledgeable technical team. Additionally, there is an opinion that the PSM department is understaffed.
7. Currently PSM and AM report to different heads of	• Size and complexity of the organisation; • Consider PSM and AM reporting to one head; • Same reporting line;	Reporting line and independence.	Based on the interview returns it was observed that there was an almost half–half

departments, what is your opinion about the reporting lines?	• Reporting is irrelevant but the independence of PSM is; • Good AM is the basis of PSM; • AM and PSM both have to understand failure modes; • AM and PSM have a critical role in assurance; • Both need to understand and manage the role of RCA; • Both departments need multi-disciplinary skills; • One head of department; • Flexibility; • Avoidance of duplication, less bureaucracy; • Better utilisation of resources.		split with some participants being of the view that the current reporting structure is basically correct, it needs some adjustments, while the other half were of the opinion that AM and PSM have a common "role" with similar activities that cannot be separated hence preferred that the two disciplines report to one head of technical department.
8. If you were given a choice to restructure and reorganise the organisation's organogram, where would you place the	• Technical department; • Maintenance or Production/Operations department; • Engineering/Operations Support or Asset Management.	Organogram positioning.	The idea of this question was to establish where PSM should be placed on the organisational structure of a hazardous chemical operations. The majority of

PSM department?			participants preferred that the PSM department should be placed in the technical or engineering departments, while a sizeable number preferred the current set up, of PSM department reporting to the SHE department.
9. In your own opinion, what must be done to improve the effectiveness of process safety management and safety to reduce the overall SHE risks?	• People involved in production should be sent for PSM training; • More resources should be available and skilled to attend to the demands of PSM; • Ensure proper PSM and AM; • Proper definition and structured development of the required skills sets; • Business owners need to take findings from audits/ assessments and own them; • Being driven at the right level.	Resource, skilling, leadership, better risk profiling, understanding, communication and coaching.	The emerging common theme seems to suggest that there is a need for training for operations personnel, skills improvement, communication and coaching on people in senior positions in the AM and PSM departments to improve competency.
10.Summarise your	• Silo creation; • Separation of duties;	Optimum effectiveness of	Generally, the participants were of

motivation on why do you believe that AM and PSM departments should or should not report to one head of department?	• Independence from operational personnel interference; • The strive for excellence and the pressure of production targets has an effect with regards to equipment integrity; • There are good practices and examples of excellent AM/PSM performance, but there is no consistency in certain areas where the risk profiles dictate that they be more; • There are systems in place which are integrated; • Currently focusing more on occupational safety than process safety; • Instead we use PSM specialists who have not been trained for auditing to conduct audits.	asset management and process safety management.	the opinion that there are good systems in place, with some pockets of excellence, but identified a number of shortcomings, e.g. lack of formal engagements to strategise on incident prevention utilising the two concepts of asset management and process safety management, departmental shortcomings in being proactive prior to process safety incidents.

4.1.2 Data Tables, Pie Charts and Graphs

The researcher compiled tables, pie charts, and a histogram from the available data from the hazardous chemical process organisation.

Table 2 displays the number of fire, explosion and release (FER) incidents tabulated from the available data over a five-year period.

Table 2: Data collected over a 5-year period indicating the number of process safety incidents and the severity classification.

Year / Incident Type	2012	2013	2014	2015	2016
Major	0	0	0	0	0
Significant	6	3	2	2	2
Moderate	3	6	5	1	3
Minor	53	49	55	39	35
Total	62	58	62	42	39
FER-SR	4.86	3.46	3.58*	3.26	2.98

Note:

- “*” the number depicts a spike against the downward trend due to the reduction in man-hours as the organisation went through a re-engineering program resulting in reduced total man-hours of permanent employed staff.

Figure 13 shows the proportion of PS incidents by PSM element before the asset management program. Maintenance integrity safety system (MISS) contributed about two thirds of the total incidents with pre-start up safety review (PSSR) contributing the least percentage number.

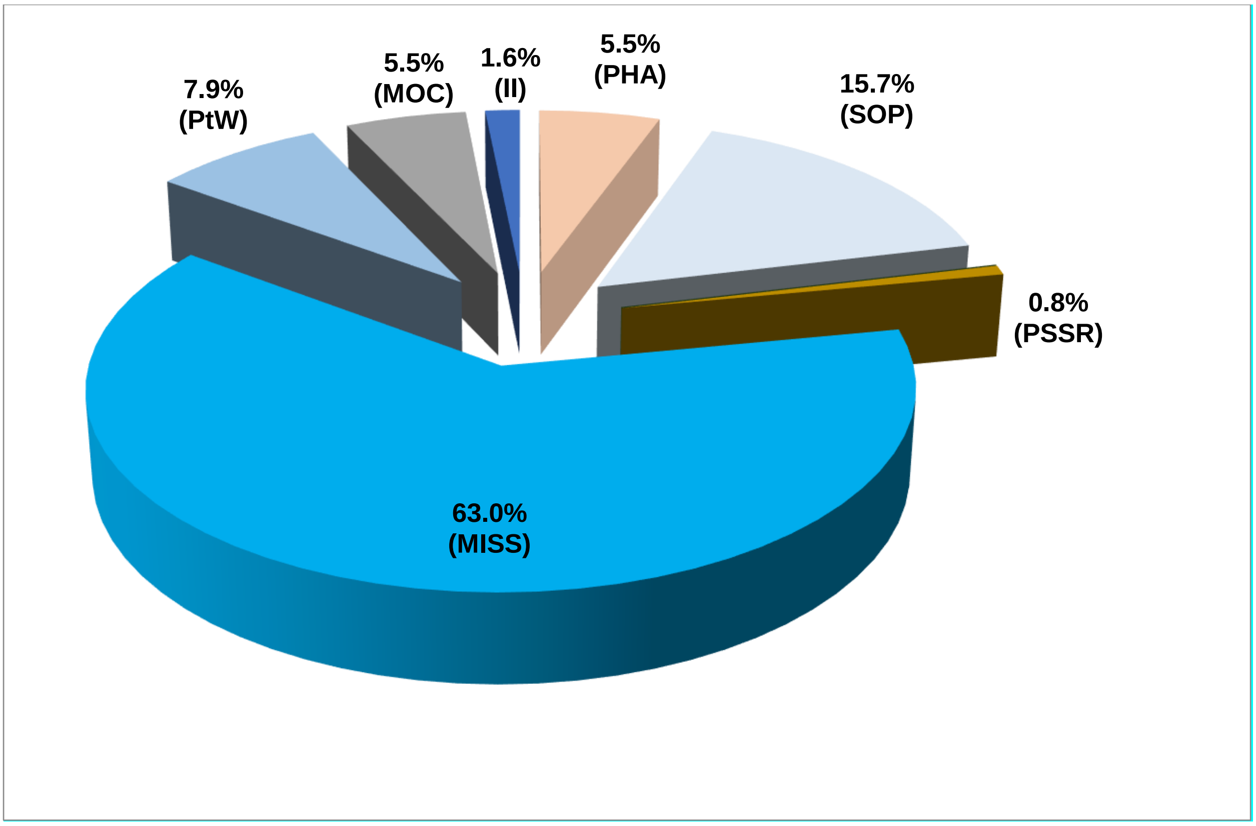

Figure 13: A pie chart showing the breakdown of process safety incidents by PSM element before the asset management program (Source: Researcher).

Figure 14 displays the sub-elements of MISS indicating the top contributing failures to the MISS element. Flange gasket failure, pinhole leaks and valve gland failure contribute to the three-top failure.

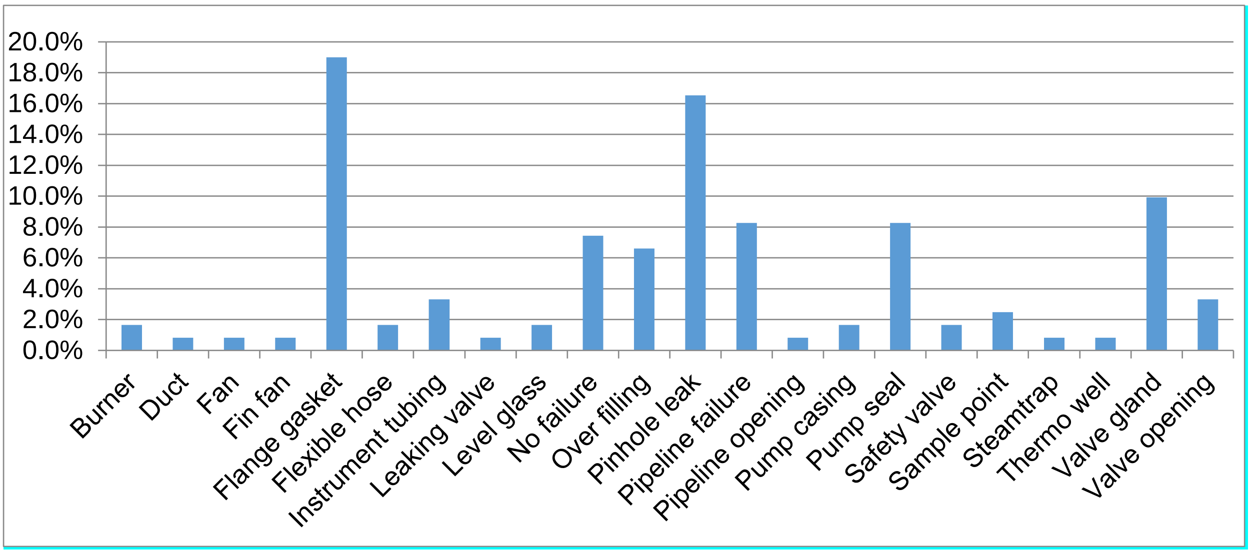

Figure 14: A graph showing the maintenance integrity safety system element incidents breakdown, a consolidation from available data, (Source: Researcher).

Figure 15 shows the proportion of PS incidents by PSM element after the asset management program. Maintenance integrity safety system contributed about half of the total number of incidents with management of change (MOC) and process hazard analysis (PHA) making the top three contributors to PS incidents.

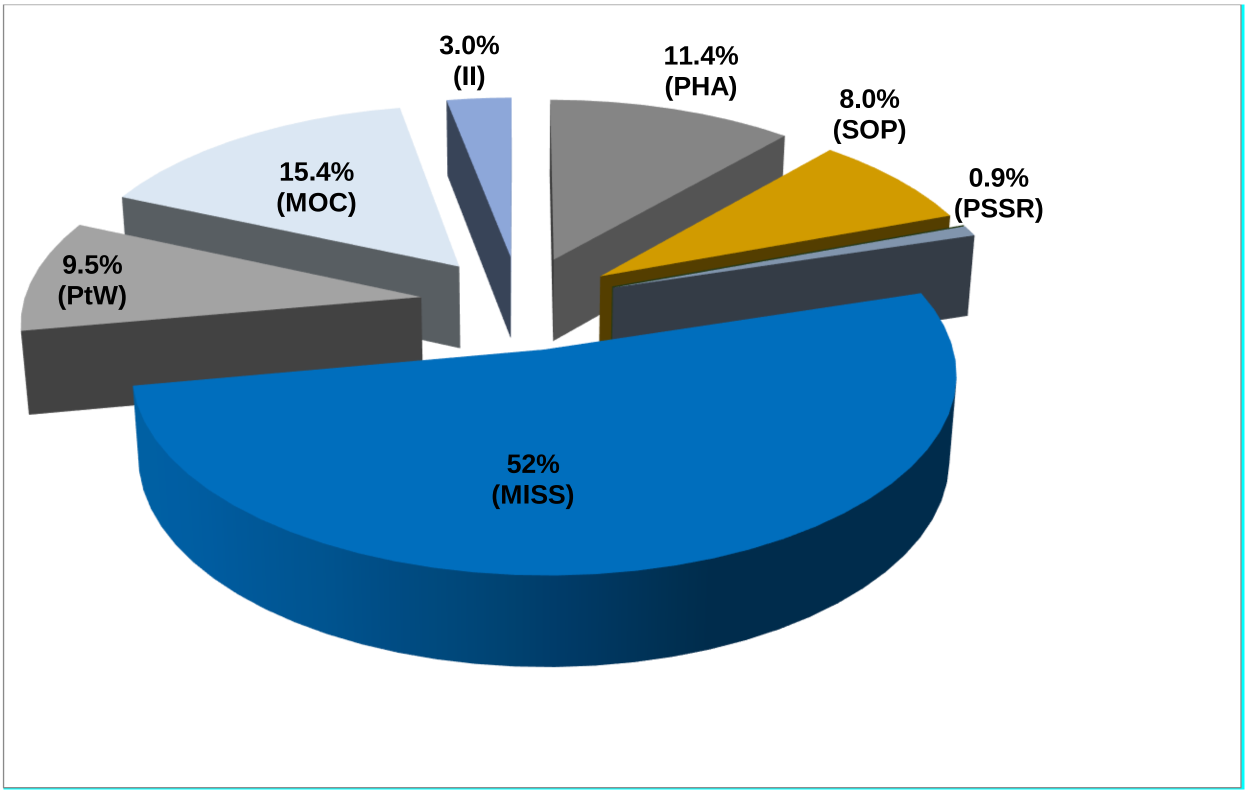

Figure 15: A pie chart showing the breakdown of process safety incidents by PSM element, after the asset management program. (Source: Researcher).

Figure 16 shows the trend on the number of PS incidents over a time period. A decline in number of incidents is observed over the five-year period.

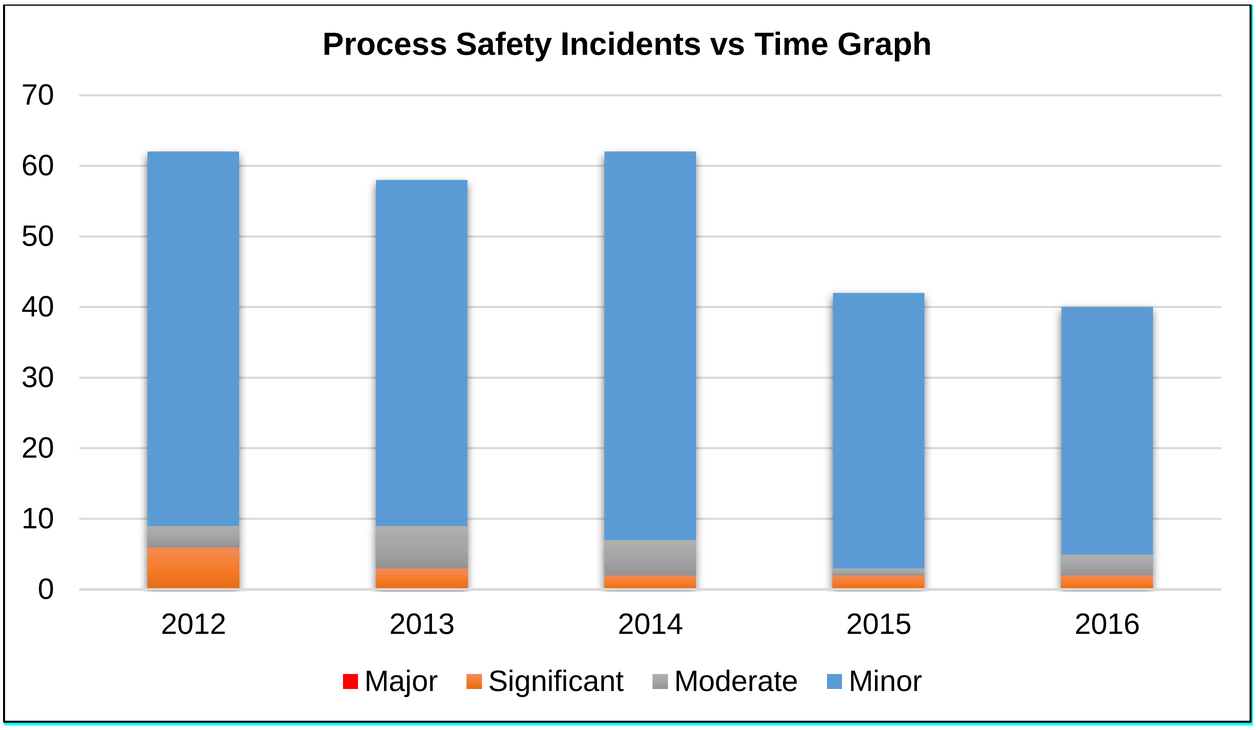

Figure 16: A graph showing the breakdown of process safety incidents by type over a time period (Source: Researcher).

Figure 17 shows the trend of the severity PS incidents over a time period. A decline in severity of the PS incidents is noticed over the five-year period.

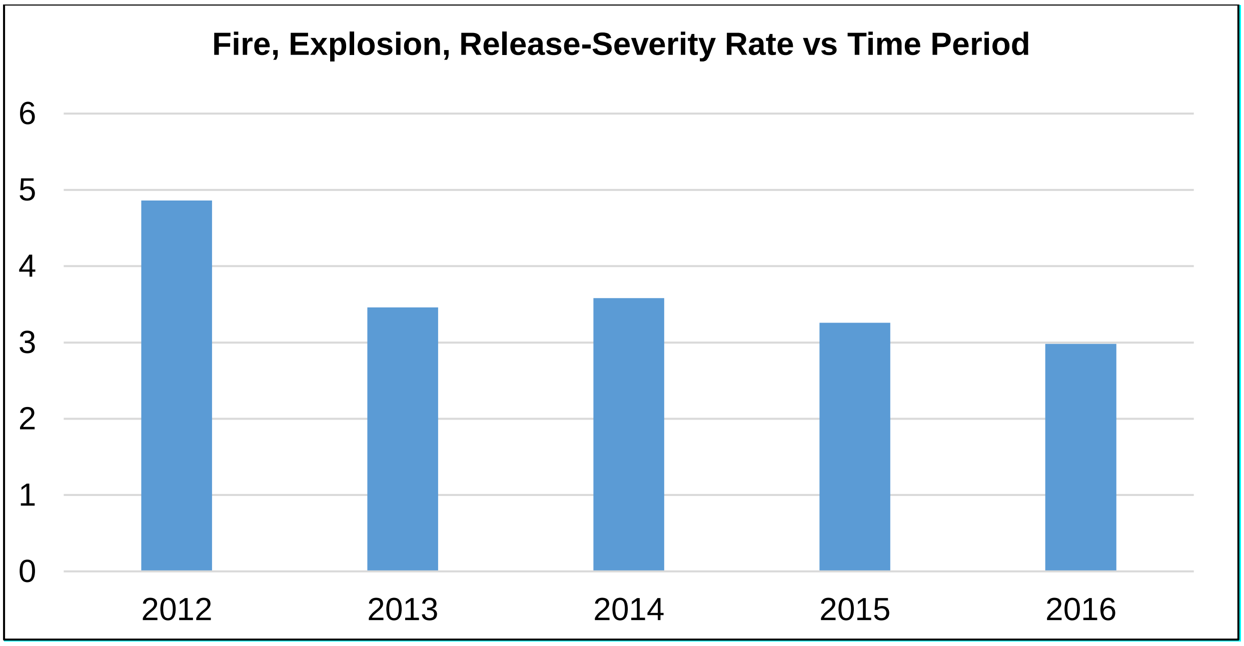

Figure 17: A graph showing the process safety incidents severity rate over a time period.

4.1.3 Audit Reports

A number of technical audits were conducted to determine the health of the assets and asset management systems between year 2012 and year 2016. Due to the large volume of the data and information combined with the limited time on this research, the researcher focussed on the PSCE audit reports only. There were a number of PSCE audits conducted during implementation of the asset management program in 2012 and subsequent PSCE audits at a hazardous chemical process operations. The researcher included a summary of two reports on PSCE for year 2012 and year 2015 to assist with the research data analysis.

The summary of the extracted reports are stated below:

4.1.3.1 Extract Report Number 1, 2012

Introduction

This report constitutes the findings of an audit conducted on the compliance to “Record Number: SHE-SGS 001: Asset Management PSCE”, conducted in May 2012.

1. The PSCE audit covered the following areas:
    - List of PSCE on new format in SAP
    - Reasons for listing equipment as PSCE
    - PSCE list accepted by Vice President/ General Manager
    - 50% of listed equipment registered in SAP with unique identifier
    - Maintenance plans, procedures and quality control plans in place for listed equipment
    - Record keeping, PSI, training and risk management
2. Audit Result

The overall audit result is 82% compliance

3. Audit Findings
    - The identification of PSCE was done according to the definition as indicated in the PSM standard
    - Some business units did not register the PSCE as PSM critical in SAP
    - The senior manager’s acceptance of listed PSCE could not be established in certain business units
    - Maintenance plans were not completed for some identified PSCE at one business unit

4. Recommendations

- The listed equipment should be identified in SAP with the unique identifier-“PSM criticality”
- Process safety specialists supporting the various business units and BU facility representatives should engage in order to assist operations in their understanding of the PSCE definition.
- The knowledge and understanding of PSCE must be used with the further roll out to the other business units in order to expedite the completion of the registration process and listing of the equipment on SAP.
- Maintenance plans with accompanying maintenance strategies should be developed for all equipment identified as PSCE, together with relevant supporting maintenance procedures to ensure the BU assurance of the PSCE program.
- Business unit leaders, their appointed facility representatives and process safety specialists, responsible for the identification of PSCE should complete the PSCE identification process and the SAP registration process as a team in order to complete the initial exercise so that the assurance can be implemented and monitored.

5. Conclusion

Some of the business units do not fully comply to the PSCE standards: Asset Management PS-PSCE and there is room for improvement with more focus on finalizing the PSCE identification and ensuring compliance to the standard.

4.1.3.2 Extract Report Number 8, 2015

Introduction

This report constitutes the findings of an audit conducted on the compliance to “Record Number: SHE-SGS 001: Asset Management PSCE”, conducted in April 2015.

1. Audit Categories

The audit consisted of the following:

- List of PSCE
- Reasons for listing equipment as PSCE by the BU
- List accepted by Vice President and signed off
- 75% of listed PSCE is registered and flagged in SAP as PSCE with a unique identifier
- Maintenance plans, procedures and quality control plans in place for listed PSCE
- Record keeping, PSI, training and risk management

2. Audit Result

The overall audit outcome result is 95% compliance

3. Audit Findings

- Information on some PSCE lists for some business units does not correspond to information on SAP
- Some business units do not use the correct cover pages
- Not all approval signatures were on PSCE lists
- Not all PSCE has accurate maintenance plans
- Not all PSCE maintenance plans have a task sheets linked
- Reason for management decision were not clearly indicated in some instances
- The PSCE lists were shared with all supervisors and maintenance personnel, but there is room for improvement in the production areas.
- Great improvement in compliance in all aspects of PSCE were observed.

4. Recommendations

- The standard template must be used for the listing of PSCE with the relevant information in all areas
- Listed equipment should be identified in SAP with the unique identifier-"PSM criticality"
- Process safety specialists supporting the various business units should ensure that their understanding of the definition and selection criteria for PSCE is such that they agree and roll out this knowledge to the business units to assist them in the identification process
- Maintenance plans with accompanying maintenance strategies should be developed for all equipment identified as PSCE, together with relevant procedures and quality control plans and all critical maintenance personnel must have copies
- Task sheets were linked to active maintenance plans
- Reasons for management decision on PSCE were indicated and there was great improvement from the previous reports
- PSCE list to be made available to production and maintenance personnel.

5. Conclusion

There is need to focus on non-PSCE to ensure better plant performance. There is an improved compliance on PSCE, but some issues identified in the previous audit are not yet resolved. Consultation with process safety for the revision of PSCE must be done on an ongoing basis and on a more regular basis. Overall statutory maintenance and PSCE is being complied with.

Acknowledgement by PSM and Asset Technical auditing team
There was support and co-operation by the responsible senior managers, in accomplishing a successful audit.

4.2 Validity and Reliability Considerations

The validity and reliability of the measurement instruments influence the extent to which one can learn about the phenomenon of studying. Validity is the extent to which the instrument measures what it is intended to measure, and reliability is the consistency with which something will yield results (Leedy and Ormrod, 2010). Dudovskiy (2018) refers to reliability as the extent to which the same answers can be obtained using the same instruments more than one time. If one's research is associated with high levels of reliability, then other researchers need to be able to generate the same results, using the same research methods under similar conditions. It is noted that reliability problems crop up in many forms.
"Reliability is a concern every time a single observer is the source of data, because we have no certain guard against the effect of that observer's subjectivity" (Babbie, 2010, p.158). Wilson (2010) states that reliability issues are most of the time closely associated with subjectivity and once a researcher adopts a subjective approach towards the study, then the level of reliability of the work is going to be compromised.

Validity of research can be explained as an extent at which requirements of scientific research method have been followed during the process of generating research findings. Oliver (2010) considers validity to be a compulsory requirement for all types of studies. There are different forms of research validity and main ones are specified by Cohen et al (2007) as content validity, criterion-related validity, construct validity, internal validity, external validity, concurrent validity and face validity.

Measures to ensure validity of a research include, but not are limited to the following points (Dudovskiy, 2018): Appropriate time scale for the study should be selected; an appropriate methodology has to be chosen, taking into account the characteristics of the study; the most suitable sample method for the study has to be selected; and the respondents must not be pressured in any ways to select specific choices among the answer sets.

This research applied the above four stated points to minimise the threats to research's reliability and validity. A time frame was set for analyses of data from July 2012 to June 2016. Convenient sampling approach was used to identify a specific group of participants with the required knowledge for a valid outcome. Connelly (2016) notes that in qualitative rather than quantitative research, the strategy of 'trustworthiness' of findings is usually adopted for establishing validity and reliability of qualitative research, which includes triangulation, this was done, respondent validation, this was done and selecting the right people for the study, this was done, among others. Despite precautions taken in qualitative studies however, the threats to reliability and validity cannot be fully eliminated and it is acknowledged at the end when reflecting on the study.

4.2.1 Research Analysis

4.2.1.1 Interview Studies

According to the interviews conducted with the questions and answers summarised on Table 1, where the participants were asked if they could relate AM to PSM, it came out that the participant were of the opinion that AM and PSM are related based on their experience and understanding of the two management concepts. The participants related how they view AM and PSM and how they think the two areas should be managed and organisationally structured according the returned answers. The interpretation of the results according to the researcher is that it appears from the participants that AM and PSM have a relationship, through business processes, systems and their application.

A common trend seemed to emerge from the decoding of the results of the interview survey that could possibly link the performance of process safety to asset management. The following trend and outcomes were observed: asset management and process safety management are understood by the people who participated in the interview study; the methodology of managing the two concepts is similar and it is understood by larger number of the participants; most of the interview participants were of the view that asset management and process safety management are technical multi-discipline fields.

4.2.1.2 Reports

The researcher analysed the performance of the AM extract reports focusing on the PSCE audits that were conducted between year 2012 and year 2016 and attached the two audit reports extracts namely: Report No.:1 (2012) and Report No.: 8 (2015). The first report seems to reveal serious AM concerns, such as the non-registration of PSCE as PSM critical in SAP and the non-completion of maintenance plans in some business units. The researcher indicates concerns on the health or the maturity level of the organisation on the AM standards and processes, in year 2012. An audit report of a similar audit conducted three years later using the same audit protocol on the same business units, shows an improvement in PSCE compliance to standards and processes. The improvement in the implementation of AM processes is reflected in the overall audit scoring of the organisation on PSCE that measured only half, (50%) of the available PSCE for compliance and the achieved audit score was 82%, when compared to measuring three quarters, (75%) of the available PSCE, with the audit score of 95%. While this research paper is based on qualitative data analysis the comparison of the two audits reports indicate a positive improvement in AM performance.

4.2.1.3 Data Tables, Pie Charts and Graphs

Table 2 provides the PSM performance of the hazardous chemical operations organisation before the implementation the asset management program in year 2012 and over a 5-year period to year 2016. The number of process safety (PS) incidents and the fire, explosion and release severity rate (FER-SR) shows a downward trend over a five-year period. The total number of process safety incidents were 62, on 30 June 2012 and the number of PS incidents decreased to 39 on 30 June 2016. There was a downward trend on the number of PS incidents in all categories (significant, moderate, minor and the total of all incidents) except in year 2014. The results trend appears to be similar to the PSCE audit results that was conducted as part of the AM health check that improved over the period under research.

Figure 13 and 15 (pie charts showing the breakdown of process safety incidents by PSM element, pre and post asset management program) are a breakdown of PS incidents by PSM element classification between 30 June 2012 and 30 June 2016 respectively. The maintenance integrity safety system failure (MISS) contributed the highest percentage of the total process safety (PS) incidents. The maintenance of chemical process equipment plays a key role on the asset management as shown on

Figure 12 (An adapted asset management integrated with process safety management diagram). An organisation with mature asset management principles implements the asset management standards and processes that result in stable asset performance and minimum unplanned equipment breakdown. It is observed from the extracted pie charts that the contribution to PSM incidents from the MISS element decreased in the period under review from about two thirds to almost half the number, (65% to 52%).

The asset management program appears to have contributed in reducing the number of the chemical process plant's mechanical equipment failure. The effect of the implementation of the asset management program could be directly linked to the percentage number of mechanical integrity safety system failure.

The behaviour of the PSM attributes seem to be related to the changes in AM performance in general. When the asset management's PSCE audit results scores were low, the number and severity of process safety incidents were high in year 2012 and when the AM's PSCE audit result scores improved in 2015, the number of process safety incidents, severity and the FER-SR declined.

4.2.1.4 Training needs Analysis

The researcher developed a tool that could be used for AM and PSM training needs analysis as presented in Table 3. The training tool is divided into four areas namely: process; personnel involved; selection criteria summary or barriers; and expected outcomes.

Table 3: A summary of the training needs analysis.

Process	Personnel Involved	Selection Criteria Summary/ Barriers	Expected Outcomes
Define the Targeted Job Roles	Training personnel; AM, PSM and operations management.	• Operations duties • PSM and AM subject expertise; and • Projects management knowledge.	• Job roles of personnel to be trained and prioritisation; and • Material content.
Choose Needs Analysis Method	Training and operations personnel.	• Optimal business impact.	• Develop a training syllabus.
Determine Participants	Operations, PSM and AM management.	• Current job role; and • Qualifications.	• Candidates for training.
Develop Training Protocols	Training personnel, AM and PSM SME	• Operations' needs; • Personnel location; and • Employee ranking.	• Training materials.
Anticipated Problems	Operations, AM and PSM.	• Lack of management support; • Poor turnout; • Poorly developed ; and training materials.	• Material development; • Dedicated SMEs; and • Candidates to attend the course.
Training	SME facilitators	• Experience; and • Communication skills	• Competent PSM and AM personnel

The tool sets out a clear path from how to identify categories of people who should be trained through job roles to the training outcomes being competent PSM and AM personnel.

5 DISCUSSION

This chapter looks at various outcomes from the results and analysis in Chapter 4 in line with the research objectives. The chapter explores the research objectives and uses the interview study results, data analysis and the audit reports to discuss the defined objectives.

5.1 Interview Study Results

The AM models utilise the plan, do, review and improve models over the asset life cycle, which is used in the risk-based safety management of process safety. In both processes there are similar actions and sub actions that have to be implemented and these were highlighted by a number of the interview study participants on relating AM to PSM. The interview study participants when asked on question 3 (Is there any relationship between asset management and process safety management and explain your thinking?), the majority of the interview study participants seemed to suggest that asset management and process safety cannot be separated from each other and there is a closer link between the two concepts.

However, there were a minority of the study interview participants who were of the view that while the concepts could be of similar nature they were not related and felt that the management of the two disciplines should be managed separately as is the current status in the hazardous chemical process organisation.
A number of interview study participants when presented with question 4 from the questionnaire, (In your own experience in the organisation, do you think AM and PSM are properly understood currently and why?) seemed to doubt the understanding levels on AM and PSM standards and business processes as mature to combine and integrate the two departments. Some participant even questioned the benefits of integrating the two concepts and departments. The other interview study participants were of the opinion that there is a knowledge gap that should be closed on the understanding and application of the two concepts, before benefits could be fully achieved. This is linked to one of the objectives on what are the current challenges that negatively influence the link between asset management and process safety management.

The researcher explores the asset management and process safety management department staffing from the questionnaire on question 6 (Do you think the process safety management department is correctly and optimally staffed and why?). The staffing of PSM and SHE departments has always been a subject of discussion in the organisation where the research was conducted. Several books discuss the staffing under competency building and the current trend is to staff the PSM department with chemical and process engineers, however, there seems to be changes in thought. A few number of the interview participants appear not to have enough knowledge on how to staff the AM and PSM departments. A bigger number of the participants appear to suggest that the PSM department lacks the necessary engineering discipline spread and the expected competency to execute its mandate.

The interview study participants mention that the staffing of personnel numbers are inadequate when compared to the scope of work for the PSM department.

To further understand the current challenges that could negatively influence the link between asset management and process safety the researcher explores to understand the current reporting lines and what the participants would regard as ideal or optimal organisational structure. The interview participants appear to think that the current organisational reporting structure encourages working in silos and creates gaps. The interview participants seem to think that the roles of the two departments overlap each other and are both of a technical nature, hence they should be reporting to one head of department. The interview study participants when further probed about their opinion about in which department PSM should be reporting, it appears that the interview study participants prefer PSM department to report into a technical department, not in the SHE organisational structure.

Despite the interview study participants being of the view that PSM should be moved from reporting under the SHE organisational structure, it could be argued that the reporting structure re-organisation is irrelevant and not necessary based on the PSM performance data. The basis of the argument could be if one analyses the results on Table 2, (Data collected over a 5-year period focusing on the number of process safety incidents and the severity classification), the PSM performance improved with the right initiative programs irrespective of the organisational structure and the personnel staffing. One could argue as well that the change in the organisational structure could further improve the current performance, optimise resources and consolidate the link between AM and PSM.

The researcher analysed the answers from the interview study where the participants think that there are current integration gaps in the asset management and process safety management models as shown on Figure 1. According to the researcher the optimal situation to manage AM and PSM is shown on the bottom part on Figure 1, where the asset management and process safety management activities are integrated.

The researcher further proposes the development of an adopted asset life cycle integrated with process safety. In the proposed model on Figure 3, the researcher links each of the 4 stages of asset management processes and standards to the process safety elements to create a clear link between asset management and process safety management.

5.2 Data Tables, Pie Charts and Graphs

The data analysis on Table 2 (Data collected over a 5 year period on the number of process safety incidents and the severity classification) and Figure 16 (A graph showing the breakdown of process safety incidents by type over a time period) shows that the number of process safety incidents as measured over a 5 year period was in decline except for year 2014.

If one views the model on Figure 1 (An overview of asset management and process safety managed separately and what could happen if AM and PSM were to be integrated), the top two diagrams appear to be in opposition due to competing interests. The asset management diagram only focuses on asset management and the other diagram only focuses on process safety management and yet if the two concepts standards are integrated there appears to be commonality between them as shown in the bottom diagram, which could eliminate the silo scenario. This could result in better resource and knowledge utilisation and possibly improve the organisational performance.

It could also be argued that combining the two could create a central bureaucratic department, which could lose focus that is achieved by leaner and more focussed specific departments, each with a particular area of focus. While AM and PSM could share the same business processes and standards they are best applied individually.

5.3 Audit Reports

The audit results on the PSCE although not conclusive seem to support the notion that the process safety performance has a direct relationship with the asset management health status.

However, this can be challenged as coincidental which could be attributed to other organisational programs that the researcher might not have been aware of that were being undertaken by the organisation or simply a change in leadership focus. While this notion cannot be fully discarded, the data, information collected and analysed over the research period and the interview study conducted seem to support a direct relationship between asset management implementation and process safety performance.

Process safety incidents by nature result in either equipment damage, multiple occupational injuries, health issues as well as environmental harm or incidents. The harm that results from the process safety incidents usually has huge economic cost in addition to increased safety risks, which generally increases the SHE risks of an organisation. Hazardous chemical process organisations generally group risks together and process safety risks fall under the SHE risks. The poor the process safety performance is, the poor the general performance of the SHE category and the higher the SHE risks.

6 CONCLUSION

The purpose of this research was to establish the link between asset management implementation and the process safety performance in a selected South African hazardous chemical operation, with the view of proposing possible improved integration of asset management and process safety management. The integration of the AM and PSM could improve the process safety performance, which has a direct effect on the safety performance in particular and generally contributes to the safety, health and environment performance of the organisation. This improvement could result in (SHE) risk reduction for the hazardous chemical operations. This was done by exploring the AM and PSM processes to understand where they overlap and share business processes and systems.

To carry out this research a number of professionals with extensive experience in both asset management and process safety management were interviewed in order to answer the research question. The research question sought to interrogate the relationship between asset management and process safety management.

In order to assist with the understanding and answer the research question, 4 research objectives were set and defined. The researcher carried out an interview study with 14 participants and the research might need further research on all the 4 objectives on an expanded sample of participants and possibly covering a number of hazardous chemical operations. It is expected that further research might deliver valuable insight that could lead to some hazardous chemical operations reviewing the roles and staffing of asset management and process safety departments.

6.1 The Research Purpose

The purpose of this research was to establish the link between asset management application and process safety performance, to determine the outcome with the view of proposing possible enhanced integration of asset management and process safety management.

The research purpose was achieved as the link was established and a proposal was recommended

6.2 Research Question

This research revolves around the central research question on the relationship between asset management and process safety performance:

- What is the link between asset management and process safety performance?

The research question was answered through interview studies, data and audit results

6.3 Research Objectives

The objectives of this research project are:

1. To assess the relationship between focused implementation of asset management systems and the outcomes of process safety performance in a hazardous chemical operations company;
2. To determine improvements needed to integrate the current asset management models with process safety management principles in a South African hazardous chemical process operations company;
3. To develop a conceptual framework for an integrated asset and process safety management standards; and
4. To make recommendation on areas of improvement to the asset management model utilisation in the process safety management in a hazardous chemical operations organisation.

The objectives of the research were fulfilled based on the stated objectives.

6.4 Research Limitations

The research was only limited to one hazardous chemical operation organisation, hence the sample used in this research study might not represent the full picture of the hazardous chemical industry in its entirety. The analysed data were for a limited period of 5 years only, when an asset management and process safety management was initiated. The 5-year period might need a longer time frame to have a more objective conclusion, which might have a different result altogether. The researcher used the convenience sampling technique to gather information and a proportion of the population was sampled. The result is that the sample used in this research study might not represent the entire population accurately hence, the results of the research study should not be generalised over the entire population group of hazardous chemical operations.

The 4 objectives are expanded below:

Objective 1: To assess the relationship between the implementation of asset management program and the outcomes of process safety management performance in a hazardous chemical operations company.

This analysis was done on the available data and audit reports on asset management performance measured against standards through compliance audits and the performance of process safety recorded over a period of 5-year period. The research was further supported by interview studies that were conducted. The period was taken from the start of the implementation of the asset management program. Based on the literature review and the observed results from the data analysis there appears to be an overlap on process of AM and PSM. This could possibly support the thinking that there is a link between AM and PSM.

Objective 2: Establish some of the challenges that could influence the link between asset management with process safety performance and determine the improvements needed in integrating the current asset management models to process safety management in hazardous chemical operation company.

The first step was to establish the link between the AM and PSM through discussion if there was a link indeed. Once the researcher found out that there is a link between the two concepts, the researcher explored what are the challenges that could negatively influence the linkage between asset management and process safety management. The interview study participants highlighted the deficiencies and what could be possible actions to close the deficiencies identified. The interview study participants made some suggestions that included the re-organisation of the staffing organisational structure to reviewing the staffing of process safety management personnel. However, the available information was not conclusive.

Objective 3: Propose an integrated asset management and process safety management model.

At the beginning of the literature review the researcher introduced Figure 1 that shows how the 2 concepts are managed with competing goals at the top and how they could be integrated at the end of the PSM literature review in Figure 3. The researcher analysed the data and reports that were available and came to the conclusion that is similar to the outcomes of the interview study participants. The researcher, with the two outcomes that reflected a similar trend from different sources and proposed an integrated asset management and process safety management model, Figure 3.

Objective 4: Recommend any areas of improvement to the asset management model utilisation in the process safety management in a hazardous chemical operation organisation.

The professionals and specialists who participated in the research study interviews have the competency in both asset management and process safety management. Although there was no full agreement from all the participants, the larger number of the participants suggested possible areas of improvement in the staffing and skilling of the PSM department and in the organisational re-structuring of the two departments.

6.5 Recommendations

The study found some gaps in the current models and makes six recommendations which are broken down into two parts: the first part is on the organisational staffing structure in a chemical process organisation at large; and the second part suggests recommendations that affects the process safety management department.

It is recommended that the following actions should be considered when setting up and managing the organisational structures for asset management and process safety management departments in hazardous chemical process operations:

1. Asset management and process safety management should possibly be integrated and report to the head of the technical department. Currently the AM personnel report into the Technical Support structure while the PSM staff report into the Safety, Health and Environment. PSM is more technical in nature, better aligned with AM life cycle integration when compared to Occupational safety and Environmental management. AM and PSM set the standards and norms of compliance, the researcher is of the opinion that the AM and PSM should report to the Vice-President: Technical Support and Risk Management. This should enhance better AM and PSM integration and effective AM and more focus on asset risk management focus;
2. Further investigations should be conducted on how PSM should be staffed to ensure that a variety engineering disciplines (chemical, mechanical, instrumentation et al.) and operational experience is utilised. Instead of the current trend of staffing PSM department with chemical engineers, mechanical

engineers and instrumentation and control should be placed into the PSM fraternity to embed maintenance and layers of protection principles. In addition, while the focus is on degreed candidates, competent personnel with lower qualifications but more operational experience should be recruited in the PSM department. This enhances diversity in knowledge and improves the practicality of knowledge application;

3. The independence of safety, with PSM department in particular is to some extent compromised, due to its dual role of supporting and monitoring plant operations personnel through audits and reporting directly into the operations. The researcher is of the opinion that to improve governance and the quality of audit outcomes, the Vice President: Technical responsible for AM and PSM should have an indirect reporting function, while reporting as high as possible in the organisation, with a reasonable access to the chief executive officer of the organisation;
4. A cultural change program should be initiated in the hazardous chemical organisation to change employees' paradigms on safety and process safety in particular. The change program will improve the lower ranked employees' knowledge and minimise the myth that PSM is a highly technical discipline executed by a small team of PSM personnel, to PSM being integrated in their day to day job roles. This cultural change will enable PSM understanding through training of people who are in lower ranks of the organisation who operate and maintain the assets, the assets will perform better and could have a positive influence on PS performance.

In addition, to enable an optimal process safety management performance there are two suggestions below:

1. The number of process safety personnel positions in the hazardous chemical organisation should be reviewed to enable the process safety department focus on a broad spectrum of process safety rather than the critical few; and
2. The role of process safety management department in a hazardous chemical organisation should be reviewed to create better integration of the AM and PSM and enable formal engagements between the two management functions.

6.6 Future work

There is need for further research on the topic to improve the link between asset management and process safety management in hazardous chemical operations. The current research was limited to 14 study interview participants and restricted to one hazardous chemical process operations. There is need to expand the research to a variety of hazardous chemical process operation organisations in South Africa. Further research that is representative might come to the same conclusion as this research or might produce a different outcome.

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Note
*Company means Campbell J and associated group of companies, Petroskills, OGCI Training Inc.

Appendix 1

Research Questionnaire: Linking asset management implementation to process safety performance and SHE risks.

The following questions are for research purposes to provide guidance on your understanding of asset management and process safety management; how these departments should be staffed and what reporting lines should be?
Please note: There is no right nor wrong answer

1. What do you understand about Process Safety Management?
2. What is your understanding of Asset Management?
3. Is there any relationship between asset management and process safety management and explain your thinking?
4. In your own experience in the organisation, do you think AM and PSM are properly understood currently and why?
5. How do you think the staffing in process safety management should be done?
6. Do you think the process safety management department is correctly and optimally staffed and why?
7. Currently PSM and AM report to different heads of departments, what is your opinion about the reporting lines?
8. If you were given a choice to restructure and reorganise the organisation's organogram, where would you place the PSM department?
9. In your own opinion, what must be done to improve the effectiveness of process safety management and safety to reduce the overall SHE risks?
10. Summarise your motivation on why do you believe that PSM and AM departments should or should not report to one head of department?