

Engineering a process safety culture in the chemical processing industry

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PREFACE AND ACKNOWLEDGEMENTS

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ABSTRACT

Industries where fire, explosion or releases (FERs) of hazardous chemicals may occur are administered by process safety management (PSM). Such events have the potential to cause catastrophes resulting in fatalities, facility and adjacent area damage or detrimental environmental impacts. Despite governments and institutions promulgating comprehensive standards, legal prescriptions, guidance notes and best practices since 1992, such major incidents still occur today. It has been over 26 years since PSM legislation was conceived, yet we still experience major process safety incidents where significant loss of life occurs. Analysis of past process safety incidents reveals that inadequate process safety commitment, leadership, conduct of operations and poor organisational culture have been recurring. **Therefore, the research problem is that current PSM systems are deficient in addressing process safety culture in the chemical processing industry.**

This study endeavours to further understand how to improve and sustain process safety management in the chemical processing industry. **The contribution to a new body of knowledge (BOK) sciences is to produce a practical and sustainable framework for improving process safety culture in the chemical processing industry.**

The literature survey consisted of reviewing existing PSM systems, occupational safety culture practices, human mind influencers and maintenance error. Publications from other high-risk high-reliability industries with catastrophic consequences were also evaluated. Delving into process safety culture systems revealed numerous human factor engineering practices and only a handful of process safety culture practices. Only two PSM systems included process safety culture, namely the Centre of Chemical Process Safety (2008) and the International Oil and Gas Producers (2008). However, there is an abundance of occupational safety culture literature available. Approaches for occupational safety culture were mainly cited as well as psychological literature that provides guidance on positively influencing human behaviours. Human factor error also impacts asset integrity; hence this was incorporated into the literature survey.

High-risk high-reliability industries, specifically nuclear and civil aviation sectors, were also reviewed to provide an external view on safety culture approaches. There was also an abundance of safety culture literature available for these sectors. Thus, several safety culture approaches were uncovered, much of which resided in the occupational safety culture domain. **Therefore, it is evident that our research problem exists, and that globally there is very limited guidelines into holistically managing process safety culture in the chemical processing industry.**

A qualitative mixed methods approach was selected, and comprehensive verification, validation and reliability techniques were reviewed. Theory building was highlighted as an additional literature survey required to assist in the development of the process safety culture framework.

All the process and occupational safety culture approaches from the literature surveyed was collated and analysed. Identified trends revealed some themes which featured repeatedly across the different safety culture approaches in the diverse environments investigated. A total of nine process safety culture (PSC) constructs were derived. These nine PSC constructs were summarised along with their associated critical aspects. A process safety culture is inferred through process safety climate assessment. Hence, the PSC constructs were transformed into the PSC elements, process safety climate attributes, which collectively intertwine to develop the process safety culture framework. The original nine PSC constructs formed twelve final PSC elements. The four quadrant focus areas, safety capital principles and the process safety culture elements were adapted and overlapped, ultimately resulting in further grouping of the process safety culture elements into four pillars.

The four process safety culture pillars are [1] systems, [2] integrity, [3] people and [4] performance. This was graphically represented to incorporate all the process safety culture elements and pillars, to form the PSC framework. Sustainability aspects, discussed in Section 2.5 and Section 2.7, were incorporated into the PSC framework. Accompanying this, is the PSC implementation cycle and the PSC maturity chart.

The intended research validation, as described in Chapter 3, was to pilot the process safety culture framework at a chemical processing facility. Financial impact and each PSC elements' effective implementation were observed as the greatest challenges opposing validation. The implementation phase was estimated to require 2 to 4 years and was largely dependent on the magnitude of the chemical processing facility. The pilot phase required leadership to actively drive the PSC framework. This was estimated to require at least a year of testing, in order to perform an adequate assessment of the PSC elements and the framework.

Thus, a total period, inclusive of implementation and field pilot testing, of between 3 to 5 years was estimated. Therefore, the initial intended validation approach was not viable. An alternate approach was undertaken and the proposed PSC framework, was critically reviewed by Subject Matter Experts (SMEs) in the chemical processing industry and their feedback was incorporated. A total of ten SMEs were consulted, with combined experience in operations, engineering and process safety, exceeding 190 years. The SMEs are from three different provinces across South Africa, and are in roles across operations (production, maintenance), process engineering, behavioural transformation and process safety. Most of the SMEs consulted were very senior and

instrumental in implementing (facilitating or guiding) process safety practices/programs at a chemical processing facility.

Despite the implementation and field pilot testing challenges, after consultation with these SMEs from operations, engineering and process safety at chemical processing facilities, they concur that the PSC framework is implementable and will yield positive PSC performance. However, this could not be quantified without field pilot tests.

The PSC framework was updated to incorporate the builds by the SMEs. The major difference between the PSC framework revision 0 and revision 1, is the inclusion of the critical aspects of the now thirteen, previously twelve process safety culture elements. The additional PSC element is committed leadership, which although included, was diluted in the people pillar. The process flow diagram was also reviewed to better depict the relationships between the PSC pillars. This one-page high level overview greatly assists in summarising the PSC framework for ease of implementation as well as understanding.

A PSC assessment tool was also suggested to support this framework. Therefore, the PSC questionnaire was developed and tailored to the PSC framework. Findings raised from the PSC questionnaire will inform the PSC implementation cycle. Thus, this will greatly complement the implementation of the framework and assist in pin-pointing the framework's substandard process safety pillars.

Leadership expectations in the form of a "*how to guide*" was suggested to assist in practically executing the PSC framework. Therefore, a PSC roles and accountabilities guideline was developed. Leadership was identified through all levels in a typical chemical processing business from the highest board member positions to the entry foremen level positions. The guideline also included all front-line operation personnel and other personnel with no direct reports, as process safety culture requires the participation from everyone in an organisation. Examples of other personnel include engineering, functional support and service providers. There were thus five levels of leadership. These levels included board member/executives, senior managers, plant managers, foremen and front-line operation personnel and other personnel.

The PSC framework is a holistic approach to PSC, focusing on various aspects of process safety climate attributes which jointly contribute toward assessing and improving PSC in the chemical processing industry. It does not concentrate on influencing a positive PSC, but rather engineering a positive PSC practically and sustainably through systematic and continuous improvement focused initiatives.

This model however has two dependencies: [1] existence of an active Occupational Safety and Health Administration (or equivalent) PSM system and [2] it is actively driven by leadership. The overarching prerequisite of this framework, is that a chemical processing facility is in a good financial position and is able to upgrade its safety instrumented systems, implement a resource structure according to strategy and integrate digital solutions incorporating Safety, Health and Environment (SHE) and maintenance programs.

This research study addressed the following two cases with a converse hypotheses:

H₁: There is a practical, sustainable and implementable process safety culture framework for the chemical processing industry. **H_{1.0}:** There is **no** practical, sustainable and implementable process safety culture framework for the chemical processing industry.

From the literature survey, it was also evident that our research problem exists, and that globally there is very limited guidelines into holistically managing process safety culture in the chemical processing industry. Therefore, based on this outcome, although very limited, it does appear that **H₁** is applicable and there is a practical, sustainable and implementable process safety culture framework for the chemical processing industry.

H₂: Implementation of a PSC framework will improve process safety incident case rates. **H_{2.0}:** Implementation of a PSC framework will **not** improve process safety incident case rates.

Despite the challenges experienced with the validation and reliability of the PSC framework, it has been theoretically reviewed by experienced SMEs, to assure that it will improve PSC at a chemical processing facility, albeit unquantifiable. Therefore, it does appear that **H₂** is applicable, and that implementation of the PSC framework will improve process safety incident case rates theoretically.

Three research objectives were proposed. Two research objectives were achieved, and one research objective was partially achieved due to the **H₂** case explained above. A total of four recommendations are proposed for future work.

Key Terms: Process Safety Culture, Chemical processing, Process Safety Management, Process Safety

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LIST OF ACRONYMS

Acronym	Definition
AHP	Analytic Hierarchy Process
AIChE	The American Institute of Chemical Engineers
AIM	Asset Integrity Management
AI-PSM	Asset Integrity and Process Safety Management
AQAL	All Quadrant, All Level
BARS	Basic Aviation Risk Standard
BOK	Body of Knowledge
CCPS	Centre of Chemical Process Safety
CHAOS	Change Hardware and/or Software
CI	Continuous Improvement
CPWR	Centre for Construction Research and Training
CSB	Chemical Safety and Hazards Investigation Board
ECCE	European Congress of Chemical Engineering
EPA	Environmental Protection Agency
EPSC	European Process Safety Centre
FER	Fire, Explosion or Releases
GSG	General Safety Guides
GSR	General Safety Requirements
HMI	Human Machine Interface
HRM	Human Resource Management
HRO	High reliability organisation
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
IET	Institution of Engineering and Technology
INSAG	International Nuclear Safety Advisory Group
IOGP	International Association of Oil and Gas Producers
IOSH	Institution of Occupational Safety and Health
IPS	Instrumented Protective System
KUE	Key Undesirable Events
LOPA	Layers of Protection Analysis
MIRM	Minerals Industry Risk Management
MiRoR	Methods in Research on Research
MOC	Management of Change

Acronym	Definition
NEI	Nuclear Energy Institute
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
OECD	Organisation for Economic Co-operation and Development
OMS	Operating Management System
OSHA	Occupational Safety and Health Administration
OWAP	Operating Within Agreeable Parameters
PHA	Process Hazard Analysis
PSAN	Petroleum Safety Authority Norway
PSC	Process Safety Culture
PSI	Process Safety Information
PSLG	The Process Safety Leadership Group
PSM	Process Safety Management
PSSR	Pre Start-up Safety Reviews
RBI	Risk Based Inspection
RBIM	Risk Based Inspection Modelling
RBPS	Risk Based Process Safety
SEMS	Safety and Environmental Management System
SF	Safety Fundamentals
SGS	Specific Safety Guides
SHE	Safety, Health and Environment
SIS	Safety Instrumented System
SME	Subject Matter Experts
SOP	Standard Operating Procedures
SSR	Specific Safety Requirements
TI	Technical Integrity

CHAPTER 1 INTRODUCTION

Warren Anderson (past CEO Union Carbide), “What is the minimum amount of this PSM stuff I have to do”

1.1. Background

A hazard is commonly defined as something with the potential to cause harm. However not all hazards are equal, therefore this results in very different consequences. In the chemical processing industry, safety hazards are differentiated into occupational or process safety hazards.

Professor A. Hopkins suggests the following example to illustrate the difference between occupational and process safety (CCPS, 2008): *“An important safety concern in the airline industry is injuries to baggage handlers from lifting and carrying – for example, back muscle strains (personal safety). But no airline would ever think that their efforts to reduce these injuries would improve flight safety (equivalent to process safety). Different activities and programs are required to manage these different safety concerns.”* Therefore, occupational safety is concerned over one’s personal safety, and can include how one performs a task, the type of personal protective equipment worn, tools used and so on. Whereas process safety hazards may cause major incidents which can affect multiple persons. In the aforementioned example, that would be a flight related incident impacting all the passengers.

For chemical process facilities, process safety hazards can affect both employees inside the plant and members of the public who reside nearby. Such events have the potential to cause catastrophes resulting in fatalities, process equipment/facility damage or detrimental environmental impacts. Industries where fire, explosion or releases (FERs) of hazardous chemicals may occur are managed and prevented by a process safety management (PSM) system. Such industries include the chemical, energy, food and mining sectors. It also encompasses both onshore and offshore facilities that deal with the manufacturing, storage or transportation of hazardous products. This study will focus specifically on the chemical processing industry.

Figure 1 depicts a collection of process safety disasters with their associated consequences. The top left-hand corner picture [1] depicts a toxic chemical release into the nearby river resulting in significant water environmental impacts. The top right-hand corner picture [2] depicts a chemical explosion which injured numerous persons and significantly damaged equipment. The bottom

picture [3] depicts a chemical fire resulting in significant equipment damage and major air environmental impacts.



Figure 1. Collection of Process Safety Disasters ([1] CSB, 2007; [2] Chron, 2020; [3] CSB, 2010)

In 1984, the Union Carbide Corporation released a chemical methyl isocyanate into the atmosphere. This chemical was used to manufacture pesticide for the Indian market. A leak on a methyl isocyanate tank occurred due to the incorrect introduction of water into this tank, resulting in a violent chemical reaction. Water contamination occurred due to the non-adherence of the water washing procedure by a disgruntled operator. Many other significant management and leadership failures resulted, which contributed to the occurrence of this chemical release. The gas affected thousands of nearby residents in Bhopal India, as it occurred during the early morning hours when residents were still fast asleep. This led to a major loss of life with the release immediately killing at least 3800 people and causing significant premature death for many thousands more (Broughton, 2005).

The American Institute of Chemical Engineers (AIChE) was assigned the responsibility to address this challenge and lead this collaborative effort to prevent the occurrence of such major process safety incidents (AIChE, 2020). In 1985, AIChE formed the Center for Chemical Process Safety (CCPS), who set out to publish its first process safety guideline book.

A PSM system focuses on three critical aspects of a chemical plant, namely: technology, facility and employees. It encompasses topics such as design and engineering of facilities, hazard analysis, equipment integrity, incident investigation, management of change, effective

preventative process controls, emergency management, employee training and competency of employees.

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

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

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

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

For simplicity, PSM was defined to govern the safe handling and production of hazardous substances through safe process operation. This is achieved through the management of systems, compliance to legislation and maintaining a safety culture. A typical PSM system is composed of key elements, designed to provide governance, execution, managerial and auditing guidelines for a hazardous chemical processing facility. Therefore, PSM is a multi-disciplined framework for managing the integrity of hazardous operating processes by applying good design principles, as well as engineering and operating practices.

In 1992, Occupational Safety and Health Administration (OSHA) promulgated the PSM of Highly Hazardous Chemicals in the United States of America (OSHA, 2000). Figure 2 illustrates the OSHA PSM system with its fourteen element approach. These elements cover diverse aspects of a chemical processing facility to ensure its continued safe operation and prevention of process

safety incidents. Process Safety Information (PSI) and Process Hazard Analysis (PHA) document the design practices and risk aspects of the facility, which is transferred into the Operating Procedures. Tailored training programs are developed for both internal employees and external persons, for example, contractors.

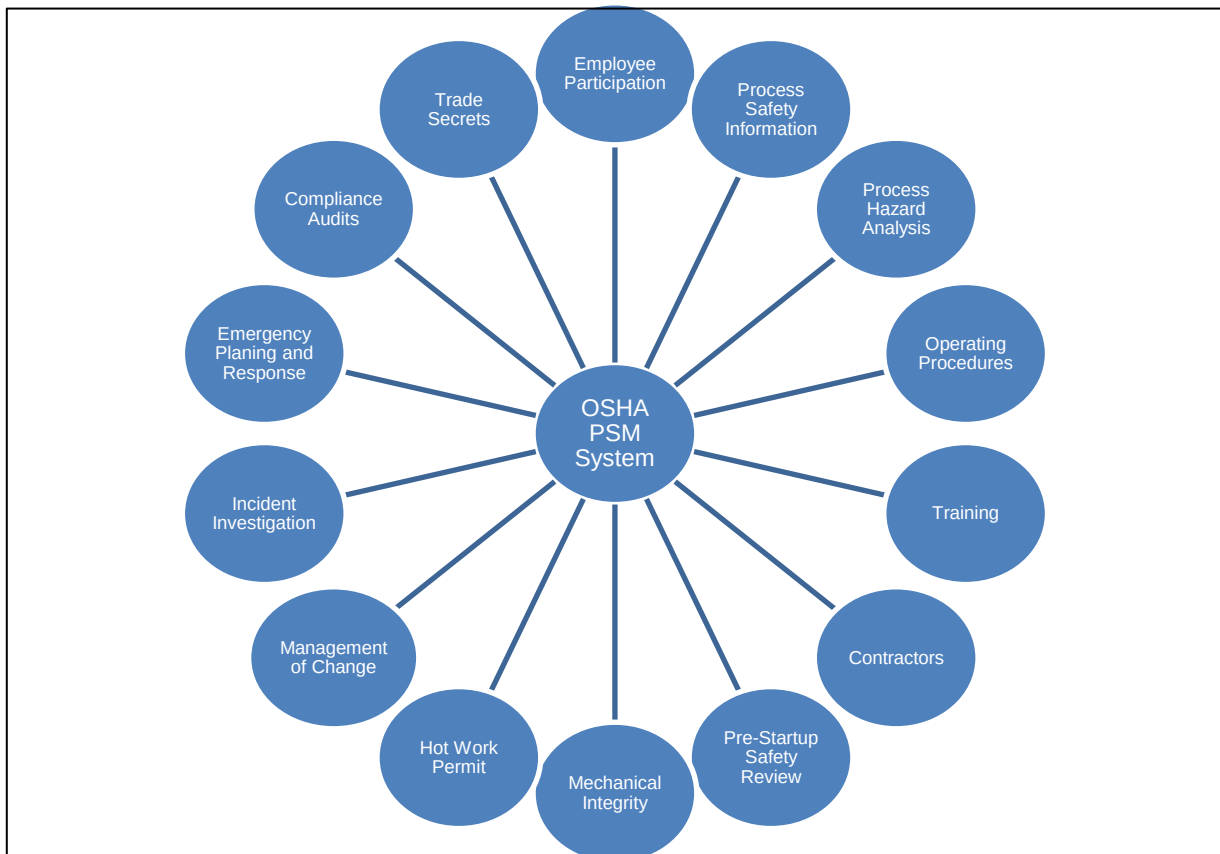


Figure 2. OSHA PSM System (OSHA, 2000)

Commissioning checks are performed through Pre Start-up Safety Reviews (PSSR). Assets are maintained through mechanical integrity programs and execution of work is managed through Hot Work Permits. Modifications to the facility is handled through the Management of Change (MOC) process. Incident investigations drive learning and prevention of repeat incident occurrence. Emergency Planning and Response detail plans to combat against process safety incidents that result. Assurance programs are driven through Compliance Audits. Intellectual property management is administered through Trade Secrets. Last, but not least, Employee Participation is the link between all these aforementioned elements, as key involvement is required to ensure the success of a PSM system.

From the Bhopal incident (Broughton, 2005) described earlier, the dire consequences of a major process safety incident were observed. Thus, a successful PSM system will assist in the prevention of major loss of life or detrimental environmental impacts. However, there are also

other benefits realised when such a PSM system is effective. The business case for process safety was well documented and published by CCPS (2006). The following is a summary from this publication, of the major benefits and reasoning for implementing and sustaining an effective PSM system are (CCPS, 2006):

- **Corporate responsibility**
 - Displays the commitment to corporate responsibility and social responsibility, thereby establishing a positive reputation to stakeholders.
- **Creates business flexibility**
 - Through demonstration of strong process safety culture an organisation invokes confidence to both internal and external stakeholders. This will lead to amicable relationships with these stakeholders and translate into successful collaborations when the organisation grows profitably whilst satisfying all stakeholders.
- **Risk reduction and management**
 - Reducing risk and loss prevention contributes significantly to the overall profitability of an organisation. This is achieved through risk identification, analysis and preventative control management. Corrective controls, such as emergency management will greatly assist in reducing the consequences from process safety incidents. Therefore, effective risk management also translates into sustainable and profitable operations.
- **Creating sustained valued**
 - The organisation by virtue of its continued success with respect to PSM and positive stakeholder relationships, increases its value. If the company is listed on the stock market, the share price will indicate the increasing value.

A PSM system's main focus is to prevent the loss of life, and in doing so, other benefits are realised. By preventing the release of hazardous chemicals, the environment is also preserved. Equipment damage is the least severe consequence from a process safety incident point of view. This ultimately results in having a partial or no chemical processing facility. This significantly hampers a company and its ability to satisfy customers, as it can no longer produce saleable chemicals. Hefty fines could be imposed on the company, dependant on the nature and significance of the process safety incident consequences.

These unforeseen and significant financial costs may cause a company to become insolvent, and as a result their employees lose their jobs. Therefore, effective PSM is rationalised as sound business principles for the socio-responsible and sustainable chemical industry.

1.2. Statement of the problem

Dr P.F. Drucker, “Culture eats strategy for breakfast”

Chemical processing results in the consumption of fossil fuels for transportation purposes, energy generation and the production of plastics and rubber to name a few. Transportation is predominantly achieved through the combustion of fossil fuels, for large scale goods transport as well as public and personal transport. Energy is generated through coal processing and more nuclear power plants are being established to support this sector. Therefore, the risk of major process safety incidents occurring will always be present, as long as mankind utilises industrial processes to produce energy and valuable end products.

Through the years, since the industrial revolution, with each advent of technology and processing ability, many process safety incidents have occurred as illustrated by Figure 3. Significant losses are depicted above US\$500 million from 1987 to 2017 (Marsh, 2018). Therefore, the need arose to better manage and govern this industrial growth. Improved engineering and process safety guidance notes were published to address the rising occurrence of major process safety incidents. History reveals that major process safety incidents have been occurring across the globe since the industrial revolution, and such incidents shaped and formed PSM.

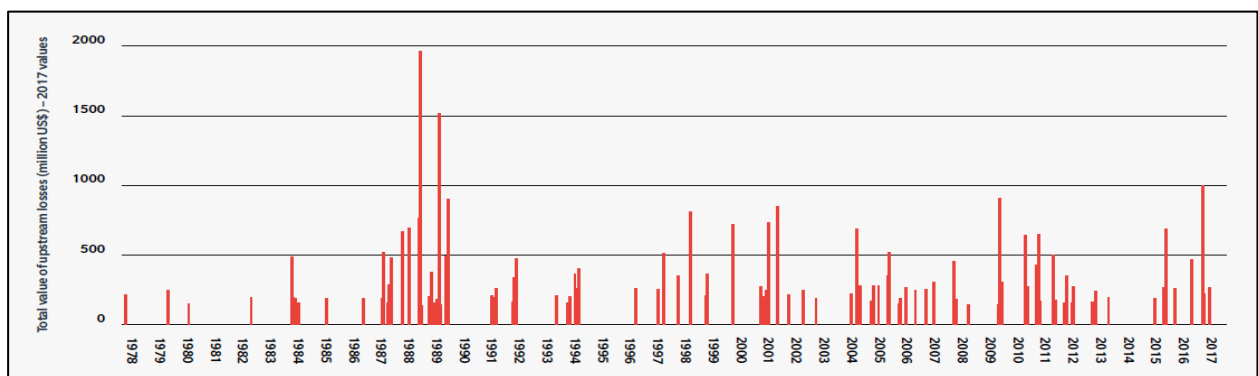


Figure 3. Distribution of the 100 Largest Losses by Year (Marsh, 2018)

Figure 4 lists some of the major process safety incidents that have occurred globally spanning over 44 years. These major incidents resulted in significant loss of life, some with detrimental environmental impacts and all with excessive equipment and company reputational damage. Three major process safety incidents, specifically the 1974 Flixborough explosion, the 1976 Seveso toxic release and the 1984 Bhopal toxic release, contributed to the foundation for drafting the PSM system elements. Despite governments and institutions promulgating comprehensive standards, legal prescriptions, guidance notes and best practices since 1992, major process safety incidents still occur today. It has been over 26 years since PSM legislation was conceived,

yet we still experience major process safety incidents where significant loss of life occurs. These incidents are not localised to geographic regions, implying that first world countries are also vulnerable and have not yet managed to find the golden solution to successful and sustainable PSM. This begs the question, what are we doing wrong?

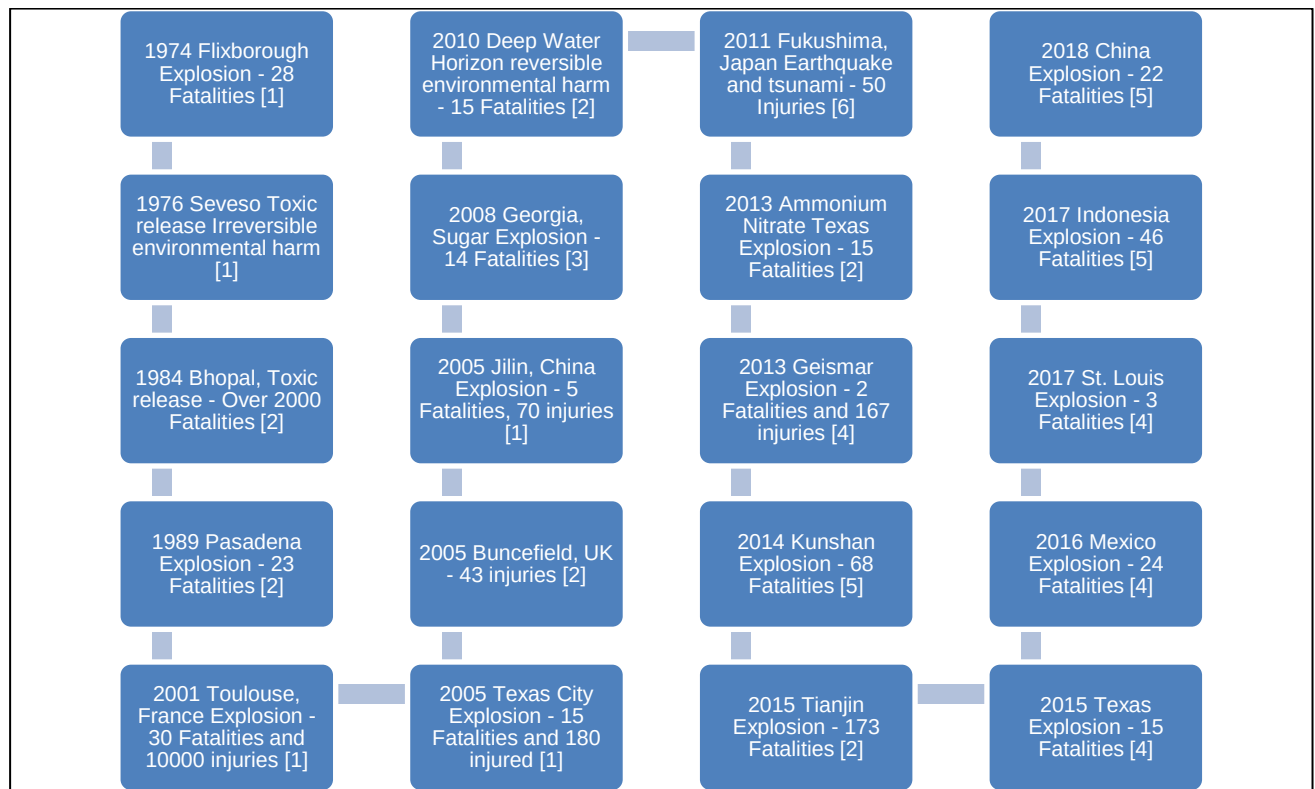


Figure 4. Global Process Safety Incidents ([1] ICIS, 2020; [2] Monarch SMS, 2020; [3] FEN Learning, 2020; [4] CSB, 2020; [5] BBC, 2020; and [6] TEPCO, 2013)

Since the industrial revolution there has been significant improvements toward the successful management of safety, including process safety. Historically Loss Prevention, also known as Process safety, broadened its scope significantly as depicted by Figure 5. This graph shows the trend in safety level improvement from the early 1960 to late 2020, where initial problems were mainly focused on improving technical and chemical aspects. More recently, after 2000, the focus is organisational and human factors. Legislation and the change to preventive thinking has largely shaped this improvement. Similarly, Lowe and Kariuki (2003) illustrated the effect of era specific safety initiatives against safety improvement. Engineering solutions assisted with a step up in safety improvement from the industrial revolution to the 1980s. Similarly, safety management systems contributed to a step up in safety improvement to the mid-1980s. Both Pasmán and Fabiano (2021) and Lowe and Kariuki (2003) concur that industry is presently in the human factor age, namely the process safety culture age, and unfortunately have yet to see a marked safety improvement in culture and resilience.

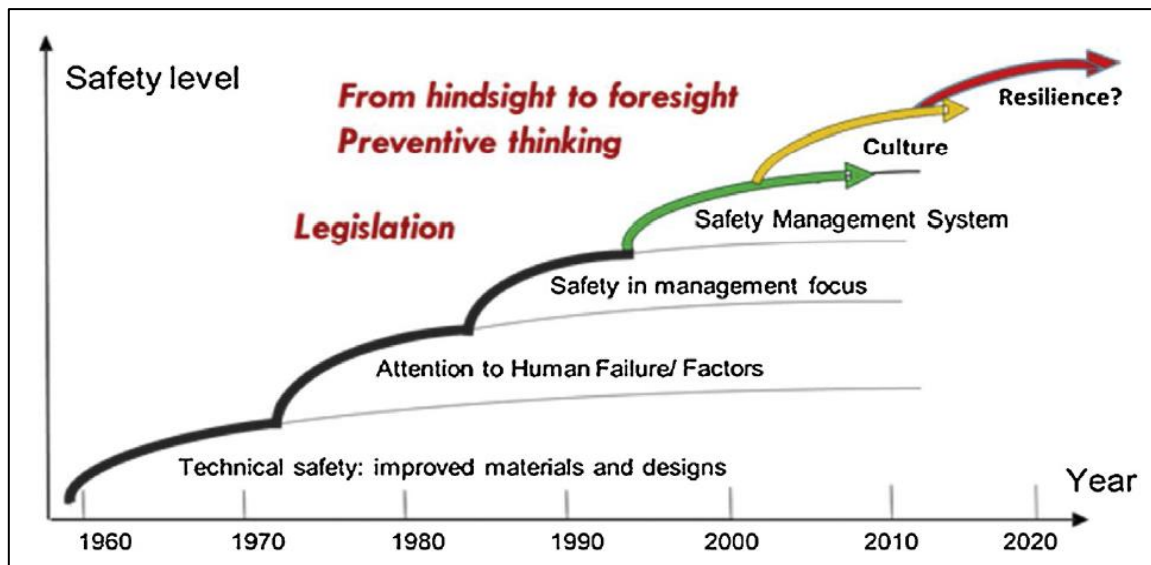


Figure 5: Safety improvement from 1960s to 2020 (Pasman and Fabiano, 2021)

The Health and Safety Executive (HSE) also believes that engaging with the workforce is fundamental to the success of a safety strategy (HSE, 2010). However, building a safety culture with committed leadership is a daunting task for many organisations, specifically process safety managers. Often there is no sustainable solution to tackle this problem, as each working environment is unique. Den Bakker (2012) depicts the journey to PSM implementation in Figure 6. The fourth and fifth stages are of most interest: HSE leadership, HSE culture and commitment. These stages bring new challenges and resemble the human factor age as seen in Figure 5.

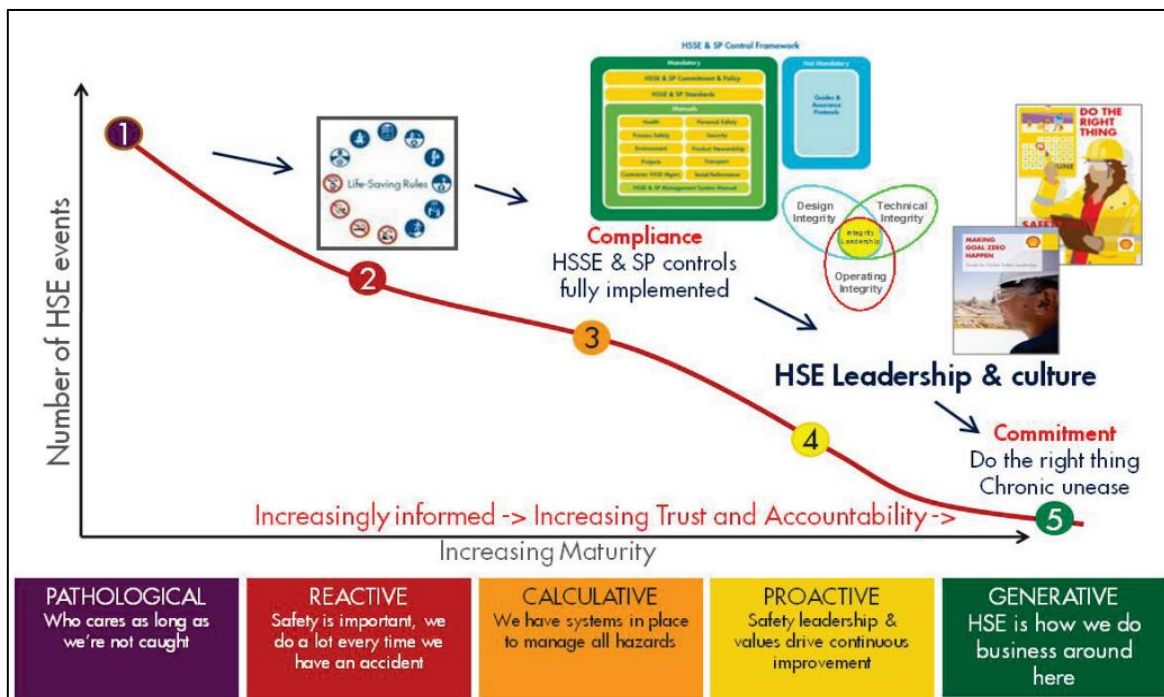


Figure 6. Journey to PSM implementation (Den Bakker, 2012)

The process safety journey to excellence, as described by the Centre of Chemical Process Safety (CCPS), includes procedures and management systems, with risk-based safety approach and strong PSM cultures at the centre of its Vision 2020. Gallagher (2016) describes the financial case for employee engagement, indicating that a company with 1000 full time employees could lose as much 3.3% annually. Highly engaged employees often feel more a part of an organisation, often extending to being stakeholders. Therefore, engagement brings involvement and commitment to a process safety program and on toward supporting an organisation's vision.

The challenge begins with firstly understanding what human factors are composed of and thereafter effectively managing them to create highly engaged employees. A psychologist will state that a human being is a very complex organism, and one that is quite difficult to completely understand. This is the main reason why various techniques to manage human factors are still being investigated. Often, it could be required that multiple and different techniques must be simultaneously applied.

Reddy and Yarrakula (2016) analysed 70 process safety incidents that occurred in chemical process industries, from 1998 to 2015 across 30 countries. Their findings are thus raised from a global standpoint. This study found that improved process safety and robust enforcement of regulatory legislation is required more so in developing countries. The two main aspects of this study are that process safety legislation is insufficient for this generation and governance thereof is ineffective. New directions would assist in uplifting PSM performance, considering the new technical age and the human generation post the millennium. Building on this, improved governance could commence with reviewing the performance metrics monitored and corrective management taken against non-conforming indicators.

Naicker (2014) analysed 50 process safety incidents which occurred in diverse industries, from 1974 to 2012 across the six continents: Europe, North America, South America, Asia, Africa and Australia. This study also raised findings from a global perspective. Employee participation and mechanical integrity were concluded as the most deficient elements that manifested into process safety incidents. The OSHA PSM Employee Participation element requires that employers develop a written plan of action for implementation. Employers were required to consult with employees on the conduct and development of process hazard analysis (PHA) as well as other PSM elements. Employee participation entails involvement from all levels within an organisation. Participation from varied backgrounds with diverse yet extensive experience is required in design, risk management, change management, procedural drafting through to process safety initiative development. If one does not feel involved through participation, one would not effectively drive or action the required initiative. Similarly, this relates strongly to the process safety culture aspect.

Effective mechanical integrity is achieved through healthy asset management practices. Unhealthy asset management results in repeated breakdowns, which translates into crisis management. This negatively affects employee morale and fatigue (e.g. overtime, after normal working hours and standby callouts), by creating additional activities resulting in time-sensitive and stressful work environments. If not managed well, such environments greatly increase the probability of errors which may translate into process safety incidents. Thus, repeated equipment breakdowns negatively impact process safety culture.

Kannan *et al.* (2018) analysed 96 global process safety incidents for one calendar year from 2014 to 2015. This study was based on the CCPS risk based process safety (RBPS) framework, and they were divided into four categories: [1] commit to process safety, [2] understand hazard and risk, [3] manage risk and [4] learn from experience. The RBPS framework is a newer PSM system incorporating a more forward-thinking approach. The study outcome indicated that [3] risk management and [1] commit to process safety respectively contributed to 43% and 30% of the failures. Risk management involves the correct identification and analysis with prescribed associated mitigation measures. Without robust risk management techniques and key participation for experienced persons from different disciplines, risk management will ultimately be poorly concluded. Process safety commitment is very easily stated on paper, however quite difficult to practice, as participation and resilient conviction is required across all levels of an organisation. Both of these themes relate strongly to process safety culture.

Deficiencies were also indicated in safe work practices, operating procedure and conduct of operations (Kannan *et al.*, 2018). A lack of comprehensive safe work practices or operating procedures may result from poorly concluded risk management. If the risk was not identified or assessed correctly, the risk can definitely not be managed correctly. Hence the correct mitigation measures and its associated assurance checks would not be incorporated. The conduct of operations relates to the correct behaviours of the employees and relates to disciplinary or consequence management. These deficient themes also all relate strongly to a process safety culture.

Baker *et al.* (2017) analysed 770 major process safety incident cases in the chemical processing industry from investigation reports compiled by leading authorities in America, Europe, Singapore, Malaysia and Japan. This is another global study which concluded that design and technical reasons (53%) and management related causes (47%) were the two major deficient factors. Their findings are depicted in Figure 7, which ranks these PSM elements according to deficiencies. process hazard analysis, operating procedures and employee participation ranked as the top 3 deficient process safety elements. PHA is a risk management technique that incorporates design

and technical aspects. The design and technical issues can be apportioned to risk management inadequacies raised by Kannan *et al.* (2018) as described above. Similarly, the management related causes resemble the safe work practices and operating procedures raised by Kannan *et al.* (2018) and employee participation raised by Naicker (2014).

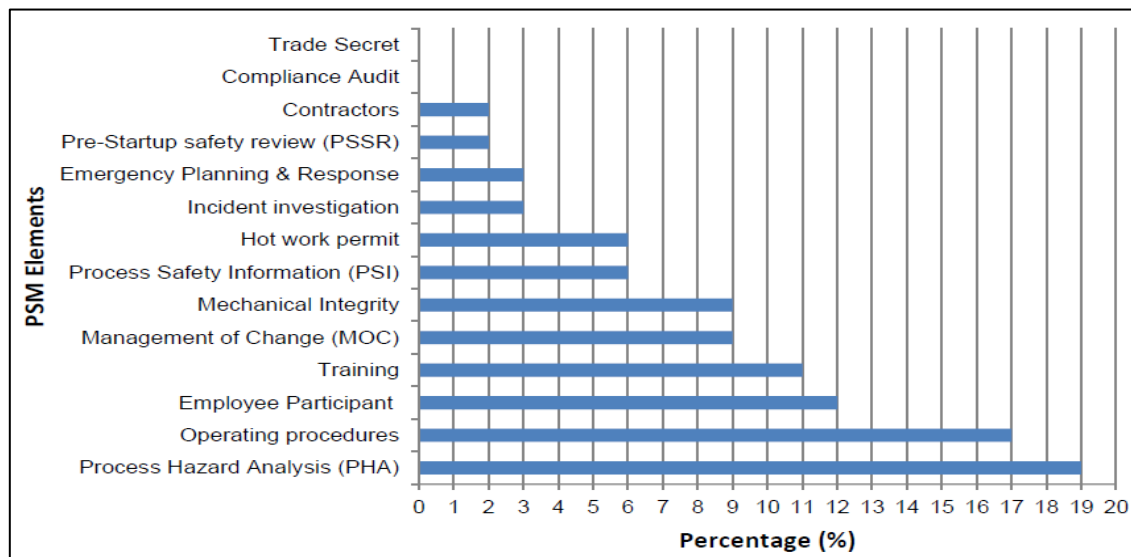


Figure 7. Contribution of PSM element failures to incidents (Baker *et al.*, 2017)

The process safety culture problem is simply that more often employees only practice it when someone of authority is watching. Similarly, leadership can also create a negative process safety culture, for example by creating production pressures after a shutdown or trip. Such practices compound this problem. This is not industry or regional specific, it is just the way we as humans are genetically made up. If a short-cut is available and there is no apparent risk present, there is a higher probability that the quicker approach will be taken. Often this results in no immediate negative impact. As time progresses, even greater risks may be taken and eventually an immediate negative impact will occur. Generally, a combination of such shortcuts may result in a minor injury or even worse a significant process safety incident. Therefore, a poor safety culture may have disastrous impacts on an organisation's reliability, competitiveness, profitability and reputation.

Four independent studies were reviewed that were conducted by Reddy and Yarrakula (2016), Naicker (2014), Kannan *et al.* (2018) and Baker *et al.* (2017). These studies were performed on a global scale, and investigated PSM deficiencies, from 2014 to 2017, three of which were specifically in the chemical industry. The findings from these studies were reviewed to detect common themes arising. Employee participation, risk management and operating procedures featured strongly, and these themes support and relate to the process safety culture deficiencies experienced. These themes reveal inadequacies in process safety commitment, leadership,

conduct of operations and organisational culture. The aforementioned studies indicate that there are still major challenges with effectively sustaining PSM, with people, specifically culture being at the cornerstone. Reddy and Yarrakula (2016) confirmed a need for a new approach to PSM, specifically targeted to address the human factor as depicted in Figure 5 and Figure 6.

This is the research problem: Current Process Safety Management (PSM) systems are deficient in addressing process safety culture in the chemical processing industry.

1.3. Aims and Objectives of the study

Naicker (2014) found that the OSHA process safety element, employee participation, was the foundation of their process safety program. Due to its interdependency with other process safety elements, safety culture and leadership emerged as strong themes from the employee participation element. **The study aim is to produce a practical and sustainable framework for realising process safety culture improvement in the chemical processing industry.**

Emphasis was placed on the framework being practical, to assist with implementation whilst supporting and integrating into the organisation's business rhythm. This is a process safety culture framework that can be easily adopted at a chemical processing facility and successfully driven to assure and sustain PSM performance improvements. Arguable process safety culture and leadership is not an exact science, attributed by fact that many organisations struggle to sustain employee participation. Employee participation is referred to differently in other PSM programs such as DuPont (2008), CCPS Risk Based PSM framework (2008) and Energy Institute (2010). However, the intention is the same, with all PSM systems mandating employee involvement and engagement across the organisation's structure, toward building and sustaining process safety.

Naicker's (2014) study also concluded that inadequate mechanical integrity programs contributed significantly to the occurrence of process safety incidents. Equipment and control failure emerged as strong themes from the mechanical integrity element. Asset integrity is required to assure reliable and safe operating of hazardous high-pressure equipment. A poor maintenance process safety culture could significantly contribute to severe incidents. The nuclear industry, much like the civil aviation industry, demands stringent risk management. The consequences of inattention or poor control are well understood by those employed in these industries. Hence the study question arose, *what can be learnt from other industries?*

Three research objectives were devised that support achieving this study's aim. They are as follows:

1. To propose a multi-disciplined and integrated process for managing the integrity and performance of hazardous operating processes through improved process safety cultures.
2. To understand how high-risk high-reliability non-chemical processing industries, maintain better incident case rates through improved safety cultures.
3. To validate the theory through empirical testing.

Figure 8 depicts the study process and outcome which is essentially the study aim. The culmination of some of the aforementioned investigative routes, will facilitate the development of a practical process safety culture framework. This skeletal study process overview consists of four diverse research legs, which also contribute to achieving the study's objectives. It incorporates the review of existing process and occupational safety culture approaches, asset integrity safety culture dimensions, high-risk high-reliability non-chemical processing industries and case studies on international chemical processing companies.

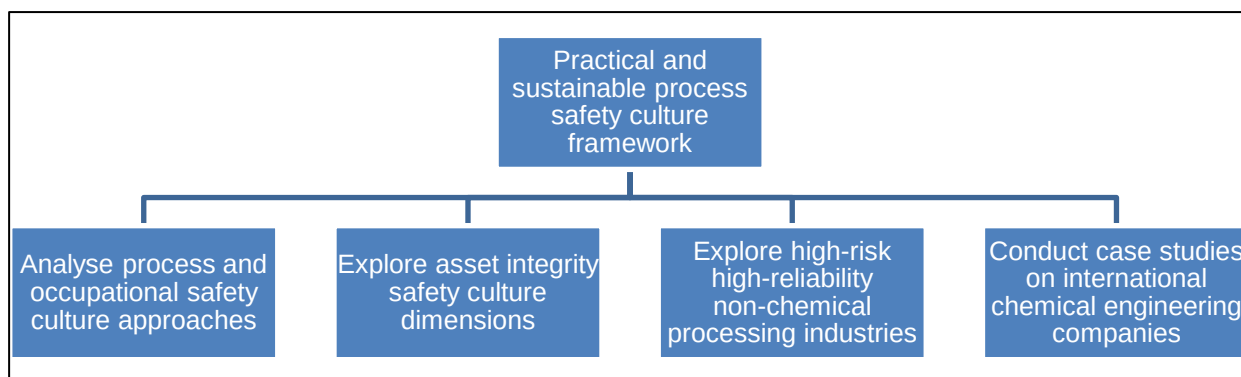


Figure 8. Study Process and Outcome

1.4. Research Hypothesis

The aim of this study is to produce a practical and sustainable framework for improving process safety culture in the chemical processing industry. Two hypotheses were developed that complemented this aim.

This research addressed the following hypotheses:

H₁: There is a practical, sustainable and implementable process safety culture framework for the chemical processing industry. **H_{1.0}:** There is no practical, sustainable and implementable process safety culture framework for the chemical processing industry.

H₂: Implementation of a process safety culture framework will improve process safety incident case rates. **H_{2.0}:** Implementation of a process safety culture framework will not improve process safety incident case rates.

1.5. Original Contribution

OSHA promulgated PSM in 1992, and this element based system did not specifically focus on process safety culture. As the field of PSM evolved, recent new PSM program iterations, post 2008, started to include process safety culture or leadership commitment. Therefore, process safety culture is still a relatively fresh field in the chemical processing industry. **This research contribution to a new body of knowledge (BOK) sciences, is to produce a practical and sustainable framework for improving process safety culture in the chemical processing industry.**

1.6. Outline of this study

It was imperative to identify the gaps in the existing PSM systems in order to propose an effective PSM program targeted to improve process safety culture. A qualitative mixed methods study was conducted through a rigorous literature review. This study consisted of eight chapters which are described below. Chapter 1 introduced the reader to the background of PSM and its associated global performance in reducing process safety incidents. The research problem was also presented, along with the study's outcome.

Chapter 2 consisted of the literature survey and review of existing PSM systems and chemical company case studies, specifically understanding their process safety culture approaches. Occupational safety culture practices from diverse industries were also investigated along with understanding the human mind and maintenance error to successfully leverage associated human factors. Publications from other high-risk high-reliability industries with catastrophic consequences were also evaluated. The nuclear and civil aviation industries were selected, and their safety culture approaches explored.

Chapter 3 discussed the methodology and rationale applied to perform the qualitative mixed methods study. Efforts were focused on verification, validation and reliability of the study. Chapter 4 presented the results of the various culture approaches that were interrogated and their findings thereof. The findings discovered were further surveyed in Chapter 5 to support in their respective interpretation. After this examination, the theory was assimilated to produce the process safety culture framework in Chapter 6. The newly proposed framework was scrutinised by process safety experts. Their feedback and improvements were discussed and incorporated in Chapter 6. The study conclusions were outlined in Chapter 7. And finally in Chapter 8, the proposed recommendations were postulated to uplift the merits of this study whilst contributing to its refinement.

CHAPTER 2 LITERATURE REVIEW

Dr Trevor Kletz, “For a long time, people were saying that most accidents were due to human error and this is true in a sense but it’s not very helpful. It’s a bit like saying that falls are due to gravity”

2.1. Introduction

In this chapter literature was scrutinised to provide constructive inputs into the development of a sustainable process safety culture framework. Safety is divided into occupational and process safety as discussed in chapter 1. International PSM systems were reviewed and investigated for process safety culture elements and their associated application. Safety culture and climate definitions were reviewed for suitability in this study. Thereafter occupational safety culture approaches were explored. Theory on the human mind was investigated to determine other mechanisms to positively influence human beings. The influence of process safety culture in asset integrity management was scrutinised. Publications from other high-risk high-reliability industries were briefly reviewed to extract their safety culture best practices. Industries investigated included nuclear process safety, large chemical processing corporations (Shell, BP, Sasol and Chevron) and the aviation environment.

2.2. Process Safety Culture Approaches

Numerous PSM systems have been developed for application across different geographical positions and industry sectors. A total of nine independent PSM systems were reviewed from 1992 to 2013. Each originating from either legislation of a country or consultancy derived through experience. Some of the more internationally recognised PSM systems were reviewed as illustrated in Table 1. The number of PSM elements varied from three to thirty elements, with OSHA being the founding PSM system. Early PSM systems were quite rigid in their approach, requiring many elements with a blanket approach. However more recent PSM systems, such as the DuPont (2008), EPA (2012) and CCPS (2008), are more comprehensive with a risk-based approach taking precedence. This greatly assists in directing thinking of a chemical processing facility’s leadership. This approach incorporates the Pareto principle (Dunford *et al.*, 2014), also known as the 80/20 rule. Essentially it implies that about 80% of the effects come from 20% of the causes.

In PSM, 20% of the plant is the major hazard aspect, referred to as “*the cause*”, and 80% is the risks associated with the plant due to for example inadequate management, referred to as “*the effect*”. Therefore, by directing efforts on managing the major hazards, the highest risks are well controlled. This could be achieved through the development of enhanced process management

systems or practices, improved operating procedures, rigorous assurance programs and so on. Indirectly, the other 80% of the causes with the 20% effect are addressed, as the solutions implemented for the highest risks are generally applied across an organisation, thereby reducing its overall risk profile.

Table 1. Overview of PSM Systems

Origin	Current Model	Number of Elements	Summary of PSM systems
Occupational Safety and Health Administration (OSHA)	1992	14	Promulgated the Process Safety Management of Highly Hazardous Chemicals standard in the United States of America (USA)
DuPont	2008	14	Pioneered the concepts and implementation of a PSM system in the 1960s which later evolved into a PSM model
International Association of Oil and Gas Producers (IOGP)	2008	6	A global forum focused on asset integrity management driven PSM model
Energy Institute	2010	3	High level framework PSM model applicable to the energy sector
Safety and Environmental Management System (SEMS)	2011	15	Regulatory requirements formed for offshore facilities after the 2010 BP Deepwater Horizon incident
Environmental Protection Agency (EPA)	2012	20	Under the Clean Air Act Amendments, EPA published the Risk Management Plan (RMP) Rule. Recommends OSHA as PSM practice and guidance
Centre of Chemical Process Safety (CCPS)	2008	20	Formed under the supervision of the American Institute of Chemical Engineers (AIChE) created the Risk Based Process Safety (RBPS) Management system
ABB	2012	3	A consultancy and compliance service offering through experience developed a PSM model
Kienbaum and TÜV SÜD	2013	6	Developed a Process Safety Excellence Model consisting of 6 elements with 5 sub-elements each

Table 2 is a comparison of the reviewed PSM systems above in Table 1. It highlights which PSM systems include process safety culture elements. Only the International Association of Oil and Gas Producers (IOGP) (2008) and the Centre of Chemical Process Safety (CCPS) (2008) PSM systems include such elements, namely: human factors and process safety culture.

Table 2. Comparison of PSM Systems

PSM Elements	1. Employee Participation	2. Process Safety Information	3. Process Hazard Analysis	4. Operating Procedure	5. Training	6. Contractor	7. Pre-startup review	8. Mechanical integrity	9. How work permit	10. Management of Change	11. Incident Investigation	12. Emergency planning and response	13. Compliance Audit	14. Trade Secrets	15. Quality Assurance	16. General Provisions	17. Safe Work Practices	18. Records and Documentation	19. Process safety culture	20. Capital project review and design procedure	21. Management review and continuous improvement	22. Measurement and Metrics	23. Conduct of Operations	24. Stakeholder outreach	25. Process safety competency	26. Human factors	27. Standards, codes and laws
OSHA	X	X	X	X	X	X	X	X	X	X	X	X	X	X													
DuPont		X	X	X	X	X	X	X		X	X	X	X		X												
IOGP			X	X				X				X										X				X	
Energy Institute	X		X	X		X	X	X	X	X		X	X				X	X			X	X	X	X			X
SEMS	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X									
EPA	X	X	X	X	X	X	X	X	X	X	X	X	X	X													
CCPS	X	X	X	X	X	X	X	X		X	X	X	X						X		X	X	X	X	X	X	X
ABB	X		X	X				X					X							X	X				X		
Kienbaum and TÜV SÜD		X			X	X	X	X	X	X		X								X		X	X		X		

Only two of the nine PSM systems included process safety culture elements. Therefore, the CCPS (2008) and IOGP (2008) PSM systems were subsequently further assessed to understand how they incorporated process safety culture elements.

The CCPS (2008) endeavoured to address “*blindness*” in an organisation by building on the original process safety management ideas published in the early 1990s. Hence, in 2007 they published Guidelines for Risk Based Process Safety (RBPS), shown in Figure 9, which consists of four pillars: [1] commit to process safety, [2] understand hazards and risk, [3] manage risk and [4] learn from experience.

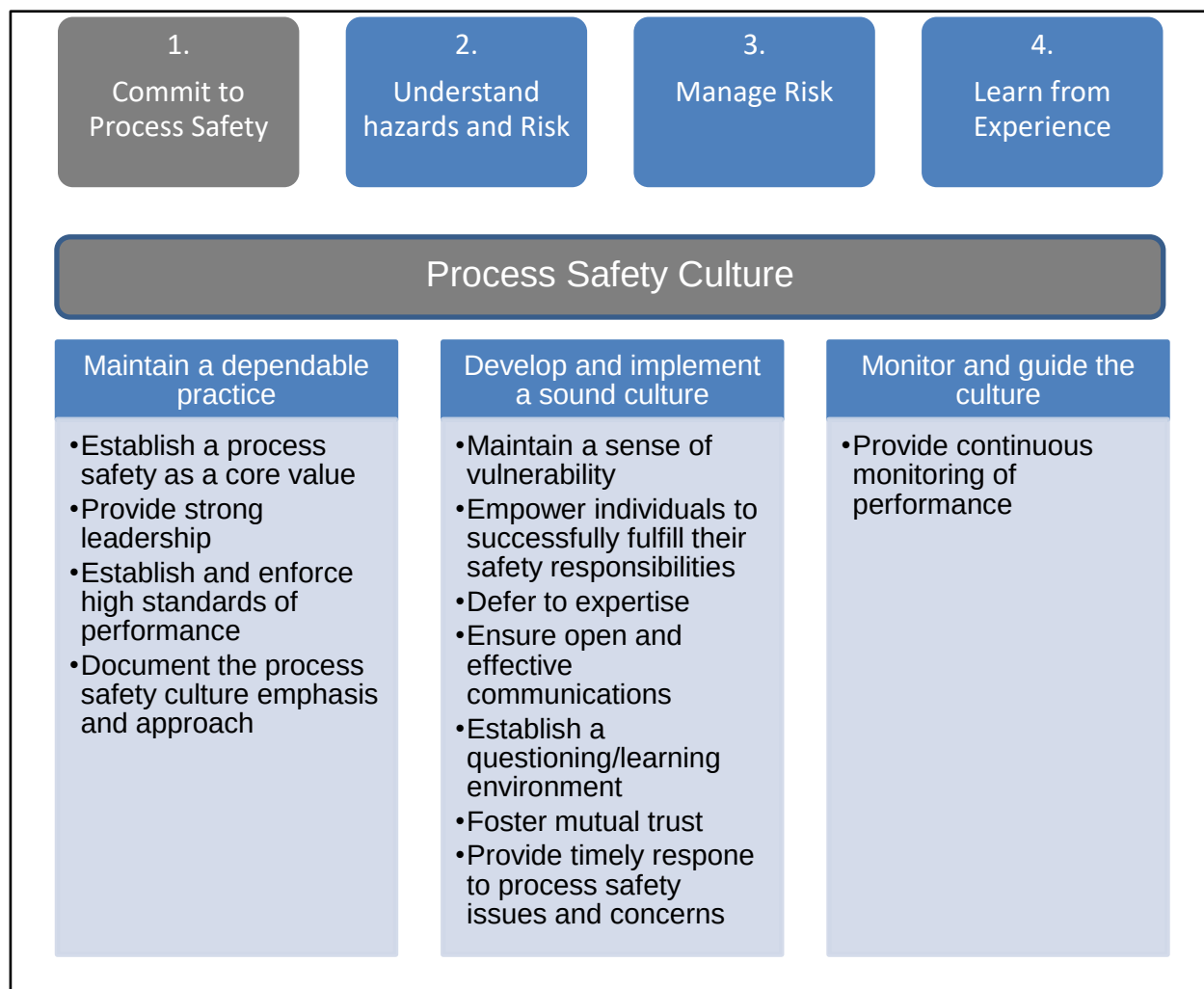


Figure 9. Adapted from Process safety culture from the RBPS system (CCPS, 2007)

This framework was geared toward the next generation of process safety. The RBPS approach (CCPS, 2007) acknowledges that all hazards are not equal, therefore it advocates, that resources should focus on more significant hazards and higher risks. This is discussed earlier and unpacked as the Pareto principle (Dunford *et al.*, 2014). The RBPS approach (CCPS, 2007) prescribes for following for each of the twenty elements: overview, discussion of key principles and essential

features, suggestions on possible work activities, suggestion on how to improve effectiveness in existing programs, ideas on metrics, suggestions on management review and references.

Commitment to process safety is one of the foundational blocks of this PSM system, which includes process safety culture. The RBPS approach (CCPS, 2007) recommends that this behaviour be consistently nurtured and celebrated throughout the organisation.

The CCPS Vision 2020 was an initiative intended to improve process safety performance through this decade. It comprised of a roadmap to the year 2020, which mandated the characteristics that companies will require in order to achieve great process safety performance.

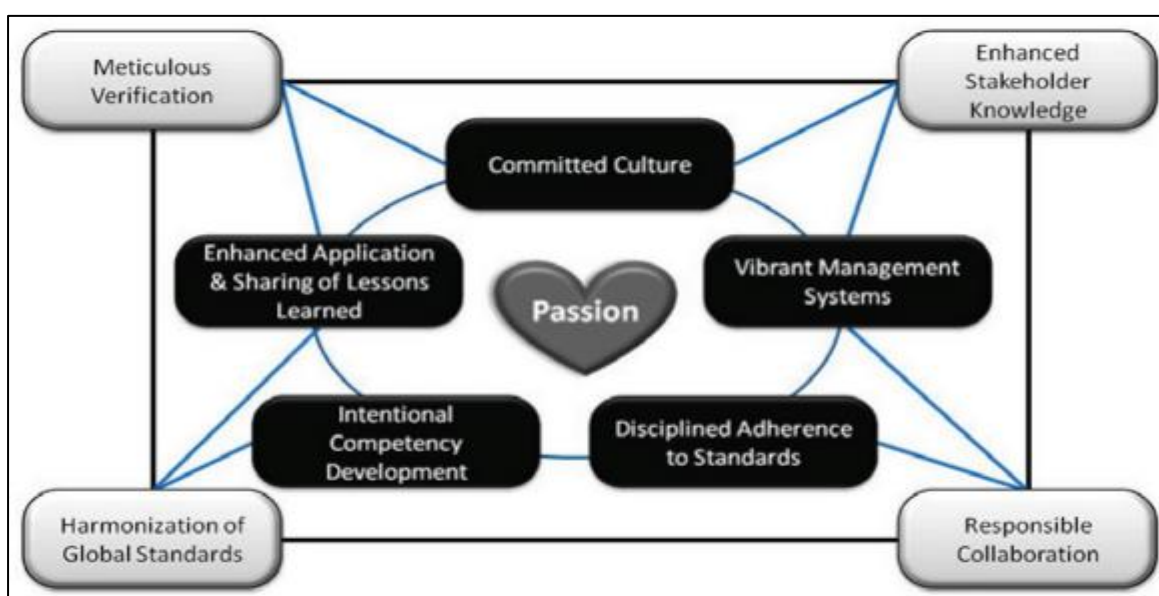


Figure 10. Interrelationship of characteristics (McCavit *et al.*, 2013)

As depicted in Figure 10, the central theme of this CCPS Vision 2020 approach was passion, which translated into a combination of functions working in synergy to achieve great process safety performance. A committed culture, application and sharing of lessons, competency, disciplinary and management systems were the five characteristics that were interrelated. If these characteristics were leveraged, an organisation's process safety performance would dramatically increase.

The European Congress of Chemical Engineering (ECCE) held an engagement session with various key stakeholders on Process and Plant Safety. One of the common themes from this conference (DECHEMA, 2012), was that process safety training should be provided to an organisation's leadership team (top) and ground level employees (bottom). This was observed to compliment the CCPS Vision 2020 approach and establish the passion theme.

In the same way, the Western Engineering (Orr *et al.*, 2013) module on PSM depicted the interrelationships of the elements from various internationally published PSM systems, shown in Figure 11. This illustration groups the PSM elements into four bodies, namely: [1] commitment, [2] hazard assessment, [3] continuous enhancement and [4] risk management. Interestingly it is only in America where the safety culture element is included as part of the PSM system. This was also confirmed during the study conducted by Baker *et al.* (2017). Similarly, the European Process Safety Centre (EPSC) recognised the importance of a process safety culture in preventing the occurrence of process safety incidents.



Figure 11. Possible Process Safety Management Elements (Orr *et al.*, 2013)

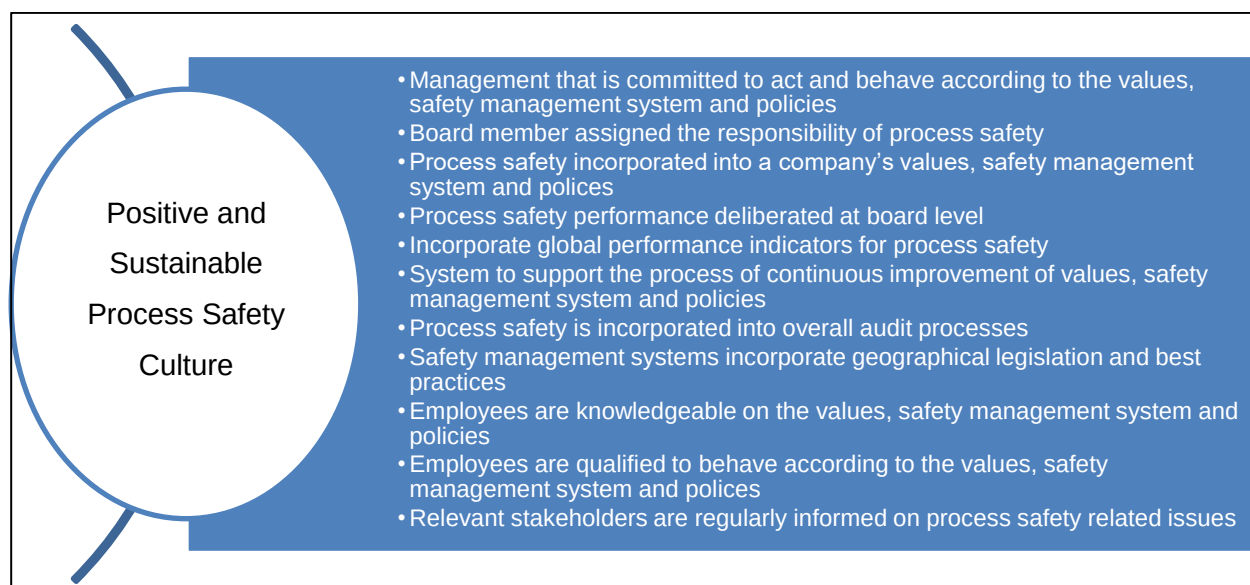


Figure 12. Adapted from Positive and sustainable process safety culture (EPSC, 2012)

EPSC (2012) outlines a safety culture as persistent, transcending organisational employees and is often passed onto new employees becoming reborn. Reflecting on their incident investigations, five components of process safety culture were identified, namely: [1] values, [2] attitudes, [3] perceptions, [4] competencies and [5] behaviour. Taking these components into account, the following actions were recommended toward a positive and sustainable process safety culture, as seen in Figure 12.

A high reliability organisation (HRO) is one where significant process safety incidents rarely occur. In terms of process safety culture, that is the desired result. Organisation for Economic Co-operation and Development (OECD) (2012) defines a HRO as one that produces product relatively error-free over a long period of time. Error-free also being inclusive of infrequent process safety incidents. There are two key attributes that define such an organisation, and they are listed below (OECD, 2012):

1. Having a chronic sense of unease, namely lacking any sense of complacency. For example, not assuming that because no incidents occurred for 10 years, one will not happen imminently.
2. Making strong responses to weak signals, by setting a very low threshold for intervening. If something doesn't feel correct, they are very likely to stop operations to investigate. This implies that they accept a considerably higher level of false alarms than is commonly practiced in process industries.

These two attributes can be summarised simply. Attribute one, indicative of being unsatisfied with great process safety performance and always striving to improve. Attribute two, extensive use of leading process safety performance metrics and proactively responding to poor performing metrics.



Figure 13. Essential elements of corporate governance for process safety (OECD, 2012)

OECD (2012) further identified the essential elements of corporate governance for process safety, shown in Figure 13. It comprises of five themes: [1] leadership and culture, [2] risk awareness, [3] information, [4] competence and [5] action. Clearly, strong leadership is pivotal, as it is central to an organisation, and it is the culture which influences employee behaviour to a process safety mind-set. This model resembles a plan-do-act cycle; however, it begins with understanding the hazard and risk, transposing it into usable and measurable information, and ensuring that the organisational team is competent to manage and assess such a facility. Action is the last step, which ties the entire cycle, requiring continuous improvement. Guidance for senior management was developed and illustrated in Table 3.

Similarly, to OECD (2012), HSE (2011) defines a HRO as one that can manage and sustain almost error-free performance despite operating in hazardous conditions. In such organisations the consequences of such errors could be catastrophic, yet HRO's tend to possess positive safety cultures. HSE (2011) surveyed available literature and discovered six concepts, as depicted in Figure 14, typical of a HRO; [1] definition, [2] containment of unexpected events, [3] effective problem anticipation, [4] just culture, [5] learning orientation and [6] mindful leadership.

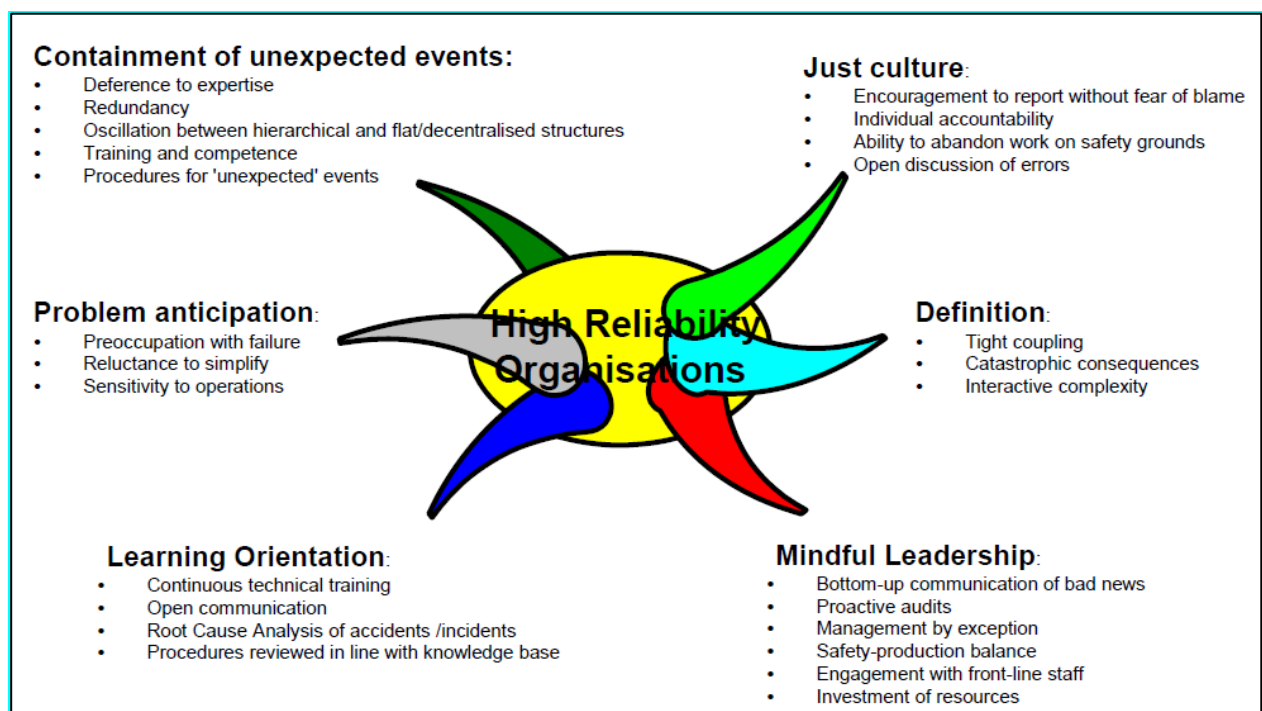


Figure 14. Mind map of HRO processes and characteristics (HSE, 2011)

Table 3. Guidance for Senior Leaders in High Hazard Industries (OECD, 2012)

Elements	Overview	Description
Leadership and Culture	CEO and leaders create an open environment	• Keep process safety on their agenda, prioritise it strongly and remain mindful of what can go wrong • Encourage people to raise process safety concerns, or bad news to be addressed • Take every opportunity to be role models, promoting and discussing process safety • Delegate appropriate process safety duties to competent personnel whilst maintain overall responsibility and accountability • Are visibly present in their businesses and at their sites, asking appropriate questions and constantly challenging the organisation to find areas of weakness and opportunities for continues improvement • Promote a safety culture that is known and accepted throughout the enterprise
Risk Awareness	CEO and leaders broadly understand the vulnerabilities and risks	• Know the importance of process safety throughout the life cycle – whether it is the design, operation, and maintenance phases of their manufacturing facilities, or storage, logistics and decommissioning at those location • Understand the critical and different layers of protection that are in place between a hazard and an accident and seek to strengthen those layers continually • Ensure appropriate and consistent management systems for analysing, prioritising and managing risk, including strong management of change processes for people technology and facilities • Personally involve themselves in risk assessing proposed budget reductions for process safety impacts and provide incentive schemes which don't encourage production at the expense of process safety risk • Take responsibility for emergency planning for the range of consequences from a process safety incident including the credible worst case scenario • Know the hazards and risks at installations where there are hazardous substances
Information	CEO and leaders ensure data drive process safety programmes	• Ensure that the organisation analyses audit and assessment results • Monitor site and corporate level process safety key performance indicators and near misses • Have metrics which help to monitor the health of the process safety culture and management systems • Actively share experiences and learning within their own organisation and within other high hazard sectors and ensure appropriate, high quality follow up • Establish safety management systems and monitor/review their implementation. Seek continuous improvement
Competence	CEO and Leaders assure their organisation's competence to manage the hazards of its operation	• Understand which questions to ask their people and know which follow up actions are necessary • Ensure there are competent, management, engineering, and operational personnel at all levels • Ensure continual development of process safety expertise and learning from new regulation and guidance • Provide resource and time for expertise-based hazard and risk analyses, effective training and comprehensive scenario planning for potential accidents • Defer to the expertise of personnel, and do not dismiss expert opinions. They provide a process or system to ensure company leaders get expert process safety input as a critical part of the decision-making process for civil projects or activities • Ensure that the organisation monitors and reviews the process safety competency of contractors and third parties • Are capable of openly communicating critical aspects of process safety with all internal and external audiences
Action	CEO and leaders engage in articulating and riving active monitoring and plans	• Assure practices are consistent with corporate process safety policies • Safety measures should be incorporated at the earliest conceptual and engineering design stages of an installation to enhance the intrinsic (inherent) safety of the installation wherever practicable • Incorporate process safety considerations into major capital investments, long range planning and integration of mergers and acquisitions • Ensure process safety risk mitigation plans and emergency response plans are developed and maintained for all sites within their business and at an organisation –wide level, with appropriate levels of competent resources available to execute the plans • Ensure implementation of process safety risk mitigation plans and reviews of progress versus the plans at site and corporate level • Monitor that corrective actions are applied and closed out promptly following audits and after thorough root cause investigations of all incident or potentially high consequence near misses

Table 4. Eight Principles for Major Hazard Leadership (COMAH, 2019)

Eight Principles for Major Hazard Leadership		Organisation and Resources (how this is delivered)
Principle 1	Safety leadership is at the core of managing a major hazard business	Major hazard safety accountabilities should be defined and championed at board/senior leadership level. Board members, senior executives and managers should be held accountable for major hazard leadership and performance
Principle 2	Major hazard leadership requires board level involvement and competence	At least one board member/senior leader should be fully conversant in major hazards in order to advise the board/senior leadership team of the status of major hazard risk management within the organisation and of the major hazard implications of their decisions Staff with major hazard management responsibilities should have, or develop an appropriate level of competence
Principle 3	Good major hazard management does not happen by chance and requires constant active engagement	Appropriate resources should be made available to ensure a high standard of major hazard safety management throughout the organisation
Principle 4	Board-level visibility and promotion of major hazard leadership is essential to set positive safety culture throughout the organisation	Organisations should develop a programme for the promotion of major hazard safety by active senior management engagement with the workforce, both direct and contract staff, to underline the importance of major hazard safety leadership and to support the maintenance of a positive major hazard safety culture within the organisation
Principle 5	Engagement of the workforce is needed in the promotion and achievement of good major hazard control leadership	Systems and arrangements should be in place to ensure the active involvement of the workforce in the design of major hazard safety controls and in the review of major hazard safety performance
Principle 6	Monitoring major hazard performance is central to ensuring business risks are being effectively managed	Business risks relating to major hazard safety should be assessed and reviewed regularly using an appropriate business risk analysis methodology Leading and lagging major hazard safety indicators should be set for the organisation and periodically reviewed to ensure they remain appropriate for the needs of the business Information on major hazard safety performance should be routinely reviewed at senior leadership team level
Principle 7	Publication of major hazard performance information provide important assurance about the management of risks by an organisation	Performance in the management of major hazard safety risk should be published
Principle 8	Sharing best practice across industry sectors, and learning and implementing lessons from relevant incidents in other organisations, are important to maintain the currency of corporate knowledge and competence	Systems and arrangements should be in place to ensure the retention of corporate knowledge relating to major hazard safety management. Such arrangements should include information on the basis of safety design concept of the plant and processes, plant and process changes, and any past incidents that impacted on major hazard safety integrity and the improvements adopted to prevent a recurrence. Companies should actively engage with others within their sector and elsewhere to share good practice and information on major hazard safety incidents that may benefit others. Companies should have mechanisms and arrangements in place to incorporate learning from others within their major hazard safety management programmes

The Process Safety Leadership Group (PSLG) developed the eight principles of major hazard leadership, shown in Table 4. Their approach is expanded into more detail as compared to OECD (2012). It was quite evident across different literature, that leadership was observed as being core to the success of a process safety culture.

Roberts (2012) expands on these concepts and recommends the following five components of a HRO; [1] process auditing, [2] reward systems, [3] quality degradation, [4] risk perception and [5] command and control. The first component, process auditing, is the typical assurance process and extends to equipment testing. The second component, reward systems, has powerful influences on the behaviour of individuals. The third component, quality degradation, encompasses the entire quality of the system extending to all aspects. The fourth component, risk perception, ensures risks are understood and managed with associated controls. The fifth component, command and control elements, can be further segregated into five aspects; [1] migrating decision making, [2] redundancy, [3] senior managers who see the big picture, [4] formal rules and procedure and [5] training.

Weick and Sutcliffe (2007) state that we can't plan for everything and the more volatile an environment, the more vital it is to respond well in the moment. They describe five principles of HROs; [1] monitor small failures, [2] reluctant to accept simplification, [3] sensitive to operations, [4] commitment to resilience, and [5] deference to expertise. Therefore, they recommend becoming more reliable by anticipating failures, tracking failures, and using this information as input to become more resilient. Emphasise learning, fast communication with adaptation and less simplification to make a more mindful organisation.

Hollnagel *et al.* (2006) advise the notion of resilience, which has gradually emerged as the logical approach, to overcome the limits of existing approaches to risk assessment and system safety. Resilience is a typical attribute of HROs and has appeared as a next step in the loss prevention as illustrated in Figure 5. They suggest adapting resilience and safety to the requirements and age of the respective systems. Hudson (2001) also adapted the evolutionary culture framework for organisations to change and acquire a safety culture. HROs typically are a generative culture. It was evident that Proactive and Generative cultures seem to be easily attained with small organisations.

Engineering systems is an emerging field that is at the intersection of engineering. Levenson (2011) describes a new accident causality approach which includes the new generation of engineered systems. Traditional accident causality models focus on component failure, whilst Levenson's (2011) model focus is on enforcing behavioural safety constraints from reliability to control. The Systems-Theoretic Accident Model and Processes (STAMP) model incorporates three main concepts, namely, [1] safety constraints, [2] hierarchical control structures and [3] process models.

Hollnagel (2014) suggests that a safety analysis process should not only focus on negative causes and events, but also incorporate the successful activities that become invisible and insignificant as they appear normal. Hence, Safety-III was developed, which is a combination of Safety-I (infrequent events) and Safety-II (frequent events). Hudson *et al.* (1994) developed the Tripod-DELTA, which is a checklist-based approach to executing safety health assessments. At its foundation, is the human error accident causation model. Feedback from this form a repository from which these checklists are generated to support remedial safety plans.

In IOGP (2008), human factors are an essential component toward operating in a safe and efficient manner. It addresses and focuses on the interaction of people with three aspects. These aspects consist of other people, facilities, and management systems. Both exploration and production activities in the oil and gas industry depend on advanced human-machine interfaces. In our technological driven age with continuous digitalisation, the need for improved human-machine interfaces is very clear. Therefore, IOGP (2008) believe that by carefully considering these interactions between humans, technology, and organisational elements of a system, it is possible to significantly increase the system's productivity and reliability. In doing so, the risk of human error is significantly reduced, thereby reducing the occurrence of process safety incidents and uplifting PSM. Gruhn (2011) agrees and suggests that Human Machine Interface (HMI) design is critical to ensure that an operator can effectively and promptly process the plant information. Improved HMI efficacy will thus contribute to decreased process safety incident case rates.

The IOGP (2008) and Gruhn (2011) approaches are more along human error reduction or rather prevention practices. There are numerous approaches available on this topic, which were further explored. The late Trevor Kletz is renowned for his work in process safety, and his work on human error prevention was investigated. In his career, there are three richest pearls of wisdom which traverse along geographical locations, industries, and cultures. They are as follows (Kletz, 2003):

1. What you don't have, can't leak:
 - Refers to inherent safer process design practices (substitute, minimize, moderate, and simplify).
2. Try to change situations, not people:
 - Avoid the accident by engineering the hazard out of the equation completely.
3. Organisations have no memory:
 - Lessons learnt from past incidents are not effectively maintained or adequately implemented. Hence a repeat incident occurs.

Building on human error (point 2 above), Kletz (2003) based his work on Reason's (1997) framework, preferring an engineering solution to eliminate the problem. Human error can be classified into four groups, which are: [1] mistakes, [2] violations, [3] mismatches and [4] slips/lapses of attention. For each error type, he suggests implementing change hardware and/or software (CHAOS) action. Hence in this approach the human factor failure can be designed out, as displayed in Table 5.

Table 5. Human error actions (Kletz, 2003)

ERROR TYPE	ACTION
MISTAKES – Does not know what to do	Better training & instructions/CHAOS
VIOLATIONS – Decides not to do it	Persuasion/CHAOS
MISMATCHES – Unable to do it	CHAOS
SLIPS & LAPSES OF ATTENTION	CHAOS
CHAOS = <u>C</u> hange <u>H</u> ardware <u>A</u> nd/ <u>O</u> r <u>S</u> oftware	

Sanders (2004) looked at various chemical plant incident case studies. His incident causal themes uncovered topics such as: [1] good intentions, [2] water and steam, [3] preparation for maintenance, [4] maintenance – induced accidents and process piping problems, [5] one-minute modifications: small quick changes in a plant can create bad memories, [6] accidents involving compressors, hoses, pumps, etc. [7] failure to use, consult or understand specifications. The proposals made to address these issues span across a few themes, principally: role of mechanical integrity, effectively managing change, near miss and incident investigation and sharing. It was observed that these incident causal themes relate well to Kletz's (2003) point 2 and 3 pearls of wisdom.

However, the prerequisite for Kletz's (2003) human error actions approach is that hardware and/or software changes need to be derived from a human error analysis or investigation perspective. Rigorous root cause analysis during incident investigations will greatly assist in identification of critical hardware and/or software changes. Ideally, such an exercise should be proactively conducted during the design stage, and therefore it is incorporated into the design process as an inherent risk reduction technique. The field of human factor engineering expands on this idea and was subsequently investigated.

Human factor engineering design guidelines, as described by Lowe and Kariuki (2003), should include five stages as depicted in Figure 15. These stages and their sub-elemental analysis, collectively assist during the design stage to reduce human error precursors, thereby proactively preventing an incident occurrence. These stages although expanded, incorporate the three-

aspect human-machine interface concepts as described by IOGP (2008). The five stages consist of: [1] process control and monitoring, [2] automation, [3] work environment, [4] maintainability and operability and [5] process operations and layout.

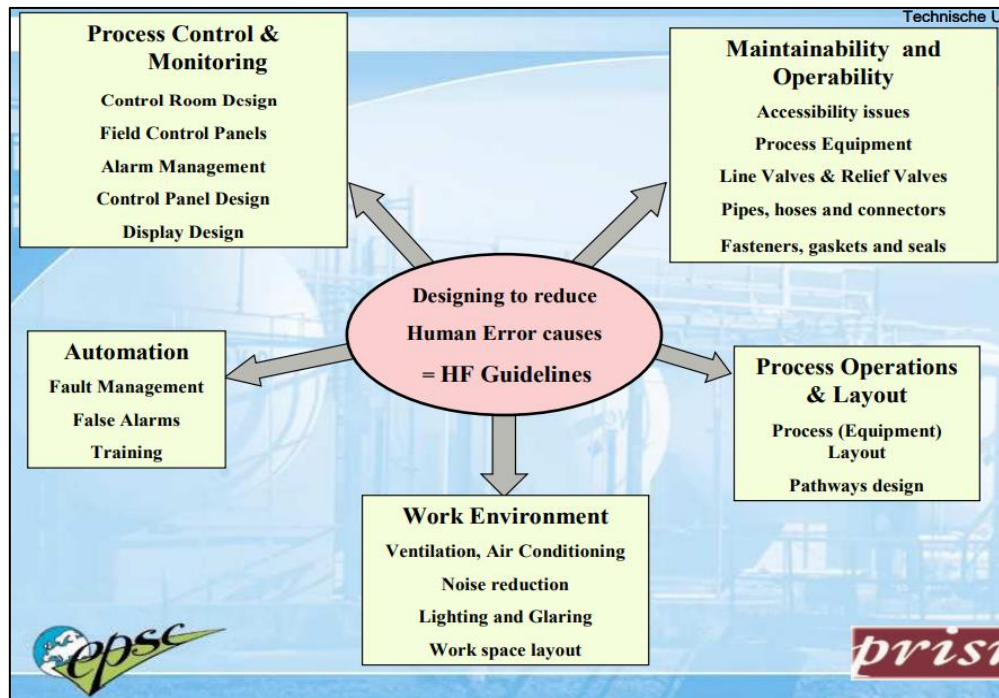


Figure 15. Main human factor elements (Lowe and Kariuki, 2003)

At the 2016 National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA), Mitchell (2016) presented a similar depiction, with relationships between the organisation, individual and the job, as seen Figure 16. The interaction between these three characteristics directly influences error prevention. Therefore, the healthier the relationship between these three characteristics, the better the error prevention achieved.

Error prevention is affected by human reliability, which consists of desired performance and human error. Human error may arise from repeated events, inadequate training programs, incorrect leadership practices and the lack of near miss learning. This negatively impacts human reliability and the desired performance. Similarly, this approach resembles the three-aspect human-machine interface concepts as described by IOGP (2008).



Figure 16. Human performance (Mitchell, 2016)

Failure to learn from incidents is another aspect that was observed to be recurring in the literature investigated. Halim and Mannan (2018) found that often process safety incidents are linked to internal organisational issues, however the journey to process safety excellence begins with external influences including commitment from the highest levels of leadership, which is similar to the CCPS (2007) RBPS system. These four roadblocks are [1] regulations based on science, [2] competence, [3] operational discipline and [4] learning for incidents, as illustrated in Figure 17, which are continuously reoccurring and are interrelated (Halim and Mannan, 2018).



Figure 17. Interaction of all these factors enhance process safety operations (Halim and Mannan, 2018)

The study by Qi *et al.* (2012) exposed challenges in process safety that explicitly addressed three critical aspects opposing the effective implementation of PSM, shown in Figure 18. Failure to learn from past incidents and incorporation of those lessons reoccurred as previously noted. Insufficient attention to leading indicators as well as an increase in process operation complexity and lack of communication were the other two aspects raised.

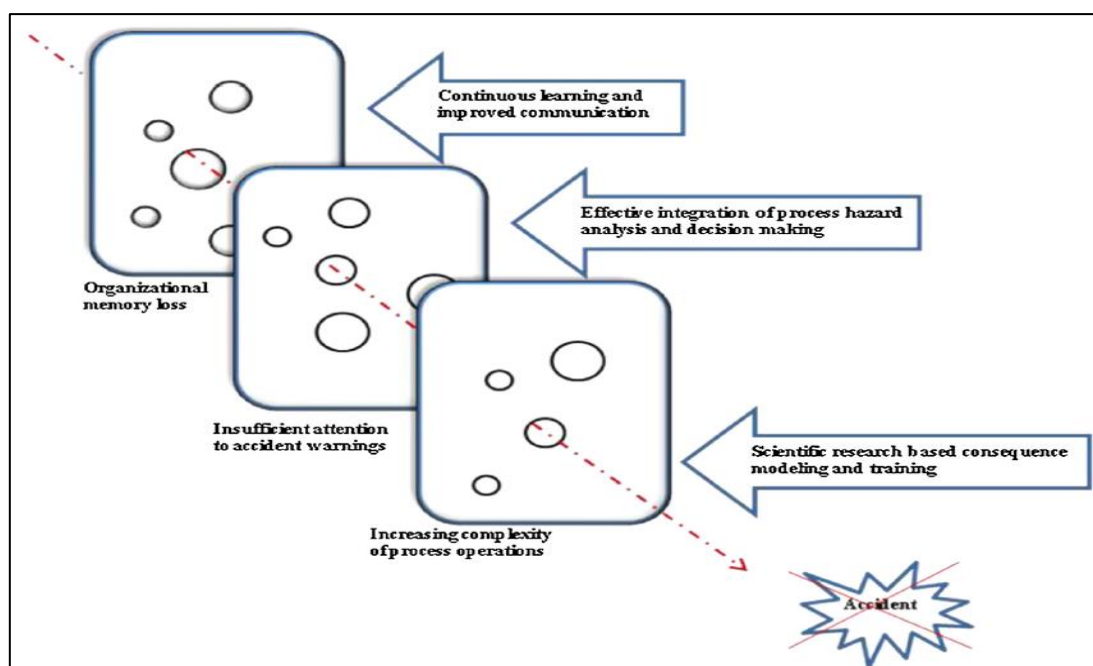


Figure 18. Summary of critical process safety aspects and proposed solution (Qi et al., 2012)

Similarly, this study found that deficiencies exist in the incident learning process which is compounded by weak response to early signals. This is a characteristic required for high reliability organisations as described by OECD (2012). Explored literature revealed other gaps uncovered in PSM systems. Bridges and Tew (2010) identified human factors deficiencies in existing PSM systems. Their findings, presented at the American Institute of Chemical Engineers (AIChE), also documented a proposed comprehensive process safety element on human factors. Using the OSHA's PSM standard as a baseline, they recommended six additional improvements, as depicted in Figure 19. Incident learning does not feature as a failure in this study; however, it does feature other aspects of the work performed by CCPS (2008), Qi et al. (2012), and Lowe and Kariuki (2003).

Bridges and Tew (2010) stated that, *"If an organisation does not directly control risk, the organisation cannot directly control quality, safety, environmental impact, or production to acceptable levels. An organisation must sustainably control human error to manage the risk of accidental losses that impact quality, safety, the environment, production, or assets"*. This is a critical concept indicating the relationship of control of human error to control of risk from a process or activity. It also supports the indirect benefits of an effective PSM system, where the success and profitability of an organisation is positively impacted as discussed in Section 1.1.

Fitness for duty	• This typically covers exertion, fatigue, stress and generally fitness
Attention and motivation	• Leadership drive, engineered system, procedures, optimization and incentives
Staffing Issues	• Competent (qualification and experience) persons required as per the role, staff capacity,
Human system interface design	• Operability, maintainability and flexibility of system designs
Task design	• Evaluation and mitigation of task risks during execution
Communication between workers	• Sending and receiving errors through communication channels becoming unclear

Figure 19. Adapted from PSM gaps relating to human factors (Bridges and Tew, 2010)

Additional work performed by Bridges and Tew (2010) uncovered a sustainable approach to control risk. Sustainable control of human error (human reliability) is impacted by three dimensions. They consist of root cause analysis/investigation, understanding risk and management systems to control human error/failures. Management systems assist by controlling the interaction of people with one another and with the different processes. Figure 20 depicts this relationship and displays how to implement control between these interfaces. This process resembles the human performance approach depicted by Mitchell (2016). Incident learning was also observed to be included in this risk control model.

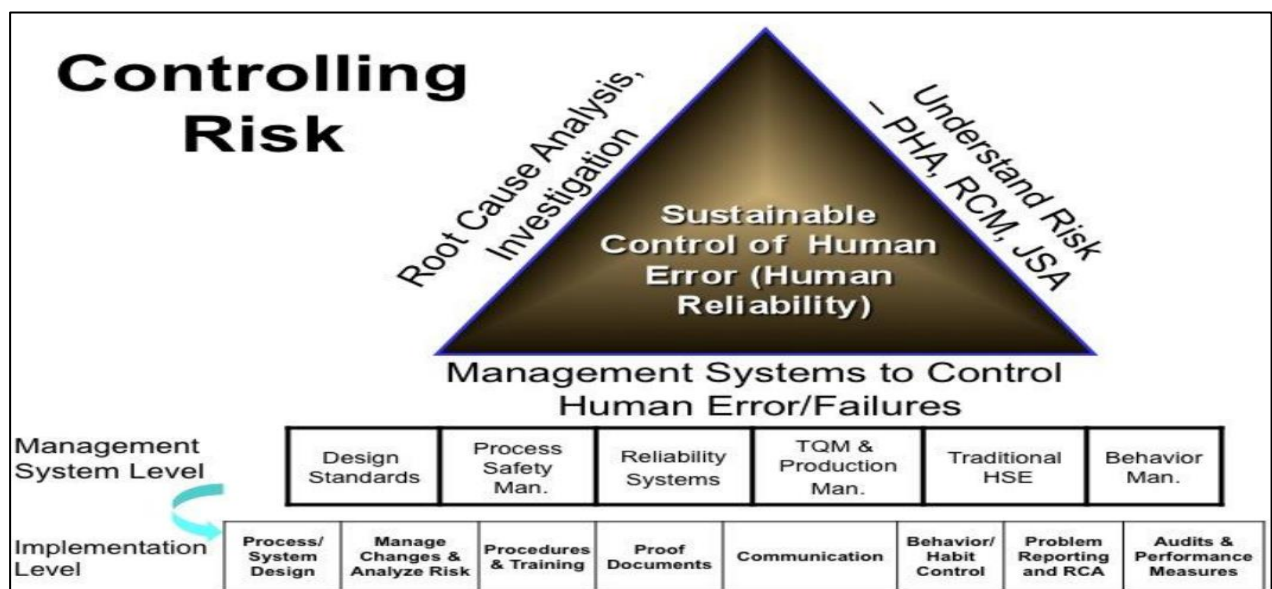


Figure 20. Controlling Risk - Sustainable control of human error (Bridges and Tew, 2010)

The HSE (2016) considers human factor as the interaction between three main factors: [1] the job, [2] the individual and [3] the organisation. Figure 21 depicts this interaction between the main factors. From the HSE (2016) inspections and investigations, they have found that many companies invest more time describing the reliability of the hardware and not enough time on the reliability of the person operating the hardware. For the human factor element, an equally rigorous and structured approach is required. Again, this process resembles the human performance approach depicted by Mitchell (2016).

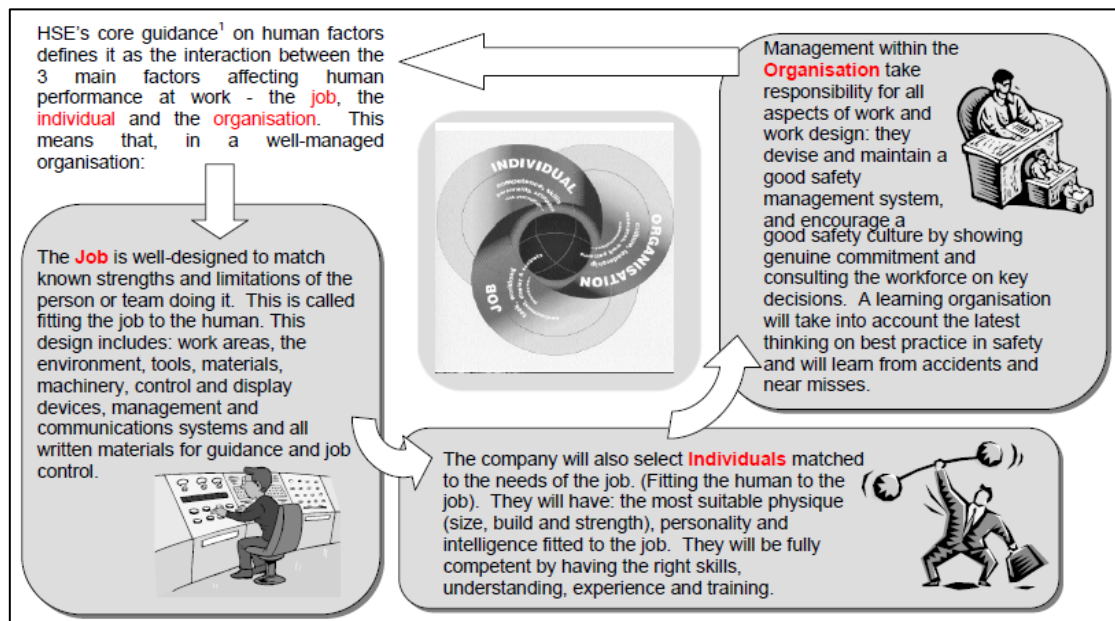


Figure 21. Human Factor elements (HSE, 2016)

After the tragic BP Texas City refinery event (ICIS, 2020), an independent study was conducted to evaluate process safety at the BP refineries. There were ten recommendations from the Baker report (Baker Panel, 2007) as listed in Table 6. These recommendations resemble the essential elements for corporate process safety by OECD (2012) and the eight principles for Major Hazard Leadership by COMAH (2019). Unfortunately, the Deepwater Horizon event (Monarch SMS, 2020), another severe incident, occurred years later. There were two Deepwater Horizon investigation recommendations (BP, 2010) which broadly cover: [1] drilling and Well operations practice (DWOP) and operating management system (OMS) implementation and [2] contractor and service provider oversight and assurance. The work by Halim and Mannan (2018) also shares similar recommendations.

Table 6. Summary of Baker Report Recommendations (Baker Panel, 2007)

Recommendation Number	Description
1. Process Safety leadership	The Board of Directors of BP p.l.c, BP's executive management (including its Group Chief Executive), and other members of BP's corporate management must provide effective leadership on and establish appropriate goals for process safety. Those individuals must demonstrate their commitment to process safety by articulating a clear message on the importance of process safety and matching that message both with the policies they adopt and the actions they take.
2. Integrated and comprehensive process safety management system	BP should establish and implement an integrated and comprehensive process safety management system that systematically and continuously identified, reduces, and manages process safety risks at its U.S. refineries.
3. Process safety knowledge and expertise	BP should develop and implement a system to ensure that its executive management, its refining line management above the refinery level, and all U.S. refining personnel, including managers, supervisors, workers, and contractors, possess an appropriate level of process safety knowledge and expertise.
4. Process safety culture	BP should involve the relevant stakeholders to develop a positive, trusting, and open process safety culture within each U.S. refinery.
5. Clearly defined expectations and accountability for process safety	BP should clearly define expectations and strengthen accountability for process safety performance at all levels in executive management and in the refining managerial and supervisory reporting line.
6. Support for line management	BP should provide more effective and better coordinated process safety support for the U.S. refining line organisation.
7. Leading and lagging performance indicators for process safety	BP should develop, implement, maintain, and periodically update an integrated set of leading and lagging performance indicators for more effectively monitoring the process safety performance of the U.S. refineries by BP's refining line management, executive management (including the Group Chief Executive), and Board of Directors. In addition, BP should work with the U.S. Chemical Safety and Hazard Investigation Board and with industry, labour organisations, other governmental agencies, and other organizations to develop a consensus set of leading and lagging indicators for process safety performance for use in the refining and chemical processing industries.
8. Process safety auditing	BP should establish and implement an effective system to audit process safety performance at its U.S. refineries.
9. Board monitoring	BP's Board should monitor the implementation of the recommendations of the Panel (including the related company) and the ongoing process safety performance of BP's U.S. refineries. The Board should, for a period of at least five calendar years, engage an independent monitor to report annually to the Board on BP's progress in implementing the Panel's recommendations (including the relate commentary). The Board should also report publicly on the progress of such implementation and on BP's on-gong process safety performance.
10. Industry leader	BP should use the lessons learned from the Texas City tragedy and the Panel's report to transform the company into a recognized industry leader in process safety management.

The U.S. Chemical Safety and Hazards Investigation Board (CSB) (2013) has been in existence since 1990 and are tasked to independently investigate chemical incidents and promote prevention. They offered eight key attributes for a Safety Culture Survey, as illustrated in Figure 22. These attributes bring forth some other aspects to human factors not commonly appearing in the literature reviewed. Tolerance of deviations and transparent communication featured as other human factor considerations. Communication was found as a gap during the critical process safety aspects study performed by Qi *et al.* (2012).

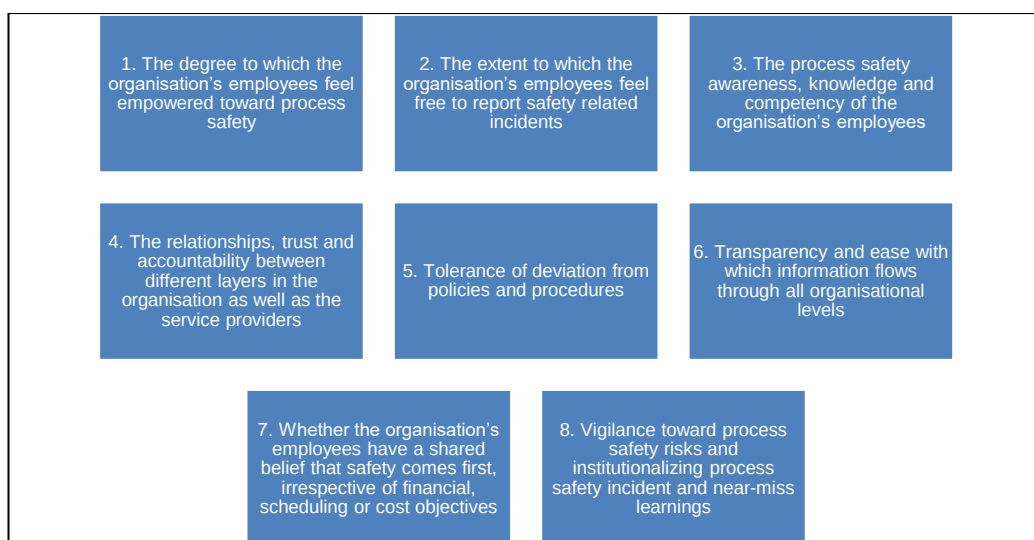


Figure 22. Adapted from Key attributes for a Safety Culture Survey (CSB, 2013)

In summary numerous process safety culture practices were uncovered, many independent of existing PSM systems, excluding the CCPS (2008) and IOGP (2008) systems. Many of these practices focused on leadership commitment to process safety. They focused on the soft issues, which is positively influencing human behaviour. In the author's experience, positively influenced individuals often make the right choices and adhere to the correct practices. Although this is rather challenging to achieve in practice, it is the most cost-effective measure. The greatest challenge observed was despite having the correct practices and right conversations, human beings are not machines. Simply meaning that human beings are often susceptible to being preoccupied psychologically. This is where the focus on the task at hand is disrupted, paving the way for errors to occur. Other practices opted to improve human factor engineering through design techniques and this is a hard control which is easier to influence. Improved instrumentation, HMI and learning from incidents were highlighted repeatedly through the different approaches reviewed. Unfortunately, this approach although easier to achieve in practice, is a far more cost-intensive measure. It appears that a balanced approach of soft and hard controls is the most optimum approach. There are also numerous human reliability related tools, such as the comprehensive evaluations suggested by the HSE (2009).

2.3. Comparison of Shell, BP, Sasol, and Chevron

Process safety culture approaches existing in PSM systems were evaluated. Expanding in this direction, chemical processing companies practising PSM were surveyed to understand their process safety culture practices. Large scale, international and well recognised chemical

processing companies were selected, namely Shell, BP, Sasol, and Chevron. Their process safety culture approaches were investigated and discussed.

Shell (2011) has integrated the bowtie methodology in the 1990s and adapted to a systematic approach to risk management. They focus on six preventative barriers to achieve zero process safety incidents, as shown in Figure 23. This is similar to the risk-based approaches discussed during the PSM system reviews. The standard asset integrity management approach is composed of integrity leadership at the centre, and it is supported by design integrity, technical integrity, and operating integrity. The preventative barrier with the minimum two tested and independent barriers approach alludes to hardware and the reliability of their processes in minimizing the likelihood of a major process safety incident. Human behaviours and culture are the other softer aspects which compliments the hardware installed.

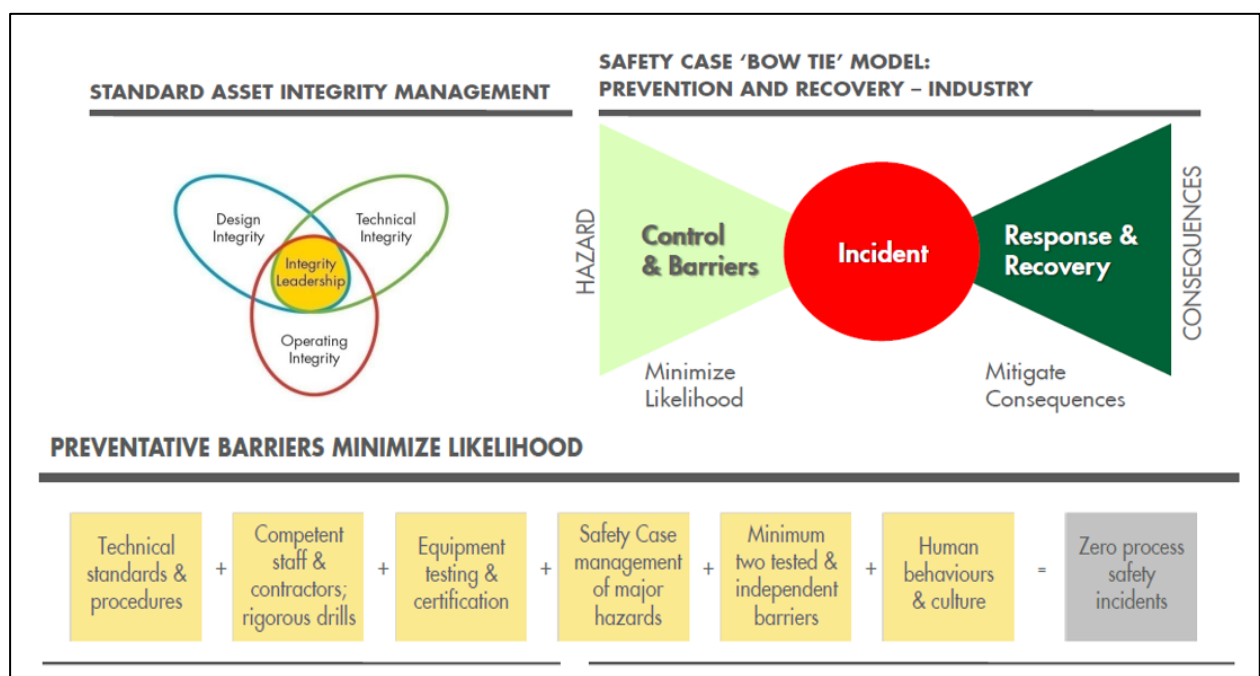


Figure 23. Shell's Risk Management Approach (Shell, 2011)

Shell's (2011) approach to safety culture consists of seven facets. These facets although vary, are interrelated to work harmoniously to achieve their safety objectives. Shell's safety culture is based on the following facets (Johnston, 2013):

1. Three golden rules: comply (commit), intervene (act) and respect (care) and a goal zero being a mind-set. However, they apply twelve HSE Golden Rules to contractors considered as lifesaving rules (Shell, 2012).

2. They have a HEROS (helping every rig operate safely) program for stop work authority (stop work intervention policy, roles and responsibilities, intervention protocols, reporting, follow-up, recognition, training).
3. Growing safety culture with a mind-set of care for both personal and process safety with an overarching chronic unease as a product of behaviours.
4. Safety leadership is another pillar.
5. Good training program essential to a strong safety culture.
6. Learning from internal past and external incidents.
7. Robust assurance process with multiple levels: corporate level, business level, local level, external third parties.

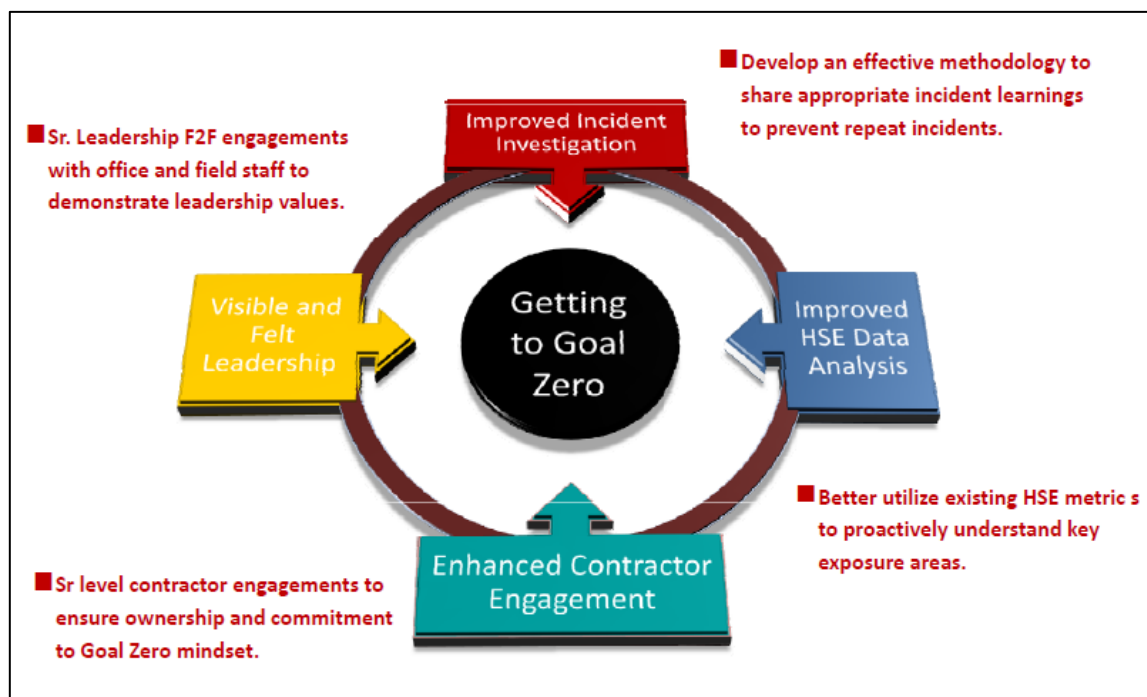


Figure 24. Shell's Safety Leadership (Shell, 2011)

Shell (2011) introduced a Safety Leadership program which consists of four dimensions, as depicted in Figure 24. These dimensions are [1] improved incident investigation, [2] improved HSE data analysis, [3] enhanced contractor engagement and [4] visible and felt leadership. Committed leadership with integrity, is at the centre of their PSM system. Their enhanced contractor engagement dimension involved the development of a Shell contractor electronic resource site. This site includes process safety and Shell shares their ten Process Safety Fundamentals to encourage healthier contractor process safety practices (Shell, 2018).

From 2005 to 2010, BP (2017) experienced serious accidents and in the years since transformed itself. They introduced new training programs, innovation technologies and strengthening its

safety value. Their efforts have indicated positive safety results with significant improvement. BP (2017) also rolled out company-wide guidelines for how to operate, titled: Operating Management System (OMS). They organised people according to their functional responsibilities, each with their own rules and requirements. Consultations are available centrally through the company's Safety and Operational Risk (S&OR) organisation, which offers an additional layer of assistance and expertise. BP's (2017) values, OMS, functional organisations, and S&OR team provide the framework and support assisting them to operate safely.

Training programs evolved to include classroom instruction and hands-on virtual reality simulators. These simulations replicate both likely and potentially challenging scenarios. At their Cherry Point Refinery, BP (2017) employs phased array ultrasonic testing to confirm the safety and integrity of piping systems and pressure vessels. They also promote a strong speak-up culture, where anyone is encouraged to raise questions or concerns. Recently BP (2018) has focused on human performance safety, where more than 900 employees have completed this training since 2017. This intent of the program is to eliminate human error, by enabling leaders and the workforce to identify factors that may contribute to mistakes. They have an improved operations management system and new data tracking systems to assure they remain a learning organisation.

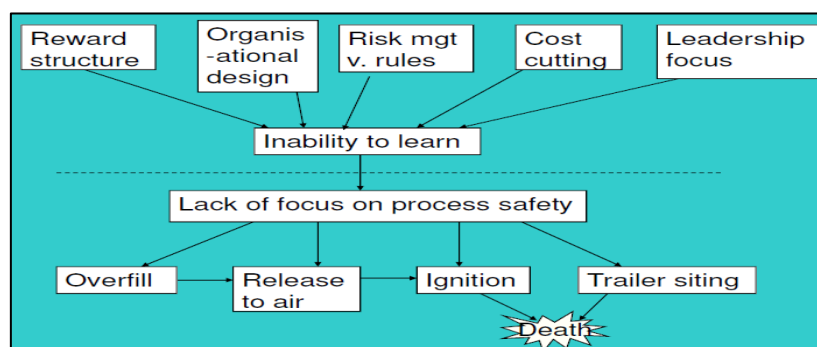


Figure 25. Texas City Inability to Learn (Hopkins, 2009)

Learning is a contentious exercise and is composed of three aspects: [1] learning from own incidents, [2] learning from audits and [3] learning from elsewhere. The Texas City incident (Hopkins, 2009) had five key issues, depicted in Figure 25, that greatly impacted its process safety ability: [1] reward structure, [2] organisational design, [3] risk management and rules, [4] cost cutting and [5] leadership focus. Leadership focus during management inspections must include process safety. Unfortunately, often this is seen as just an occupational safety exercise. The art of this exercise is to elicit information from employees, as they often know best when something is amiss.

Evaluating the Deep-Water Horizon Incident, the following leadership recommendations were made in preparation for a management inspection (Hopkins, 2011):

1. Remind themselves of possible (future) significant and major process safety events that are possible and have occurred. Understanding of the incident mechanisms is crucial and aids in improving inspection and understanding of the operation.
2. Understand the control measures and their function to prevent or mitigate such process safety events. This will assist with the effective verification of each control.
3. Remind themselves of past (occurred) significant and major process safety events that are possible and those that have occurred. Understanding of the incident mechanisms is crucial and aids in improving inspection and understanding of the operation.
4. Dedicate inspection to thorough critical control verification.
5. Understand the challenges specifically at the facility just before the management inspection and focus efforts on verifying their controls. Reduced activities should not include reduced inspection rhythms. Perception with the facility team will be that it is not important.
6. Where leadership lacks the technical understanding, include experts on the field as part of the management inspection team.

Sasol (2014) published its new standardised risk-based safety, health, and environment (SHE) management approach manual. It consists of three parts, namely: One Sasol SHE excellence approach, Key Undesirable Events and Group Controls and the Risk-based implementation methodology. This methodology resembles the approach adopted by Shell (2011); however, it is a more holistic approach to SHE management rather than specifically PSM.

The one Sasol SHE excellence approach was unpacked, and the first part comprehensively documents the overview, intent, direction, delivery tools, delivery people, SHE results and stakeholder focus. The second part covers the understanding of key SHE undesirable events which enables Sasol to manage these risks by preventing the events and minimising the consequences. The group controls serve to manage these risks in a standardised manner. The derivation of these controls follows the basic plan, do, review, and improve approach. This is coupled to another element, which is continuous improvement. In line with their risk-based approach, Sasol (2014) identified twelve key undesirable events (KUE) as illustrated in Figure 26. This informed the company's highest risks, to guide their leaders on where to focus management and attention. This follows the Pareto principle (Dunford *et al.*, 2014), also known as the 80/20 rule as previously discussed. Essentially it implies that about 80% of the effects come from 20% of the causes, which are namely the twelve KUEs.

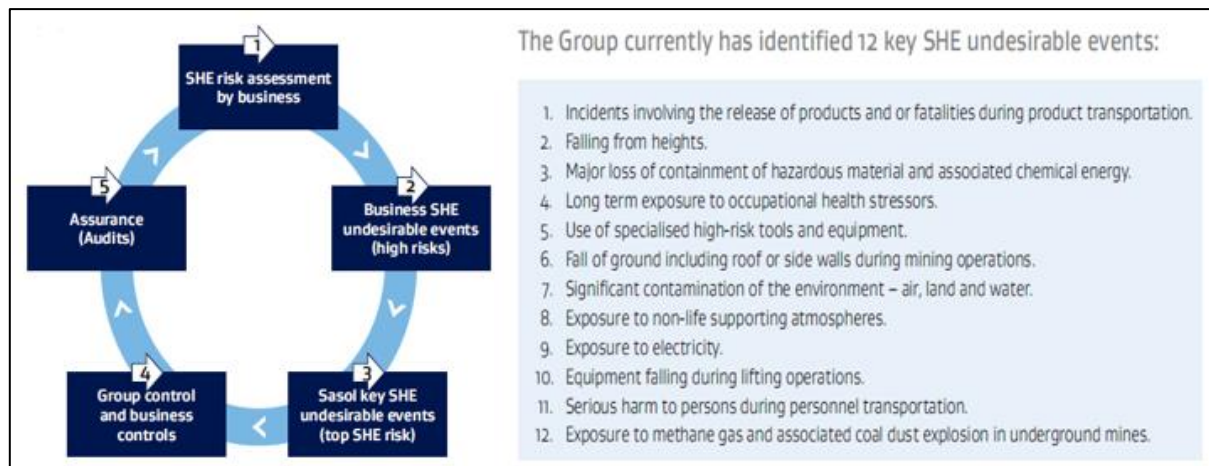


Figure 26. Adapted: Deriving Group Controls (Sasol, 2014)

The third part provides guidance on how to execute the standardised risk-based implementation based on this approach, as depicted in Figure 27. Similarly, to part 2, part 3 also follows a basic plan, do, review, and improve approach. However, this has adapted to form a five-step process (Sasol, 2014): [1] build a foundation of knowledge, [2] risk-based planning, [3] risk-based SHE management, [4] risk-based monitoring and assurance and [5] risk-based improvement. Building on this initiative, Sasol (2015) further entrenched their safety improvement plan framework and behavioural-based safety process.

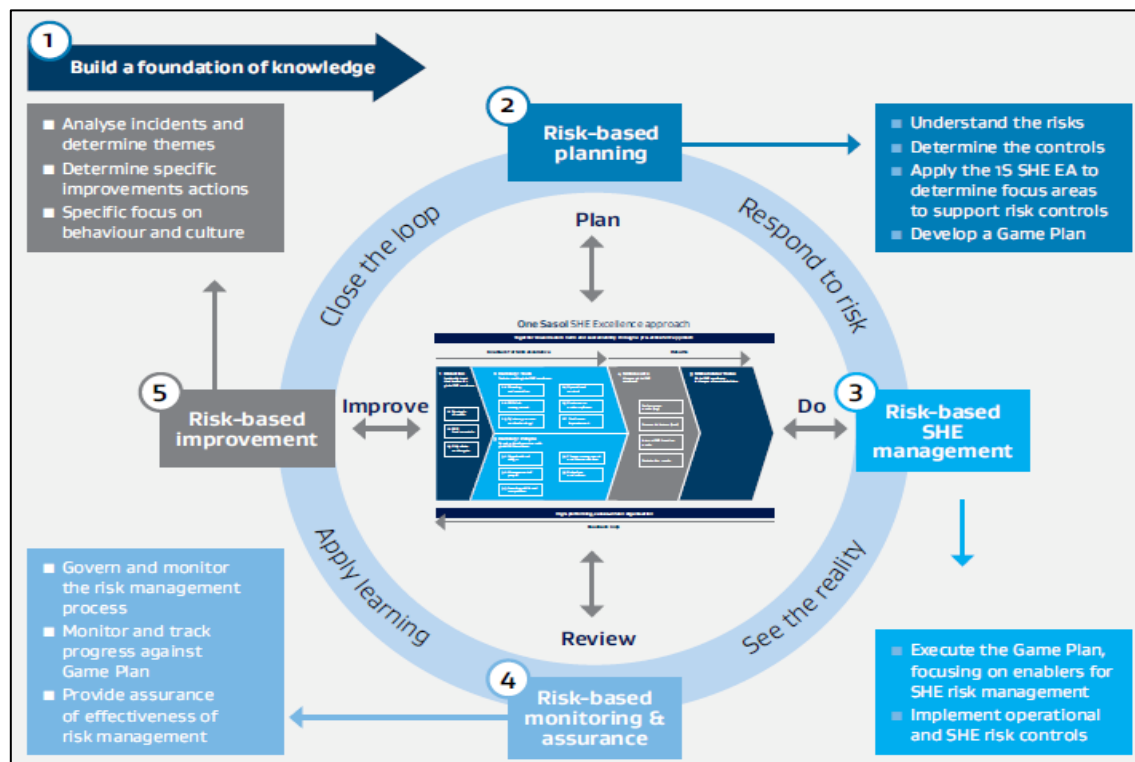


Figure 27. Sasol Risk-based implementation (Sasol, 2014)

Process safety is the foremost SHE risks, and Sasol are focusing on these four aspects (Sasol, 2014): [1] process safety operations roadmap and training programme, [2] competency of process safety specialists, [3] improved metrics and incident investigation and [4] updated process safety information. These efforts translated into Sasol shaping their improved SHE culture.

Chevron (2013) relentlessly focuses on safety, believing that zero harm can be achieved through operational excellence. Figure 28 displays how process safety is integrated into this model, and it covers a condensed approach to the OSHA PSM model. Chevron's (2013) PSM system approach is similar to Shell's approach, in that it is specifically targeted toward PSM and consists of an elemental based approach. Their PSM system is the Process Safety in Operational Excellence model, shown in Figure 28. At its centre is leadership accountability to execute the management system process. Leadership again being a common theme raised by the various international chemical companies.

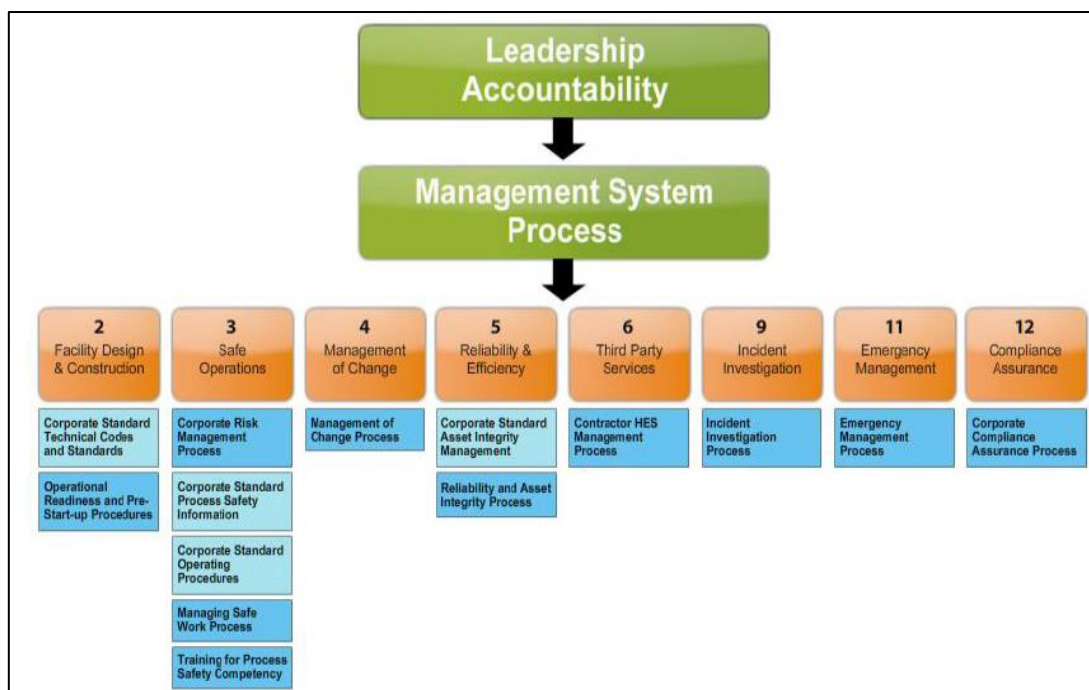


Figure 28. Process Safety in Operational Excellence (Chevron, 2013)

Process Safety in Operational Excellence model consists of eight elements: [1] facility design and construction, [2] safety operations, [3] management of change, [4] reliability and efficiency, [5] third party services, [6] incident investigation, [7] emergency management and [8] compliance assurance. In the model these elements are numbered inconsistently, indicating that they are a part of a larger SHE program. In 2004, Chevron (2018), launched their Operational Excellence

Management System (OEMS), which is a comprehensive and prescriptive system to improve their health, environmental and safety performance, seen in Figure 29.

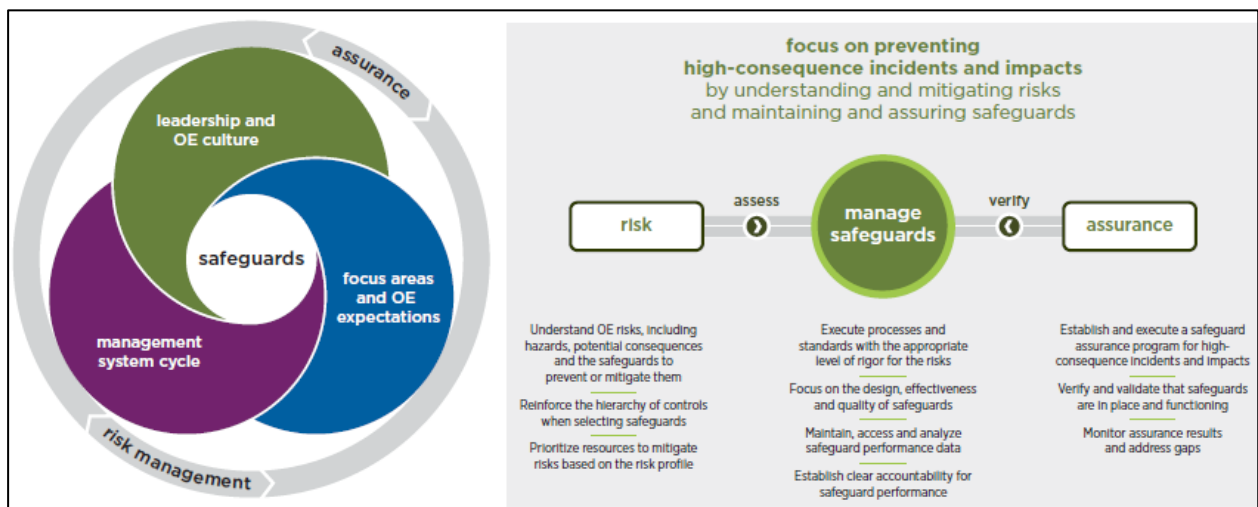


Figure 29. Adapted: Operational Excellence leadership Culture (Chevron, 2018)

To improve process safety culture, Chevron (2018) incorporated ten tenets of operations which are guided by two key principles: [1] do it safely or not at all and [2] there is always time to do it right. Unlike the Shell (2011) model, it doesn't include an element that specifically focuses on human behaviour and culture. Rather the existing elements are integrated and include the process safety culture aspects. Their approach resembles Sasol's (2014) approach to the key SHE undesirable events and Shell's (2011) approach to the bow-tie methodology. Essentially a risk-based approach is adopted. Chevron's principles and tenets of operation resemble Shell's golden rule approach.

2.4. Safety Culture and Climate

PSM was defined earlier on in Chapter 1, so the concepts of safety culture and climate were investigated in the literature survey. The safety culture term was first introduced and defined following the Chernobyl process safety incident by the International Nuclear Safety Advisory Group (INSAG) of the International Atomic Energy Agency (IAEA) (1991).

Guldenmund (2010) differentiated safety culture and climate according to a general framework based on the organisational culture work by Schein (1983). Table 7 lists his findings on safety climate and culture definitions from 1980 to 1997. Guldenmund (2010) found that culture and safety management have an often misunderstood but direct relationship albeit unintentionally in practice.

Table 7. Definitions of safety climate and safety culture (Guldenmund, 2010)

Author(s)	Definition of safety culture/climate
Zohar (1980)	A summary of molar perceptions that employees share about their work environments (safety climate)
Glennon (1982)	Employees' perceptions of the many characteristics of their organisation that have a direct impact upon their behaviour to reduce or eliminate danger (safety climate) and, Safety climate is a special kind of organisational climate
Brown & Holmes (1986)	A set of perceptions or beliefs held by an individual and/or group about a particular entity (safety climate)
Lutness (1987)	Not explicitly stated (safety climate)
Cox & Cox (1991)	Safety cultures reflect the attitudes, beliefs, perceptions, and values that employees share in relation to safety (safety culture)
Dedobbeleer & Béland (1991)	Molar perceptions people have of their work settings (safety climate)
International Nuclear Safety Advisory Group (1991)	Safety culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance (safety culture)
Pidgeon (1991)	The set of beliefs, norms, attitudes, roles, and social and technical practices that are concerned with minimising the exposure of employees, managers, customers, and members of the public to conditions considered dangerous or injurious (safety culture)
Ostrom <i>et al.</i> (1993)	The concept that the organisation's beliefs and attitudes, manifested in actions, policies, and procedures, affects its safety performance (safety culture)
Safety Research Unit (1993)	Not explicitly stated (safety climate)
Cooper & Philips (1994)	Safety climate is concerned with the shared perceptions and beliefs that workers hold regarding safety in their workplace (safety climate)
Geller (1994)	In a total safety culture (TSC), everyone feels responsible for safety and pursues it on a daily basis (safety culture)
Niskanen (1994)	Safety climate refers to a set of attributes that can be perceived about particular work organisations and which may be included by the policies and practices that those organisations impose upon their workers and supervisors (safety climate)
Coyle <i>et al.</i> (1995)	The objective measurement of attitudes and perceptions toward occupational health and safety issues (safety climate)
Berends (1996)	The collective mental programming towards safety of a group of organisation members (safety culture)
Lee (1996)	The safety culture of an organisation is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, and organisation's health and safety management (ASCNi) (safety culture)
Cabrera <i>et al.</i> (1997)	The shared perceptions of organisational members about their work environment and, more precisely, about their organisational safety policies (safety climate)
Williamson <i>et al.</i> (1997)	Safety climate is a summary concept describing the safety ethic in an organisation or workplace which is reflected in employees' beliefs about safety (safety climate)

Aubrey Daniels International (ADI) (Agnew, 2015), have been in existence since 1978, defines safety culture as “a set of core values and behaviours that emphasize safety as an overriding priority.” Hoover (n.d.) suggests that engagement is the fundamental layer toward creating both

a safety climate and culture, *“Whether engagement comes easily or is almost impossible to achieve depends on the atmosphere – the safety climate and organizational culture – that leadership creates. When these things are right, engagement becomes easy.”*

ACSNI (HSC, 1993) described safety culture as, *“...the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficient of, an organisation’s health and safety management.”*

They conclude that characteristics successful of safety cultures, include communications built on trust and the importance of safety which is mutually shared with the effectiveness of preventative measures. This agrees with the work conducted by Guldenmund (2010). Culture was found to be more challenging to change compared to climate, as it reflects deeper and more pervasive assumptions. Climate however is more malleable to change, as it requires deliberate organisational actions and communication.

Similarly, to Guldenmund’s (2010) safety climate and culture definition survey in Table 7, Vu and De Cieri (2014) reviewed sixty-six safety culture definitions from various recognised institutions and experts from 1991 to 2013. After careful consideration they propose that a regulator use the definitions for safety culture and climate, as listed in Table 8 and Table 9. Vu and De Cieri (2014) suggest that selection of the safety culture and climate definitions be aligned to the area of application. After reviewing literature on the human mind, in Section 2.7, the all quadrant, all level (AQAL) model defined culture as being influenced by experience which then influences the meaning of interactions framing relationships (Tonnesvang *et al.*, 2015). Upon reflection, HSD (UK) (2005) definition for safety culture and climate distinguishes between culture and climate.

For purposes of this study, this definition seemed more suited. Consequently, a combination seemed most appropriate, and the HSD (UK) (2005) safety culture and climate definition was adapted to incorporate the AQAL model culture definition. The resultant combined definition for safety culture and climate for this study is:

The terms safety culture and safety climate may both be used to describe the ways in which members of an organisation make sense of the overall safety of their work environment. Safety culture is influenced by experiences which then influences the meaning of future interactions. Safety climate is often used to describe the more tangible outputs of an organisation, through which safety culture can be assessed. These safety climate attributes are measurable and easier to influence.

Table 8. Safety Culture and Climate definitions (Vu and De Cieri, 2014)

Safety Culture and Climate		
NIOSH, NORA Construction Sector Council, US (2008)		Safety culture reflects the attitudes, values, and priorities of management and employees and their impact on the development, implementation, performance, oversight, and enforcement of safety and health in the workplace (p.65).
WorkCover NSW (n.d.)		Your safety culture reflects the values, attitudes, and behaviours of your organisation with regards to health and safety. It's not just what safety systems you have in place. In a positive safety culture: • Everyone in the organisation believes they have a right to work in a safe and healthy environment. • Everyone accepts personal responsibility for ensuring the health and safety of themselves and of others. • Supervisors and managers see safety as important. • Management behaviours and actions demonstrate a commitment to health and safety (p.1)
Wiegmann <i>et al.</i> (2002)		Safety climate is the temporal state measure of safety culture, subject to commonalities among individual perceptions of the organisation. It is therefore situationally based, refers to the perceived state of safety at a particular place at a particular time, is relatively unstable, and subject to change depending on the features of the current environment or prevailing conditions (p.10).
HSD (UK) (2005)		The terms safety culture and safety climate may both be used to describe the ways in which members of organisation make sense of the overall safety of their work environment, Safety culture, however, exists at a higher level, relating in part to overarching policies and goals. Safety climate, on the other hand, is often used to describe the more 'tangible' outputs of an organisation's safety culture. For example, how people perceive and describe the importance given to safety issues by the organisation at a particular point in time, and how local arrangements are seen to reflect this. Safety climate exists at a more localised level, and thus provides a tangible focus for the assessment of some aspects of safety culture. (p.6).

Table 9. Safety Culture definitions (Vu and De Cieri, 2014)

Regulator definitions – Safety Culture	
IRF Member	Definition
NOPSEMA	The shared basic assumptions, held by most members of an organisation, which create and reinforce group norms of thoughts, language, and behaviour in relation to major accident event prevention.
C-NLOPB	Safety culture is defined as the attitude, values, norms, and beliefs which a particular group of people share with respect to risk and safety.
PSA	A culture can be defined as the knowledge, values, norms, ideas, and attitudes which characterise a group of people. A sound HSE culture can be observed in an enterprise which facilitates continuous, critical, and thorough efforts to improve health, safety, and the environment.
BSEE	The BSEE defines safety culture as the core values and behaviours resulting from a collective commitment by leaders and individuals to emphasize safety, over competing goals, to ensure protection of people and the environment.

2.5. Sustainable Process Management

Sustainable is an adjective and means able to continue over a period (Cambridge University Press, 2020). This definition aptly describes the intent of a sustainable process safety culture framework. Different sustainability approaches in process safety and engineering were surveyed.

Arendt and Manton (2015) stated that only a few process industry companies have fully mastered formal management systems to pursue process safety improvements for over 20 years. They suggest one of the possible reasons for this is that it is lack of deeper investigation into causes due to significant effort required. Therefore, they propose three systematic approaches for process safety performance management (Arendt and Manton, 2015): [1] early recognition of process safety performance degradation, [2] diagnosis of the technical, management practice, behavioural and cultural causal factors that affect performance and [3] monitoring long-term slow degradation of organizational HSE performance. Similarly, Arendt and Manton (2015) also propose methods a company can adopt to reach the above process: [1] redefine leading and lagging indicators, [2] improve the quality of incident investigations to extract the cultural root causes and to cross correlate these with audit findings, [3] ensure leading indicators have accident prevention value and receive site management review on a quarterly basis and [4] monitor real-time measure for overall safety culture.

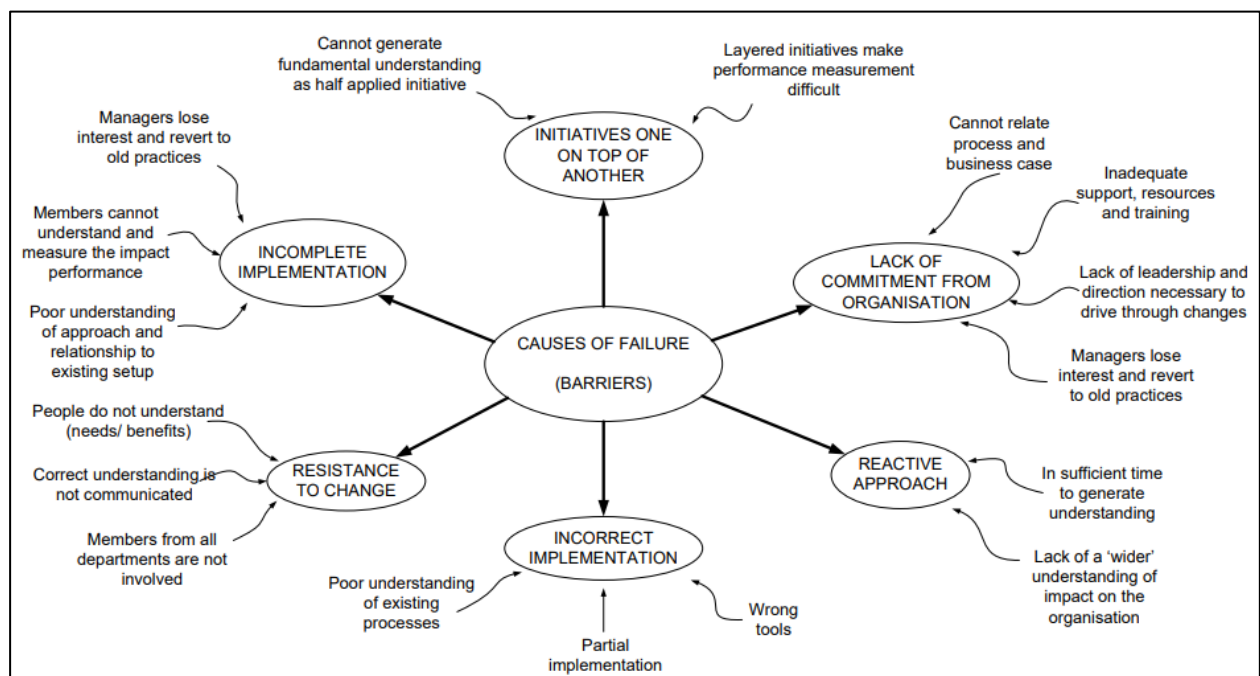


Figure 30. Cause of failure and barriers to realising manufacturing improvement (Hicks and Matthews, 2010)

Hicks and Matthews (2010) determined six barriers to realising sustainable process improvement as depicted in Figure 30: [1] lack of commitment from the organisation, [2] reactive approach, [3] incorrect implementation, [4] resistance to change, [5] incomplete implementation and [6]

initiatives one on top of another. These barriers generally arise from a lack of understanding, or inability to communicate understanding, or an inability to generate the correct understanding. These barriers can be used to ensure the methods by Arendt and Manton (2015) remain effective.

PennState (2020) compared traditional engineering to sustainable engineering approaches as depicted in Table 10. Their perspectives on engineering sustainability approaches complements the work on barriers conducted by Hicks and Matthews (2010), mandating the inclusion of a broad viewpoint, or holistic process safety culture management. As discussed in Section 1.3 objectives one and two appropriately investigate a global context across different high-risk high-reliability non-chemical processing industries. This will assist toward achieving the sustainable aim.

Table 10. Sustainability Approaches in Engineering (PennState, 2020)

Traditional Engineering	Sustainable Engineering
Considers the object or process	Considers the whole system in which the object or process will be used
Focuses on technical issues	Considered both technical and non-technical uses synergistically
Solves the immediate problem	Strives to solve the problem for infinite future (forever?)
Considers the local context	Considers the global context
Assumes other will deal with political, ethical, and societal issues	Acknowledges the need to interact the experts in other disciplines related to the problem

The common intent observed by these approaches was best summarised by the process safety performance management approach to sense, learn and correct the problems (Arendt and Manton, 2015). Following this approach process safety culture practices can be sustained.

2.6. Occupational Safety Culture Approaches

Process safety culture at a chemical processing facility would certainly be incorporated into the safety culture of that facility. As previously discussed, safety is composed of two aspects, process, and occupational safety. Their differences were described in Chapter 1. Many approaches have been developed to assist industry in creating an occupational safety culture. As a part of the research methodology, occupational safety culture practices were investigated to assist in the development of the process safety culture framework. A reflection on culture and climate from academic literature as well as industry practises was surveyed.

The early work by Schein (1983) describes organizational culture and cultural elements to be embedded as directed by the founder/owner, or professional manager of an organisation. Albeit a founder/owner and professional manager of an organisation possess different backgrounds and values of leadership.

Table 11 captures the differences between a Founder/Owner and Professional Manager. The former possessing a more personal vested interest, whilst the manager has a more unvested short-term view with self-prioritised values. Nonetheless, this powerful leadership role has far reached affects with the ability to shape positive or destructive organisational impacts from employees.

Table 11. How do Founder/Owners differ from Professional Managers (Schein, 1983)

<i>Motivation and Emotional Orientation</i>	
Entrepreneurs/founders/Owners Are	Professional Managers Are
Oriented toward creating, building.	Oriented toward consolidating, surviving, growing.
Achievement-oriented.	Power-and influence-oriented.
Self-oriented, worried about own image; need for "glory" high.	Organization-oriented, worried about company image.
Jealous of own prerogatives, need for autonomy high.	Interested in developing the organization and subordinates.
Loyal to own company, "local."	Loyal to profession of management, "cosmopolitan"
Willing and able to take moderate risks on own authority.	Able to take risks, but more cautious and in need of support.
<i>Analytical Orientation</i>	
Primarily intuitive, trusting of own institutions.	Primarily analytical, more cautious about intuitions.
Long-range time horizon.	Short-range time horizon.
Holistic: able to see total picture, patterns.	Specific: able to see details and their consequences.
<i>Interpersonal Orientation</i>	
"Particularistic," in the sense of seeing individuals as individuals.	"Universalistic," in the sense of seeing individuals as members of categories like employees, customers, suppliers, and so on.
Personal, political, involved.	Impersonal, rational, uninvolved.
Centralist, autocratic.	Participative, delegation oriented.
Family ties count.	Family ties are irrelevant.
Emotional, impatient, easily bored.	Unemotional, patient, persistent.
<i>Structural/Positional Differences</i>	
Have the privileges and risks of ownership.	Have minimal ownership, hence fewer privileges, and risks.
Have secure position by virtue of ownership.	Have less secure position, must constantly prove themselves.
Are generally highly visible and get close attention.	Are often invisible and do not get much attention.
Have the support of family members in the business.	Function alone or with the support of non-family members.
Have the obligation of dealing with family members and deciding on the priorities	Do not have to worry about family issues at all, which are by definition irrelevant.
family issues should have relative to company issues.	
Have weak bosses, board that are under their own control.	Have strong bosses, boards that are not under their own control.

This impact stems from the founder/owner's or professional manager's direct messages or acts of behaviours responding to situations inconsistently resulting in conflicted communication to

subordinates. Therefore, Schein (1983) describes organisational culture as dependent for its existence on a definable organization, in which several people interact with each other, with the intent of accomplishing some goal in their defined environment. Verbeke *et al.* (1998) surveyed 54 definitions of culture and discovered that centrally it consists of shared behavioural norms with underlying beliefs and values that form the ways of working or interacting in the organisation. This agrees with the work by Schein (1983).

Zohar (1980) constructed and validated a 40-item measure of organisational climate for safety from 20 industrial organisations. This measured the relative importance of safe conduct in their occupational behaviour. The study found that management views safety as a technical and independent aspect of the production process, disconnected from other management operations. Grimaldi (1970) recommends that safety be regarded as an integral part of the production system, rather closely related to the overall management of a production processes. Similarly, Zohar (1980) concludes that a successful attempt at improving the safety level in industrial organizations will require two prerequisites: [1] sincere change in management attitudes and [2] increased commitment.

Similarly, INSAG (1991) and Reason (1997) set out to formulate safety culture which they believe is either existent or non-existent. This is a more rudimentary approach, absent of distinguishing levels of culture. On the contrary, Larder *et al.* (2001), Parker *et al.* (2006) and Westrum (1993) proposed a developmental hierarchy, describing several phases of increasing safety culture. Building on these approaches, Zohar and Hofmann (2012) suggest that organisational climate has multiple coexisting climates in an organisation as depicted in Figure 31. They propose an integrative framework positioned at understanding the deep layer of organisational culture than is commonly assumed. The nature of these organisational culture relationships between coexisting climates can be categorised into three groups, namely; [1] independent, [2] interactive and [3] causal effects.

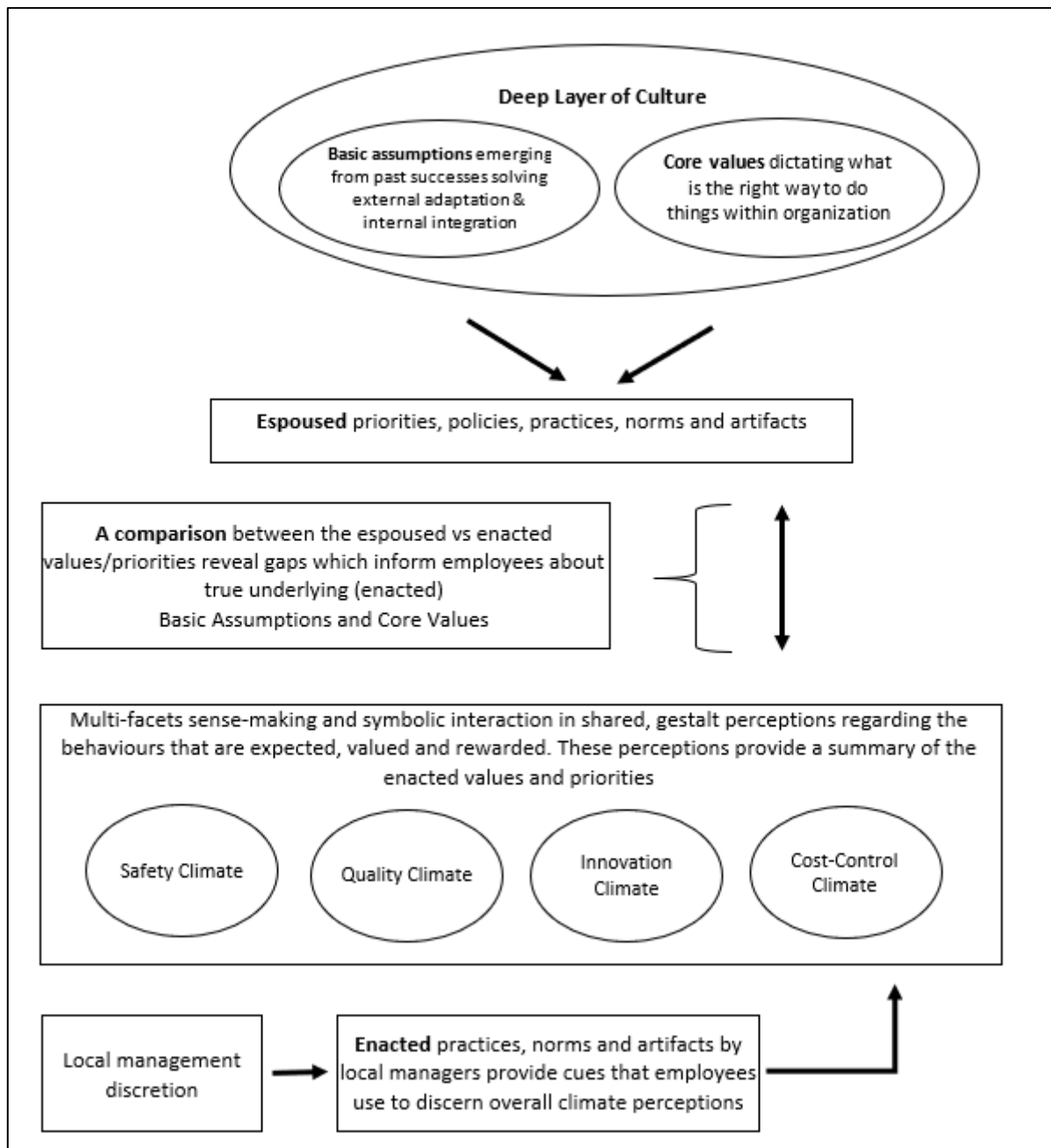


Figure 31. Graphical representation of theoretical model (Zohar and Hofmann, 2012)

Figure 32 presents an adaptation of the earlier work conducted by Guldenmund (2010) whilst examining safety culture and climate. The first column contains the three main elements or layers; [1] artefacts (the what?), [2] espoused values (the why?) and [3] basic assumptions (underlying shared beliefs regarding safety). Artefacts are typically readily visible but are in practice quite difficult to understand in terms of underlying culture. However, they play a significant role toward creating the correct climate. The espoused values advocate the artefacts imposed and are more pivotal in maintaining the correct safety climate. Actions also need to be followed through to enable the correct basic assumptions of a safety culture. This compared to the work by Schein

(1983) as previously discussed. An effective safety management system (SMS) is at the centre of assessing a safety culture. Guldenmund (2010) and Reason (1997) suggest that the secret of success, lies with the establishment of such a working system, which is often attributed to safety culture.

Levels of culture	Visibility	Examples
1. Outer layer – artefacts	Visible, but often hard to comprehend in terms of an underlying culture	Slogans/ logos, buildings, dress codes/ personal protective equipment, posters/ bulletins, reports (accident, incident, inspection), minutes, training manuals, job descriptions, procedures, celebrations, rituals
2. Middle layer – espoused values	(Relatively) explicit and conscious	All spoken statements/ justifications, attitudes* (e.g. as determined through surveys), interview and focus group data, ambitions/ intentions, all perceptions
3. Core – basic assumptions regarding: 1. The nature of reality and truth 2. The nature of time 3. The nature of space 4. The nature of human nature 5. The nature of human activity 6. The nature of human relationships	Mainly implicit: • Obvious to the members • Invisible • Pre-conscious	Have to be deciphered from artefacts and espoused values

Figure 32. Framework for safety culture (Guldenmund, 2010)

Guldenmund (2000) found that assessing the safety attributes or safety climate through questionnaires was the second part of the safety culture assessment approach. From this study two safety culture alternatives were recommended, namely; [1] change the basic assumptions, or [2] change the safety attitudes. The latter being the more feasible choice, albeit requiring a significant transition period. To achieve this transition, one first needs to know where one lies on a safety culture scale.

Historical climate research suggests, a long-held proposition, that leaders create climate (Lewin *et al.*, 1939). This notion has not changed since. Zohar (2010) reviewed literature from over 30 years ago, either based on scholars or his own work, on validating safety climate as a robust leading indicator or predictor of safety outcomes. He concluded that the next phase of scientific inquiry is upon us and that constructs should be augmented to test relationships between antecedents, moderators, and mediators, including other established constructs. Although Leadership was found to remain as a climate antecedent, more research is required to augment safety climate theory. Zohar (2010) suggests three areas of inquiry; [1] safety climate perception targets, [2] level adjusted analysis across an organisation and [2] level-specific subscales to enhance measurement sensitivity and conceptual rigor.

Hudson (2007) developed a safety culture ladder to allow an organisation to assess its safety maturity level. Upon knowing a safety maturity level, an organisation can then take the necessary steps to successfully climb up the ladder. This approach consisted of five stages from the pathological to generative, which is the weakest to strongest culture as depicted in Figure 33. These stages are the foundation for the journey to PSM implementation depicted by Den Bakker (2012) in Section 1.2, Figure 6.

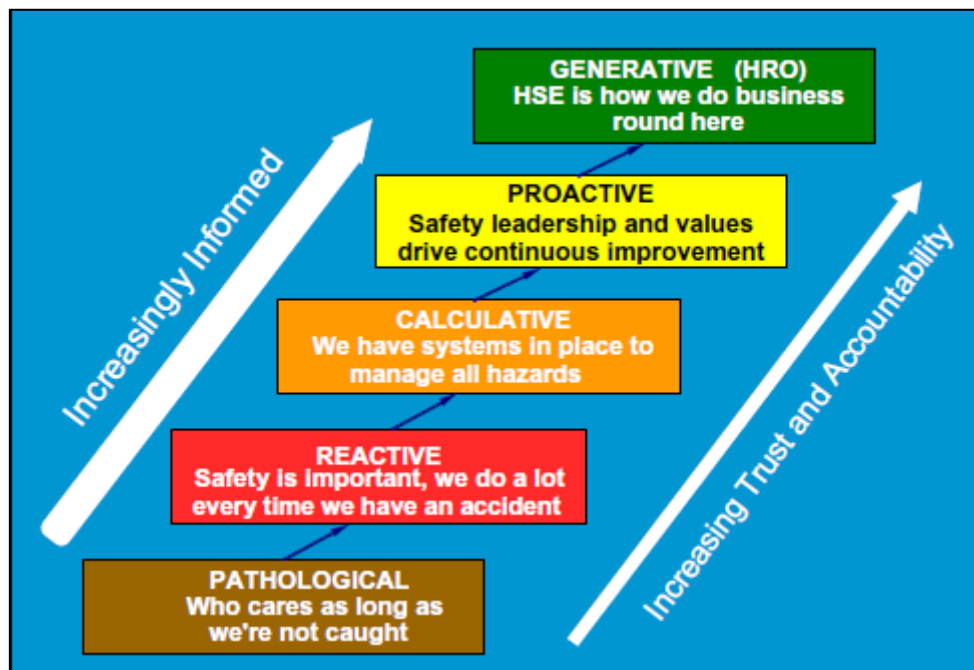


Figure 33. Safety culture ladder (Hudson, 2007)

Once this baseline safety culture assessment is completed, the next step will be to develop a safety culture improvement plan. When Reason (1997) described how to engineer a safety culture, he proposed these five elements of an effective safety culture:

1. Safety information system collects, analyses, and disseminates information from near misses and incidents, including frequent proactive inspections.
2. Reporting culture where people openly report errors, mistakes, and violations.
3. Culture of trust where people are encouraged and even rewarded to provide essential safety information. A clear line between acceptable and unacceptable behaviour is drawn.
4. Flexible in terms of ability to reconfigure the organisational structure in the face of a dynamic and demanding task environment.
5. Willingness and competence to draw the right conclusions from its safety system and implement corrective measures when required.

Ertuğrul (2015) found that safety culture is influenced by all layers in an organisation, stating that, *“a workforce which is convinced that the organisation fully supports process safety as a core value will tend to do the right things, in the right ways, at the right times – even when nobody is looking.”*

The organisation was divided into four tiers, from workplace all the way up to executive management. An organisation’s philosophy, policy, procedures and practice of unsafe acts formed the key aspects to each respective tier as illustrated in Figure 34.

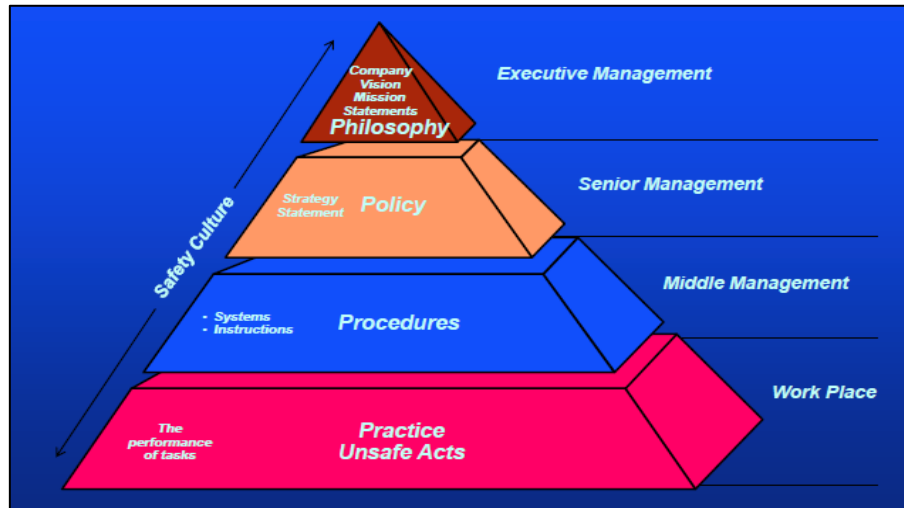


Figure 34. Safety culture impacts at all levels of the organization (Ertuğrul, 2015)

Safety culture is not just a top-down approach from executive management, but rather it is the holistic involvement and engagement from each workforce layer that contributes toward sustaining a safety culture.

The safety culture is the attitude of the work force and leadership. To put this into perspective, you could drive down a road that you know has no fixed speed traps and no law enforcement officials behind bushes. Eventually you realise that it is waste of time to stick to the speed limit, and so you normally excessively exceed this road’s speed limit day in and day out. So, essentially a safety culture boils down to what you do when no one is looking. If safety was truly embedded, then you would stick to the speed limit day in and day out, even when everyone else is not.

After understanding the differences between safety climate and safety culture, you are probably thinking that you perhaps may have been guilty of the aforementioned. Now the challenges to transform a working culture into a safer one become more apparent. Psychologists would say that you need to understand the employee mind-set and that’s in its own right a challenge. Your company is not in the business of psycho analysis, your primary game is to produce a commodity and generate revenue, oh and keep safety under control.

Mearns (2017) reviewed twenty-six safety climate studies from 2001 and identified the most common themes. Management commitment was discovered to be the foundation to healthy safety climate, followed by personal involvement, safety practices, training and communication.

Therefore, management commitment and personal involvement of operations personnel in safety should be a part of the manufacturing process from start to end. Having an embedded safety system will result in employees practicing safety unconsciously.

Similarly, to Reason (1997), Geller (2001) developed a model for total safety culture based on eleven principles, depicted in Figure 35. These principles were to serve as the foundation for a safety culture initiative. Geller's (2001) approach emphasized the importance of a two-prong engagement channel between the work force and the senior management teams.

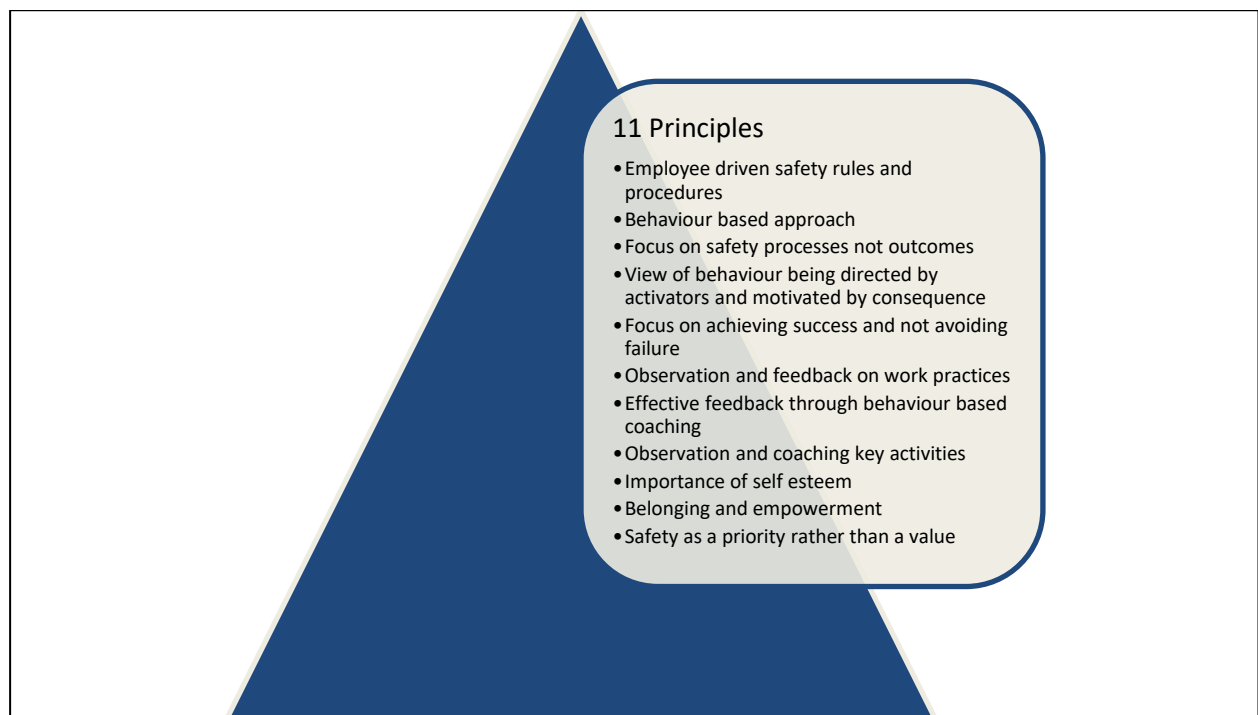


Figure 35. Adapted from Safety Culture Principles (Geller, 2001)

Cooper (1999) proposed the Reciprocal Safety Culture model, which revolved around three dependant elements: [1] person, [2] situation and [3] behaviour. This model emphasized that safety cultures could be quantified by examining the interaction between employees' safety perceptions, employees' actual safety behaviour and safety management systems. Three dimensions dominate this assessment: safety climate, safety management system and behavioural, as seen in Figure 36.

Mitchell's (2016) human performance model was also composed of three aspects, namely: person, job and organisation. However, Cooper's (1999) model is definitely more complex possessing an iterative methodology.

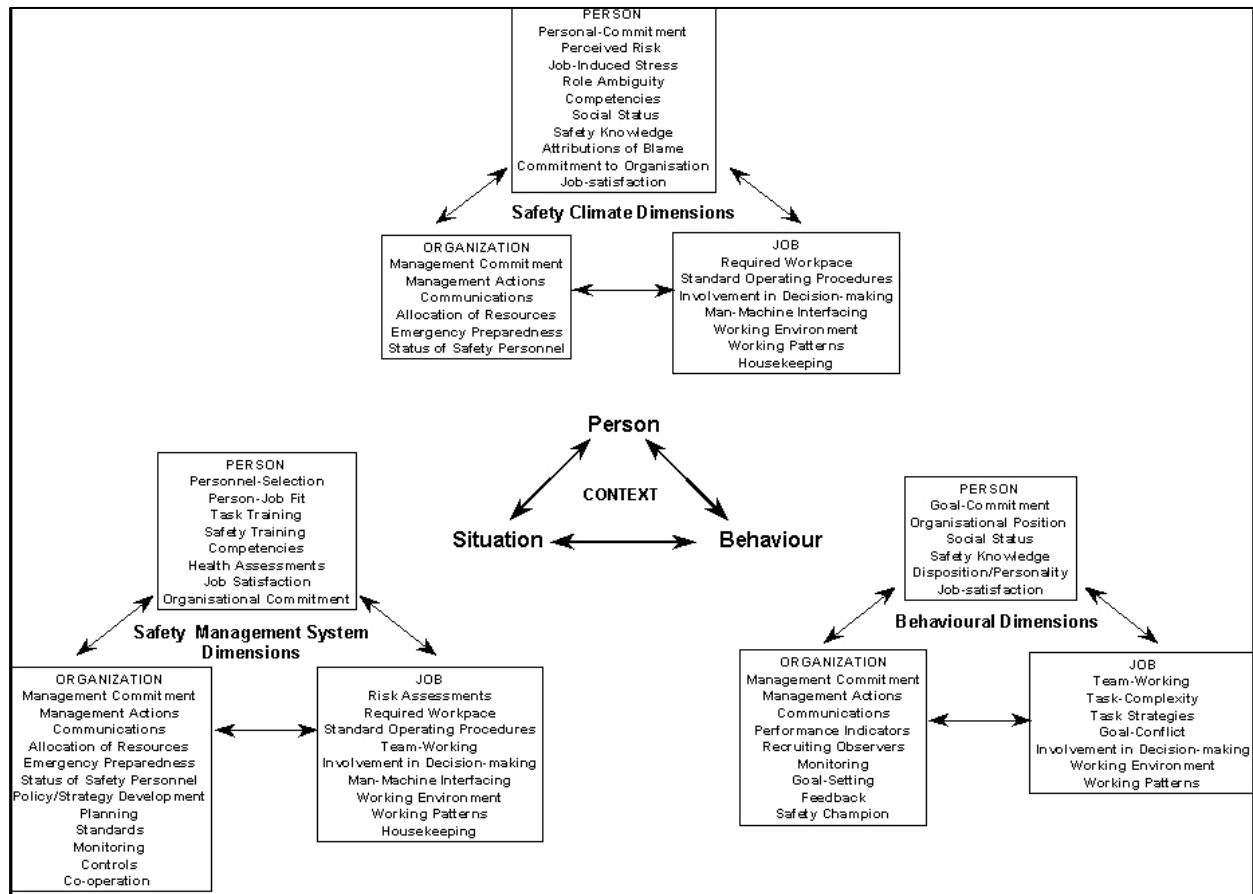


Figure 36. Reciprocal Model of Safety Culture (Cooper, 1999)

After ADI's (Agnew, 2015) extensive experience in the safety culture arena, they presented seven keys to an effective safety culture, as seen in Figure 37. These keys resemble Geller's (2001) eleven principles with some of these themes overlapping.

Driving out fear and celebrating success were found to be new concepts. Fear was suspected to diminish health reporting of incidents. So, if this is addressed, an improved incident reporting would result. The celebration of successes achieved creates a sense of acknowledgement and gratification for work expended. This creates a healthy working environment.

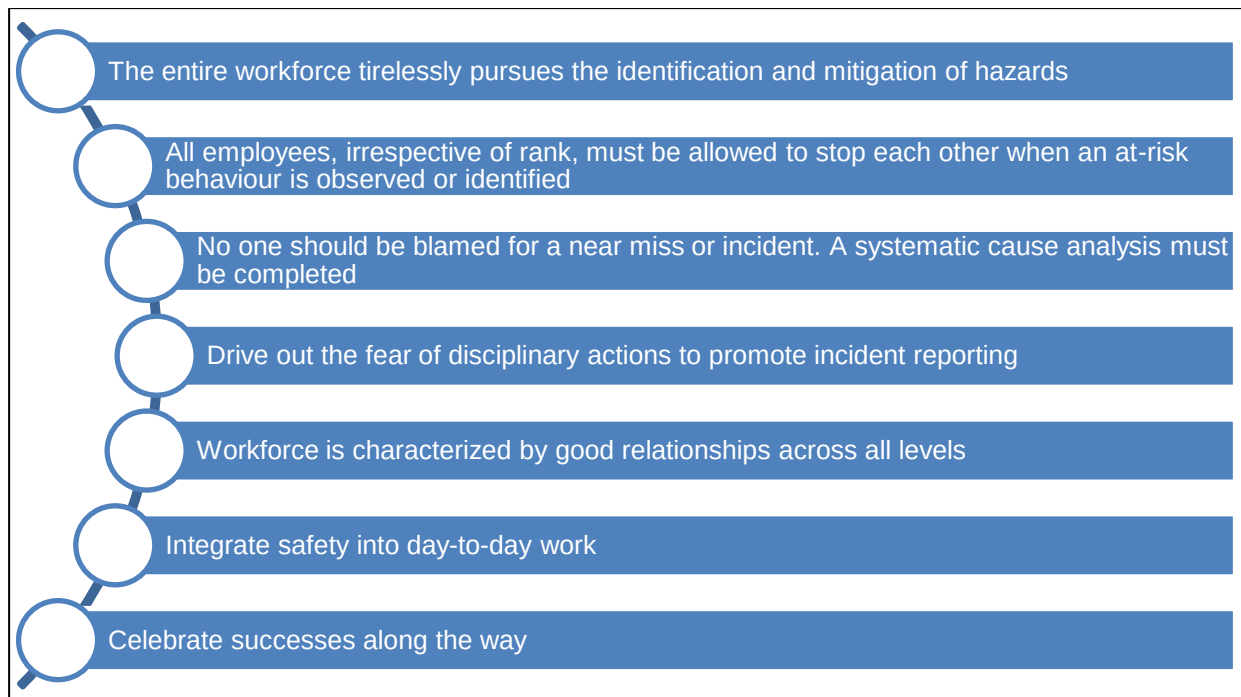


Figure 37. Adapted from Seven keys to an effective safety culture (Agnew, 2015)

CPWR (Hecker *et al.*, 2014) are dedicated to the improvement of the culture and safety climate in the construction industry through research and training. They identified six of these key factors for safety climate that amount to overall safety climate improvement, as seen in Figure 38.

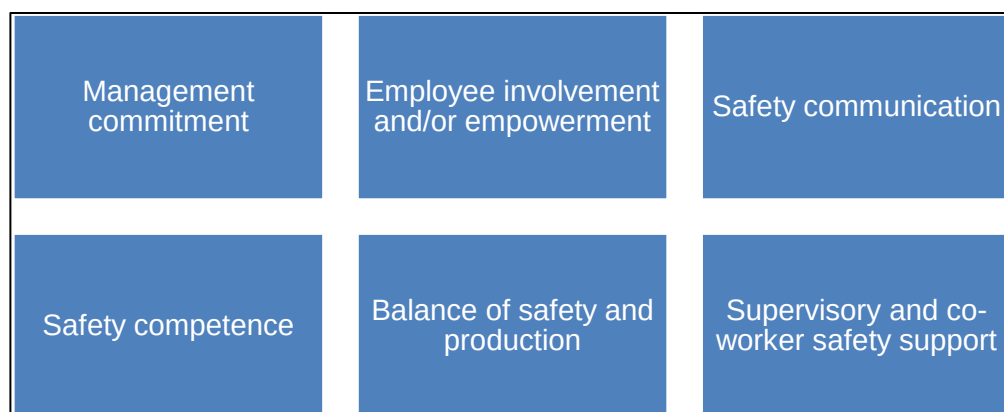


Figure 38. Adapted from Key safety climate factors (Hecker *et al.*, 2014)

The Institution of Engineering and Technology (IET) (2017) investigated various studies into safety culture and discovered five strong factors characteristic of a positive safety culture, as shown in Figure 39. Visible leadership prioritize decisions on safety, competent workforce, effective communication and continuous improvement are the key characteristics, which echo the Hecker *et al.* (2014) factors.



Figure 39. Adapted from Factors characteristic of a positive safety culture (IET, 2017)

The Institution of Occupational Safety and Health (IOSH) (2003) has global presence and state that there are three key elements characteristic of a positive safety culture, as seen in Figure 40. Continuous improvement, clear rules and compliance form the basis of this approach, which seems to also resemble Geller's (2001) principles.



Figure 40. Adapted from Elements characteristic of a positive safety culture (IOSH, 2003)

There are numerous safety climate and culture surveys, each with their own merit. IOSH (2003) recommend seven factors to include in safety climate surveys factors as depicted in Figure 41. These seven factors are unpacked from the three safety culture elements proposed above.

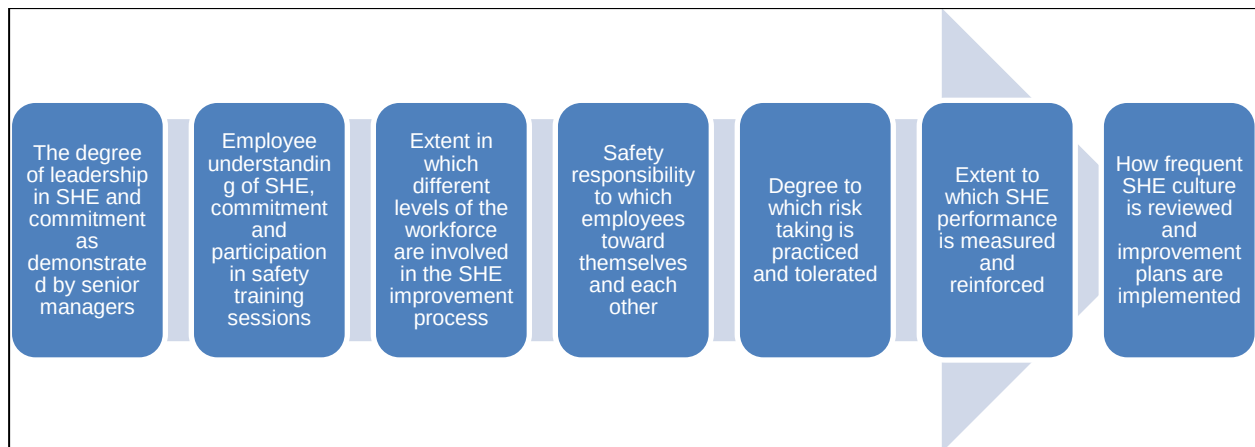


Figure 41. Adapted from Safety climate survey factors (IOSH, 2003)

Human factors specialist Mearns (2017) examined external influences and discovered eight factors that impact safety culture, which is depicted in Figure 42. Business, regulatory, organisational and socio-political environments are strong contributors to climate factors. Whereas organisational history, national culture, worker characteristics and work and technology are strong contributors to culture factors. The landscape in which one operates significantly influences safety culture programs. Mearns (2017) also proposed the usage of a questionnaire-based checklist to evaluate an organisation's safety culture position.



Figure 42. Adapted from External influences impacting Safety Culture (Mearns, 2017)

Quayzin (2012) investigated ten safety incidents that spanned seven different industries and the impact safety culture played. Findings from this study indicate the organisational culture generally has a strong resilience, and that transformation is achievable by repeated effort from leadership. Figure 43 depicts the integration of his findings into a Leadership and Safety Culture Organizational model. This model incorporates many of the elements from other proposed models. Human resource management and financial and investment strategy are new elements proposed.



Figure 43. Leadership and Safety Culture integration (Quayzin, 2012)

The governing safety body in Australia (S.I.A, 2014) also supports an organisational change methodology, which embeds safety into practices that have direct and immediate impacts on workplace safety.

Reason (1998) a foremost authority on behavioural sciences, suggests that one should equate safety culture to an informed culture. In essence, it is where the employees within an organisation understand and respect the hazards within their operations and are cognizant of ways in which the safety systems can be ineffective. The key pillars of this approach include a healthy and transparent reporting system coupled to a robust and fair consequence management system.

Cooper (2016) a pioneer in the UK on behavioural safety, investigated the application of a safety culture construct in preventing process safety incidents resulting in catastrophic consequences. His work concluded that the sole use of psychological factors, namely safety culture surveys, as a representation of safety culture is fatally flawed. He affirmed that organisations should rather concentrate efforts on situational and behavioural factors. Similarly, these factors include the application of integrated safety management systems and managerial safety influencing behaviours as indicated in Figure 44.

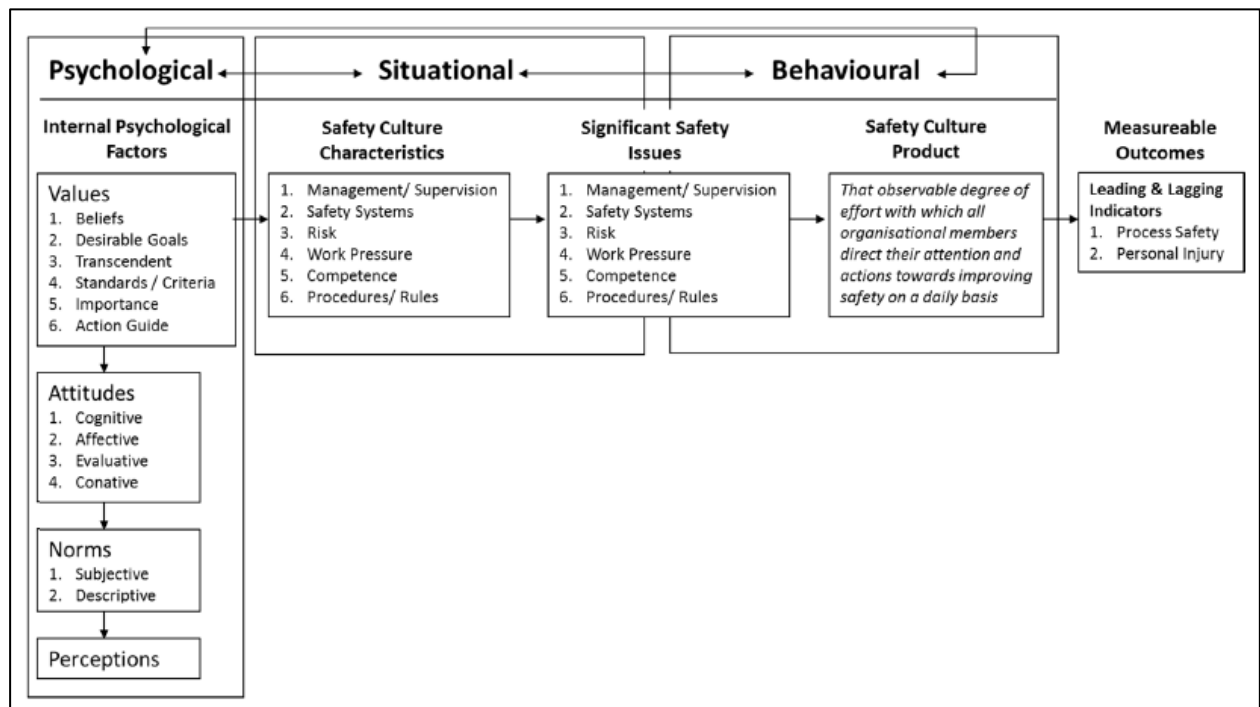


Figure 44. Cooper's construct applied to the Reciprocal Safety Culture model (Cooper, 2016)

Vu and De Cieri (2015) reviewed fifteen well publicised key fundamental theories and conceptual models of safety culture and climate measurement from 1978 to 2005. They proposed two main approaches: a model-based approach or a pragmatic approach. The model-based approach uses a framework to guide the development of a safety culture measure. Most of the models reviewed was based on this approach as it enables one to define potentially relevant variables for measurement. Whereas a pragmatic approach uses elements of different conceptual models and theories of safety. This approach is more flexible and allows one to measure vastly different aspects in a safety culture.

Fleming and Scott (2011) prepared a regulatory guide to the Canadian Offshore Petroleum Boards on safety culture and leadership. They reviewed different safety culture models and identified common themes, which is illustrated in Figure 45. Their work concluded that an organisation or regulator should adopt a conceptual model or framework and an approach to

assess safety culture. Six elements form the basis of this framework: [1] safety value, [2] safety leadership, [3] safety integration, [4] safety accountability, [5] resiliency and [6] safety learning.

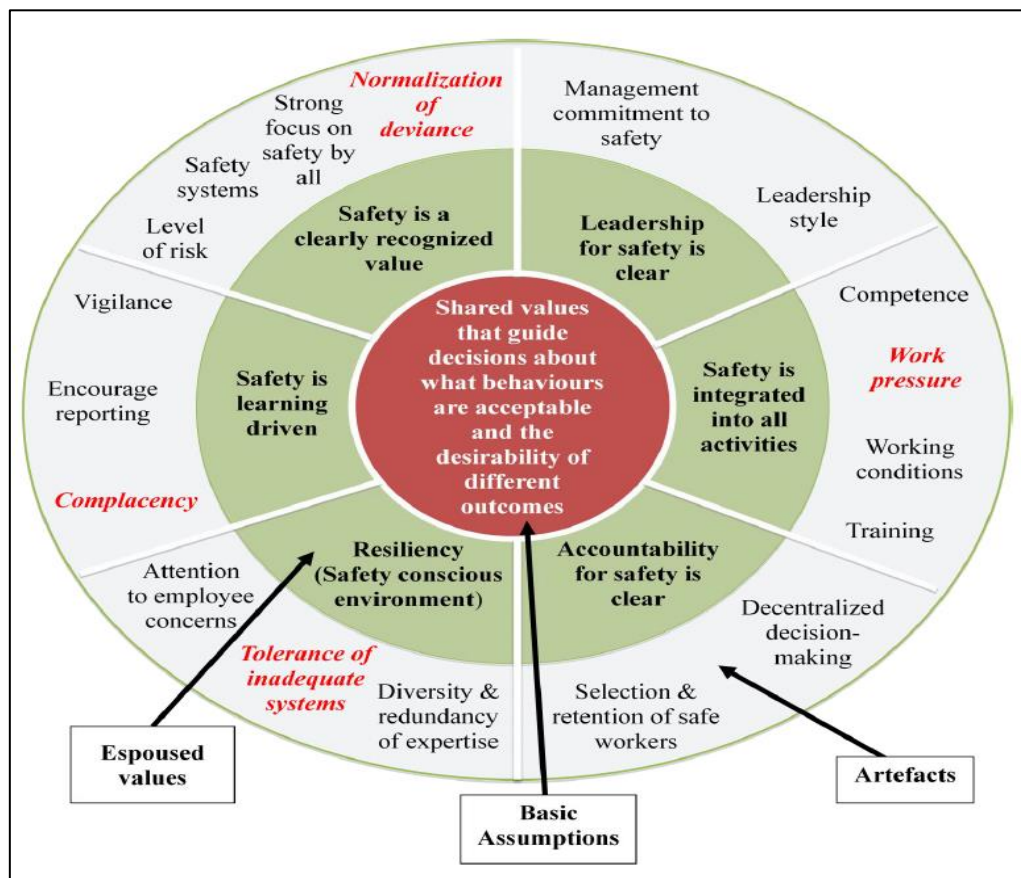


Figure 45. Multi-dimensional safety culture framework (Fleming and Scott, 2011)

The Australian Roads and Maritime Services (RMS) (2017) safety leadership and culture program provides guidance on building a mature safety culture. Effective safety leadership was considered as the major contributor to the development of a mature safety culture. They consider five key indicators, as depicted in Figure 46: [1] management commitment and leadership, [2] reporting and learning culture, [3] worker involvement, [4] just and fair culture and [5] risk awareness. These indicators were found to directly influence one another, and their relationships are as follows (RMS, 2017):

- The level of [3] worker involvement will influence the [2] reporting and learning.
- The level of [2] reporting and learning will affect the level of [5] risk awareness.
- The level of [4] just and fair culture will influence the extent of [2] reporting and learning.



Figure 46. Adapted: Key indicators for a safety culture (RMS, 2017)

Petroleum Safety Authority Norway (PSAN) evaluated principals to encourage a sound and healthy safety culture. There are four pillars to their approach (PSAN, 2002): [1] reporting culture, [2] just culture, [3] flexible culture and [4] learning culture. A just culture refers to the way in which an organisation systematically and repeatably handles consequences management. A flexible culture refers to the ability in which an organisation can implement improved procedures or optimised systems. This closely resembles the approaches prescribed by Reason (1998) and also echoed by Carrol (2013). Carrol (2013) illustrates how poor diagnosis leads to poor fixes and ultimately failure, as seen in Figure 47.

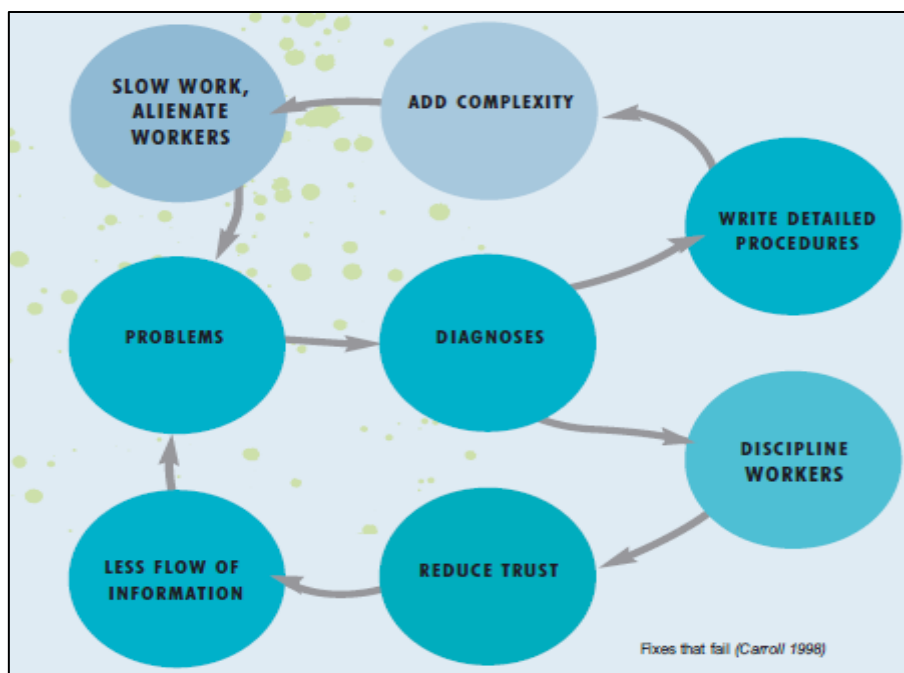


Figure 47. Fixes and fails as barriers in safety culture is often this that is applied (Carroll, 2013)

Foster and Houlth (2013) developed a Safety Maturity Model for the UK Coal Mining Industry. Using this self-assessment model as a baseline, the level of compliance and effectiveness of the safety management system was determined. After establishing the level of maturity, improvement plans were implemented where weaknesses were identified. The foundations of their model were based on the Minerals Industry Risk Management (MIRM) Maturity Chart, which was developed by the University of Queensland, as illustrated in Figure 48. This MIRM maturity chart consists of five levels. It closely resembles Hudson's (2007) safety culture ladder with its five stages.

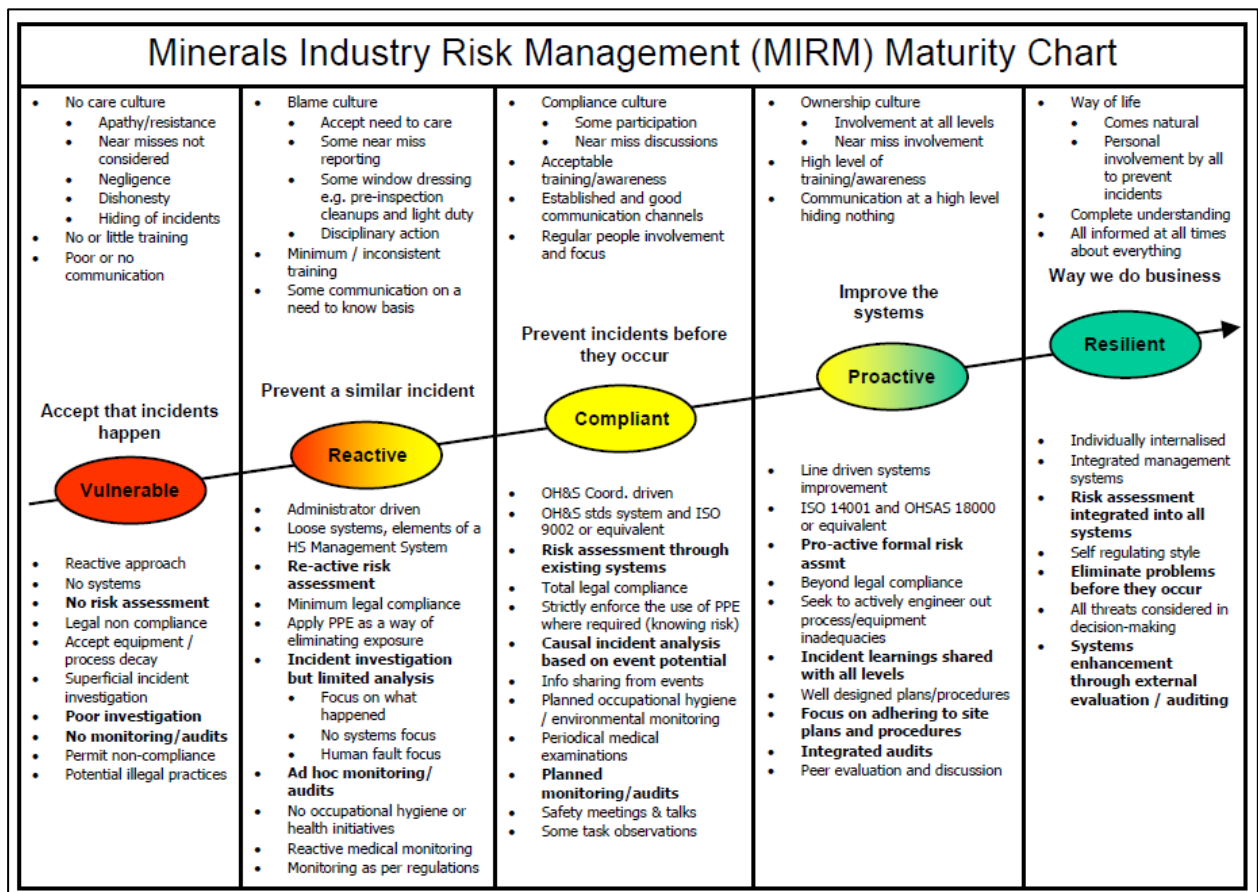


Figure 48. Minerals Industry Risk Management (MIRM) Maturity Chart (University of Queensland, 2008)

These five levels from lowest to highest are: [1] vulnerable, [2] reactive, [3] compliant, [4] proactive and [5] resilient. New safety management systems are thought to be at the vulnerable level. Existing average safety management systems are thought to be at the compliant level. Forward thinking and successful safety management systems are thought to be at the resilient level. Therefore, all safety management systems should aspire to be at the resilient level and continue to sustain that position.

Coupling the Anglo American Plc maturity model to this model, Foster and Houlth (2013) created a maturity model question set, based on the five stages of this MIRM chart. Questions are tailored

to the organisation's safety management system and incorporate geographical location constraints. Corrective actions with targets are devised after the assessment, and once sustained another self-assessment is administered to calibrate the new baseline. Through this iterative process, an organisation's safety culture would improve, progressing from a vulnerable to reactive and so forth.

Vecchio-Sadus (2007) from CSIRO Process Science and Engineering believes that safety culture can be enhanced through effective communication. Her work was validated by a case study in which an organisation decreased its injury performance through a variety of safety communication techniques. Apart of this study, many safety culture communication elements were reviewed. The fundamental communication elements were identified by Vecchio-Sadus (2007), along with its respective safety culture element attribute, which is depicted in Table 12. Effective communication mechanisms are critical to enable employee engagement in safety activities. Such mechanisms should complement the practical and technical safety strategies. Their improvement steps for safety communication are shown in Figure 49. Vecchio-Sadus (2007) safety communication improvements align with the safety culture framework proposed by Lardner *et al.* (2011), depicted in Figure 50. Lardner *et al.* (2011) provided more detail including specific requirements from key role players. This was deemed valid and reliable as it was tested practically and achieved improved safety culture ratings coinciding with improved process and occupational safety performance.

Table 12. Safety Culture Communication Elements (Vecchio-Sadus, 2007)

Safety Culture Element	Requirement	Communication Element
Putting in place methods for controlling hazards	Everyone shows support	Displaying rules and procedures to remind everyone to work safely
Management commitment to minimising risks in the operations, and complying with all relevant health and safety legislation	- Accept responsibility for HSE - Become involved in HSE - Provide resources - Change attitude to risk	- Demonstrating the employer's personal commitment, values and expectations - Supervising and monitoring work performance
Employees contribute most effectively in an organisational culture based on trust and cooperation	Atmosphere of trust, encouragement and reward in terms of HSE	- Assessing competency and providing revision of training when required - Providing feedback on HSE - Motivating staff - Recognising and rewarding achievement
Employees must be provided with the necessary information and training to broaden their knowledge and to gain new skills to behave and operate safely	Willingness and competence to implement reforms and changes	Providing instructions on how to work safely with equipment, tools, materials and processes
Employees contribute most effectively in an environment that provides a framework for consultation and communication	Individuals encouraged and prepared to report errors and near-misses	Meeting to discuss HSE issues such as hazard and incident reports, risk assessments and operating procedures

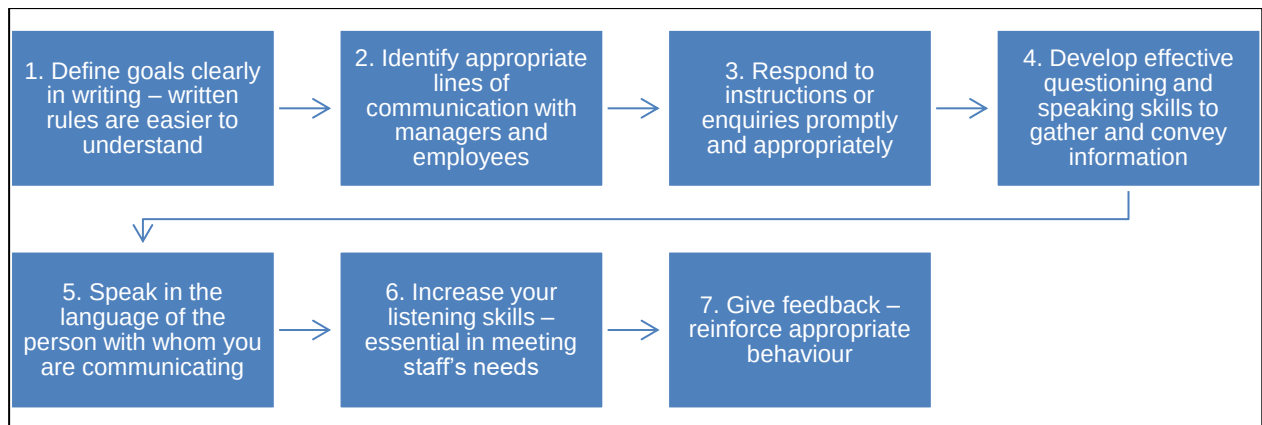


Figure 49. Adapted from Improve safety communication (Vecchio-Sadus, 2007)

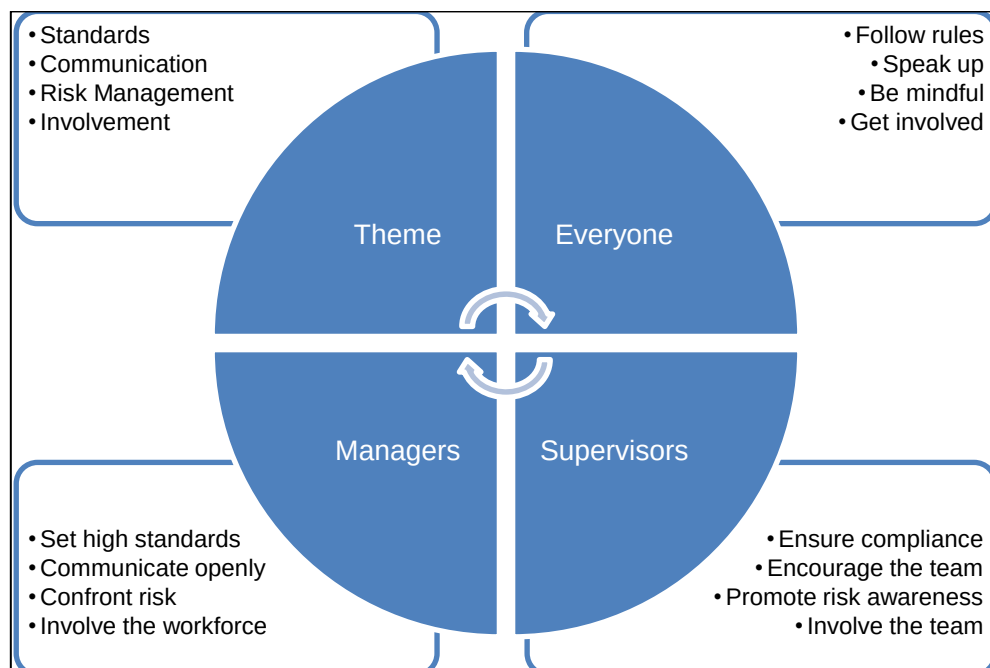


Figure 50. Adapted from Overview of a safety culture framework (Lardner *et al.*, 2011)

Lipe (2012) describes leadership strategies for building and sustaining a culture of safety. A safety program is required to drive the safety culture within an organisation. Figure 51 illustrates that a safety program has a lifespan. After overcoming the initial resistance which humans naturally exhibit, a safety program will yield great results. This is classified as the Acceptance and Integration Phase, where active participation and commitment to the safety program is displayed. Eventually the active participation and commitment drive slowly declines, and this is where Lipe (2012) suggests reinventing the safety program to create drive once again. This only buys the safety program a little extra time before it becomes obsolete. Before this happens, a new safety program should be on the table to create drive once again.

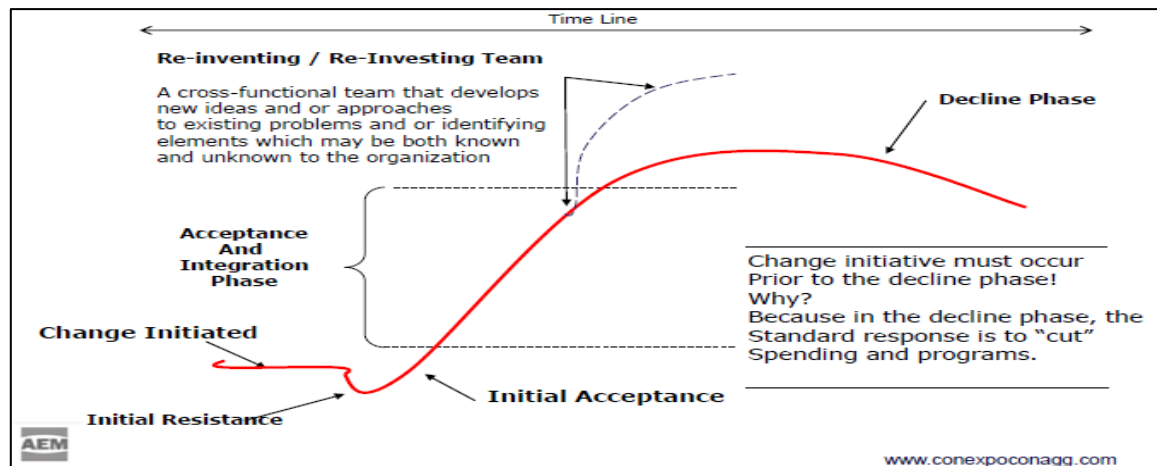


Figure 51. The dynamic curve of change (Lipe, 2012)

Beukes (2015) a safety management system specialist, proposed a phased change implementation strategy to improve safety culture. His approach considered the characteristics of a healthy safety culture as well barriers and challenges. This seven phased change implementation strategy, is depicted in Figure 52. It compares well to the Keil Centre Safety Culture Maturity Model and the British Standard Institution's Management Systems Guide (Lardner, 2002). Parker *et al.* (2006) investigated a framework for understanding the development of organisational safety culture through interviews with twenty-six very experienced oil and gas company executives. Their study focused on the Hudson's (2007) safety culture ladder model: pathological, reactive, calculative, proactive and generative phases and focused concrete and abstract questioning on the following themes, as shown in Figure 53.

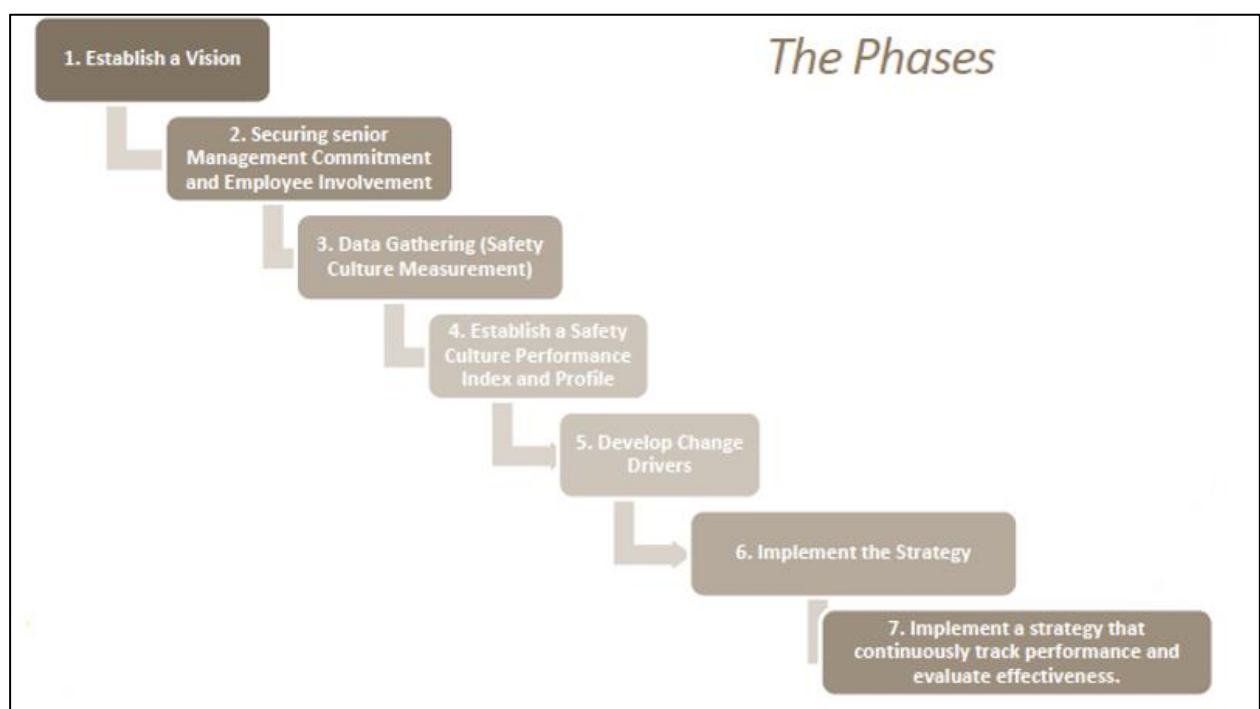


Figure 52. Seven Phased Change Implementation Strategy (Beukes, 2015)

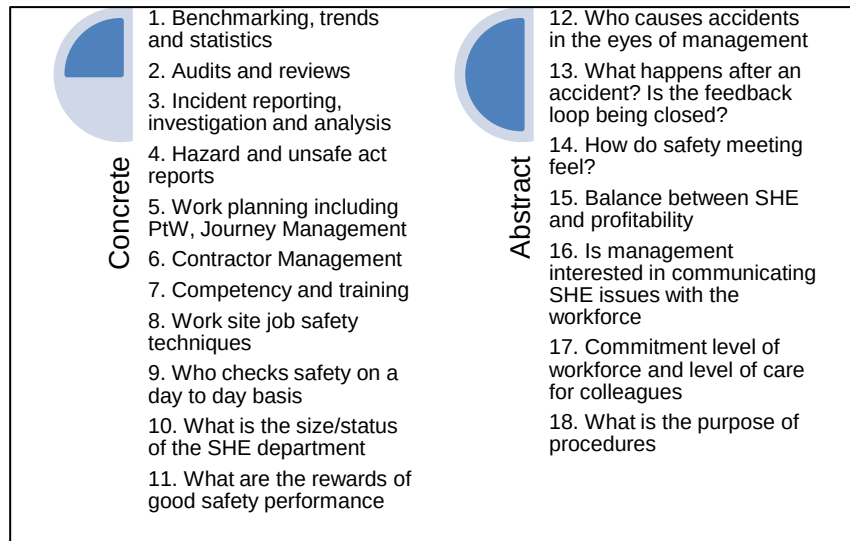


Figure 53. Adapted from Concrete and abstract questioning themes (Parker *et al.*, 2006)

NOPSEMA (2013) analysed interview transcripts and identified four common themes in relation to the elements of a safety culture: [1] leadership, [2] people, [3] systems and [4] communication. Each theme has very diverse content which led to the development of many subthemes. Naturally, relationships were drawn between themes and subthemes. These themes, subthemes and relationships essentially form the elements of a safety culture, displayed in Figure 54.

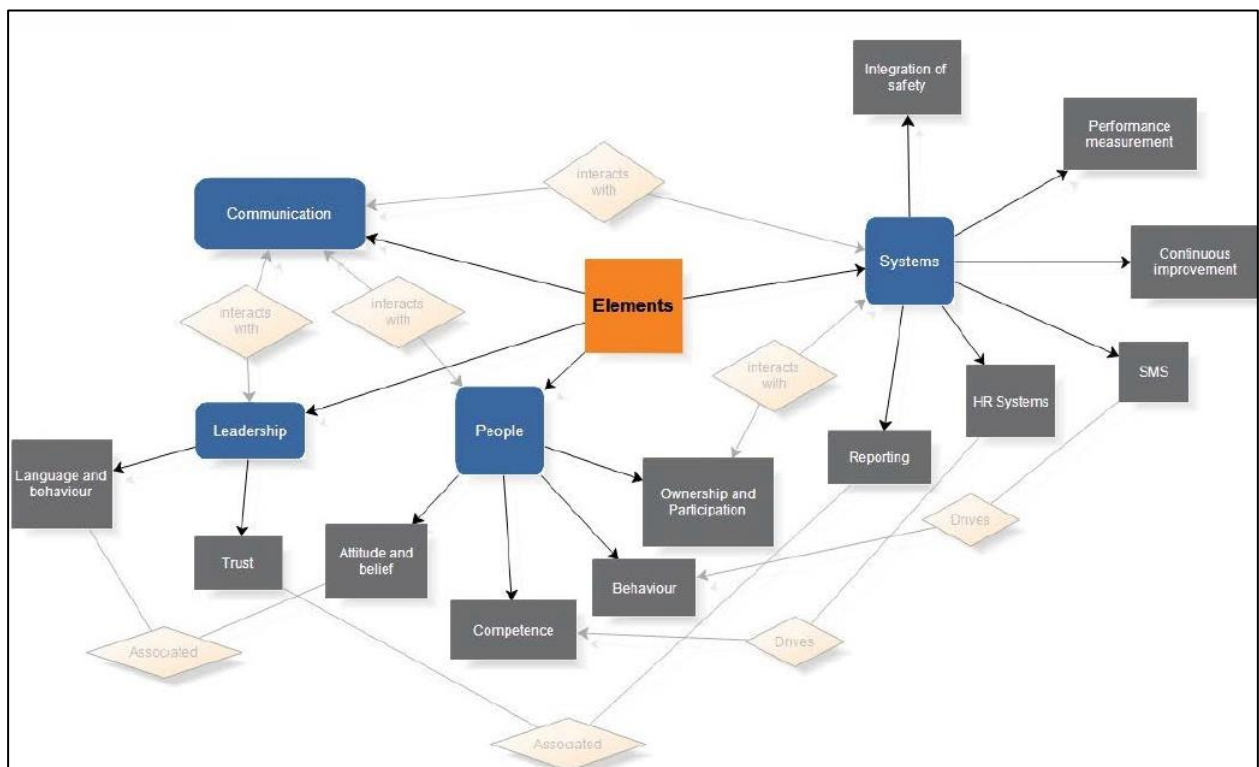


Figure 54. Conceptual model of safety culture (NOPSEMA, 2013)

The state of Queensland developed a guidance document to assist organisations in the understanding and development of their safety culture. They insist that “*strong leadership and management commitment is directly related to safety performance as it demonstrates by example to employees what actions will be rewarded, tolerated or punished, which in turn influences what actions and behaviour employees initiate and maintain*” (The State of Queensland, 2013). They developed a Construction Safety Competency Framework consisting of nine culture actions, as listed in Table 13.

Table 13. Adapted from Construction Safety Competency Framework (The State of Queensland, 2013)

1. Communicate company values
• Relate behaviours, decisions and attitudes that are expected, supported and valued by the company
2. Demonstrate leadership
• Act to motivate and inspire others to work towards achieving a particular goal or outcome by sending clear and consistent messages about the importance of work health and safety
3. Clarify required and expected behaviour
• Clarify to immediate employees the specific behaviours required and expected of them
4. Personalise safety outcomes
• Make work health and safety more obvious, relevant and emotional for individual to personalise their role in preventing and eliminating risks and hazards
5. Develop positive safety attitudes
• Foster the development of attitudes and beliefs that support safe behaviour
6. Engage and own safety responsibilities and accountabilities
• Increase input, actions and involvement in the safety management process by individuals
7. Increase hazard/risk awareness and preventative behaviours
• Increase the individual's understanding of the work health and safety outcomes associated with their decisions, behaviours and actions
8. Improve understanding and effective implementation of safety management system
• Enable individuals to increase their knowledge of specific ways in which hazards are managed, as well as their ability to apply and implement the actual workplace health and safety processes
9. Monitor, review and reflect on personal effectiveness
• Frequently use various sources of information to gain feedback on the effectiveness of culture actions and other safety related behaviours

SafeCare BC (2015) developed a Workplace Health and Safety Culture Framework, which was heavily informed by the Patient Safety Culture Improvement Tool. This framework consists of eleven levels. Again, leadership commitment and organisational learning featured. Table 14, shows its adaptation to address workplace health and safety culture whilst considering governing

legislation from Canada and Britain. They also agree that it is a multi-dimensional concept with Parker *et al.* (2006) and Mearns *et al.* (2009).

Table 14. Safety Culture Dimensions (SafeCare BC, 2015)

LEVEL	DESCRIPTION
1. Commitment to prevention and continuous improvement	Examines general commitment and attitudes towards prevention and continuous improvement, including purposes of policies and procedures.
2. Priority given to staff safety	Examines organizational priorities, as well as the role of risk management systems and the extent to which they are implemented.
3. Perceptions of the causes of staff safety incidents and their identification	Examines organizational understanding of the causes of incidents, reporting systems, and whether incidents are recognized as opportunities for blame or organizational improvement.
4. Investigating staff safety incidents	Examines extent to which incidents are investigated, how the information gathered is put to use, and timeliness of responses.
5. Organizational learning	Examines extent to which organizational learning is systematically integrated, and how change is implemented and managed.
6. Communication and consultation	Examines the extent to which there are formalized communication strategies and record keeping systems in place, as well as the degree of transparency between and within all levels of the organization.
7. Staff and safety issues	Examines organizational approach to recruitment, selection and retention of staff, including systems of support and performance appraisal.
8. Staff education and training about safety issues	Examines organizational approach to staff education, including motivation for training staff members, and extent of resources and support made available for training purposes.
9. Team and partnership working	Examines the extent to which the organization encourages team and partnership working between and within all levels of the organization.
10. Leadership commitment	Examines the extent to which leaders are trained regarding safety leadership behaviors, including interpersonal competencies, and techniques used to evaluate leadership performance (i.e., leading indicators).
11. Workload management	Examines the extent to which the organization recognizes and adheres to evidence-based staffing levels, and implements and monitors an active fatigue management plan.

2.7. The Human Mind

Understanding of the human mind supports understanding of human factors. Dr P. Calitz as introduced in Annexure C, suggested this literature review with specific investigations into the work of Wilber (1997) to understand the integral theory of consciousness.

The concept of the collective unconscious by Jung (2008) has been found to be applicable to almost all academic disciplines from mythology to religion to quantum physics, and to almost all aspects of modern life. Essentially the unconscious mind manifests inherited, universal themes which run through all human life. The collective unconscious contents are archetypes (collection

of behaviours associated with a role in society) and primordial images that reflect basic patterns that common to us all. They have existed universally since the dawn of time.

Similarly, the world channel study by Mindell (1996) implies that there are moments when one is influenced by the world around one's self, and that this is a meaningful and significant experience. Leveraging these principles to positively influence a process safety culture is more daunting. Conversely, the integral theory of consciousness by Wilbur (1997), suggests that an all quadrant, all level (AQAL) approach is the minimum degree of sophistication required to influence a culture, as depicted in Figure 55. The four quadrants being intentional, behavioural, cultural and social. Each of these dimensions unfold into many levels, and the combination of quadrants and levels yields the integral theory of consciousness that is quite comprehensive in its nature and scope.

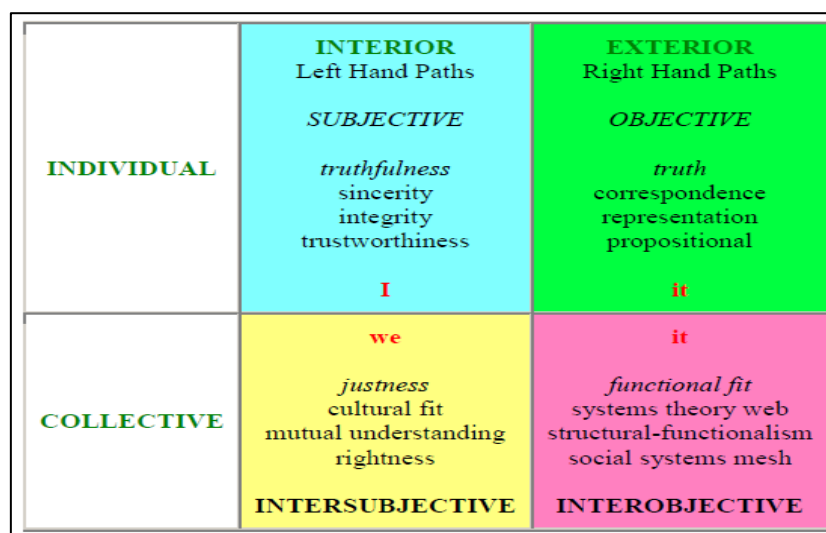


Figure 55. AQAL model (Wilber, 1997)

The individual subjective quadrant focuses on how the person feels about the task, either based on experience or perception. The individual objective quadrant focuses on the task and behaviour with consideration to methodology (how to). The collective intersubjective quadrant focuses on the economic, social and other macro systems that affect the organisation. The collective interobjective focuses on how the person experiences or interacts with the organisation and its people. Tonnesvang *et al.* (2015) expanded on Wilber's (1997) work developing fresh interpretation and observation perspectives of the quadrant model. Figure 56 depicts their work and this quadrant model was observed to be more suited for this study on positively influencing process safety culture.

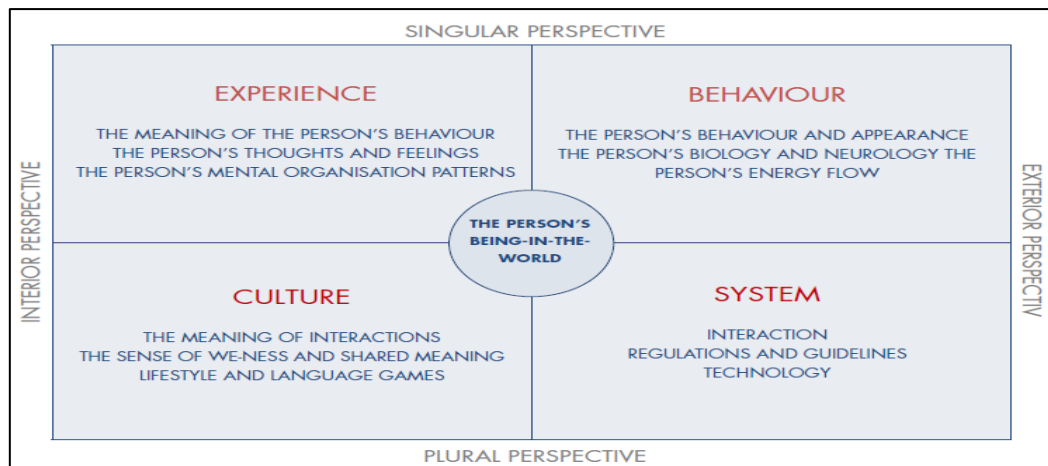


Figure 56. Four quadrants with focus on behaviour, experience, culture and system (Tonnesvang et al., 2015)

The Barrett (2016) model has two stages: seven levels of consciousness and psychological development. Together they provide a clear understanding of human motivations. It is based on Abraham Maslow's hierarchy of needs, which was developed well before the consciousness movement began. The seven existential needs are principal motivating forces in all human affairs. Values form the basis to this model, and Barrett (2016) suggests selecting values that best describes the organisation, as depicted in Figure 57. This is highly dependent on the nature of the chemical processing facility as well as its geographical location.

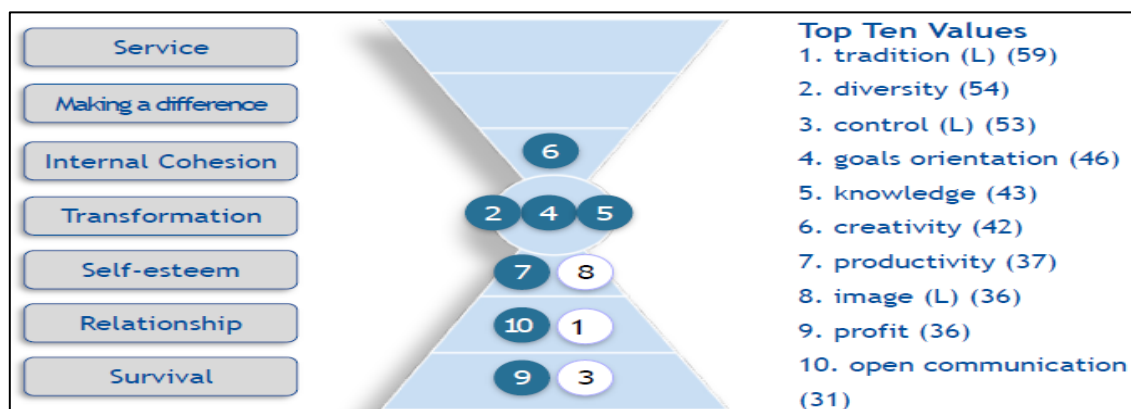


Figure 57. Building a values-driven organisation (Barrett, 2016)

Cultural entropy is the amount of energy consumed in an organisation performing unnecessary or unproductive work that does not add value, therefore preventing the organisation from operating at peak performance (Barrett, 2016). Likewise, safety capability can be defined as the capacity of an organisation to maintain safe operations through turbulent operating environments, as illustrated in Figure 58. Safety capital is generated by three other diverse capitals, namely: [1] human, [2] social and [3] organizational. Each of these diverse capitals are composed of specific elements. Casey et al. (2017) proposed four control strategies to manage and sustain safety capital, as listed in Table 15. These strategies consist of [1] energise, [2] adapt, [3] leverage

and [4] defend. The energise strategy aims to bring about new vigour. The adapt strategy entails the ease and speed in which a preventative action results upon detection of nearing an undesired event. The leverage strategy endeavours to best optimise existing systems to their full capacity. The defend strategy entails the ease and speed in which a corrective action results upon an undesired event. This is similar to the adapt strategy.



Figure 58. Organizational, Human and Social capital enabling safety capital (Casey *et al.*, 2017)

A high cultural entropy will lead to higher unproductiveness. Similarly, the lower the safety capital the lower its ability to maintain an effective PSM system. After concluding a survey, the cultural entropy or safety capital can be ascertained to guide improvement programs. Therefore, safety capital and cultural entropy are good indicators to manage and assess process safety culture sustainability.

Further investigation was conducted into cultural holons. Wilber (2001) states that the world is not composed of atoms or symbols or cells or concepts, rather it is composed of holons. Mella (2009) concludes that holon does not mean an object or concept, but rather a way of connoting objects and concept, through a vision of the world, the holonic vision. Holon is a term derived by Arthur Koestler (Mella, 2009) in his fundamental works. Koestler (Mella, 2009) endeavoured to interpret nature, the structure of dynamics of autonomous biological and social systems (typically organisations), believing that holons display the tendency for both survival and integration.

Table 15. Overview of control strategies (Casey *et al.*, 2017)

Energize	Adapt
Control measures that seek to promote safe production in a changing environment (e.g., changes in technology, the availability of supplies or resources, customer demand, competitors, organizational strategy, structure, or operating conditions). These control measures change the system boundaries to enhance efficiency and safety performance. This is done by developing a shared vision for safe production as an aspirational goal, inspiring a collective sense of purpose or commitment to these goals, providing autonomy, and involving operators in decision-making. Safety climate: Perceptions of employee consultation and involvement practices. Safety culture: Beliefs around the nature of human activity, and specifically safety initiative. The system is proactive and forward-looking with a view to exploring new opportunities and capitalizing on them to improve efficiency and/or safety.	Control measures that seek to protect against harm or economic loss in novel accident scenarios (e.g., loss of process control, hazard release). These control measures exert a counter-pressure that pulls the system operating point back into the safe zone. This is achieved by implementing well-practiced emergency routines, and adjusting procedures, practices, technology or strategy to prevent future reoccurrences. Safety climate: Perceptions of emergency readiness and error management practices. Safety culture: Beliefs about the consequences of speaking up about errors/mistakes, and the causes of accidents. The system is reactive and reflective with a view to improving future performance through exploiting current capabilities to restore safety, and ensuring the system adapts and learns from its failures.
Leverage	Defend
Control measures that seek to promote safe production in a stable and routine environment. These control measures push the system towards an optimal production/safety balance. Constraints are established through setting aspirational standards, monitoring progress, and rewarding success and accomplishment. It requires the removal of barriers or constraints that impede progress. Effective planning and coordination are hallmarks of this control strategy. Safety climate: Perceptions of safety recognition, communication, and planning practices. Safety culture: Beliefs about the nature of human relationships, particularly cooperation to achieve shared safety goals. The system is proactive and forward-looking with a view maintaining a dynamic equilibrium between safety and efficiency.	Control measures that seek to protect against harm or economic loss in a stable and routine environment. These control measures exert a force that pulls the operating state back into the safe zone and constrains variability to reduce risk as low as possible. Defend exerts control by setting and enforcing safety standards, monitoring compliance, and acting to correct deviations. The emphasis is on top-down control. Disciplinary practices aim to eliminate violations and performance variability. Safety climate: Perceptions of safety procedures and practices. Safety culture: Beliefs about the nature of rules, organizational justice, and distribution/use of power. The system is reactive and reflective with a view to eliminating sources of performance variability and resisting the pressures exerted by production and efficiency goals.

Wilber (2001) incorporated Koestler's holon theory into the Integral Model as part of its evolution. The intent was to enable the AQAL framework to focus and analyse any developmental event. The holon structured approach facilitates deeper inquest into cultural dimensions through elemental breakdown. The detection and understanding of these cultural elements greatly assist toward developing specific targeted solutions to positively influence the process safety culture.

2.8. Asset Integrity

Well maintained and reliable processing equipment reduces the likelihood of integrity failures, which ultimately may result in the occurrence of a major process safety incident. Therefore, culture dimensions in asset integrity were investigated to contribute to the development of the process safety culture framework.

Virovac *et al.* (2016) investigated human factor as a safety barrier used to prevent incidents of aircrafts. This work entailed gathering and systematisation of errors caused by human factors over a five year period. The positive effects of pro-active human factor integration in maintenance are illustrated in Figure 59 and Figure 60. Therefore, improved human factors in maintenance significantly reduces business impact and costs.

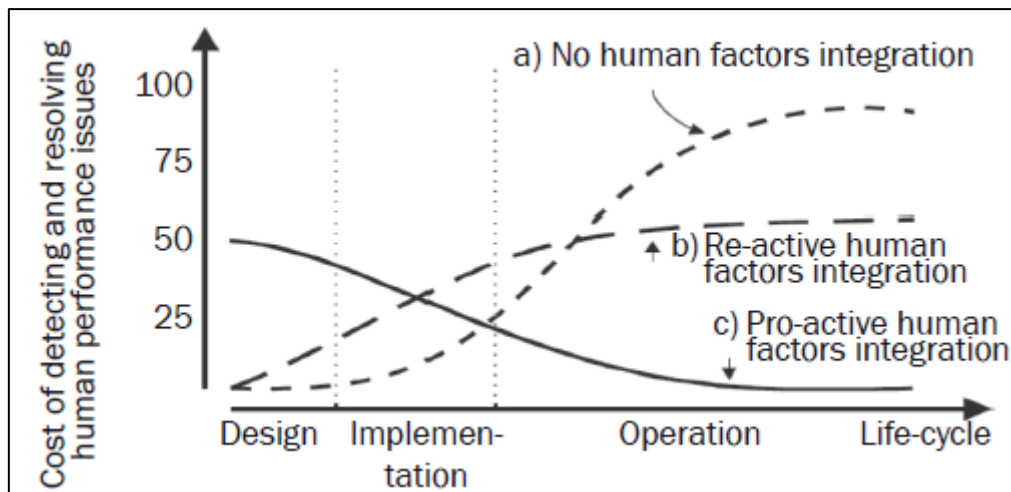


Figure 59. Cost scenarios of three different life-cycle strategies (Virovac et al., 2016)

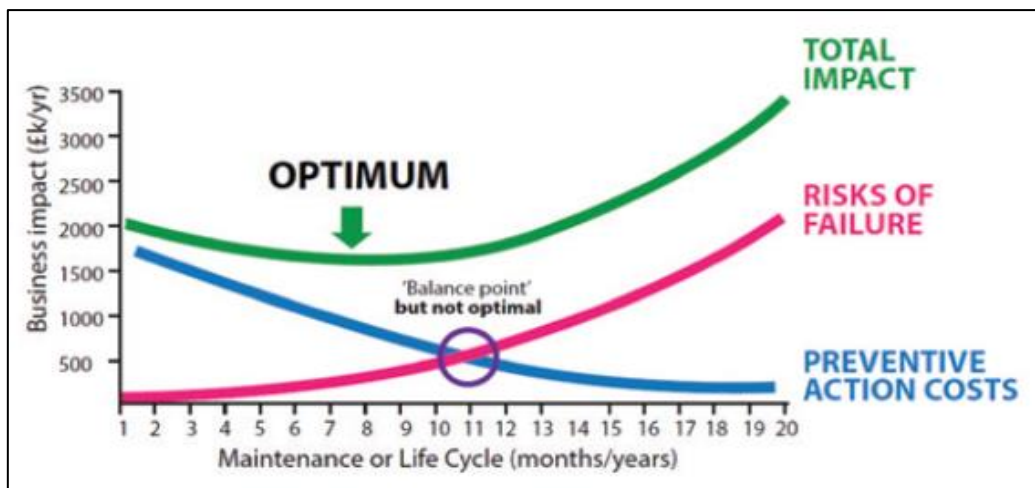


Figure 60. Optimum value achieved by optimizing total cost/risk/performance impact (IAM, 2014)

Dunn (2003) developed an asset integrity assurance process which incorporated four elements. These elements include: [1] risk, [2] environmental, [3] maintenance and [4] safety management processes. This work outlined the limitations of this process as well as an alternative asset integrity approaches toward preventing high consequence, low probability process safety events. A plan-do-check-act cycle was proposed as illustrated in Figure 61.

Kusumawardhani and Markeset (2015) identified seven groups of Asset Integrity Management (AIM) challenges. These challenges and their respective possible solutions are illustrated in Table 16. The seven challenges consist of: [1] knowledge transfer, [2] information management, [3] data transfer between onshore and offshore, [4] information technology processes and security, [5] quality of data, [6] integrated technology processes and security and [7] introducing and adapting to new technology. Knowledge management and information system practices were observed as the main challenges in maintaining the asset integrity of petroleum installations. This study focused on installations in Houston and Singapore.

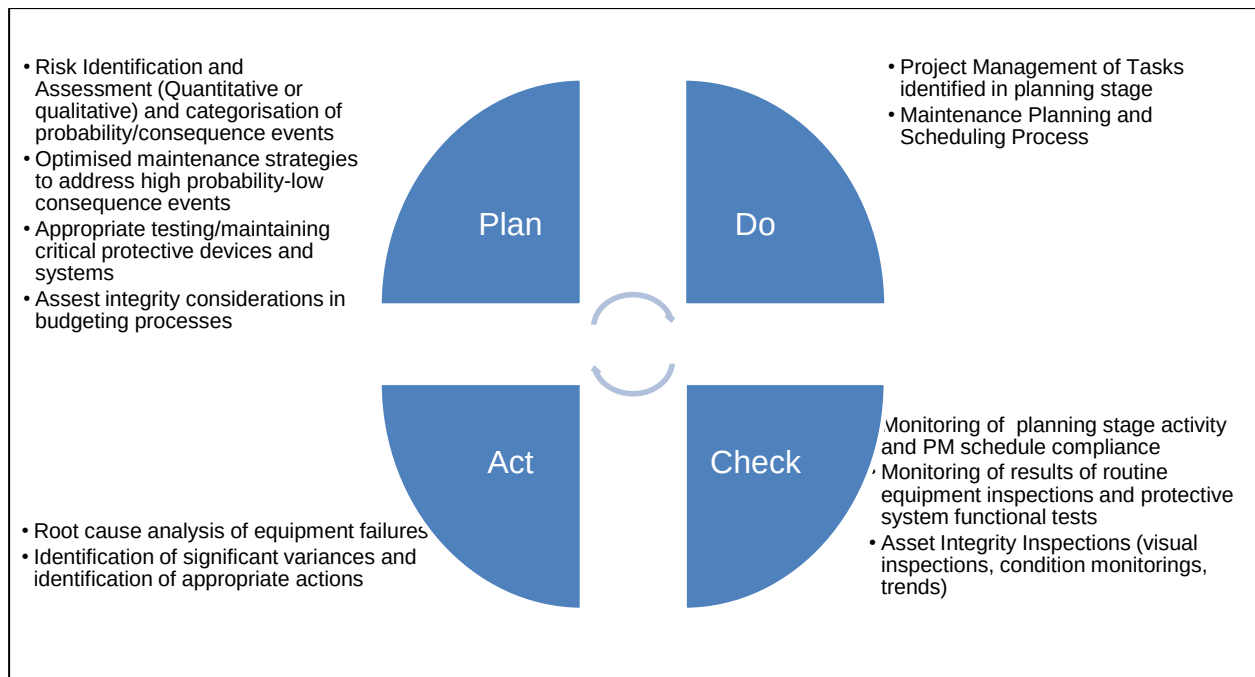


Figure 61. Adapted from Plan-do-check-act cycle (Dunn, 2003)

Knowledge transfer from experienced maintenance artisan to junior artisan is best resolved through documenting the practices in a formal procedure. Information technology processes and security are included in process safety information, an element in the PSM system. Therefore, this element, if not managed well also appears to translate into difficulties with maintenance execution.

Table 16. Seven AIM Challenges (Kusumawardhani and Markeset, 2015)

KM challenges	Possible solutions	Industrial service providers	Potential benefits
Knowledge transfer	Establish procedure for knowledge transfer, establish a shared network to exchange information, establish lessons learned registers.	Data architecture services, network services, etc.	Custom-made solutions, increased mobility, increased reliability, etc.
Information management	Integration between operating systems, software and various geographical locations.	Data architecture services, software services, etc.	Integrated solutions, increased availability, increased reliability, etc.
Data transfer between onshore and offshore	Establish tailor-made technology and network solutions.	Data architecture services, fiber optic services, etc.	Custom-made solutions, increased security, increased reliability, etc.
Information technology (IT) processes and security	Application of custom-made information technology, network and architecture according to requirements and regulations.	Data architecture services, fiber optic services, IT security services, etc.	Custom-made solutions, increased security, increased reliability, core competences focus, etc.
Quality of data	Ensure reliable data for input and processing into information from the beginning of field development through decommissioning.	Engineering services, information system services, operation readiness services, asset management services, etc.	Cost saving, competitive abilities, increased reliability, etc.
Integrated system	Establish a control system integrated with different departments and decision-makers to have coordination to support the overall organization objective.	Asset management services, IT services, engineering services, etc.	Increased safety, custom-made solutions, increased responsiveness, technology adaptation, etc.
Introducing and adapting to new technology	Organization may opt to outsource new technology requirement to service providers; that way risk is distributed and organization is avoiding high initial investment.	Engineering services, equipment manufacturer and services, field services, etc.	Cost saving, competitive abilities, technology adaptation, etc.

Chandima Ratnayake and Markeset (2010) proposed a performance measurement model, incorporating an analytic hierarchy process (AHP) framework for technical integrity management, as displayed in Figure 62. The model's intent is to assist in making decisions related to the maintenance strategy selection for the Oil and Gas industry.

It is a four-level approach. Level 0 covers the goal of the maintenance system. Level 1 deals with the criteria applicable for the specific installation. Level 2 and 3 build on the criteria identified in level 1. Level 4 documents the possible alternatives available in line with the goal established in level 0.

The alternatives are plotted against performance measures to determine the soft savings or additional impact where applicable. There are five performance measures, from lowest to highest: [1] reactive, [2] planned, [3] predictive, [4] reliability and [5] enterprise. Deferred maintenance is reactive and results in the highest savings with the lowest performance output. On the opposite end, integrated maintenance in the form of an enterprise, results in the lowest savings with the highest performance output.

The merit of an equipment's maintenance strategy is heavily dependent on its associated process safety consequence and risk. Level 2 and 3 therefore need to be comprehensively populated in order to correctly assign maintenance strategies and manage risk in process safety.

Kusumawardhani (2016) investigated why many organisations in the petroleum industry still fail in AIM practices, despite the current developments and literature available for the field. Three main challenges were identified: human resource, knowledge management and information technology challenges. This work proposed the use of service providers to tackle some of these challenges.

At the 7th CCPS Latin American Conference on Process Safety, Torres-Echeverria *et al.* (2016) presented the Asset Integrity Management House model. It incorporates process safety and physical asset integrity management supported in reliability foundations. This model is focused on risk management toward the reduction of severe process safety events.

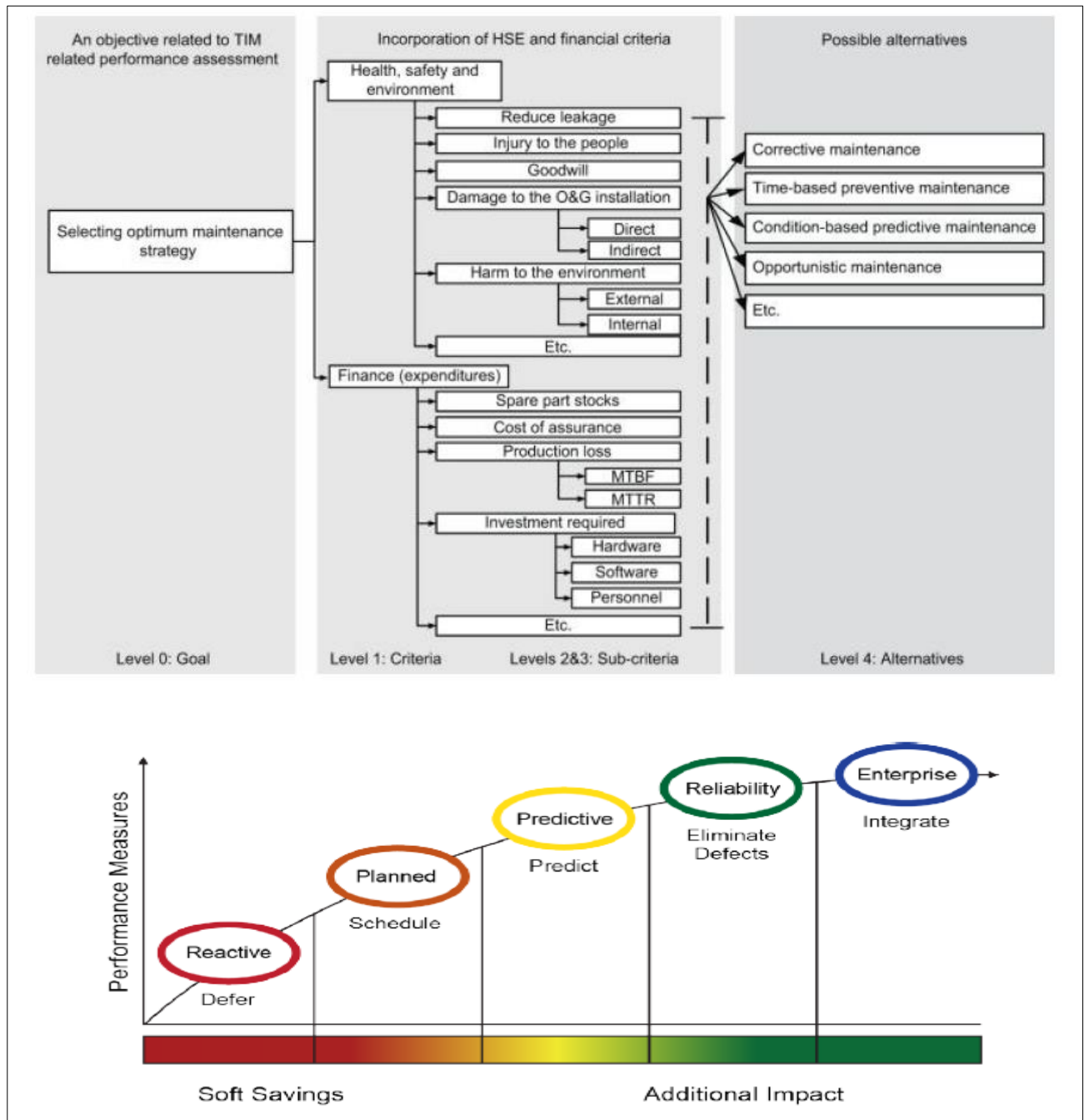


Figure 62. Model for selecting optimum maintenance strategy (Chandima Ratnayake and Markeset, 2010)

Figure 63 depicts the Asset Integrity Management House model, which is sub-divided into three floors as listed below (Torres-Echeverria *et al.*, 2016):

1. Integrated Physical AIM System

- a. This combines and integrates the Asset Integrity and Process Safety Management Systems. Such an approach allows a management system to be built on elements of other management systems, such as health and safety, environment, quality

and risk management. This subsequently improves integration across different disciplines and improve cross-functional coordination.

2. Integrity, Reliability & Process Safety Assessment

- a. Integrity Assessment entails the assessment and follow up of processes traditionally assigned to physical asset integrity management.
- b. Reliability Management deals with the assessment, monitoring and assurance of asset dependability, encompassing reliability, availability and maintainability.
- c. Hazard Analysis and Risk Assessment is concerned with risk management: identification of hazards, analysis, evaluation and treatment.
- d. Safety Case Analysis documents, monitors and reports on overall SHE performance and its management thereof.

3. Performance Assurance

- a. This covers the physical asset performance assurance at the operations ground level to maintain the design intent through life: Maintenance, inspection and testing. Analysis of results drive continuous improvement activities.

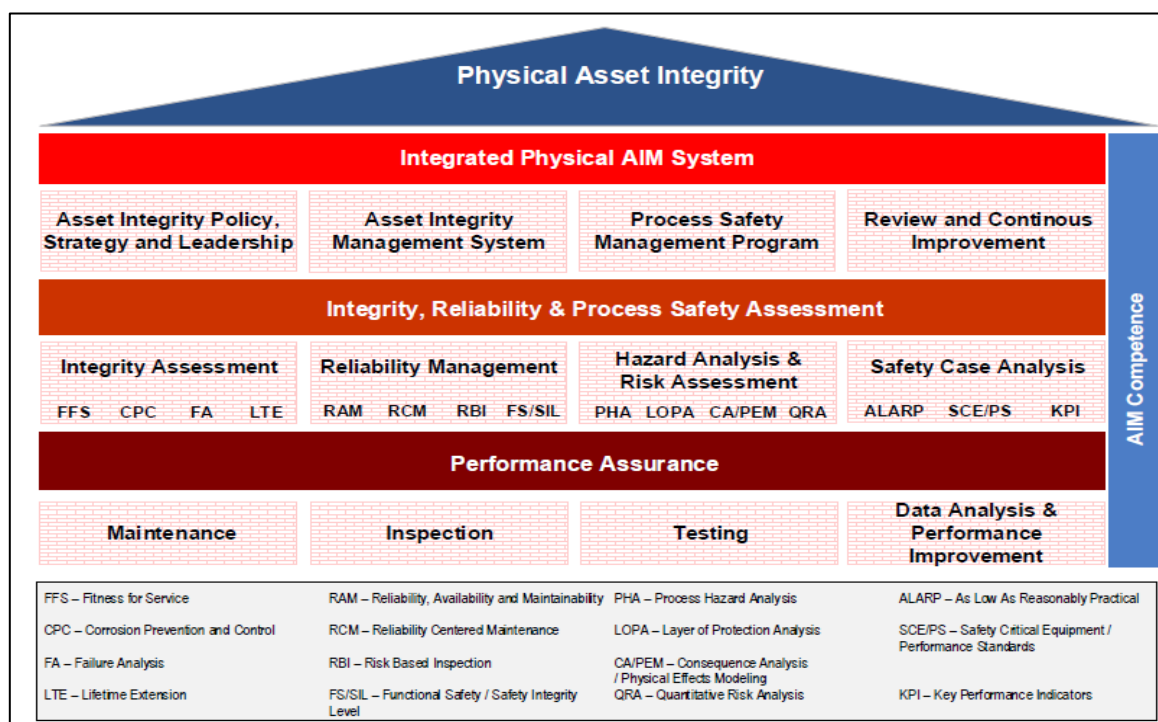


Figure 63. The Physical Asset Integrity Management House (Torres-Echeverria *et al.*, 2016)

Mahound (2014) discussed the concepts and methodologies to Asset Integrity and Process Safety Management (AI-PSM) of hydrocarbon operations at the PSAM Conference. Specifically investigating inherently safe design as a predictive method at the design stage and encouraged the use of technologies to aid focused asset integrity review, performance monitoring and integrity

barriers. Figure 64 depicts the incorporation of Technical Integrity (TI) into both asset integrity and process safety. Asset integrity consists of design and construct (build TI), while process safety consists of operate and sustain TI. Together, asset integrity and process safety form the AI-PSM process.

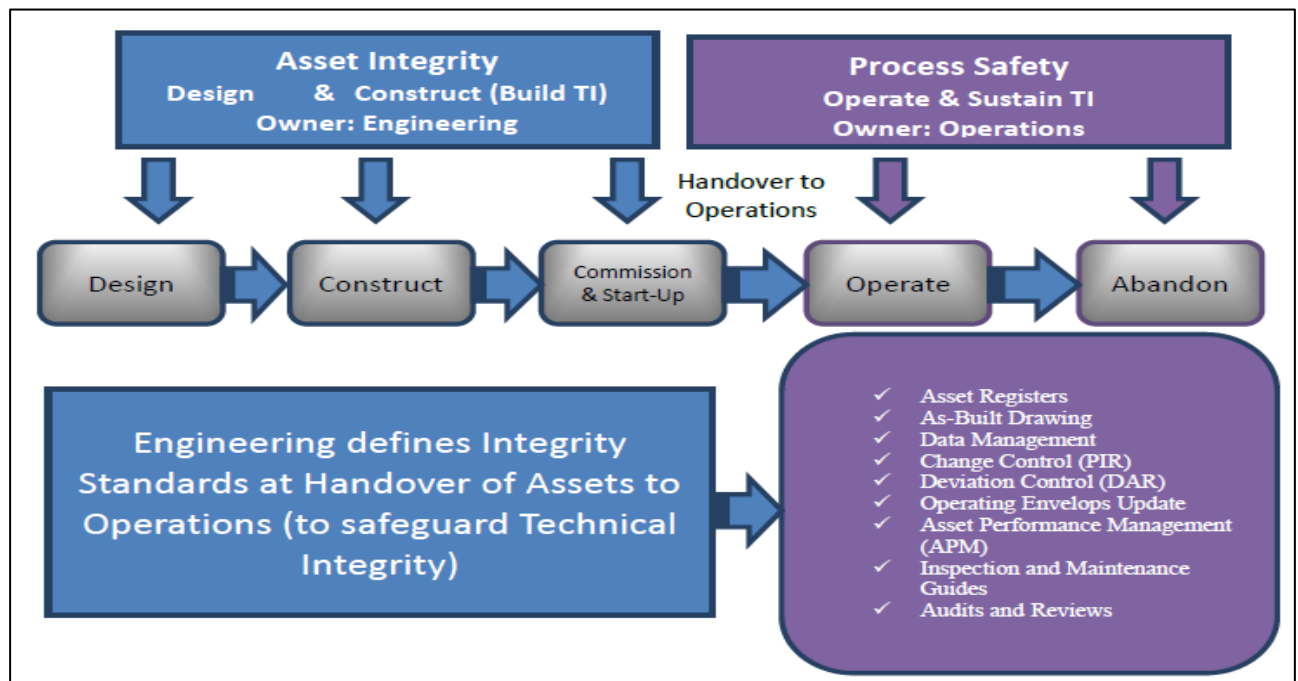


Figure 64. AI-PSM Process (Mahound, 2014)

In 2008, the Australian Transport Safety Bureau (ATSB) (2008) study suggested two paths to address organisation response to maintenance error. Firstly, the probability of maintenance error can be minimised by identifying and counteracting error-producing conditions in the organisation. This involves addressing fatigue management, human factor training, appropriate tooling and equipment. Secondly, acknowledge that maintenance errors can never be entirely eliminated. Organisational resilience with regard to human error can be maximised by ensuring that appropriate risk controls are in place to minimise the consequences.

Similarly, Reason and Hobbs (2003) published a practical guide to managing maintenance error. They propose five key themes to manage, in order to reduce maintenance error and create a safe culture (Reason and Hobbs, 2003): [1] person, [2] task, [3] team, [4] workplace and the [5] organisation. Their work resembles the human performance work by Mitchell (2016) and the human factor elements by HSE (2016) as discussed in Section 2.2. The interactions between the aforementioned five key themes directly influences error prevention. The healthier the relationship between these five key themes, the better the error prevention achieved.

Khan (2012) conducted research into the optimisation of risk based inspection modelling (RBIM) for the oil and gas industry. This work was tailored for installations situated in hard operating conditions with uncertainty in degradation mechanisms. The framework developed focused on answering these questions, as seen in Figure 65. These are basic questions yet fundamental in establishing a RBIM system for assets.

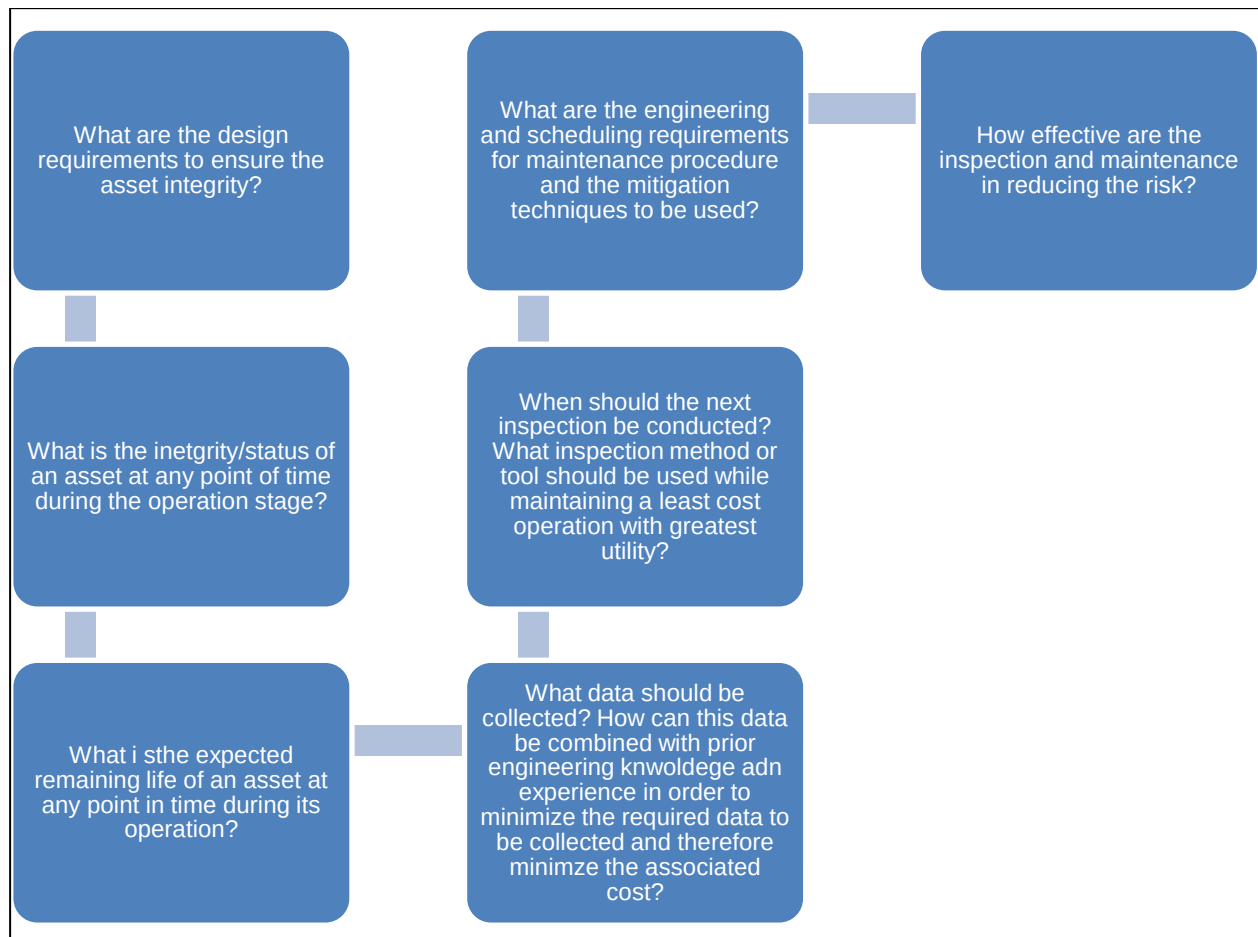


Figure 65. Adapted from Framework of questions (Khan, 2012)

Khan's (2012) research culminated into the following RBIM framework tasked to minimize the cost of inspection and maintenance over the lifetime of a deteriorated asset or system without comprising safety, as illustrated Figure 66. This approach resembles Chandima Ratnayake and Markeset (2010) proposed performance measurement model which incorporated an analytic hierarchy process (AHP) framework for technical integrity management.

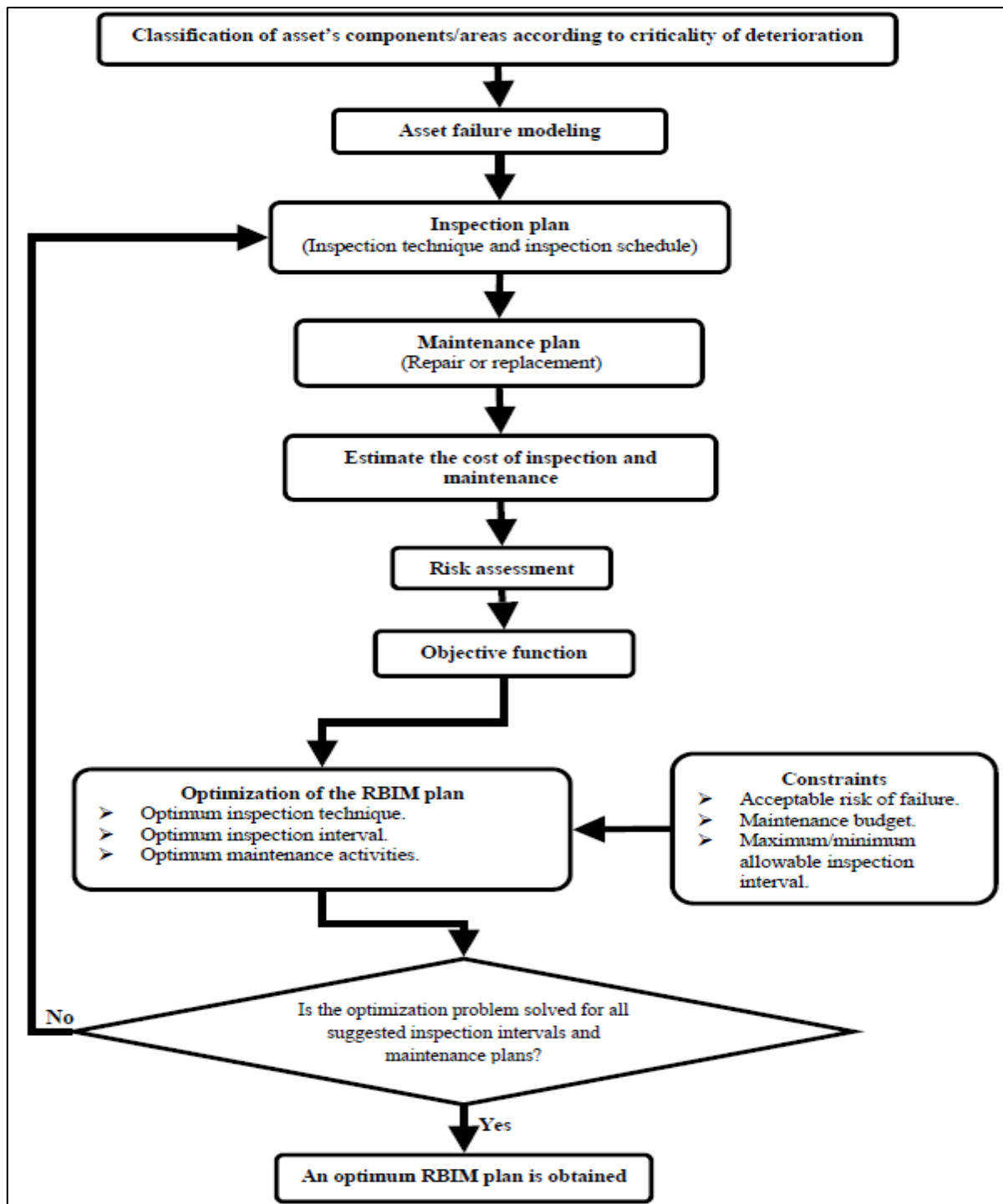


Figure 66. The developed methodology framework for RBIM (Khan, 2012)

The resultant optimised RBIM plan is illustrated in Figure 67, where R is a fraction of the inspection intervals. This is more of a quantitative approach to optimise a maintenance program. Optimisation is achieved through manipulation of four aspects, namely the objective function, maintenance cost, inspection cost and risk of failure. This follows the risk based PSM system concepts as previously discussed.

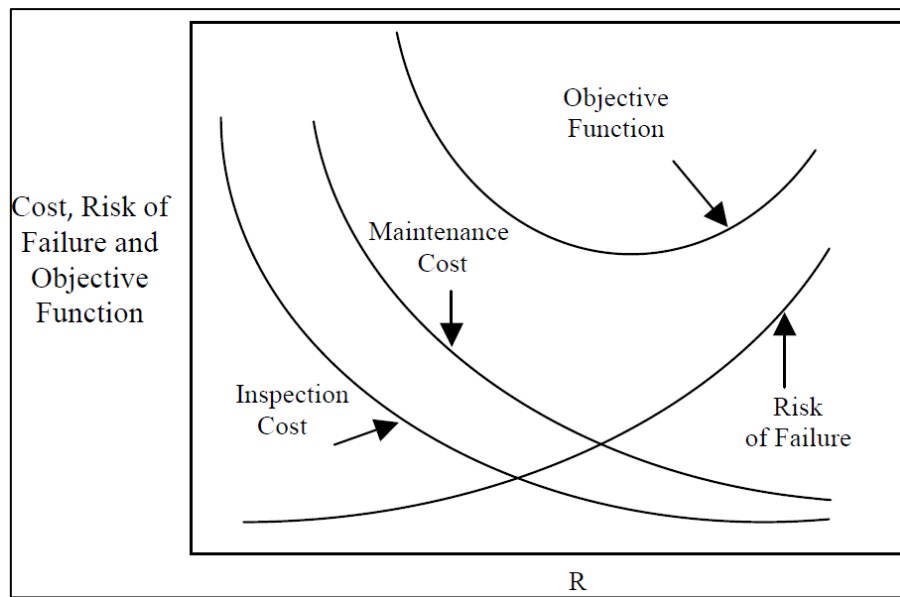


Figure 67. Cost (inspection and maintenance), risk of failure and objective function versus different values of R for a suggested inspection and maintenance plan (Khan, 2012)

Similarly to Khan (2012), the work conducted by Emslie and Gibson (2010) emphasized the limitation of the current Risk Based Inspection (RBI) process. They identified two missing aspects, namely the clear link between cost and business information. Incorporating these missing aspects, they proposed including the following initiatives to resolve these issues, as depicted Figure 68.

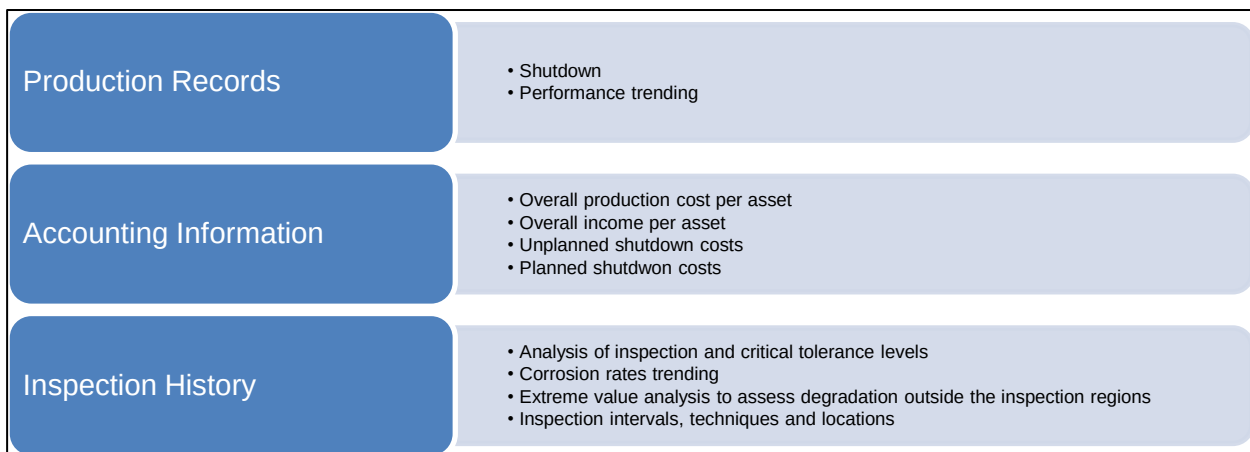


Figure 68. Adapted from Missing cost and business information (Emslie and Gibson, 2010)

Similarly to Emslie and Gibson (2010), Martin (2016) published an Asset Integrity Theme Landscaping Study which specifically looked at the Oil and Gas Industry in the United Kingdom. This report further unpacked the current advancements in asset integrity inspection and detection techniques. Such techniques can be adapted for the RBI process.

2.9. Other High-Risk High-Reliability Industries

There are also other higher risk environments like the oil and gas, where the consequences could be catastrophic (hundreds of fatalities). Generally, this manifests into multiple fatalities. The specific industries considered were the civil aviation and nuclear sectors. There are numerous civil flights transferring many thousands of people daily. In this highly demanding environment, the aircrafts are required to be in service most of the time, placing significant pressure to ensure high levels of design, thorough maintenance and rigorous strategies. The risk of an incident inflight may result in over 200 fatalities. Similarly, a nuclear disaster has the potential to affect millions of residents in its vicinity. Due to their high consequence impacts, these two sectors were selected for investigation. They provide an alternate environment to explore and gain insights into safety culture.

2.9.1. Nuclear Process Safety

The nuclear industry is regulated with many standards and procedures which were developed to assure safe practices. The International Atomic Energy Agency (IAEA) is the foremost authority in nuclear safety and provide requirements that should be met for the establishment for an adequate and effective regulatory infrastructure for safety. Many safety standards were developed, such as and in order of formation and hierarchy, Safety fundamentals (SF), General Safety Requirements (GSRs), Specific Safety Requirements (SSRs), General Safety Guides (GSGs) and Specific Safety Guides (SGSs).

Rzentkowski (2016) highlighted the key elements to safety culture in the nuclear environment. It consists of ten principles as listed in Table 17. The role of government (principle 2) and protection of present and future generations (principle 7) were new concepts observed. The role of government entails improving safety regulations and imposing stricter citations with low tolerances for deviations. Protection of present and future generations covers sustainability and protection of the people and environment.

The IAEA (2002) identified the main characteristics of a safety culture through research findings, lessons learned from organisational failures and the safety professionals in this environment. This three-level model is shown in Table 18, and consists of the artefact, espoused and basic assumption levels. Artefacts relates closely to espouse values and is composed of objects, language, stories, rituals and behaviour. Essentially espoused values are the application of artefacts. Basic assumptions are generally the collective experience or thinking from the team.

Table 17. Key elements to safety culture (Rzentkowski, 2016)

Primary safety objective: Protection of people and the environment from harmful effects of ionizing radiation	
• Principle 1: Responsibility for safety • Principle 2: Role of government • Principle 3: Leadership and management for safety • Principle 4: Justification of facilities and activities • Principle 5: Optimization of protection • Principle 6: Limitations of risks to individuals	• Principle 7: Protection of present and future generations • Principle 8: Prevention of accidents • Principle 9: Emergency preparedness and response • Principle 10: Protective actions to reduce existing or unregulated radiations risks must be justified and optimized

Table 18. Characteristics of Safety Culture (IAEA, 2002)

Artefact and/or espoused value level	Top management commitment to safety	Strategic business importance of safety	Management of change	Employees have a questioning attitude
	Visible leadership	Absence of safety versus production conflict	Quality of documentation and procedures	Man, technology and organization knowledge
	Systematic approach to safety	Relationship to regulators and other external groups	Compliance with regulations and procedures	Clear roles, responsibilities and accountabilities
	Self-assessment	Proactive and long term perspective	Sufficient and competent staff	Motivation and job satisfaction
	Involvement of all employees	Proper resource allocation	Measurement of safety performance	Relationship between managers and employees
	Good working conditions with regard to time pressure	Collaboration and teamwork	Handling of conflict	Awareness of work process
	Good housekeeping			
Espoused value level	High priority to safety	Safety can always be improved	Openness and communications	Organizational learning
Basic assumption level	Time focus	View of mistakes	View of safety	Systems thinking
	Role of managers	View of people		

INSAG (1991) documents the importance of a safety management system and the fundamentals towards ensuring its effectiveness. Currently redundancy in process automation has been paramount, as the likelihood of failure of such a system is very low. In this new age we have artificial intelligence, autonomous vehicles and soon the civil application of drones. These advances in technology all bring with it adaptations and the potential for the next evolutionary step in the process industry. However, these more complex process coded systems coupled with inadequate understanding of the vast application risks and uncharted testing may lead to severe process safety catastrophes.

The Nuclear Plant Journal (NPJ) (2012) actively partnered with the Nuclear Energy Institute (NEI) to develop the Safety Culture Guidance document. This program raises the corrective action process as the key theme, encompassing the identification of issues, obtaining responses, remediation of problems and feedback with recognition to persons raising issues. The Sentara Safety Initiative (Yates *et al.*, 2005) was derived to improve human performance specifically in the nuclear power and manufacturing sector. Sentara applies a three-step approach targeted to behaviours for error prevention. Establishing expectations, education and managing accountability for results from its basis, as shown in Figure 69.

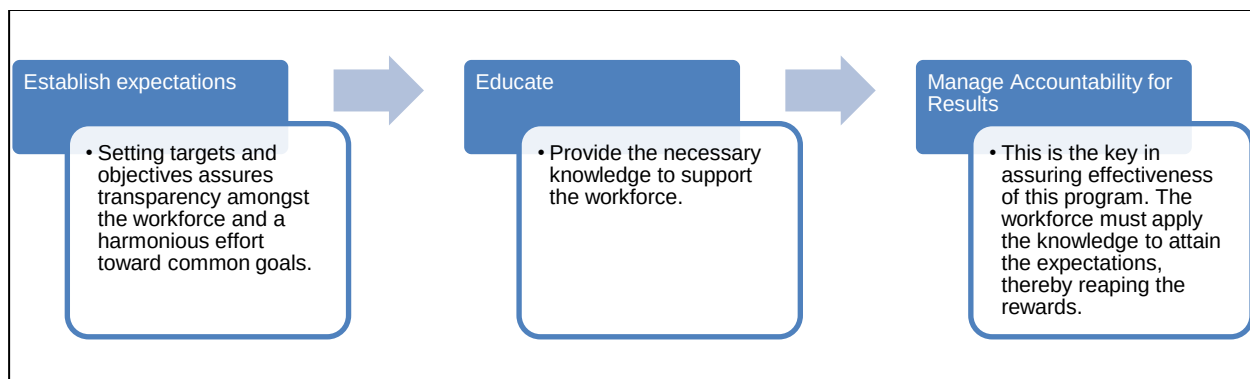


Figure 69. Adapted from Sentara three-step approach (Yates *et al.*, 2005)

The Energy Institute (2010) and OSHA (2000) provide more detail on the PSM framework which is widely opted throughout America and Euro-Asia. These programs are comprehensive, and some case studies involved Tokyo Electric Power Company (TEPCO) and Chubu Electric Power. Both TEPCO (2013) and Chubu Electric Power (2013) highlighted the importance of an effective risk management program to prevent incidents as well as emergency response and mitigate measures for events that have occurred. Such a program included a risk management team, risk prioritisation, safety cultures and risk management cycles, which all contribute towards a company's business sustainability plan.

Parnas *et al.* (1994) assessed safety critical software in nuclear power plants and proposed a rigid process to assure that such systems work from activation. The last key step outlined from this study is Quality Control, which is composed of: product testing, examination of the code and assessment of the design personnel and the method applied. Companies will also need highly specialised engineers to support such complex process automation and assure its continued reliability. TEPCO (2013) discussed many lessons uncovered with respect to design after the Fukushima Nuclear Accident, and the one that seems most prevalent in today's climate changing environment is external events. Most facilities are not designed to handle tsunamis, hurricanes, earthquakes, gale force winds or torrential thunderstorms.

Fleming (2017) is a Professor in safety culture and reviewed the nuclear sector's attributes toward safety culture. The Regulator Safety Culture is composed of five themes, as depicted in Figure 70. Leadership is again observed as being of utmost importance and is Theme 1. It formed the basis of the other themes. Theme 2 is proactive, risk informed, and flexible approach alludes to active engagement and ease of application. Theme 3 is continuous learning and self-improvement involves applying incident learnings and conducting audit assessments. Theme 4 is unwavering ethical standards entails commitment and visible display of such integrity through all levels within an organisation. Theme 5 is transparency through communication essentially through all levels within an organisation with clear, concise and ease to understand methods.

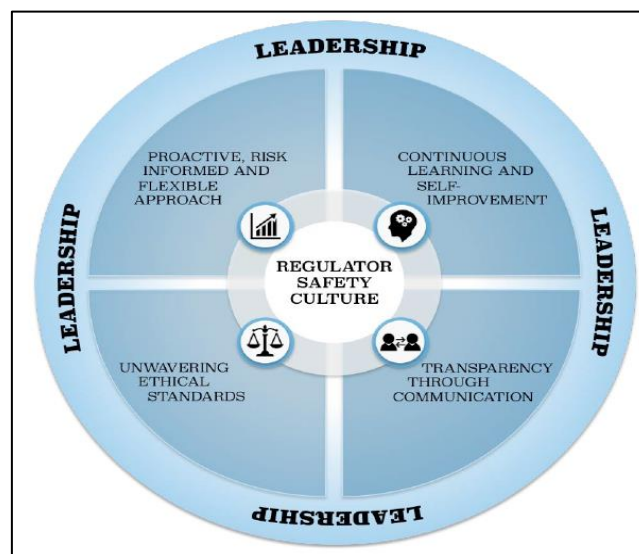


Figure 70. Regulator safety culture (Fleming, 2017)

From 2016, through a methodically and rigorous process, the IAEA developed and refined a safety culture questionnaire to assist in their regulator assessments. Building on the five themes mentioned, the culture questionnaire dove into their critical aspects, as listed in Table 19. This questionnaire could be adapted for use in a chemical processing facility, process safety culture assessments. Obadia (2011) examined the safety culture practices in the nuclear sector and concluded that an integrated management system approach is required. He believes that this is the most practical and tangible way to influence culture holistically. It will sustain the desired change toward an enhanced safety culture.

Table 19. Safety culture questionnaire (Fleming, 2017)

Themes	Questionnaire dimensions
Leadership commitment to creating a positive safety culture	- Leadership - Responsibility and accountability - Independence of the regulator
Proactive, risk informed and flexible approach	- Systemic regulatory approach - Decision making
Continuous learning and self-improvement	- Continuous learning, improvement and competence - Questioning attitude
Unwavering ethical standards	- Ethics and moral courage - Psychological safety
Transparency through communication	- Openness, transparency, external cooperation and communication - Inter-disciplinary internal cooperation

2.9.2. Civil Aviation Industry

The civil aviation industry is another high-risk high-reliability environment. Similarly, it is also regulated with many standards and procedures which were developed to assure safe practices. Such standards and procedures were explored and are discussed in more detail. Basic Aviation Risk Standard (BARS) (2017) are concerned with promoting safety culture in maintenance. They propose three strategies and supporting pillars for managing human error, as depicted in Figure 71. BARS (2017) recommend five supporting pillars toward a positive safety culture, namely: [1] changing attitudes and behaviours, [2] management commitment, [3] employee involvement, [4] promotional strategies and [5] training and seminars.

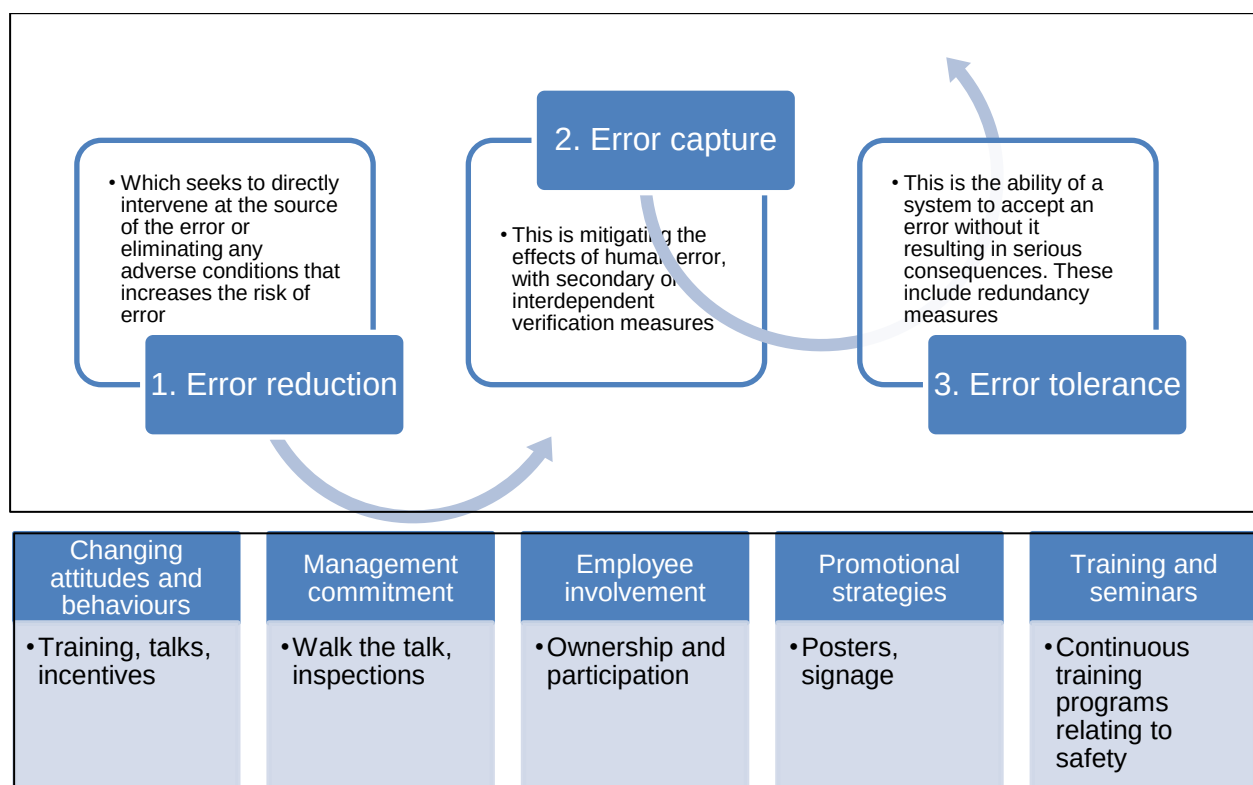


Figure 71. Adapted from Three strategies and supporting pillars for managing human error (BARS, 2017)

The Civil Air Navigation Services Organisation (CANSO) (2008) safety culture definition and enhancement process defined eight key elements to safety culture, as listed in Table 20. These elements reflect work by Reasons (1998) and pose important interrelationships between one another. The role of management in establishing the policies, procedures and tools is required to foster the elements and committing to their success.

Table 20. Key elements to safety culture (CANSO, 2008)

Element	Description	Explanation
Just Culture	An atmosphere of trust in which people are encouraged for providing essential safety-related information, but in which they are also clear about where the line must be drawn between acceptable and unacceptable behaviour.	An informed culture relies on a reporting culture which in turn relies on a Just Culture. All employees must clearly understand and recognise that it is unacceptable to punish all errors and unsafe acts regardless of their origins and circumstances while it is equally unacceptable to give blanket immunity from sanctions to all actions that could, or did, contribute to organisational accidents. A prerequisite for engineering a just culture is an agreed set of principles for drawing the line between acceptable and unacceptable actions.
Reporting Culture	Managers and operational personnel freely share critical safety information without the threat of punitive action.	The issue is not whether the organisation has a reporting system, it is whether, as a matter of practice, errors, near misses, hazards and risks are reported. A reporting culture depends, in turn, on how the organisation handles blame and punishment. If blame is the routine response to error, then reports will not be forthcoming. If, on the other hand, blame is reserved for truly egregious behaviour, involving recklessness or malice, reporting in general will not be discouraged. Rather than a blanket no-blame approach, what is required, Reason argues, is a just culture.
Informed Culture	Those who manage and operate the system have current knowledge about the human, technical, organisational and environmental factors that determine the safety of the system as a whole.	Management fosters a culture where people understand the hazards and risks inherent in their area of operation. Personnel are provided with the necessary knowledge, skills and job experience to work safely, and they are encouraged to identify the threats to safety and to seek the changes necessary to overcome them. An informed culture relies on having a strong reporting culture.
Learning Culture	An organisation must possess the willingness and the competence to draw the right conclusions from its safety information system and the will to implement major reforms.	Reports are only effective if an organisation learns from the. Learning will occur from both reactive and pro-active safety assessments and it is promoted by an inherent organisational willingness to adapt and improve.
Flexible Culture	A culture in which an organisation is able to reconfigure themselves in the face of high tempo operations or certain kinds of danger – often shifting from the conventional hierarchical mode to a flatter mode.	A culture of safety is flexible, in the sense that decision-making processes vary, depending on the urgency of the decision and the expertise of the people involved.
Risk Perception	Individuals at all organisation levels need to have the same perceptions and judgments of the seriousness of risks, as these perceptions affect risk behaviour and appropriate decisions with regard to safety issues.	It has been found that misperceptions of the seriousness of risks occur frequently at all levels in an organisation (HSC, 1993). The perception of risk or people's judgements of riskiness is influenced by different attributes of hazards, e.g. controllable-uncontrollable. Misjudgements of risks may cause risk behaviour and inappropriate decisions with regard to safety measures and ordinary occupational accidents as well as large-scale accidents (Rundmo, T., 1997) Associations between risk perceptions and safety. <i>Safety Science</i> 24 (3), 197-209).
Attitudes to Safety	Attitudes (especially management's) in relation to safety, risk and production.	Research has shown that attitudes to safety can be associated with risk perception and safety-related behaviours.
Safety related behaviour	Safety-related behaviour has to do with directly complying with procedures, rules and regulations, but also to aspects such as coaching, recognising, communicating, demonstrating, and actively caring.	Having accurate risk perceptions does not necessarily result in correct risk and safety related behaviours. Ignorance or deliberate violations to safety rules and procedures are often due to employee attitudes towards risk and safety (HSC, 1993. Hale (2003) advances the shared purpose in safety performance, i.e. the involvement felt by all parties in the organisation, especially the workforce, in the process of defining, prioritising and controlling risk.

CANSO’s (2008) systematic safety culture enhancement process, depicted in Figure 72 coincides with the Beukes (2015) model. Essentially once safety culture expectations are established, the culture can be assessed, and enhancements recommended. Their safety culture views of different cultures (learning, informed, just, flexible and reporting) resonate to the Petroleum Safety Authority Norway (PSAN) (2002) views.

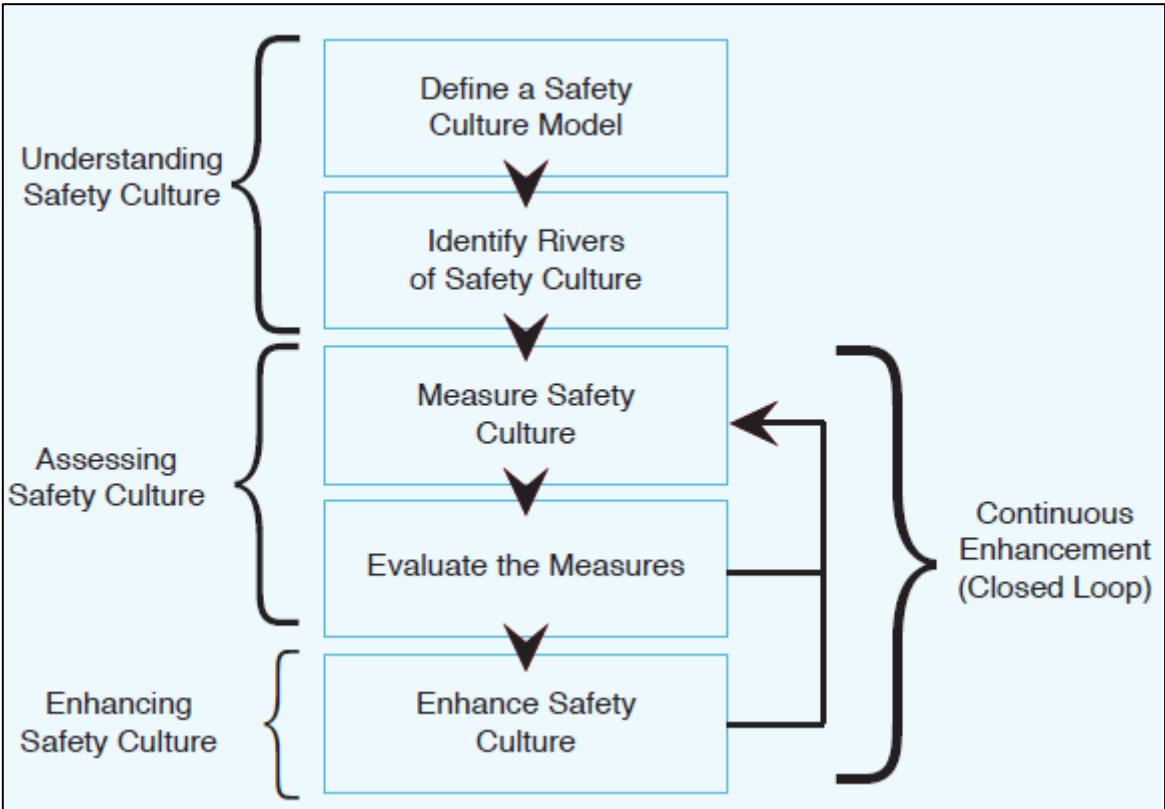


Figure 72. Systematic Safety Culture Enhance Process (CANSO, 2008)

The European Strategic Safety Initiative, ECAST (2009), investigated a safety culture framework for application in the civil aviation sector. After reviewing the main existing and emerging safety culture frameworks, they consider safety culture as a multi-dimensional construct. Similarly, they also considered the maturity stages. After careful analysis, they identified six dimensions along with their respective characteristics. The ECAST safety culture framework is displayed in Table 21.

Dumitru and Boscoianu (2015) analysed human factor and its role in aeronautical activity through the Shell model. This model consists of software, hardware, environment and live ware. This study focused on impacts from system efficiency and health of operational staff and found the most influential way to prevent them is through education. Gill and Shergil (2004) administered a safety culture survey through the Civil Aviation Authority of New Zealand and received a total of 464 complete responses. Upon analysing these responses, they found that the highest priority

was employee safety responsibility. This contrasts the norm of focusing on implementing effective safety management systems and encouraging positive safety cultures. Similarly McDonal *et al.* (2000) found deficiencies in aircraft maintenance from a study in Ireland. This indicates a need for the aviation industry to place more effort on improving aviation safety culture.

Table 21. Safety Culture Indicators (ECAST, 2009)

Characteristic	Indicators
Commitment	1. Management concern 2. Perception of importance of safety 3. Prioritization of safety 4. Safety procedures and requirements 5. Personal involvement and responsibility for safety
Behaviour	1. Employee behaviour with respect to safety 2. Mutual expectations and encouragement 3. Job satisfaction 4. Adequate equipment
Awareness	1. Pro-activity to prevent negative happenings 2. Actions with respect to negative happenings 3. Employee input
Adaptability	1. Pro-activity to prevent negative happenings 2. Actions with respect to negative happenings 3. Employee input
Information	1. Availability of information 2. Communication of work related information 3. Training 4. Safety issues reporting system 5. Willingness to use the reporting system 6. Consequence of safety reports 7. Communication of safety related information 8. Information exchange about safety issues
Justness	1. Evaluation of safety related behaviours 2. Perception of evaluation 3. Passing of responsibility

NLR (2016) is a leading international research centre for aerospace. Similarly to ECAST (2009), they propose six indicators to assess and analyse the level of safety culture of an organisation, as listed in Table 22. Their indicators are cross-referenced to Hudson's (2007) safety culture maturity levels. The Flight Safety Foundation (2006) published their global aviation safety roadmap. Their five high-level themed focus areas consisted of: [1] inconsistent implementation and compliance to standards, [2] regulations and best practices, [3] ineffective incident and accident investigation, [4] insufficient number of qualified personnel and [5] gaps in the use of technology to enhance safety.

Similarly, reviewing the International Civil Aviation Organization's (ICAO) (2013) State of Global Aviation Safety Report, some key safety culture aspects were still a challenge. Their technical

initiatives focused on institutionalising incident learnings, governance and assurance on laws and regulations, redundancy systems, fatigue management and high standards of training and competency processes, which is illustrated in Figure 74.

Mearns *et al.* (2009) developed a Safety Culture Management Toolkit for European Air Navigation Service Providers (ANSPs). Their study validated their questionnaire at eight geographical dispersed ANSPs across Europe. This questionnaire focused on five elements, as listed in Table 23. The ATSB (2004) sent surveys to 5000 civil pilots throughout Australia. This revealed that there were four important aviation factors to safety climate. These factors consist of management commitment, equipment and maintenance, training and rules and procedures.

Most accident reporting and database systems are not designed to include any theoretical framework of human error. This limits the potential of accident databases to analyse human error, which inhibits effective intervention strategies. Therefore, human factor analysis and classification (HFAC) of incidents will assist in identifying themes for corrective intervention. Shappell (2000) studied the development and theoretical underpinning of HFAC systems in the military, civil and general aviation sectors. Three critical HFAC organisational influences were identified as illustrated in Figure 73.

Resource Management	Organisational Process	Organisation Climate
• Human Resources • Selection • Staffing/manning • Training • Monetary/budget resources • Excessive cost cutting • Lack of funding • Equipment/facility resources • Poor design • Purchasing of unsuitable equipment	• Operations • Operational tempo • Time pressure • Production quotas • Incentives • Measurement/appraisal • Schedules • Deficient planning • Procedures • Standards • Clearly defined objectives • Documentation • Instructions • Oversight • Risk Management • Safety programs	• Structure • Chain-of-command • Delegation of authority • Communication • Formal accountability for actions • Policies • Hiring and firing • Promotion • Durgs and alcohol • Culture • Norms and rules • Values and beliefs • Organisational justice

Figure 73. Adapted from Human factor organisation influences (Shappell, 2000)

Table 22. Combining Hudson and Reason (NLR, 2016)

	1. Pathological	2. Reactive	3. Calculative	4. Proactive	5. Generative
Commitment	Safety is nonsense. Safety is not taken seriously. Safety plays no role in decision making and day-to-day operations.	Safety is a burden. Safety is not a core value. Safety plays a role in decision making only to meet the legal requirements.	Safety is a necessary evil. Safety is not a core value. Safety considerations are taken into account in decision making.	Safety is a prerequisite. Safety is a core value. Safety plays an important role in decision making and day-to-day operations.	Safety first, second and third. Safety is a core value. Safety is recognized as an essential for the continuity of the organisation.
Justness	Culture of fear. There are no clear evaluation standards with respect to safety related behaviour. Only if demanded by external factors (e.g. public opinion or law) is responsibility for safety occurrences sought. Responsibility for safety occurrences is only sought within directly involved parties.	Punitive culture. The evaluation standards with respect to safety related behaviour are not applied consistently. Human errors are not tolerated. Responsibility for safety occurrences is only sought within directly involved parties. The role of organisational factors in safety occurrences is barely recognized.	Blaming culture. Evaluation of safety related behaviour follows clear lines. Human errors are not tolerated. Responsibility for safety occurrences is sought in the first place within directly involved parties. Organisational factors are only investigated when obvious.	Non-punitive culture. Evaluation of safety related behaviour follows clear lines. The distinction is made between human error and negligence or intention. Responsibility for safety occurrences is sought in within directly involved parties as well as within organisational factors.	Culture of trust. Evaluation of safety related behaviour follows clear lines. The distinction is made between human error and negligence or intention. Responsibility for safety occurrences is sought in the first place within organisational factors. Directly involved parties are only held responsible if there is a matter of negligence or intention.
Information	Uninformed culture. Safety is no topic of communication. Safety training is non-existent. There is no safety reporting system. No information on safety occurrences is gathered, let alone transmitted through the organisation.	Circumstantial information exchange. Safety is only a topic of communication after severe safety occurrences. Safety training is rare. There is no safety reporting system. Only information on safety occurrences is gathered. There is no feedback on safety occurrences.	Bureaucratic information exchange. Safety is only a topic of communication after safety occurrences. Safety training is not part of normal procedures. A safety reporting system is installed because it is required by law. The safety reporting system is only used to gather information in the aftermath of safety occurrences. There is no feedback on safety.	Proactive information exchange. Safety is a regular topic of communication. Safety training is part of normal procedures. The advantages of a safety reporting system are recognized. The safety reporting system is used to detect safety issues before it is too late. There is no feedback on safety reports.	Continuous information exchange. Safety is a main topic of communication. Safety training is extremely important. The safety reporting system is considered as a main part of the organisation. The safety reporting system is continuously monitored to detect safety issues before it is too late. Feedback on safety reports is part of the reporting system.
Awareness	No safety awareness. The safety risks induced by the organisation's operation are not recognised or are ignored. No measure is taken against safety risks.	Passive awareness. The safety risks induced by the organisation's operation are recognised. No measure is taken against safety risks.	Selective awareness. The safety risks induced by the organisation's operation are recognised. Measures are taken if the safety risks are too large.	Active awareness. The safety risks induced by the organisation's operation are recognised. Measures are taken to reduce known safety risks as much as possible.	Constant vigilance. The safety risks induced by the organisation's operation are a main concern. Measures are taken to reduce known safety risks as much as possible. There is a constant vigilance with respect to unidentified safety risks.
Adaptability	Rigid culture. Even after severe safety occurrences often action is not taken. Employees raising safety concerns are not appreciated.	Conservative culture. Action is only taken after severe safety occurrences. Employees raising safety concerns are only appreciated if other interests are not at stake.	Flexible culture. Action is only taken after safety occurrences. Employees raising safety concerns are appreciated, but only taken seriously if other interests are not at stake.	Adaptive culture. If possible safety risks are revealed, measures are taken. Action is taken after safety occurrences, however small. Employees raising safety concerns are appreciated.	Learning culture. There is a continuous striving to a better safety level. Employees are stimulated to raise safety concerns.
Behaviour	Unsafe behaviour is normal. Safety considerations do not affect behaviour. Unsafe behaviour in the benefit of other interests is rewarded.	Unsafe behaviour is tolerated. Safety considerations barely affect behaviour. Unsafe behaviour in the benefit of other interests is allowed.	Safe behaviour is expected. Behaviour is affected by safety considerations. Unsafe behaviour in the benefit of other interests is sometimes allowed, but in general there is mutual expectation of safe behaviour.	Safe behaviour is normal. Safety considerations largely set behaviour. Unsafe behaviour is not tolerated.	Safety is decisive for behaviour. The code of behaviour is in the first place set by safety considerations. Unsafe behaviour is not tolerated. Safe behaviour is rewarded.

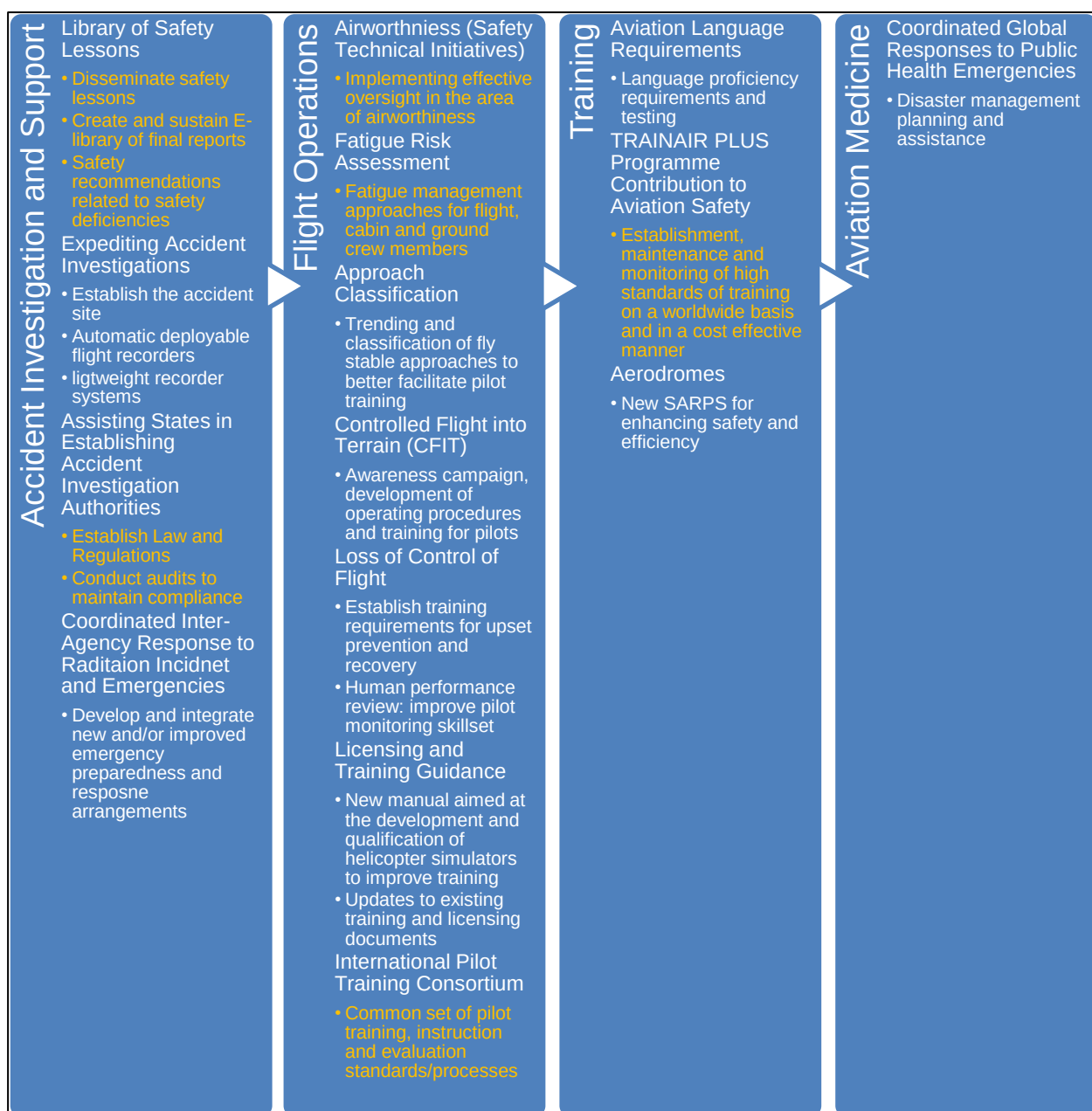


Figure 74. Adapted from Technical initiatives (ICAO, 2013)

Table 23. Safety Culture Elements and Sub-elements (Mearns *et al.*, 2009)

Safety Culture Elements	Safety Culture Sub-Elements
1. Safety Management Commitment	1. Priority of safety
	2. Responsibility for safety
	3. Resources for safety
2. Trust in Organisation Safety Competence	4. Trust in Safety Process
	5. Regulatory effectiveness
3. Involvement in Safety	6. Communication about changes
	7. Communicating problems (speaking up)
	8. Involvement of ATCOs in safety
	9. Management involvement in safety
	10. Working with contractors
4. ATCO Safety Competence	11. ATCO competence
	12. Team effectiveness
	13. Training for safety in ATC
	14. Procedures & working practices
5. A Just, Reporting & Learning Culture	15. Error tolerance, blame & punishment
	16. Rewards, incentives & performance appraisal
	17. Reporting (and investigating) incidents
	18. Learning from incidents

2.10. Summary

In Chapter 2, vast amounts of literature from diverse backgrounds was extensively surveyed and reviewed. Existing PSM systems and chemical processing company case studies were explored to specifically understand their process safety culture approaches. Occupational safety culture practices from different industries were also investigated along with understanding the human mind and maintenance error to successfully leverage associated human factors. Other high-risk high-reliability industries with catastrophic consequences were assessed. The nuclear and civil aviation industries were selected, and their safety culture approaches were also investigated.

Delving into process safety culture systems revealed numerous human factor engineering practices and only a handful of process safety culture practices. Only two PSM systems included process safety culture. Only the IOGP (2008) and CCPS (2008) PSM systems include such elements. Several other guidelines or practice notes on process safety culture approaches were examined.

Chemical processing companies practising PSM were surveyed to understand their process safety culture practices. Large scale, international and well recognised chemical companies were

selected: Shell, BP, Sasol and Chevron. Upon review, they all apply a risk-based approach closely following the CCPS (2008) RBPS systems. Process safety culture seemed to be governed by leadership and assurance programs.

Climate and culture were assessed in the literature review. These two different aspects were found to interrelate. Climate affects the environment set and is tangible. Culture entails the way in which a person interacts and is intangible. Naturally, climate is more easily influenced and maintained. Culture requires understanding and management of a multitude of human factors. Many literature definitions were surveyed for climate and culture.

For purposes of this study, a combination seemed most appropriate, and the HSD (UK) (2005) safety culture and climate definition was adapted to incorporate the AQAL model culture definition. The resultant combined definition for safety culture and climate for this study is:

The terms safety culture and safety climate may both be used to describe the ways in which members of an organisation make sense of the overall safety of their work environment. Safety culture is influenced by experiences which then influences the meaning of future interactions. Safety climate is often used to describe the more tangible outputs of an organisation, through which safety culture can be assessed. These safety climate attributes are measurable and easier to influence.

Different sustainability approaches in process safety and engineering were surveyed and a definition for sustainable was determined. Sustainable is an adjective and means able to continue over a period of time (Cambridge University Press, 2020). This definition aptly describes the intent of a sustainable process safety culture framework.

An abundance of occupational safety culture literature was available. It appeared that concepts for occupational safety culture had been more readily available and well researched, with many guidelines or approaches developed to support in its management thereof. Human factor elements were highlighted by Dr P. Calitz and therefore literature was also surveyed on the human mind. Thus, approaches for occupational safety culture were mainly cited as well as psychological literature that provided guidance on positively influencing human behaviours.

Human factor error also impacts asset integrity, and this was also explored. Management systems and quality of workmanship were highlighted as key focus areas. High-risk high-reliability industries were also reviewed, specifically the nuclear and civil aviation sectors. There was also an abundance of safety culture literature available for these sectors.

To summarise, there are many approaches to manage process and occupational safety culture. This literature was scrutinised to identify constructive inputs for the development of a sustainable process safety culture framework.

From the literature survey, it was also evident that our research problem exists, and that globally there is very limited guidelines into holistically managing process safety culture in the chemical processing industry. Thus, there is value in this study to address this gap by developing a **practical and sustainable framework for improving process safety culture in the chemical processing industry.**

In the next chapter, the research methodology and rationale, applied to perform the qualitative mixed methods study, is presented and discussed. Efforts were primarily focused on verification, validation and reliability of the study.

CHAPTER 3 RESEARCH METHODOLOGY

Albert Einstein once said, “Not everything that can be counted, counts, and not everything that counts can be counted.”

3.1. Introduction

In this Chapter, the research methodology design was outlined and discussed to support achieving this study's aim and objectives as described in Chapter 1. Young and Hren (2017) collaborated on the Methods in Research on Research (MiRoR), and illustrated the relationship between qualitative and quantitative research, as seen in Figure 75. At some point, qualitative and quantitative research overlaps and is referred to as mixed research.

Qualitative research can be broadly defined as, “*any kind of research that produces a finding not arrived at by means of statistical procedures or other means of quantification,*” (Strauss and Corbin, 1990). Qualitative research is more suitable for studies involving human elements. Ospina (2004) agreed with this approach for a study on human elements, and also investigated the merits of qualitative research on leadership and cultural inquiries. Naturally culture being composed of human elements are the corner stone for the field of study in this research study. Therefore, in line with this study's primary aim and objectives, of developing a process safety culture framework in the chemical processing industry, a qualitative approach was selected.

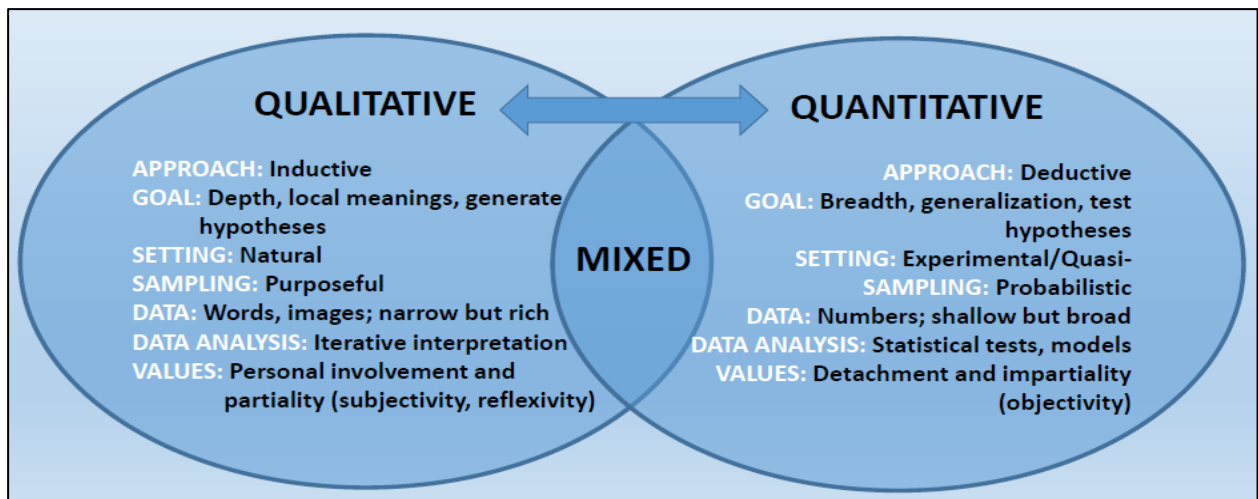


Figure 75. Comparison of Qualitative and Quantitative Research (Young and Hren, 2017)

3.2. Qualitative Studies

There are many different types of qualitative research, each with their own merit, and dependant on what is being investigated. Bickmang & Rog (2009) define applied research as, “*strives to improve our understanding of a problem, with the intent of contributing to the solution of that problem*”. Kothari’s (2004) publication on Research Methods and Techniques, as seen in Figure 76, is applicable for both qualitative and quantitative approaches, with the aim of assisting researchers in developing the appropriate methodology for their respective study. This process flow chart is comprised of seven (I to VII) steps. It is simplistic and illustrates the fundamental concepts of a research methodology. Therefore, the principles of this research process flow chart were incorporated into this study’s research methodology, as listed in Table 26. Steps I, II and III were presented and discussed in Chapter 1.

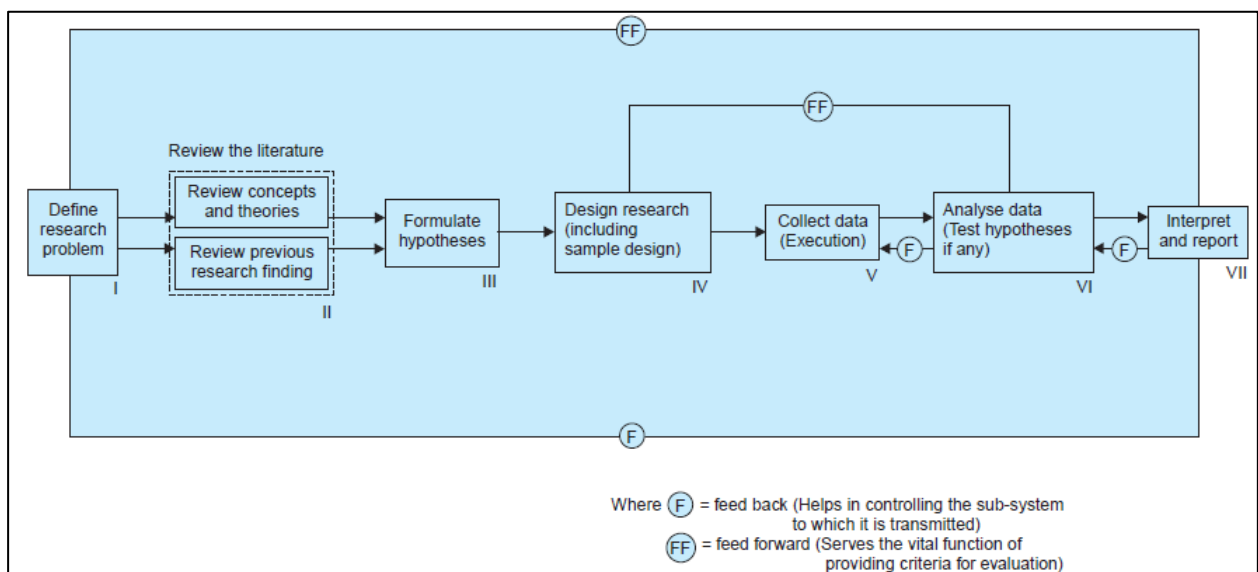


Figure 76. Flow chart of a research process (Kothari, 2004)

Step IV was still being developed as the literature review on qualitative research methodology progressed. Step V essentially describes the literature survey with respect to its breath of inclusions. Guest and Namey (2013) classified qualitative research into eight approaches. Similarly, Hancock (2002) from the University of Nottingham and Young and Hren (2017) also support their classification of qualitative research approaches. Three of these approaches were included into this study's literature survey methodology: [1] grounded theory, [2] case study and [3] mixed methods, illustrated in Table 24. A mixed methods approaches was selected, based on the nature of the research literature being freely available, and the ability to correlate these findings with selected successful chemical processing company case study investigations on process safety culture.

Table 24. Adapted from the Basic Approaches in Qualitative Research (Guest and Namey, 2013)

Type of Approach	Defining Features	Data Collection Implications
Grounded Theory	• Inductive data collection and analytic methods • Uses systematic and exhaustive comparison of text segments to build thematic structure and theory from a body of text • Common analytic approach in qualitative studies	• In-depth interviews and focus groups are the most common data collection techniques associated with this approach • Sample sized for this approach are more limited than for ITA because the analytic process is more intensive time consuming
Case Study	• Analysis of one to several cases that are unique with respect to the research topic • Analysis primarily focused on exploring the unique quality	• Cases are selected based on a unique quality • Questions and observations should focus on, and delve deeply into, the unique feature of interest
Mixed Methods	• Defined as integrating quantitative and qualitative research methods in one study • Two most common designs are sequential and concurrent	• Collection of qualitative data in a mixed methods study can be informed from a wide range of theoretical perspectives and analytic approaches • Researchers must specify up front, and in detail, how, when, and why qualitative and quantitative datasets will be integrated

Step VI entails the analysis of collected data gathered during the literature review. This study's research methodology covered diverse data which required interpretation. Step VII discusses the interpretation of the collected data and how theory was built and used to develop the study's main aim and fulfil its objectives, to develop a process safety culture framework for the chemical processing industry. Carlile and Christensen (2004) published work on the cycles of theory building in relation to management research, also involving human elements, as illustrated in Figure 77.

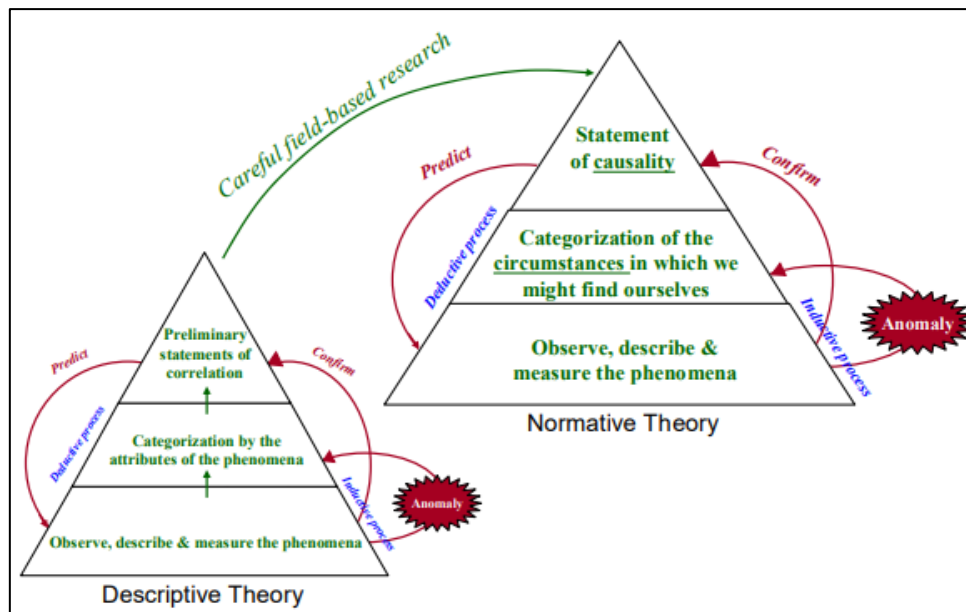


Figure 77. Transition from Descriptive Theory to Normative Theory (Carlile and Christensen, 2004)

Their paper outlined a process of theory building that links questions about data, method and theory (Carlile and Christensen, 2004). It was defined into two major stages: the descriptive stage and the normative stage, each containing steps with an overarching iterative process. However, Lynham (2002) from the Academy of Human Resource Development, investigated simplifying the logic applied in theory building research. As previously discussed, different theory building methods exist for different research processes. Many commonalities exist, hence Lynham (2002) advocated for an inherently generic theory building process. After extensive research, she proposed the following model depicted in Figure 78. This generic model to theory building proposed by Lynham (2002) is composed of five phases.

Similarly, Mason (2002) published comprehensive literature on qualitative researching which encompasses this overall approach whilst divulging into details. A combination of the aforementioned theory building approaches was undertaken. Collected data was observed and categorised by attributes of a phenomenon. This incorporates Phases 1 to 2: the conceptual development and operationalization phases. Phases 3 and 4 are related to Kothari's (2004) research process Step IV and provides prescriptions for an effective qualitative research methodology. Phase 5 is part of the iterative application process, where a study is continuously refined and developed to assure its validity and reliability.

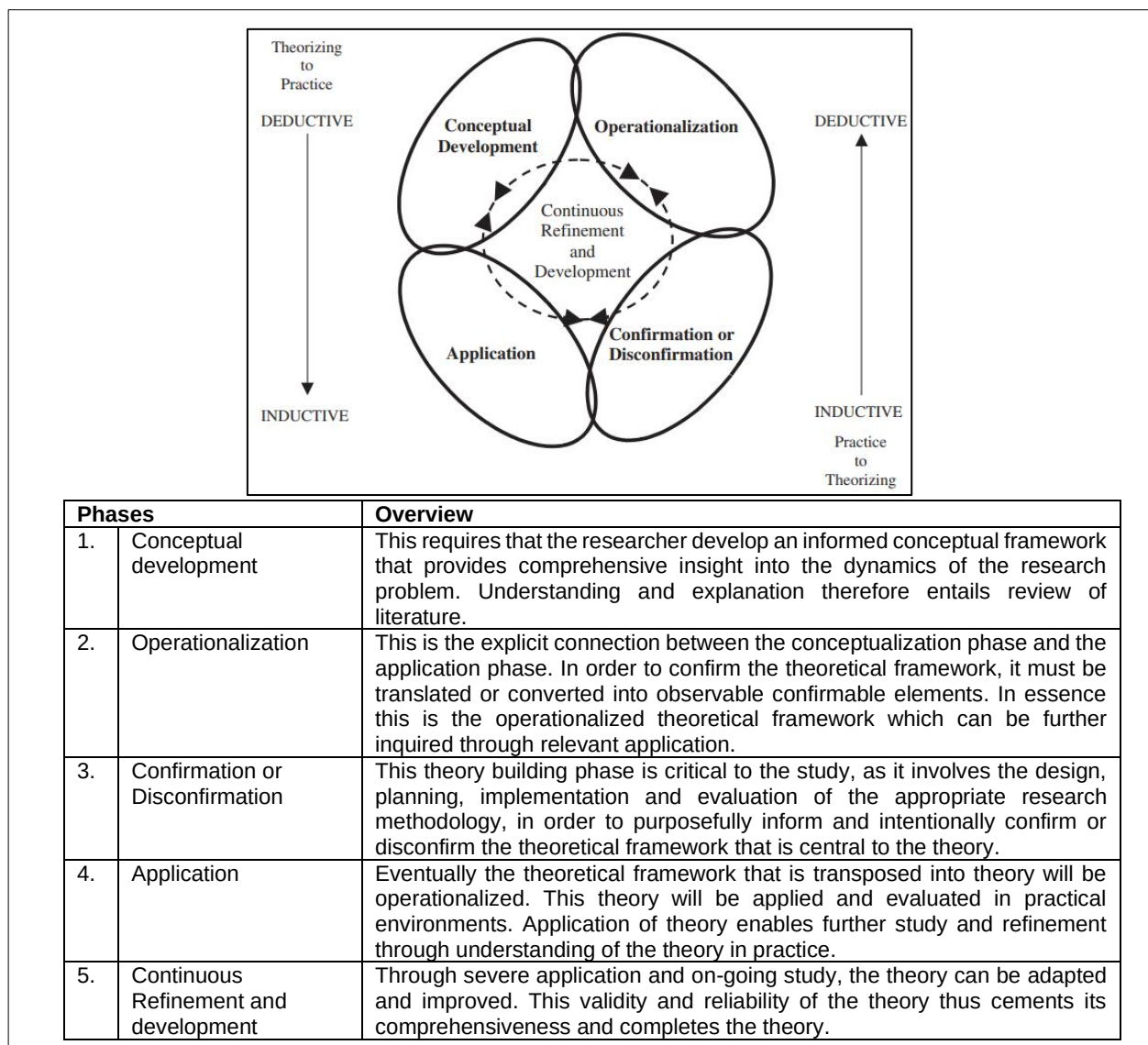


Figure 78. Adapted from the generic model to theory building (Lynham, 2002)

3.3. Verification, Validity and Reliability

The application of verification, validity and reliability concepts are very common in quantitative research; however, the credibility of qualitative studies is often questioned. This is rightfully so, as the direction of research may limit and narrow the field of view. In such a case, inadequate research or the researcher's subjectivity may cloud the interpretation of the data and lead to a false hypothesis.

Whilst there is a distinction between the application of verification, validity and reliability in quantitative and qualitative studies, it is noted that they are pivotal in qualitative studies to assure credibility and quality of the work. Therefore, upfront understanding of the limitations in the field of research at each stage is key.

Verification, validity and reliability are defined as follows:

- **Verification can be defined as (Morse *et al.*, 2002):**

Verification refers to the mechanisms used during the process of research to incrementally contribute to ensuring reliability and validity and, thus, the rigor of the study.

- **Validity can be defined as (Joppe, 2000):**

Validity determines whether the research truly measures that which it was intended to measure or how truthful the research results are. In other words, does the research instrument allow you to hit “*the bull’s eye*” of your research object? Researchers generally determine validity by asking a series of questions and will often look for the answers in the research.

- **Reliability can be defined as (Joppe, 2000):**

The extent to which results are consistent over time and an accurate representation of the total population under study is referred to as reliability and if the results of a study can be reproduced under a similar methodology, then the research instrument is considered to be reliable.

Verification is primarily concerned with building the correct process for the application. It addresses design specification, implementation requirements, effectiveness of delivery system and consistency coupled to traceability. This will enable the identification and correction of errors before they are built into the developing model. Verification strategies assist the researcher to decide when to continue, stop or change the research process in an effort to achieve validity and reliability whilst assuring rigor. Table 25 lists the five-step verification strategy incorporated into this study’s research methodology.

Golafshani (2003) examined the application of validity and reliability in qualitative studies and conceptualized it as trustworthiness, rigor and quality. Other pillars considered are the elimination of biasness and triangulation. The latter includes multiple methods of data collection and data analysis, where convergence is sought. The work conducted at the International Institute for Qualitative Methodology by Morse *et al.* (2002) and Noble and Smith (2015) compares well to Golafshani (2003).

Table 25. Five step verification strategy (Morse et al., 2002)

Verification Steps		Description
1.	Methodological coherence	Ensure congruence between the research question and the components of the method. The question matches the method and the data is therefore fit for analytic procedures.
2.	Sampling sufficiency	Include who best possess or represent knowledge of the research topic to support validation. Saturation and replication of categories ensures comprehension and completeness.
3.	Develop a dynamic relation between sampling, data collection and analysis	Mutual interaction between what is known and what is missing. Iterative approach to attain reliability and validity.
4.	Thinking theoretically	Ideas emergent from data must be verified in data already collected. This requires smaller forward steps rather than cognitive leaps.
5.	Theory development	Deliberate micro perspectives with data and macro theory understanding. Valid theories are well developed, informed, comprehensive and logical.

Validation can be categorised as internal and external. Internal validity entails the strength of conclusions drawn for the study, whilst external validity refers to the extent of relation in applying the study outcome in different environments. As described by Allison (1971), this assists to strengthen the internal validity of the study through examining a phenomenon through the lenses of different disciplines. Internal validation is essentially verification. To successfully achieve verification, included in this study methodology, is the collection of perspectives from different industries, accredited bodies, nuclear, high-risk, etc. This will serve to provide credible data for review. The limitation in external validity is that the study outcome cannot be practically tested in all conceivable environments.

3.4. Study Approach

The extent of literature for examination was quite vast, hence this research methodology framework was interdisciplinary, drawing on psychology, civil aviation, nuclear, mechanical, and chemical environments. Therefore, a process of careful consideration and selection of qualitative mixed methods research techniques ensued. This would ensure that the study's research

methodology delivered on this study's main aim and objectives, to develop a process safety culture framework for the chemical processing industry.

An overview of this study's research methodology is illustrated in Table 26. A simplistic approach was developed which is composed of a five-step research methodology process. This study research methodology was developed through extraction of the best practices from the methodologies described by Mason (2002), Kothari (2004) and Guest and Namey (2013).

Step 1 covers the intent and scope of this study, and this is described in Chapter 1. Step 2 documents this study's qualitative mixed methods research methodology and this is presented in Chapter 3. An extensive literature survey was required, and the review was deliberated in Chapter 2. Step 4 deals with the collection and analysis of the data and is explained in Chapter 4. The gathered data was interpreted to identify themes. Through a theory building exercise, additional literature on the identified themes was surveyed in Chapter 5. Step 5 covered the rationalisation of the themes and development of the process safety culture framework. The findings as well as validation and reliability aspects were deliberated. These topics were discussed in Chapter 6 and Chapter 7.

Table 26 also documents the details covering the research methodology framework, including the rationale, verification and validation requirements. Verification is paramount as it is the foundation of this study. The review entailed literature saturation with global assessment coupled to consideration of culture approaches from diverse origins. Dr P. Calitz, experienced in social psychology as introduced in Annexure C, provided guidance for this research study on human element articles to review from highly credible authors. Observations gathered from this exercise was incorporated into the development of the process safety culture framework.

Figure 79 was developed as a concise illustration of the research methodology framework, which summarises the comprehensive verification approach adopted for this study. It consists of four verification elements: [1] existing process safety frameworks, [2] chemical processing industry process safety culture approaches, [3] non-chemical processing industry safety culture approaches and [4] asset integrity safety culture approaches.

Table 26. Research Study Approach

Description of Step		Breakdown of activities	Verification Steps
Step 1	Define the study outline	Define the study's primary objective	1. Investigate what process safety culture frameworks exist 2. Review different PSM models and its elements
		Select the study's primary audience	3. Process safety primarily focusing on the chemical industry. Chemical process safety culture models
		Select the population and geographic parameters	4. Review different process safety culture practices globally 5. Focus more on first world countries where process safety practices have been well entrenched
		Determine comparative elements	6. Review non-chemical industry safety culture models focusing on low probability, high consequence industries 7. Examine the civil aviation, nuclear and occupational models
Step 2	Research Methodology	Select the qualitative approach	8. Integrating qualitative and quantitative approaches to form a mixed methods approach 9. Collection of published articles, journals, studies and data
Step 3	Generating Qualitative data	Select data sources	10. Credible scholarly, publication and specialist websites. Review of work by authorised peers in the industry (Psychology, CAIA)
		Establish sampling populations	11. Focus on saturation for process safety cultures
Step 4	Analysing Qualitative data	Organizing and indexing data	12. Comparison of the existing process safety culture models in the chemical processing industry 13. Illustration of the safety culture frameworks
		Making convincing arguments	14. Comparison to non-chemical processing industry safety culture models focusing on low probability, high consequence industries 15. Identify common safety culture elements and group where possible 16. Compare all identified common safety culture elements and review for further consolidation
Step 5	Interpret and Report	Discuss findings	17. Draw similarities, relationships and core culture framework elements through theory building 18. Develop the sustainable process safety culture framework
		Validation and Reliability	19. Review many process safety culture models from regulatory bodies and credible organisations 20. Test with Process Safety Engineers/Specialists in the field and incorporate builds 21. Pilot the process safety culture framework at a sizeable (>100000 man-hours per month, based on the author's experience) chemical processing facility and incorporate builds 22. Publish articles in Accredited Journals

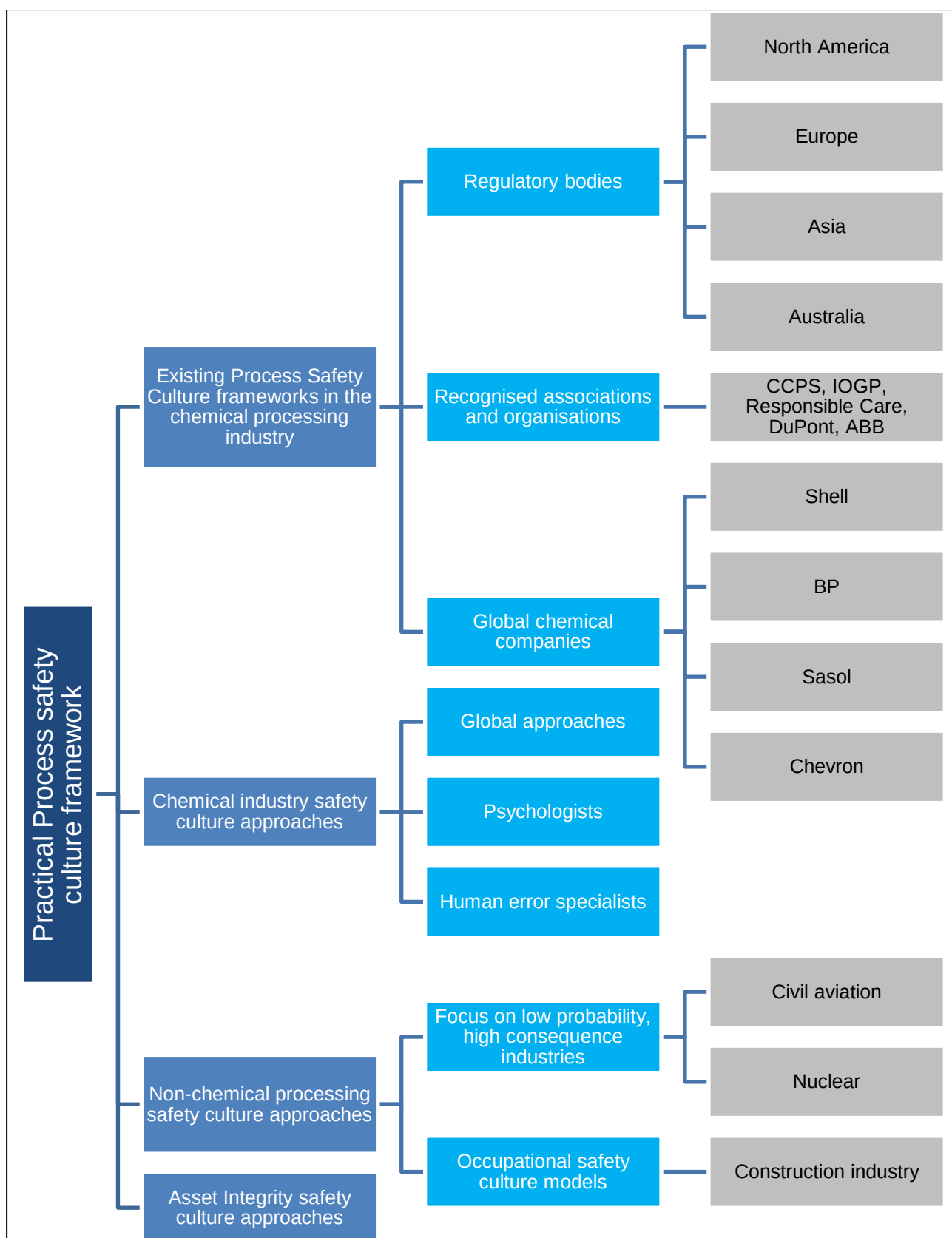


Figure 79. Research Study Approach

The collective data gathered from the literature review in Chapter 2 was analysed and interpreted to progress toward theory building in Chapter 5. The data inferred from this interpretation was newly uncovered, hence another literature survey was required to understand and build on this theory. A verification process similar to the aforementioned approach was adopted. This demonstrates the rigour of the study and greatly supports the validation and reliability aspects. Subsequently internal and external validation was also positively impacted with this verification approach.

Validation and reliability of a study is meant to confirm that the findings raised are truly representative of the area of study, thereby meeting the study's research objective. Therefore, it is very crucial that robust validation and reliability techniques are adopted. For this study, validation and reliability were addressed mainly through piloting the process safety culture framework at a sizeable chemical processing facility (>100000 man-hours per month, based on author's experience). The intent was to field test the process safety culture framework developed over an extended period in a real-world application. A typical period was considered to be between 1 to 2 years. The longer the field test duration the more accurate the reliability, given the other parameters remained the same.

Through continuous refinement and development at a chemical processing facility, the process safety culture framework can be adapted and improved to address any shortcoming identified. In conjunction, experienced Process Safety Engineers/Specialists were to also scrutinise the framework and its application in the chemical processing industry. Through these approaches, the framework's strengths and weaknesses could be assessed. The framework could be revised upon incorporating the builds raised and finalised for publication. This two-pronged approach thus complements the validation and reliability process. Articles will be drafted for publication in accredited journals, as this approach also confirms validity of this study.

To summarise, in this chapter, the employed research methodology was discussed in pursuit of achieving the aim and objectives of this study. A qualitative mixed methods approach was selected, and comprehensive verification, validation and reliability techniques were reviewed. Theory building was highlighted as an additional literature survey required to assist in the development of the process safety culture framework. The aforementioned discussed practices were then incorporated into this study's research methodology and presented in Table 26. Chapter 4 presents the themes raised from the literature review which also contributes toward the development of the process safety culture framework. Chapter 5 describes the theory building review, which is essentially an additional literature survey.

CHAPTER 4 LITERATURE ANALYSIS

In chapter 4, the literature reviewed in Chapter 2 was analysed and compiled into more useful information. Process safety culture, occupational safety culture, and other high-risk high-reliability industries were reviewed. Themes were identified from each of the safety culture approaches discussed in the literature review. They were grouped based on applicability, to assist in shaping the information for usability.

The information collated from this exercise was then transferred into tables with percentage contributions of specific aspects for easier presentation and interpretation. The intent was to use this information gathered for developing the foundation of the sustainable process safety culture framework.

Nine international and independent PSM systems were investigated as described in Chapter 1 and only two systems included process safety culture elements. Literature was then surveyed to identify other process safety culture practices outside of these PSM systems. Annexure B, Table 44 documents a total of twenty investigated process safety culture approaches reviewed in Section 2.2. From this exercise, a total of eight process safety culture themes were identified based on the percentage of common themes amongst the reviewed systems, as tabulated in Table 27.

The top three themes were: [1] continuous performance monitoring and improvement (71%), [2] empowered individuals (62%) and [3] human error engineering (57%). The first and last two themes are more hard control related, so they can be more easily influenced. The ease of influence will assist in achieving positive process safety culture results. Empowering individuals is more of a soft challenge, and when executed correctly can carry process safety culture into a higher maturity state.

Chemical processing companies with global footprints practising PSM were surveyed to understand their process safety culture practices. A total of four chemical process safety culture approaches were reviewed in Section 2.3, as listed in Annexure B, Table 45. Ten process safety culture themes were identified, and their respective percentage contributions were calculated as listed in Table 28. The top three themes were: PSM system (100%), focused on improved training programs (100%), and incident investigation and learning systems (100%). These themes are currently embedded in all PSM systems as they are foundational concepts.

Table 27. Process Safety Culture Themes

Process Safety Culture Themes	Description and contribution of themes	
1. Continuous performance monitoring and improvement	Developing process safety culture indicators for tracking and improvement. Focusing more on leading indicators rather than lagging. Conducting audits to assess effectiveness of implementation and execution	71%
2. Empowered individuals	Well-resourced with experienced and trained individuals alluding to high levels of competence	62%
3. Human error engineering	Evaluating human and machine interfaces and optimising this interaction to increase its reliability	57%
4. Strong leadership	Experienced and committed leadership from board level to first line leadership who actively drive and practice a process safety culture	48%
5. Open and effective communication	Two-way communication that is transparent, clear and frequent. Using diverse communication mediums	33%
6. Establish a learning environment	Entrenching learnings effectively and continuously learning environment	33%
7. Risk awareness and management	Identification of a facility's hazards and risk profile, along with its associated preventative and corrective controls. Highlight the critical controls and ensure the organisation manages this effectively	33%
8. Motivation	Motivated people excel at the given task. Hence develop incentives to promote and sustain a process safety culture	19%

Table 28. Chemical Process Safety Culture Themes

Chemical Process Safety Culture Themes	Percentage Contribution
1. Process Safety Management System	100%
2. Focused on improved training programs	100%
3. Incident Investigation and Learning systems	100%
4. Risk Based Safety Approach	75%
5. Auditing systems	75%
6. Emergency Response and management	75%
7. Safety leadership programs or elements	50%
8. Human behaviours and culture programs or elements	25%
9. Specific human factor training	25%
10. High intolerance to rules and standards	25%

Interestingly, the process safety culture aspects ranked far lower and included: safety leadership programs or elements (50%), human behaviours and culture programs or elements (25%), specific human factor training (25%) and high intolerance to rules and standards (25%). It is observed that developmental programs designed to improve human factor risks need to be supported by corrective programs designed to combat against such deviations reoccurring.

A total of twenty-eight independent occupational safety culture approaches were reviewed in Section 2.6, which were across different industries as listed in Annexure B, Table 46. Table 29 lists the ten occupational safety culture themes identified and their respective percentage contributions were calculated.

Table 29. Occupational Safety Culture Themes

Occupational Safety Culture Themes	Percentage Contribution
1. Engaged, value driven and committed leadership from executive to senior to front line leadership	79%
2. Positive, transparent and open communication across all levels	57%
3. Well documented safety practices, policies and procedures	54%
4. Safety driven goals, targets, performance monitoring and reward incentives	46%
5. An active safety information system which collects, analyses and records key incident causes and learnings	43%
6. Employees openly report all types of errors, mistakes and violations irrespective of how small or large	32%
7. Continuous improvement initiatives such as periodic culture surveys (maturity assessment)	29%
8. Willingness and competence of employees to function and derive the correct conclusions with associated corrective actions	25%
9. Consistent and clear disciplinary process	18%
10. Agility of an organisation to respond to arising concerns	11%

The top theme identified was engaged, value driven and committed leadership (79%). This closely resembles the findings in the process safety culture theme, where one of the top themes was empowered individuals (62%). Positive and transparent communication and comprehensive policies and procedures followed closely to the top theme identified.

Human error prevention in asset integrity was surveyed in different sectors to gain insights into best practices applied. A total of ten independent asset integrity safety culture approaches were reviewed in Section 2.8, which specifically addressed maintenance error as listed in Annexure B,

Table 47. Seven asset integrity safety culture themes were identified, and their respective percentage contributions were calculated as illustrated in Table 30. A maintenance (80%) and reliability (60%) management system were respectively the top two themes as they are at the cornerstone of successful asset integrity.

Table 30. Asset Integrity Safety Culture Themes

Asset Integrity Safety Culture Themes	Description and contribution of themes	
1. Maintenance Management System	Easily accessible, simple user electronic interface with ability to manage the maintenance aspects from scheduling, strategies, execution to archiving records.	80%
2. Reliability Management	Risk assessment, Incident and cause management, strategy optimization, critical equipment categorization, condition monitoring, performance	60%
3. Quality Assurance	Redundancy mechanisms are in place to easily detect human error through independent checks. Quality control plans developed according to equipment hazard and service requirements.	50%
4. Process Safety Information	Information (e.g. equipment data sheets, mechanical flow drawings, isometric drawings, etc.) is easily accessible, electronic, comprehensive and current.	40%
5. Well-resourced and competent workforce	Maintenance team structure is well aligned to the quantity of execution work expected. Artisans are skilled in their craft as assessed periodically.	30%
6. Knowledge transfer	Specialized skills are incorporated into existing training programs and procedures	30%
7. Appropriate tooling and equipment	Each task is assessed and tools are identified and specified to improve the efficiency of work execution. This could be OEM or specially manufactured tools.	10%

Appropriate tooling and equipment (10%) drive effortlessness and correctly driven maintenance execution, which ultimately results in high levels of workmanship. This positively impacts quality assurance (50%) and limits the need for rework thereby reducing maintenance costs. Knowledge transfer (30%) is also another pivotal concept in competency management as specialist skills can be quite easily lost if not managed correctly. This also applies to personnel who operate chemical processing facilities. Succession planning, up to date procedures and coaching programs are some mechanisms that can be leveraged to combat against loss of knowledge transfer.

Other high-risk high-reliability industries were explored to extract additional best practices in the process and occupational safety culture environment. Such industries are inherently operated with the potential to result in major catastrophe. Therefore, since the consequence cannot be influenced, the probability of such an event occurring is closely managed, alluding to high reliability. The nuclear and civil aviation industries were investigated.

The nuclear industry is heavily regulated and has an abundance of safety practices and guidelines. A total of seven nuclear safety approaches were reviewed in Section 2.9.1, as listed in Annexure B, Table 48. Seven nuclear safety culture themes were identified, and their respective percentage contributions were calculated as illustrated in Table 31. Continuous performance monitoring and improvement (43%) and a risk management program (43%) were the two equal top themes identified.

Table 31. Nuclear Safety Culture Themes

Nuclear Safety Culture Themes	Description and contribution of themes	
1. Continuous performance monitoring and improvement	Developing indicators and targets for tracking and improvement. Focusing more on leading indicators rather than lagging indicators. Conducting audits to assess effectiveness of implementation and execution	43%
2. Risk management program	Active prevention of incidents focusing on incident learning as well as emergency response and mitigation measures.	43%
3. Optimization and Recognition	Employees continuously seek optimization opportunities motivated by well-developed reward and recognition programs	29%
4. Improve human error performance	Evaluating human and machine interfaces and optimizing this interaction to increase its reliability	29%
5. Safety critical software quality control	Product testing, examination of the code and assessment of the design, personnel usability and the method applied	29%
6. Committed and active leadership	Unwavering ethical standards entails commitment and visible display of such integrity through all levels within an organization	29%
7. Artefact, espoused value and basic assumption levels	Behaviour exhibited by leadership instill the correct safety culture values	14%
8. Competent and well-resourced workforce	Provide the necessary knowledge to support the workforce	14%

Like the nuclear industry, the aviation industry is also greatly regulated with many safety culture approaches documented. A total of eleven aviation safety culture approaches were examined from Section 2.9.2, as listed in Annexure B, Table 49. Six aviation safety culture themes were identified, and their respective percentage contributions were calculated, as illustrated in Table 32. Improving technical execution (67%) and dimensional culture management (42%) were the top themes identified.

Table 32. Aviation Safety Culture Themes

Aviation Safety Culture Themes	Description and contribution of themes	
1. Improving Technical Execution	Institutionalizing incident learnings, governance and assurance on laws and regulations, redundancy systems, fatigue management and high standards of training and competency processes	67%
2. Dimensional Culture Management	Development, assessment and enhancement of culture management programs through the different dimensions	42%
3. Training and Competency	Positively influencing employee safety responsibility	33%
4. Improve human error performance	Evaluating human and machine interfaces and optimizing this interaction to increase its reliability. Focus on error reduction, capture and tolerance	17%
5. Asset Integrity	Equipment maintenance strategies and plans	8%
6. Human Factor Organisation Influences	Resource Management (recruitment, staffing, selection, equipment design, funding), Organisational Process (pressure, incentives, targets, risk management, procedures), Organisation Climate (leadership, communication, policies and adherence, culture practices)	8%

Identified trends revealed some themes which featured repeatedly across the different process and occupational safety culture approaches in the diverse environments investigated. It was clear that these common themes would shape and form the basis of a process safety culture framework. The sustainable process management survey, discussed in Section 2.5, suggested that a broad point of view be investigated. Therefore, all the information gathered from the findings were collated and presented in tabular format. Table 33 documents all the identified safety culture themes from Table 27, Table 28, Table 29, Table 30, Table 31 and Table 32.

Shared themes were collectively grouped together to assist with ease of interpretation of the data. Upon reviewing the descriptions of these grouped themes, it became apparent that each of these respectively grouped themes fall under a parent theme. Therefore, parent themes were derived for each of the respective collectively grouped themes.

A process safety culture is inferred through process safety climate assessment. These parent themes are essentially process safety climate attributes, which form the foundational layer of a process safety culture framework; hence they form its elemental makeup. These parent themes are therefore process safety culture constructs. A total of nine process safety culture constructs were derived as mapped out in Table 33:

1. Disciplinary Process, Communication
2. Complex Instrumentation
3. Knowledge Management System (Maintenance, SHE)
4. Assurance, Auditing, Quality Control
5. Incident Management
6. Resourcing, Roles and Responsibilities
7. Recognition and Reward, Metrics
8. Continuous Improvement
9. Maintenance

These nine process safety culture constructs require further understanding to determine interdependencies. Chapter 5 entails theory building of these process safety culture constructs to assist in the development of a process safety culture framework.

Table 33. Summary of Common Process Safety and Safety Culture Themes and Constructs

Common Process Safety and Safety Culture Themes							Derived Process Safety Culture Constructs
	Process Safety	Occupational Safety	Asset Integrity Safety	Nuclear Safety	Aviation Safety	Chemical Process Safety	
1	Open and effective communication (33%)	Positive, transparent and open communication across all level (57%), Consistent and clear disciplinary process (18%)				High intolerance to rules and standards (25%)	[1] Disciplinary Process, Communication
2	Human error engineering (57%)			Improve human error performance (29%), Safety critical software quality control (29%)	Improve human error performance (17%)		[2] Complex Instrumentation
3	Risk awareness and management (33%)		Process Safety Information (38%), Maintenance Management System (88%)	Risk management program (43%)		Process Safety Management System (100%), Risk Based Safety Approach (75%), Emergency Response and management (75%)	[3] Knowledge Management System (Maintenance, SHE)
4			Quality Assurance (50%)		Improving Technical Execution (75%)	Auditing systems (75%)	[4] Assurance, Auditing, Quality Control
5	Establish a learning environment (33%)	People openly report all types of errors, mistakes and violations irrespective of how small or large (32%), An active safety information system which collects, analyses and records key incident causes and learnings (43%)			Improving Technical Execution (75%)	Incident Investigation and Learning systems (100%)	[5] Incident Management
6		Well documented safety practices, policies and procedures (54%), Willingness and competence of employees to function and derive the correct conclusions with associated corrective actions (25%)	Well-resourced and competent workforce (25%), Knowledge transfer (25%)	Committed and active leadership (29%), Artefact, espoused value and basic assumption levels (14%), Competent and well-resourced workforce (14%)	Improving Technical Execution (75%), Dimensional Culture Management (50%), Training and Competency (33%), Human Factor Organisation Influences (8%)	Focused on improved training programs (100%), Safety leadership programs or elements (50%), Human behaviours and culture programs or elements (25%), Specific human factor training (25%)	[6] Resourcing, Roles and Responsibilities
7	Empowered individuals (62%), Strong leadership (48%), Motivation (19%), Continuous performance monitoring and improvement (71%)	Engaged, value driven and committed leadership from executive to senior to front line leadership (79%), Safety driven goals, targets, performance monitoring and reward incentives (46%)		Continuous performance monitoring and improvement (43%), Optimization and Recognition (29%)			[7] Recognition and Reward, Metrics
8	Continuous performance monitoring and improvement (71%)	Continuous improvement initiatives such as periodic culture surveys (maturity assessment) (29%), Agility of an organisation to respond to arising concerns (11%)		Optimization and Recognition, Improve human error performance (43%)	Improve human error performance (17%)		[8] Continuous Improvement
9			Reliability Management (63%), Process Safety Information (38%), Appropriate tooling and equipment (13%), Quality Assurance (50%)		Asset Integrity (8%)		[9] Maintenance

CHAPTER 5 THEORY BUILDING

Dr Trevor Kletz, “There’s an old saying that if you think safety is expensive, try an accident. Accidents cost a lot of money. And, not only on damage to plant and in claims for injury, but also on the loss of the company’s reputation”

5.1. Introduction

In Chapter 4 the findings gathered from the literature review was presented. Many themes were uncovered and collated to assist in interpretation. A total of nine process safety culture constructs were derived from the theme analysis. However further understanding of these process safety culture constructs was required to determine interdependencies. Therefore, in this chapter, the nine derived process safety culture (PSC) constructs were investigated.

The respective individual PSC constructs were examined to gain their respective insights. Theory building was conducted through another literature survey as outlined in this Chapter 5. Note that this literature review is different to the literature review presented in Chapter 2.

The assessment and understanding of each construct’s makeup, will enable the building of a process safety culture framework. Thus, Chapter 5 entails theory building of these process safety culture constructs to assist in the formation of a process safety culture framework.

5.2. PSC Construct One: Disciplinary Process

The disciplinary process is often associated with negative perceptions. One of the key causes (Ukpere, 2014) is due to employees feeling that the disciplinary procedures are applied inconsistently. The knock-on effect results in reduced employee morale, motivation and an unhealthy work environment. A crucial aspect of human resource management is disciplinary management, which is composed of three key dimensions (Opatha and Mithani, 2000): discipline policy, procedure and practise, which is illustrated in Figure 80.

Reason (1998) developed models to assist in transparent, fair and consistent disciplinary action. Leadership must be proficient in the disciplinary management system and practice. Opatha and Mithani (2000) simplified the process as displayed in Figure 81.

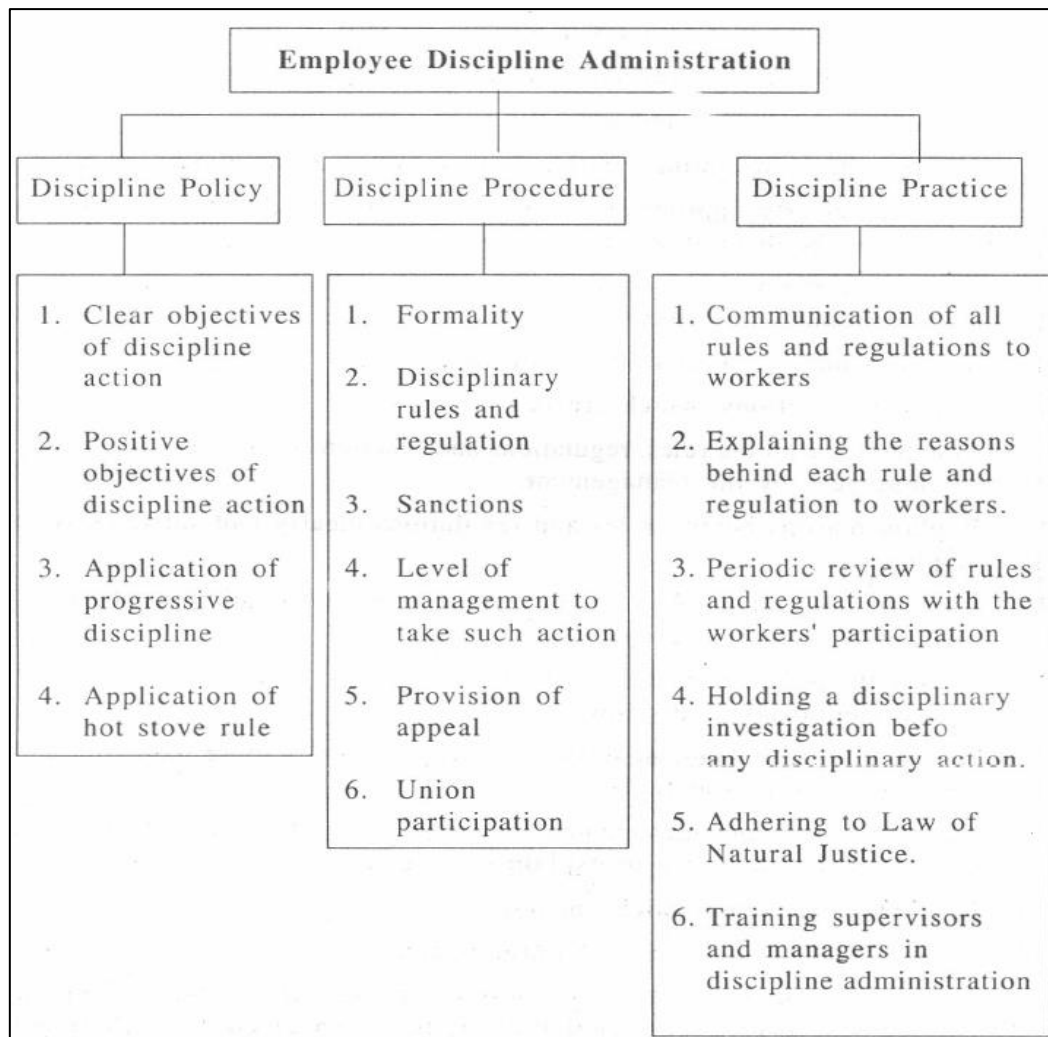


Figure 80. Dimensions and Elements of Employee Disciplinary Administration (Opatha and Mithani, 2000)

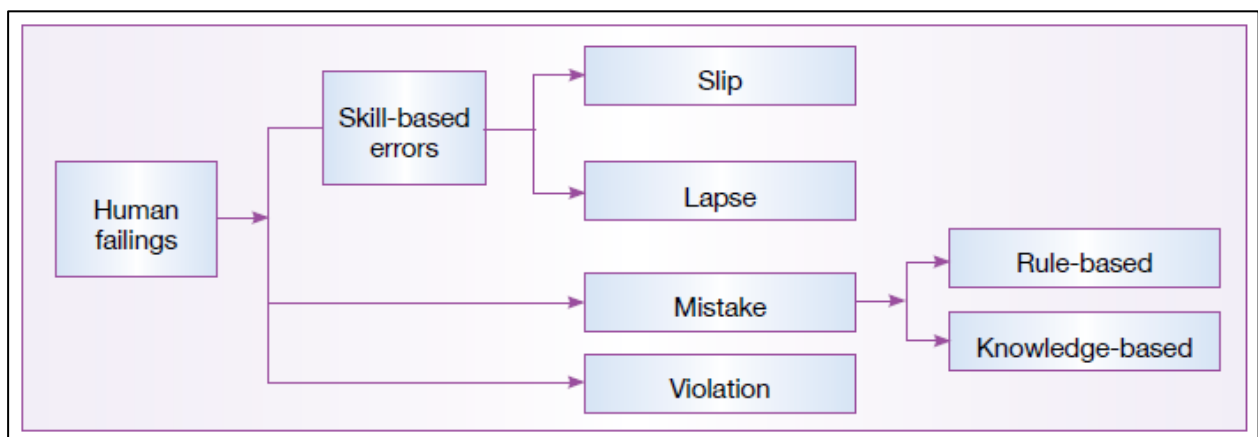


Figure 81. Dimensions and Elements of Employee Disciplinary Administration (Opatha and Mithani, 2000)

5.3. PSC Construct One: Communication

Constructive and clear process safety communication can improve knowledge and understanding that prevents the occurrence of major process safety incidents. Process safety communication mechanisms should complement the practical and technical safety strategies. Employees mirror the appropriate behaviours of leadership and face to face interactions have longer lasting positive impacts on behaviour. Employee involvement in the HSE (2010) decision-making process is characteristic of a healthy safety culture.

Process safety communication should be prescribed to both employees and service providers (contractors). However, the content of these communications should be specific to the audience. These are some key communication mechanisms (HSE, 2010): timing of messages, visually engaging information, tailored messages, real life examples (story telling), location of messages and trusted messengers.

Similarly, Vecchio-Sadus (2007) developed safety culture communication elements. Figure 82 indicates the safety culture element and requirement, with its associated communication element to achieve that requirement.

Safety Culture Element	Requirement	Communication Element
Putting in place methods for controlling hazards	• Everyone shows support	• Displaying rules and procedures to remind everyone to work safely
Management commitment to minimising risks in the operations, and complying with all relevant health and safety legislation	• Accept responsibility for HSE • Become involved in HSE • Provide resources • Change attitude to risk	• Demonstrating the employer's personal commitment, values and expectations • Supervising and monitoring work performance
Employees contribute most effectively in an organisational culture based on trust and cooperation	• Atmosphere of trust, encouragement and reward in terms of HSE	• Assessing competency and providing revision of training when required • Providing feedback on HSE • Motivating staff • Recognising and rewarding achievement
Employees must be provided with the necessary information and training to broaden their knowledge and to gain new skills to behave and operate safely	• Willingness and competence to implement reforms and changes	• Providing instructions on how to work safely with equipment, tools, materials and processes
Employees contribute most effectively in an environment that provides a framework for consultation and communication	• Individuals encouraged and prepared to report errors and near-misses	• Meeting to discuss HSE issues such as hazard and incident reports, risk assessments and operating procedures

Figure 82. Safety culture communication elements (Vecchio-Sadus, 2007)

5.4. PSC Construct Two: Complex Instrumentation

Human error prevention was identified as a recurring challenge in Section 2.2. A safety instrumented system (SIS) is useful in reducing human error in the operational space. There it plays a critical role in preventing process safety incidents and is often the last barrier between safe operation and a major event. However, the process safety challenge is balancing the cost of a high integrity SIS against the throughput and ultimately the profitability of the company, as displayed in Figure 83.

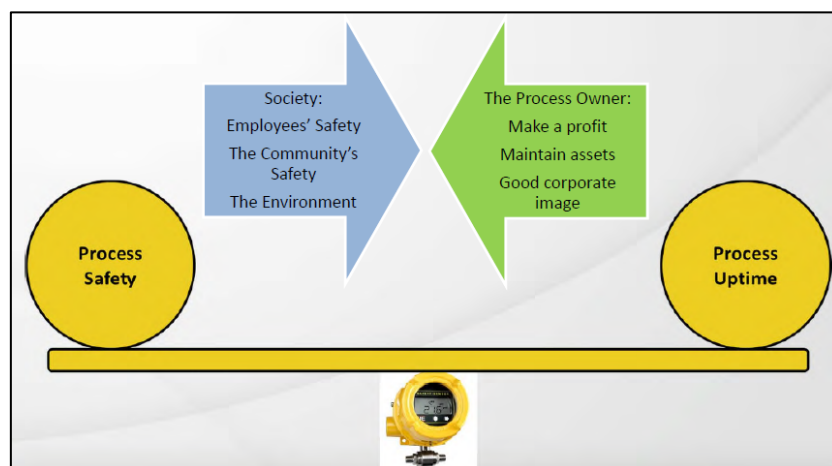


Figure 83. Balancing process safety and throughput (Pierce, 2004)

The design of a SIS is a very complex process, and it must adopt industry standards applicable to that specific facility. Specific safety integrity levels are achieved through these key factors: failure rates, proof tests and maintenance frequency. Layers of Protection Analysis (LOPA) is a process to identify process safety mechanisms to reduce its probability of a major event occurring, as illustrated in Figure 84.

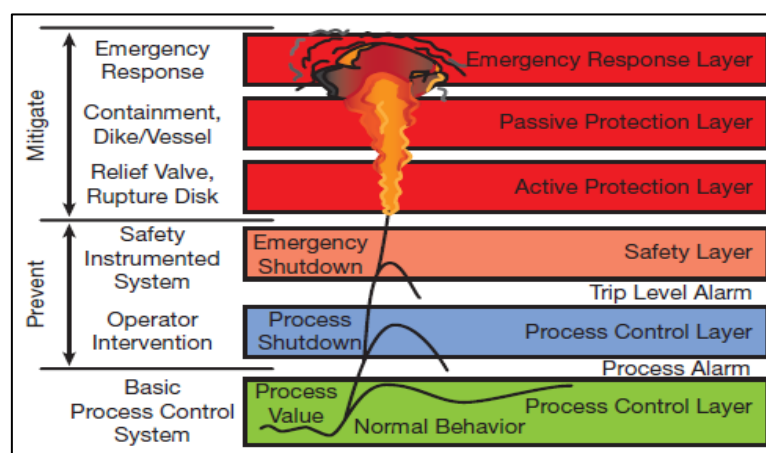


Figure 84. Layer of Protection (McGuire et al., 2015)

Instrumented Protective System (IPS) derived for continuous improvement in safety instrumented systems is displayed in Figure 85. It uses a combination of internal practices and personnel knowledge, experience and skill to achieve and maintain the core attributes of human performance throughout the lifecycle. Performance is monitored through different leading indicators, such as detected faults, process demands, dangerous and safe failures and personnel conformance to management system requirements.

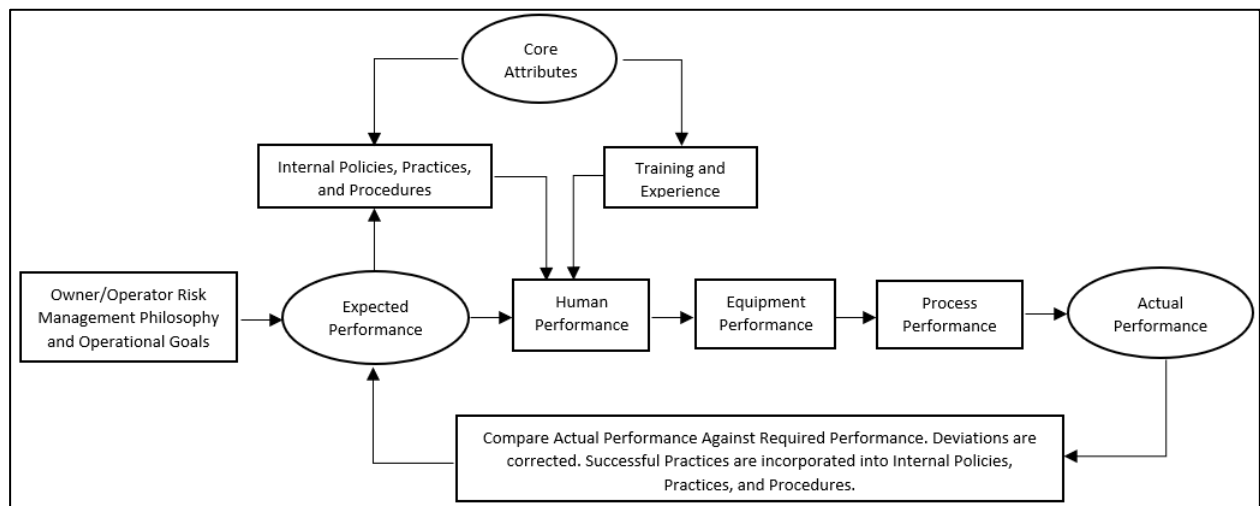


Figure 85. System relying on establishing and monitoring core attributes (Summers, 2007)

5.5. PSC Construct Three: Knowledge Management Systems (Maintenance and SHE)

Hale (2000) suggests addressing safety culture as a culture variable, because employees need to apply processes, systems, legislation and policies. Hence, they need to operate within the safety management system (SMS) parameters. Information management within a SMS is of utmost importance to ensure the transparency and accessibility of process safety risk related information. An electronic SMS must account for collection, analysis, and visualisation of relevant information to assist in operational risk management, and be expanded to include critical process safety climate aspects to assess process safety culture (Guldenmund, 2010). The interface of this system is crucial to assure ease of access, use, management, and reporting. Cotterill (2004) recommend that the software interface design stages include eight elements as tabulated in Table 34.

Sarshar *et al.* (2018) developed such an information system for the maintenance function, as depicted in Figure 86. It consists of three elements to manage system risk. It includes activity, technical and external factors.

For the American Society of Safety Engineers Conference, Freibott (2012) presented a holistic integrated SHE approach that incorporates safety culture. This model incorporates four themes, as illustrated in Figure 87, namely: [1] asset Integrity, [2] operational risk management, [3] energy and [4] resource and quality management.

Table 34. Software interface design stages (Cotterill, 2004)

Eight Elements	Element overview
1. User requirements definition (URD):	a. Based on a structured task analysis looking at input sources, target audience and end users. b. Consider the age, education and skill levels of the user population. c. Information and actions are required. d. Desired functions and capability. e. Style guides and colour guides.
2. Design Process:	a. Avoid unnecessary complexity. b. Map the design to user needs by matching tasks to functionality. c. Identify potential causes and consequences of error or hazards and eliminate them. d. Understand the operational environment, working conditions and constraints. e. Identify and adhere to applicable standards. f. Ensure consistent implementation of functions and features. g. Conduct end user usability assessments.
3. Design specification:	a. Based on the requirements for control of the system (what it will do). b. Include the URD and how the system will be operated by the end user.
4. Concept design:	a. Produce a definition of how the operator will control the system through the interface (how it will do this). b. Conduct reviews by end users and system experts to help guide and refine the interface.
5. Paper / rapid prototyping:	a. Paper or computer models can be produced to mimic the responses to user interactions. b. Feedback from this exercise must be used to help refine the interface.
6. Initial design:	a. Main design and build can proceed to develop full scale working systems. b. Assess the interface through usability criteria, user and consistency testing.
7. Detailed design:	a. System design for usability is an iterative process achieved through testing and inspection.
8. Usability heuristics:	a. Visibility of system status. b. Match between system and the real world. c. User control and freedom. d. Consistency and standard. e. Error prevention. f. Recognition rather than recall.

	g. Flexibility and efficiency of use. h. Aesthetic and minimalist design. i. Help users recognize, diagnose and recover from errors. j. Help and documentation.
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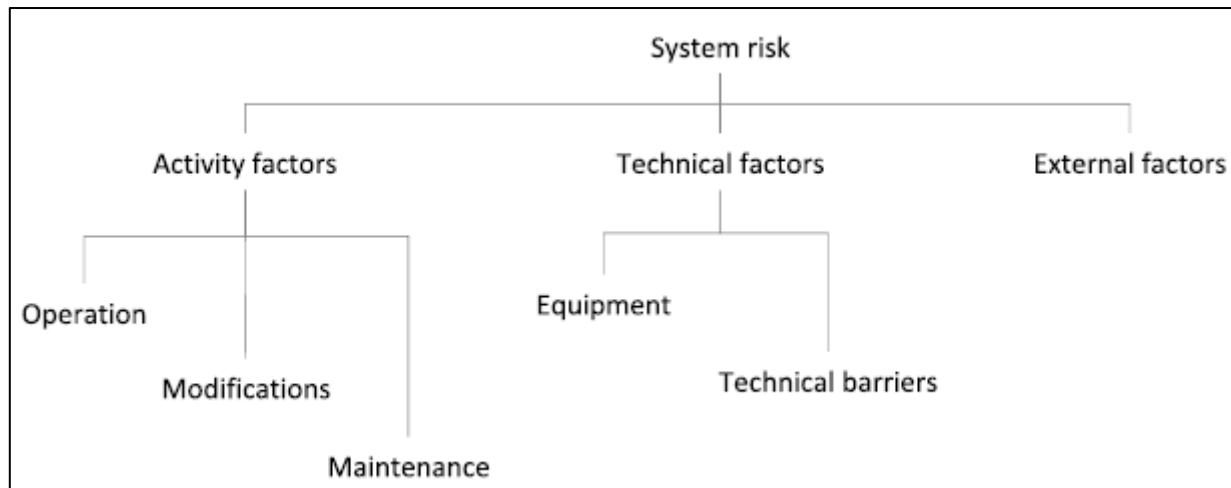


Figure 86. Risk influence structure for a system (Sarshar *et al.*, 2018)

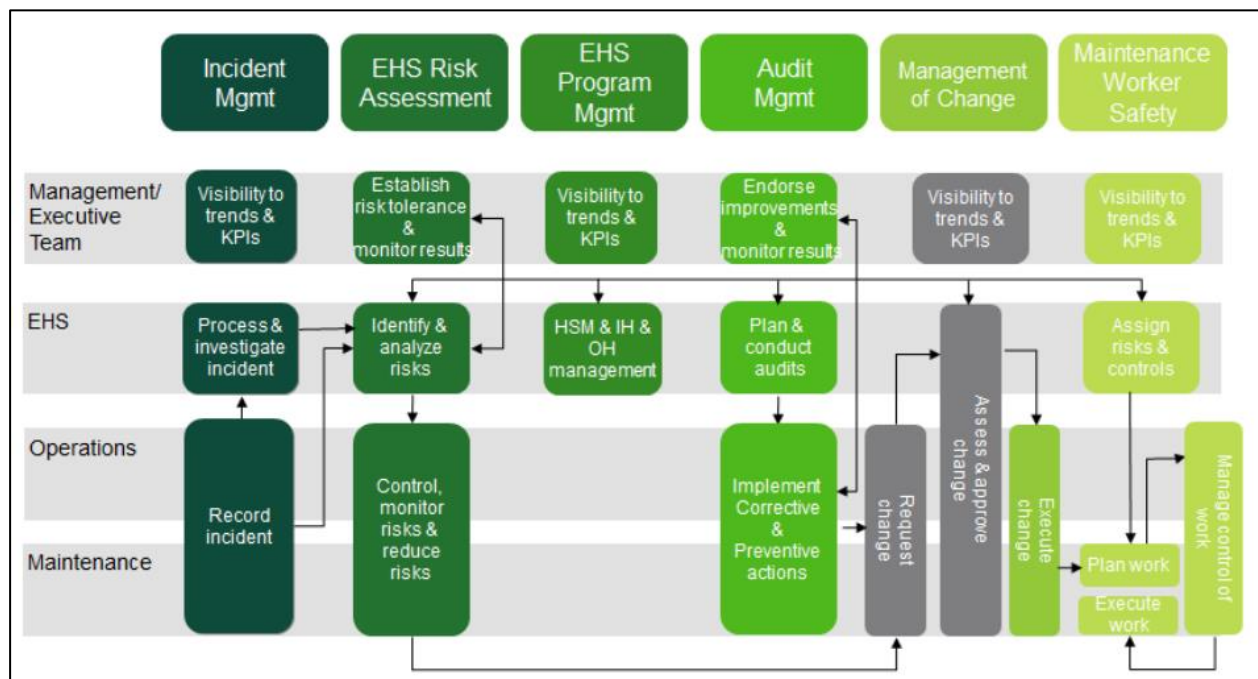


Figure 87. Comprehensive Approach to SHE (Freibott, 2012)

This system was unique as it combined aspects from the maintenance and SHE domain into one single system. It indicated the relationships between maintenance and SHE and how it can be integrated in practice.

Currently many standalone systems are available to address each aspect, such as: SAP PM, Meridium, APM, PSCMS and Deltas V. Some of which have the potential to communicate and function with each other. The challenge will be the design of the digital solution which incorporates all these aspects. It also needs to be comprehensive so as to deliver on expectations from the respective maintenance and SHE functions. This holistic system integration will still remain a costly and timely exercise to develop and implement.

5.6. PSC Construct Four: Assurance, Auditing and Quality Control

Compliance Audit is an element included in many PSM systems. The intent is to identify potential deficiencies in the PSM program used and rectify to prevent any major process incidents.

CCPS (2003) audit and inspection definition is as follows, *“An audit is a systematic, independent review to verify conformance with established guidelines or standards. It employs a well-defined review process to ensure consistency, and to allow the auditor to reach defensible conclusions”*.

An inspection is a process of physically examining a facility. Process safety audits and inspections are a way to determine the effectiveness of systems and their implementation thereof. The quality of an audit is further augmented by the experience and independency of the auditor. Some of the key prerequisites of an audit, include the open-mindedness and free sharing of the auditee and auditing against a standard with a protocol. CCPS (2003) notes that PSM system auditing program must consider scope, frequency, staffing, reporting, follow-up and quality assurance. The design of these factors are primarily dependant on the type and size of organisation.

Dupont (Rains, 2009) recommends that, *“A robust audit program is needed to bring subject matter expertise and management representatives into the operating facilities to ask the tough questions.”* First party auditing is conducted by the facility representatives, where second and third party audits are conducted by persons outside that facility. The second and third party audit are generally scheduled less frequently (typically 1 to 2 years) due to the costs associated with the objectivity of this type of audit. First party audits should therefore occur more frequently to ensure a sustainable and effective audit system. An overview of the pros and cons of these different audits are presented in Figure 88.

Audit Pros and Cons		
FIRST PARTY	SECOND PARTY	THIRD PARTY
+ Flexible Scheduling	+ Common Corporate Culture	+ Balance between standards and regs
+ Direct leader involvement	+ Results easily comparable	+ Totally objective and unbiased
+ Less formal/threatening	+ Develops internal auditors	+ Highest quality audit
+ Immediate response	+ Reasonable costs	+ Receiving organization is highly motivated to respond and act
– Limited learnings	– Weaker on local requirements	– Expensive
– Biased reporting	– Part time auditors; lower quality	– Detailed citations may miss big picture
– Easily procrastinated	– Too internally focused	– Progress difficult to track

Figure 88. Pros and Cons of First, Second and Third Party Audits (Rains, 2009)

Majid *et al.* (2014) proposed a simplified compliance audit framework based on the OSHA (2000) PSM system, as illustrated in Figure 89. This can be used as a basis to create an auditing program.

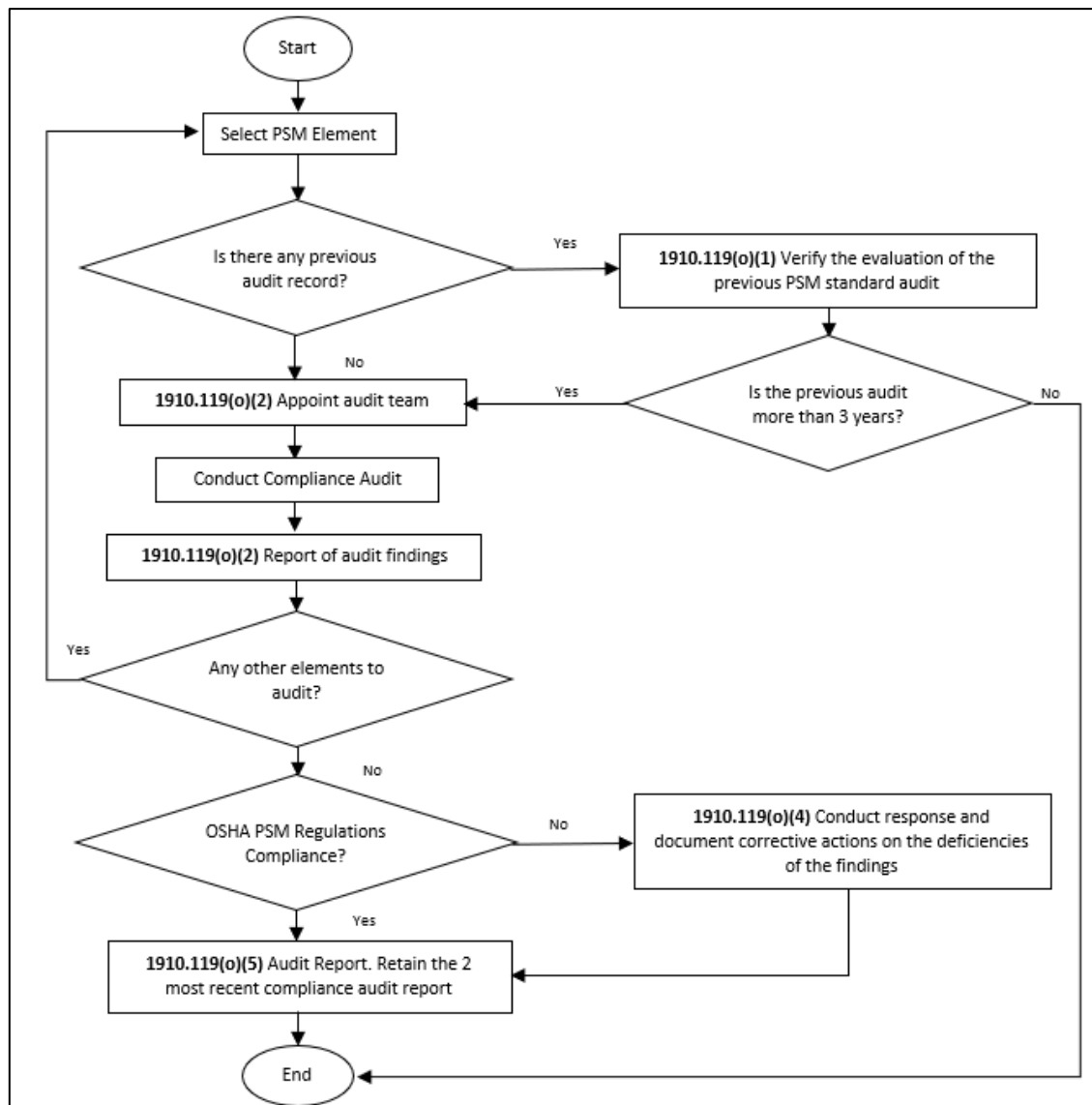


Figure 89. Simplified compliance audit framework (Majid *et al.*, 2014)

Similarly, Kung Leong *et al.* (2012) investigated theories on quality management maintenance and practices. Figure 90 depicts the Kanter's theory (Kung Leong *et al.*, 2012) for maintaining quality management systems effectively. This study of technical and non-technical approaches can be adapted to assure quality control in the maintenance function.

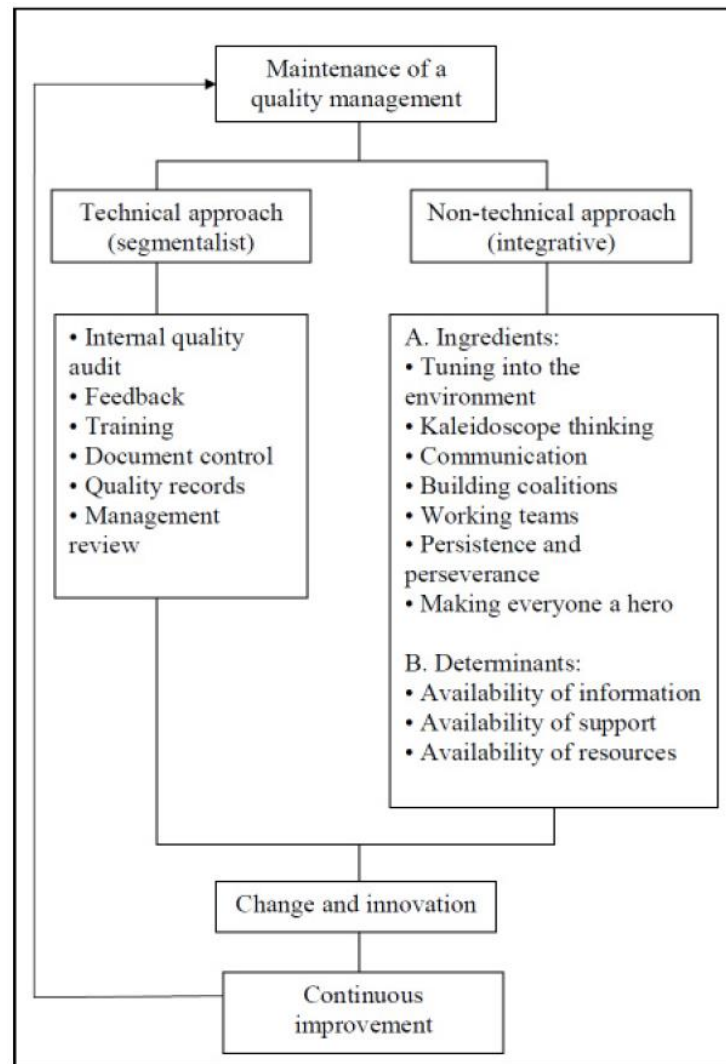


Figure 90. Kanter's theory for maintaining quality management systems effectively (Kung Leong *et al.*, 2012)

Prior (2015) created a PSM Management Walkabout Guideline for application in the chemical processing industry, specifically Sasol. His guidelines are listed in Table 35. As part of assurance, regular plant inspections must be conducted as a first level of assurance. This checklist is quite comprehensive providing good insight, especially when directing someone with little PSM experience.

Table 35. PSM Management Walkabout guidelines (Prior, 2015)

FOCUS ON PROCESS SAFETY DURING PLANT AND CONTROL ROOM WALKABOUTS	
During plant walkabouts & associated interaction with people • Look for obvious leaks on process systems or “footprints” of leaks. Was it reported and investigated? • Look for evidence of tank, bund or pit overflows and blocked drains. • Evidence that drains & vents go to safe locations. • Inspect process piping – missing bolts on flanges, missing end blanks, inadequate pipe supports. • Look for temporary modifications linked to process systems and interrogate them. • Inspect emergency equipment, deluge systems, firefighting equipment and fire proofing. • Check knowledge of the emergency procedure & condition of emergency gathering rooms & assembly rooms.	• Evaluate presence of non-essential persons & vehicles within the area, check that all vehicles have permits to be on site & are safely parked. • Evaluate open work permits & check “Touch and Tag” especially when breaking into live lines. • Flexible lines are the weakest point in any piping system. Are they registered, tested and in good shape, especially when carrying hazardous materials? • Visit outlying areas such as battery limits, loading facilities, tank farms and flares. • Interact with people doing tasks on process equipment and ask “What are you busy with? What can go wrong? What will you do if it happens?”
During control room visits and associated interaction with people: • Are there any critical activities in progress such as start-up, shutdown, safe making or commissioning? • Have the critical process safety controls been identified & are they understood & in place? • Does the plant operation appear to be stable? (process safety risks increase with unstable operations) • Ask the permit issuer about open work permits & verify if associated risks have been identified & controls implemented to prevent them. Ask some “what if” type scenario questions. • Are there specific concerns from control room staff that they want you to be aware of or need your assistance with?	• Ask about the number of nuisance alarms and active alarms. Any management action required? • Look for trips that have been bypassed & verify authorisation documents. • Check & ask about the preparedness for an emergency. • Ask about recent process safety incidents & use these as a discussion topic to demonstrate how important PSM is to you as a leader. Ask what could have been made the incident worse? What was done correctly? • Ask about recent completed or in-progress modifications & confirm that all required processes were followed.

5.7. PSC Construct Five: Incident Management

An investigation is conducted following an incident or near-miss, to understand the root causes and implement subsequent preventive and corrective measures. By conducting thorough investigations, one can prevent the occurrence of a major process safety incident. There are numerous incident investigation tools that can be used to arrive at the root causes, such as brainstorming/fishbone, logic/event tree, why trees and checklists. Figure 91 illustrates the case for effective root causes assessment as presented by Bridges and Tews (2010).

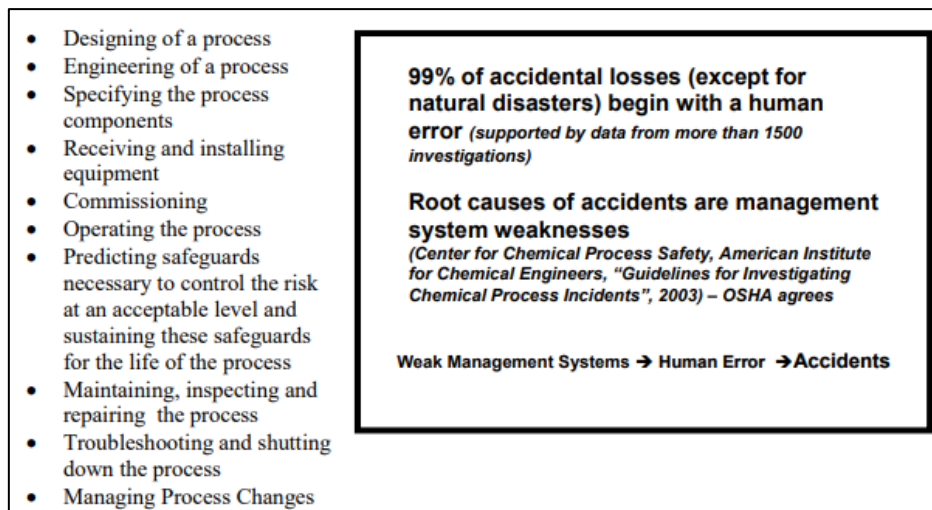


Figure 91. Most influential process-related activities for human errors (Bridges and Tews, 2010)

An efficient incident investigation process can significantly reduce additional constraints placed on many resources. Barrier analysis and elimination with the correct hierarchy of preventative controls is also imperative.

This is only the first step in incident learning. The second step is essentially ensuring that effective learning occurs. Smith and Roels (2015) developed a list of barriers to effective learning, as seen in Table 36. Solutions for each respective barrier is also discussed. Implementing these measures to combat against organisational incident learning failures is thus imperative.

These practices must be coupled to a learning process with a repository of incident recalls. Together, these three characteristics form the foundation of a successful and integrated incident management system.

Table 36. Barriers to effective learning (Smith and Roels, 2015)

Barriers to Effective Broader Learning and Evaluation	Enablers for Broader Learning and Evaluation
Difficulty in identifying broader lessons	• Leadership and technical review of investigations to identify broader lessons for dissemination. • Stakeholder identification - knowing your audience helps identify what parts of investigation/ lessons will be most relevant and also give ideas for modes of dissemination.
Common methods of sharing lessons and learning are often passive and over-simplified summaries (lacking in context)	• Make use of interactive sessions - use an incident to develop locally relevant scenarios that can be run as team sessions to identify causes and risk reducing measures. • Train supervisors in facilitation skills to run such sessions. • Do not confuse access to incident information with learning!
Insufficient time to reflect and make sense of material from investigations	• Leadership needs to clearly demonstrate value placed on LFI and be prepared to allocate sufficient resources. • Build reflection sessions into schedules of safety meetings and toolbox talks.
Legal constraints on sharing incident information widely	• Early engagement with the legal team so that they can understand what is trying to be achieved with LFI and they can advise on the legal risks. There is then the opportunity to devise a process that is the best compromise of the competing concerns. • An organisation should have in place a documented and tried and tested Incident Response Protocol incorporating "legal privilege" for internal investigations when appropriate, and access to legal advice in the event of an incident that is likely to give rise to criminal proceedings. • Turn lessons learnt quickly into good practice guidance which can help others learn but without carrying the same liability risks.
Difficulties in relating to other organisations' incidents - especially when they are in a different industry	• Make use of these in safety meetings and encourage personnel to relate them to their workplace, possibly using the interactive session/scenario approach outlined above. • Convert external incidents learning into the same format as used for internal events. • Try and create a common language of understanding incidents, e.g. the bow ties that the UK aviation industry has created for its highest risk accident categories.
Barriers to Effective Broader Learning and Evaluation	Enablers for Broader Learning and Evaluation
Embedding change for the long term can be difficult given normal corporate memory loss	• Use more experienced employees who are experienced in LFI to help revise and extend key procedures, manuals etc. prior to their release or retirement. • Provide links between past incidents and changes, e.g. if a procedure changes following an event provide a reference to that incident in the rewritten procedure, some permit systems bring up a list of events relevant to that task/ equipment, etc. • Provide a database of recommendations/ actions from incidents and what changes have occurred. • Provide training in past accidents/ incidents. • Improve the link between risk analysis and LFI (e.g. ensure that risk analyses take account of past accidents/ incidents that have happened internally to organisation and externally).
Difficulty of assessing whether an organisation has learnt from an incident or a set of incidents	• Develop indicators relating to mechanics of the LFI process, e.g. whether investigation reports are overdue, timely implementation of actions, non-compliances with reporting and investigation arrangements, etc. • Also develop indicators relating to what changes have occurred following incidents and whether these changes are effective in risk reduction. For this an organisation may need to be more creative, e.g. active measurement of learning through interviewing affected personnel one year after an event, or relating changes to a set of safety KPIs.

5.8. PSC Construct Six: Resourcing, Roles and responsibilities

Byars and Rue (2006) define Human Resource Management (HRM) as a system of activities and strategies that focus on successfully managing employees at all levels of an organisation to achieve organisational goals. Kavale (2012) stated that “*structure follows strategy*,” hence there is a direct relationship between structure and strategy.

If the structure follows strategy, the resultant effect is high performance. Therefore, in order for an organisation to be successful, it should make employee productivity a major goal as depicted in Figure 92. O’Riordan (2017) concludes that HRM can have a very positive impact on organisation performance.

As a result of these efforts, financial performance will be considerably improved. This is very similar to safety capital and cultural entropy as discussed in Section 2.7. They can also be leveraged to drive productivity and improve financial performance.

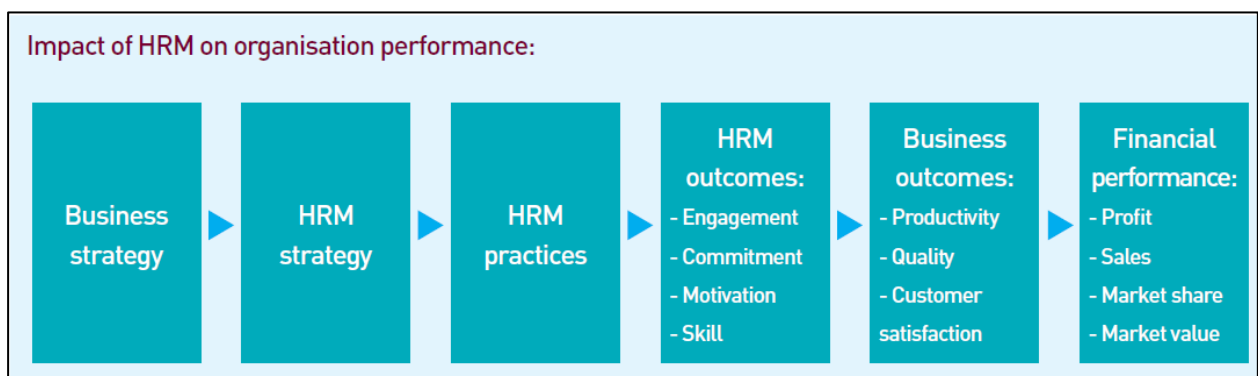


Figure 92. Impact of HRM on organisation performance (O’Riordan, 2017)

O’Riordan (2017) found that transformational or value-based leadership from top down is essential to create a positive organisational culture. Enabling this are the line managers whose actions and attitudes are responsible for bringing the human resource policies to life. To develop high-performance and effective workforce, Jones and Bartlett (2012) suggest that the organisation use HRM in the following nine areas: [1] establishment of a legal and ethical management system, [2] job analysis and job design, [3] recruitment and selection, [4] healthcare and career opportunities, [5] distribution of employee benefits, [6] employee motivation, [7] negotiations with organized labour, [8] employee terminations and [9] strategic planning.

Once the fundamental HRM practices have been implemented, a strong foundation is laid. The key is holding employees accountable to upfront agreed performance targets. Management should ensure that roles and responsibilities are clear, concise and measurable. To further

improve employee productivity, Richardson (2014) recommends five strategies (based on Maslow's hierarchy of needs). These strategies can be enhanced and are listed below:

1. Workplace environment, focusing on the level of flexibility given to employees in the organization.
2. Feedback sources in organisation, centring on measurable standards such as written evaluations and other resources provided to employees.
3. Management relationships, focusing on managers' influence on performance of employees.
4. Barriers in the workplace, examining internal and external sources that impede performance.
5. Recruitment/promotion strategies, centring on the organization's compensation incentives.

5.9. PSC Construct Seven: Rewards and Recognition

An organisation's process safety performance can be improved through creating a positive safety climate with recognition and reward programs. This is highly dependent on the organisation already having an effective PSM system in place. The program must include both employees and service providers as more concentration should be placed on the ground force level of an organisation.

Due to the high frequency of tasks involving high hazard equipment, this is where you want to influence the behaviours most positively. Evaluate the reward and recognition program to ensure that it is effective, as an ineffective program ultimately results in employees losing interest and the employers finding it costly and time consuming. Ensure that the program drives to correct behaviours and does not encourage unhealthy behaviours.

Permuth and Gazica (2014) developed the reward and recognition implementation program as depicted in Figure 93. A continuous feedback loop is at the centre of this program. It is a seven-step process and interestingly includes the program's self-evaluation to determine its success.

Similarly, it should mask design or operability issues, but rather promote identification of such concerns. The Government Accountability Office (GAO) (2012) found that rate-based programs may discourage reporting of incidents and recommended that OSHA implement criteria on safety incentive programs that prohibit employers from focusing on incident rates.

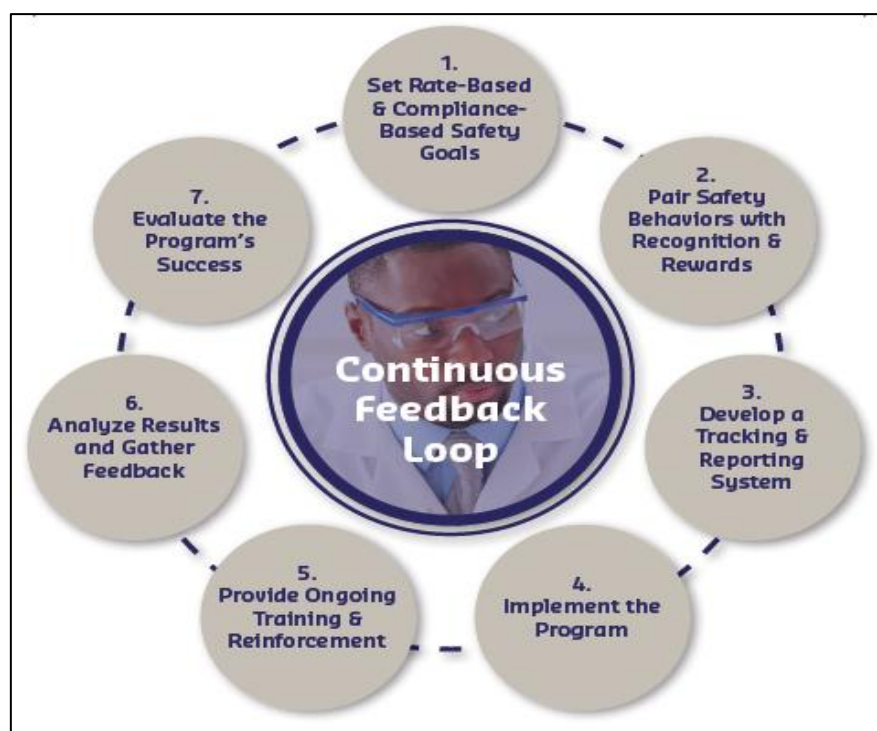


Figure 93. Reward and Recognition Implementation Program (Permuth and Gazica, 2014)

Moon and Foulke (2017) advocate avoiding these four policy mistakes when creating a reward and recognition program:

1. Policies that discipline employees because they are injured on the job, regardless of the circumstances surrounding the injury.
2. Policies that discipline employees for failing to report incidents or injuries within time limits and in the manner required by employer's policy.
3. Policies that discipline employees on the basis that the reported incident or injury resulted from a safety rule violation, where the rule is used as a pretext for discrimination.
4. Incentive and bonus programs that intentionally or unintentionally dissuade an employee from reporting an incident or injury.

Similarly, Ross and Yerger (2008) and SAIF (2008) developed additional factors for consideration when drafting a safety reward and recognition program. Table 37 summarizes these factors and presents them in a "*do and don't*" manner.

Rewards are also determined based on employee performance contracts. Process safety key performance areas can be incorporated into these contracts, focusing more so on leadership. Brown (2009) developed useful key performance indicators that could be incorporated into contracts which drive process safety improvement.

Table 37. Factors for Safety Reward and Recognition Program (Ross and Yerger, 2008; SAIF, 2008)

Do's	Don'ts
Set high expectations but ensure that activities to earn rewards are specific and achievable. Reward everyone and reward often	Focus on just the reward, also consistently educate and encourage process safety-conscious behaviour that will lead to the desired outcome
Constant repetition and consistently promote the program like marketing a product	Place emphasis on injury reports which are lagging. Programs solely based on reducing the number of reported injuries may result in inaccurate reporting. Strong reporting policies and investigation procedures
Management support and buy-in across all leadership levels (foremen to CEO)	Let the safety incentive program stand alone, incorporate it into meetings, training and suggestion programs
Commit appropriate time and money to the program. Ensure employees are able to fully support and administer the program	Take any program practiced in industry, it must be tailored to your environment. Also don't make it complicated
Make safety a core value for your organisation and involve employees in the process	Use contest or group rewards that will result in negative peer pressure due to the failure of an individual
Provide rewards that are genuine, meaningful, important and worth achieving. Make it long-lasting and have small awards to gift many (time-off, branded gifts, vouchers (meal, movies), certificates, newsletters, award ceremonies, etc.). Recognition from superiors is often seen as more personal and meaningful than tangible rewards	Create incentive awards that are taxable, as it creates perceptions of devaluation

5.10. PSC Construct Seven: Metrics

Process safety indicators essentially assist in preventing process safety incidents, by acting as an early warning system and to assess whether goals are being achieved. This assists in continuously improving upon process safety performance. At this stage we expect that the typical OSHA PSM elements are effective, as PSI, PHA, SOP, MOC and Emergency Preparedness are pivotal in influencing the process safety culture. Process safety indicators can be either leading, lagging or near miss related. Generally, a mix of these indicators are usually adopted in practice. Leading indicators measure effectiveness and efficiency of preventive and control measures, covering key work processes, operating discipline or layers of protection that prevent incidents. Operating discipline indicators may reflect process safety culture through process safety climate indicators. Examples include critical operator actions, training and audit surveys.

Indicators for key work processes can include management of change, permit to work or maintenance integrity, which also correlate to assessing process safety culture. Layers of protection indicators include mainly control and instrumentation system trips, failures and alarms. Lagging indicators measure incidents that have occurred. Near miss and other internal lagging metrics focus on less severe incidents or unsafe conditions which activated one or more layers of protection. Figure 94 depicts the hierarchy of all these different indicators in preventing major process safety incidents as suggested by CCPS (2011).

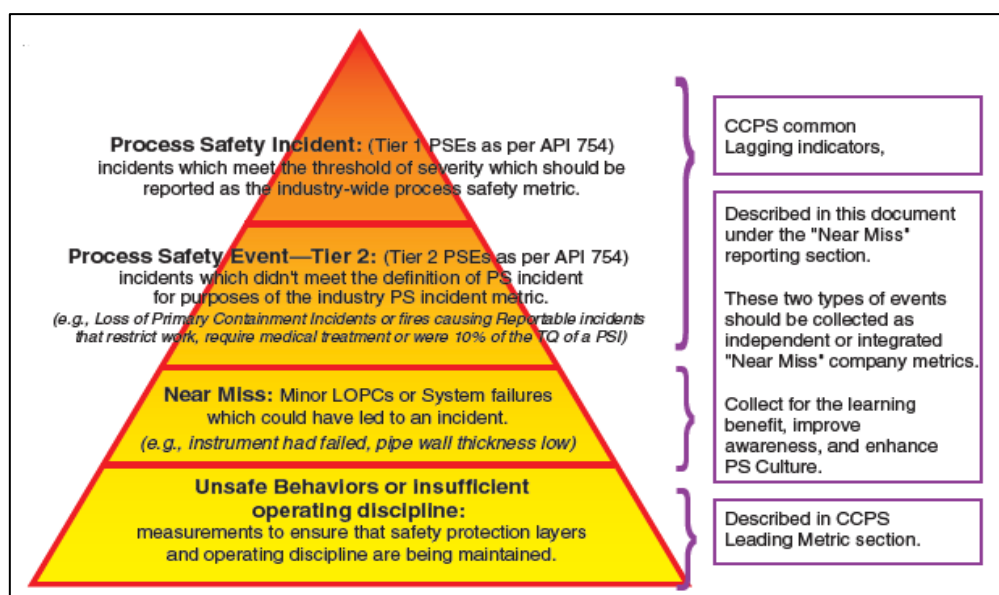


Figure 94. Process Safety Metric Pyramid (CCPS, 2011)

Although numerous process safety climate indicators have been identified, Swuste *et al.* (2016) uncovered that no “*silver bullet*” exists. It is also clear that no sustainable or critical indicator to prevent incidents has been observed. As discussed in Section 2.5, Arendt and Manton (2015) recommend early recognition of process safety performance degradation and monitoring long-term slow degradation of organizational HSE performance, typically through process safety climate indicators. Leadership behaviour can also be measured to promote a process safety culture. Similarly, Fleming and Lardner (2002) recommend three key behaviours that could be considered. They consist of frequent meetings with employees to discuss safety issues, responding quickly to safety suggestions and concerns raised by employees. Table 38 shows some process safety culture impacted metrics, which can be managed to improve process safety culture (note that this is a non-exhaustive list).

Table 38. Process safety Culture impacted Metrics

Lagging	Leading			Near miss and other internal lagging metrics
	Key work processes	Operating discipline	layers of protection	
Number of Tier 1 process safety events (FERs)	Number of temporary repairs	Process safety training and competency	Number of alarms (exceedance)	Number of near misses
Number of Tier 2 process safety events (FERs)	Maintenance of mechanical integrity	Process safety culture survey	Number of activated interlock sequences	Number of unsafe process safety behaviours
	Number of backlog MOCs	Fatigue risk management	Number of critical bypass interlocks	Number of operating within agreeable parameter (OWAP) exceedances
	PSM element compliance	Number of leadership interactions per week with front line staff	Number of process safety suggestions raised by employees per week	
	Risk Study Action management	Number of process safety concerns raised by employees per week		

5.11. PSC Construct Eight: Continuous Improvement

Mora (2014) reviewed twenty-seven continuous improvement (CI) definitions from various authors and proposed this definitive definition, “*CI is a systematic process of continuous and incremental improvements, supported in various tools previously established.*” Also concluded was the five most important CI characteristics: [1] need of a continuous learning process over time, [2] everybody in the organisation must be a participant, [3] ideas could come from anyone in the organisation, [4] keep looking for new opportunities and [5] empower the people to do experiments.

There are various models that can be used to employ continuous improvements, Lean and SixSigma being the more popular choices. Figure 95 displays the overall outlook of successful continuous improvement on business performance. The IOGP (2014) developed an Operating Management System (OMS) Framework comprising of two interdependent components: [1] four fundamentals and [2] ten elements. The four fundamentals focus on management principles which are the most important for an effective OMS: [1] leadership, [2] risk management, [3] continuous improvement and [4] implementation.

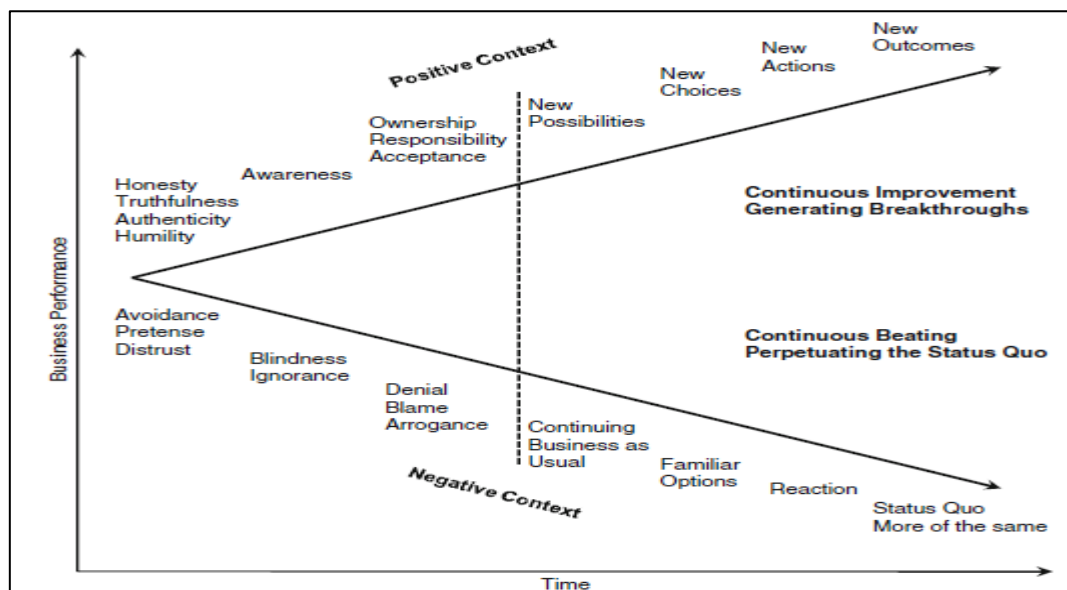


Figure 95. Two paths: Continuous Improvement versus Continuous Beating (Van Aartsengel and Kurtoglu, 2013)

These principles are not sequential and apply equally to every element. The four fundamentals and ten elements are illustrated in Figure 96. Essentially this indicates that continuous improvement is embedded into each of the ten elements. Similarly, continuous improvement should be embedded into each of the process safety culture elements. This also links to sustainable process improvement as discussed in Section 2.5.



Figure 96. OMS Framework – Four Fundamentals underpin ten Elements (IOGP, 2014)

5.12. PSC Construct Nine: Maintenance

An unreliable plant may lead to an unsafe plant. Asset life cycle management (ALCM) is imperative to ensure that assets perform optimally and reliably. The operation and maintenance phase of an asset is generally ignored or poorly assessed during the design phase. However, the application of the systems engineering methodology during development requires decisions and consideration that affect reliability, availability and maintainability (RAM) of the asset.

Mungani and Visser (2013) classified maintenance approaches into these three broader approaches, Reliability Centred Maintenance (RCM), Total Productive Maintenance (TPM) and Business-centred Maintenance (BCM). This is illustrated in Table 39. RCM is most suited for high-risk systems, TPM is more suited for assembly type industries (progression from reactive, preventive, predictive and condition-based maintenance) and BCM is focused on aligning the maintenance function with the organisation or business objectives.

Figure 97 graphically indicated the application of the Heinrich Pyramid to the DIPF (Design, Installation, Point Failure and Function Failure) curve (Latino, 2018). Essentially the probability of an injury significantly increases with non-routine maintenance activity resulting from equipment failures. This indicates a connection between the human safety aspect and equipment reliability.

Table 39. Comparison of maintenance approaches (Mungani and Visser, 2013)

RCM	BCM	TPM
ADVANTAGES		
• Traceability • Cost saving • Rationalisation • Operator & maintenance involvement • Plant reliability improvement	• Accuracy • Business-centred • Integrated auditing possibility	• Productivity improvement • Quality improvement • Cost reduction • Operator involvement
DISADVANTAGES		
• Complexity • Extensive need for data • Reliability-centred • Does not focus on economic problem	• Complexity • Extensive need for data	• Not a true maintenance concept • Lacks decision rules on maintenance policies • Does not focus on economic problem

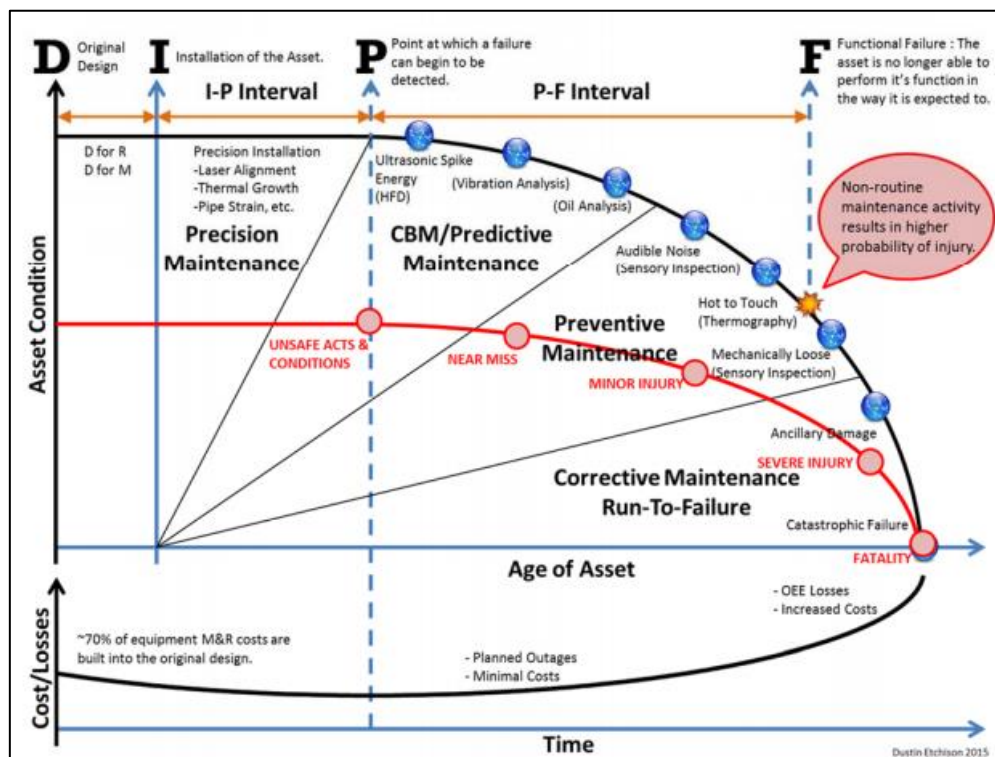


Figure 97. Application of the Heinrich Pyramid to the DIPF Curve (Latino, 2018)

Duran (2000) developed four essential elements of operation reliability as depicted in Figure 98. Operational reliability is a flexible process that optimises people, processes and technology to enhance a company's profitability by maximising availability of assets. It consists of four elements: [1] human reliability, [2] process reliability, [3] equipment reliability and [4] equipment maintainability.

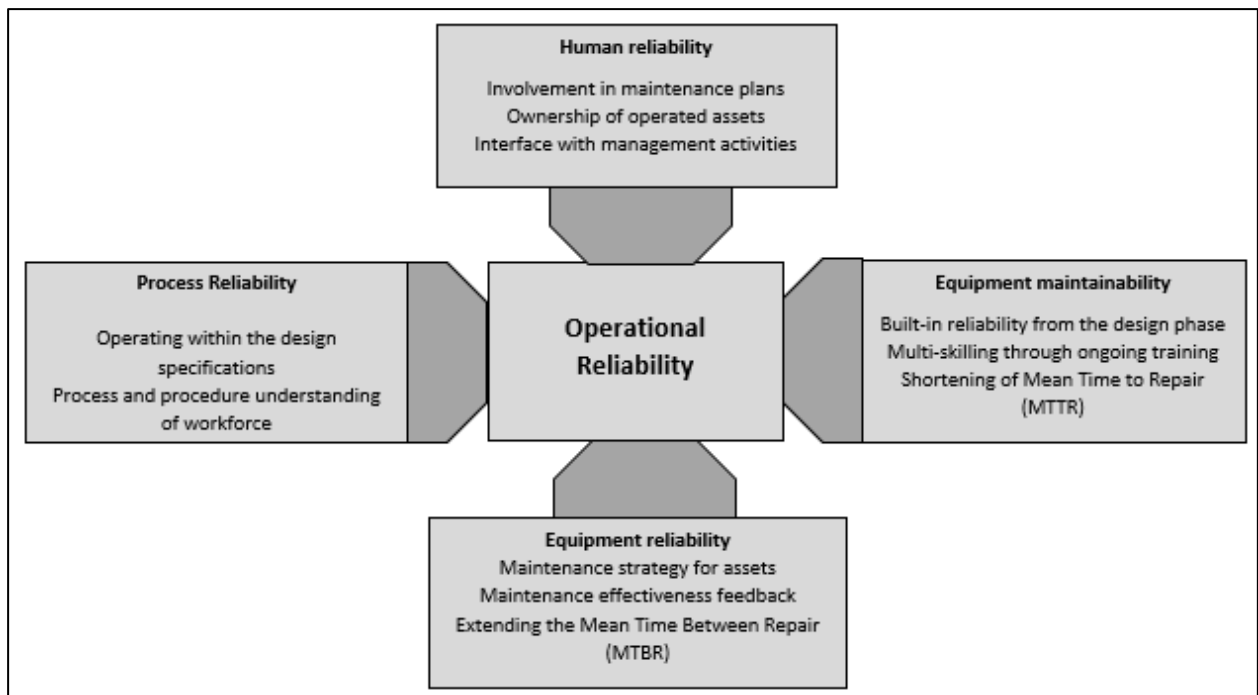


Figure 98. Four essential elements of operation reliability (Duran, 2000)

Latino (2018) also found that holistic reliability management is required and that when overall equipment effectiveness (OEE) improves, safety improves. Figure 99 depicts the relationship between human, process and equipment. Integrating these three elements' results in culture improvement in quality, safety and reliability. This approach resembles the Duran (2000) approach.

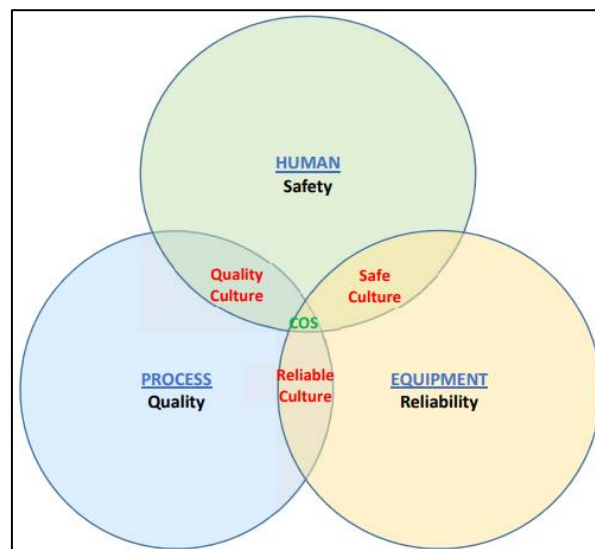


Figure 99. Holistic Reliability: Equipment, Process and Human Reliability (Latino, 2018)

CFE (2016) suggest five strategies for a system approach to achieve world-class preventive maintenance as listed below:

1. Conduct a review and understand what assets and programs (procedures and people) currently exist.
2. Establish standardised operating procedures for reactive and preventive maintenance. Include quality control and assurance plans. Tools should be optimised for the task.
3. Create a reliability and maintenance policy (objectives, goals, key responsibilities) with an improvement plan typically for 3 to 5 year period.
4. Leverage technology and implement a computerized maintenance management system (CMMS) linked to field capable portable devices to pull up asset information.
5. Secure 100% execution of preventive maintenance in line with the 10% rule so that asset maintenance is conducted regularly and consistently accounting for public holidays or weekends.

Schuman and Brent (2007) developed the Asset life Cycle Management (ALCM) model to improve physical asset performance, as seen in Figure 100. This resembles the RBI models as discussed in Section 2.8.

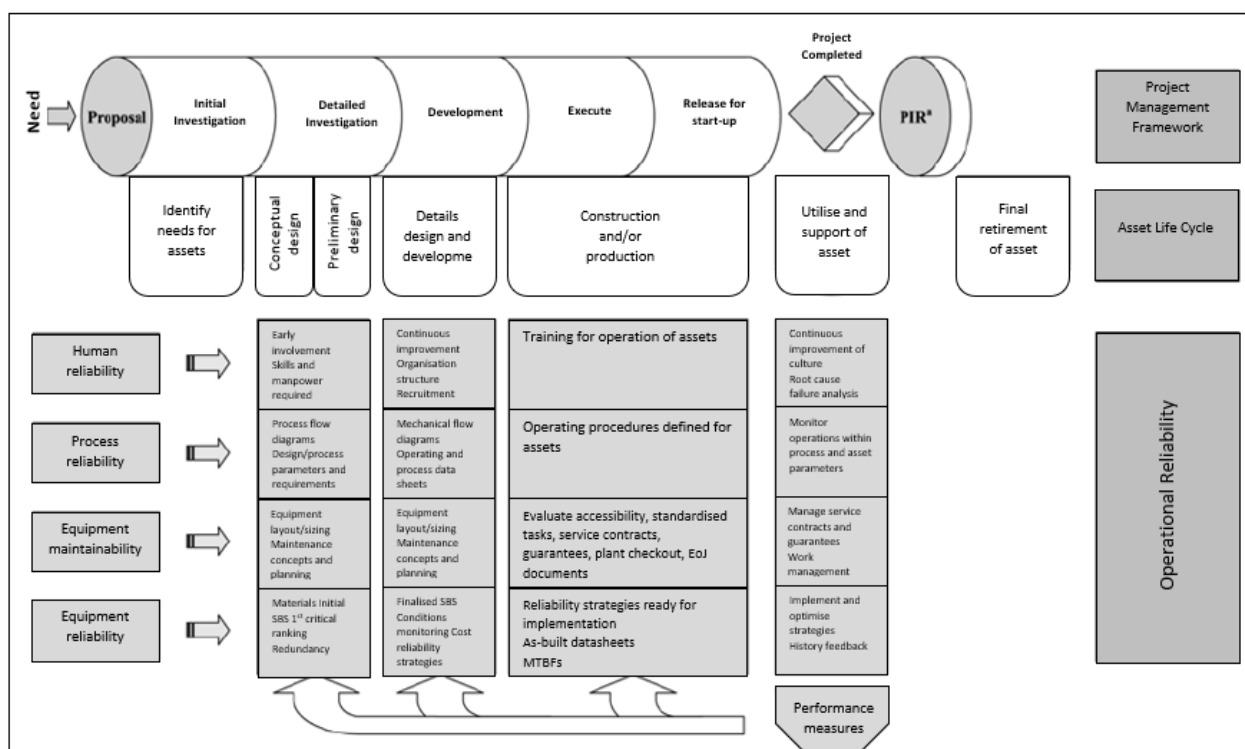


Figure 100. Asset life cycle management (ALCM) model (Schuman and Brent, 2007)

5.13. Summary

In Chapter 5 the nine derived process safety culture constructs were further investigated to understand their make-up and interdependencies with one another. Key aspects of each construct were also assessed to enable integration thereof. Table 40 gives a summary of these nine process safety culture constructs and their associated critical aspects. In Chapter 6 the development of the process safety culture framework commenced through further ascertaining the relationships of the process safety culture constructs' critical aspects.

Table 40. Summary of derived process safety culture constructs and critical aspects

Nine derived process safety culture constructs		Overview of critical aspects
1.	Disciplinary Process	James-Reason approach, consistent application, clear and freely available rules and disciplinary process, intolerant culture
	Communication	Verbal, individual, campaigns, transparent, two-way
2.	Complex instrumentation	Human error based, trip system, alarm response time, redundancy systems
3.	Knowledge Management System (Maintenance, SHE)	Electronic, simple interface, freely accessible, analysis functions, generate reports, digitalisation
4.	Assurance	Audits, compliance, inspections, walk-about, engagements
5.	Incident Management	Reporting of near-misses and incidents, comprehensive root cause analysis and remediation. Generation of learning and sharing
6.	Resourcing	Structures for human factor and contingencies, competency, fatigue management, knowledge transfer, leadership programs, human factor training, team building
	Roles and Responsibilities	Minimum responsibilities prescribed, practical approach to roles and expectations
7.	Recognition and reward	Celebrate teams/individuals, incentivise performance targets, competitive salary packages, clear performance expectations and agreements
	Metrics	Alarm Management, OWAP, inspection deviations, process safety events (FERs), Implemented learning, bypassed alarms/trips/equipment, Competency of artisans, equipment reliability
8.	Continuous Improvement	Trend analysis of incidents, optimization of existing processes and systems, tool enablers to up productivity, human factor audits
9.	Maintenance	Independent quality control, appropriate tooling and equipment for the task, reliability management, process safety information

CHAPTER 6 DISCUSSION AND FRAMEWORK

Flavell-While, “It could be argued that the most dangerous element in any process plant is not the plant, or the chemicals in it, but the people operating it”

The terms safety culture and safety climate were defined in Chapter 2. A combination seemed most appropriate, and the HSD (UK) (2005) safety culture and climate definition was adapted to incorporate the AQAL model culture definition. The resultant combined definition for safety culture and climate for this study is:

The terms safety culture and safety climate may both be used to describe the ways in which members of an organisation make sense of the overall safety of their work environment. Safety culture is influenced by experiences which then influences the meaning of future interactions. Safety climate is often used to describe the more tangible outputs of an organisation, through which safety culture can be assessed. These safety climate attributes are measurable and easier to influence.

The underpinning for this study, is that an organisation has already implemented a PSM system and is at the next step of process safety evolution, namely embedding process safety culture. **The aim of this study is to produce a practical and sustainable framework for realising process safety culture improvement in the chemical processing industry.** This is where the nine PSC constructs as derived in Chapter 4, essentially PSC elements, were evaluated to deliver on the process safety culture aim and objectives. These PSC elements are attributes of process safety climate, which are tangible and influenceable. Their assessment and successful management will ultimately result in achieving a process safety culture.

The nine derived process safety culture (PSC) constructs, as discussed in Chapters 4 and 5, were reviewed for interdependencies and upon reflection ultimately expanded. In Section 5.13, Table 40 summaries the nine derived PSC constructs which were extended. The rationale behind the expansion was purely due to the collectively grouped PSC constructs not being completely related to one another. Their independence necessitated their separation so that the PSC constructs were not diluted or lost. Three grouped PSC constructs were separated: [1] disciplinary process and communication, [2] resourcing and roles and responsibilities, [3] recognition and reward and metrics.

The PSC constructs were transformed into the PSC elements (process safety climate attributes) which collectively intertwine to develop the process safety culture framework. Twelve final PSC elements were formed as listed in Table 41.

Table 41. Process Safety Culture Elements

Process Safety Culture Elements		
Disciplinary process [1]	Incident Management [5]	Recognition and reward [9]
Communication [2]	Resourcing [6]	Continuous Improvement [10]
Complex instrumentation [3]	Roles and Responsibilities [7]	Maintenance [11]
Assurance [4]	Metrics [8]	Management System (Maintenance, SHE) [12]

These twelve PSC elements were scrutinised against the human mind literature discussed in Section 2.7. Recommendations for exploring this literature was received by industrial psychologist Dr P. Calitz as introduced in Annexure C. The four quadrant focus areas as seen in Section 2.7, Figure 56, and the safety capital as seen in Section 2.7, Figure 58, were of most interest.

Experience, behaviour, culture and system collectively formed the four quadrants. The experience quadrant relates to how an individual feels and how the organisation makes them feel. The behaviour quadrant relates to why an individual performs in a specific way. The culture quadrant relates to how an individual interacts with others, team performance and motivation. The system quadrant relates to how an individual interacts with technology, regulations, guidelines and general health of the system.

Safety capital is generated by human (expertise, motivation, energy), social (teamwork, leadership) and organisation capital (safety information systems, policies, procedure, planning). The system quadrant and organisational capital must incorporate cultural entropy so that the organisational energy consumption is optimised. Reduced cultural entropy significantly improves organisational productivity and unlocks hidden operational costs, whilst directing positively impacting process safety culture. Casey *et al.* (2017) proposed four control strategies to manage and sustain safety capital, as listed in Section 2.7, Table 15. These strategies consist of energise, adapt, leverage and defend. The energise strategy aims to bring about new vigour. The adapt strategy entails the ease and speed in which a preventative action results upon detection of nearing an undesired event. The leverage strategy endeavours to best optimise existing systems to their full capacity. The defend strategy entails the ease and speed in which a corrective action results upon an undesired event. This is similar to the adapt strategy.

Safety capital and cultural entropy are therefore good indicators to manage and assess process safety culture sustainability. The six barriers identified by Hicks and Matthews (2010) and the

holistic engineering sustainability approaches by PennState (2020), can be leveraged to reduce cultural entropy and achieve sustainable process safety culture improvement as discussed in Section 2.5.

These aforementioned principles and the process safety culture elements were adapted and overlapped in Figure 101. Several PSC elements had numerous relationships with the four quadrants, hence they were repeated in the different quadrants. The twelve PSC elements integrated and well represented the four quadrant focus areas. The combination of all these concepts would culminate in achieving effective and sustainable process safety culture. This ultimately prevents the occurrence of major process safety incidents.

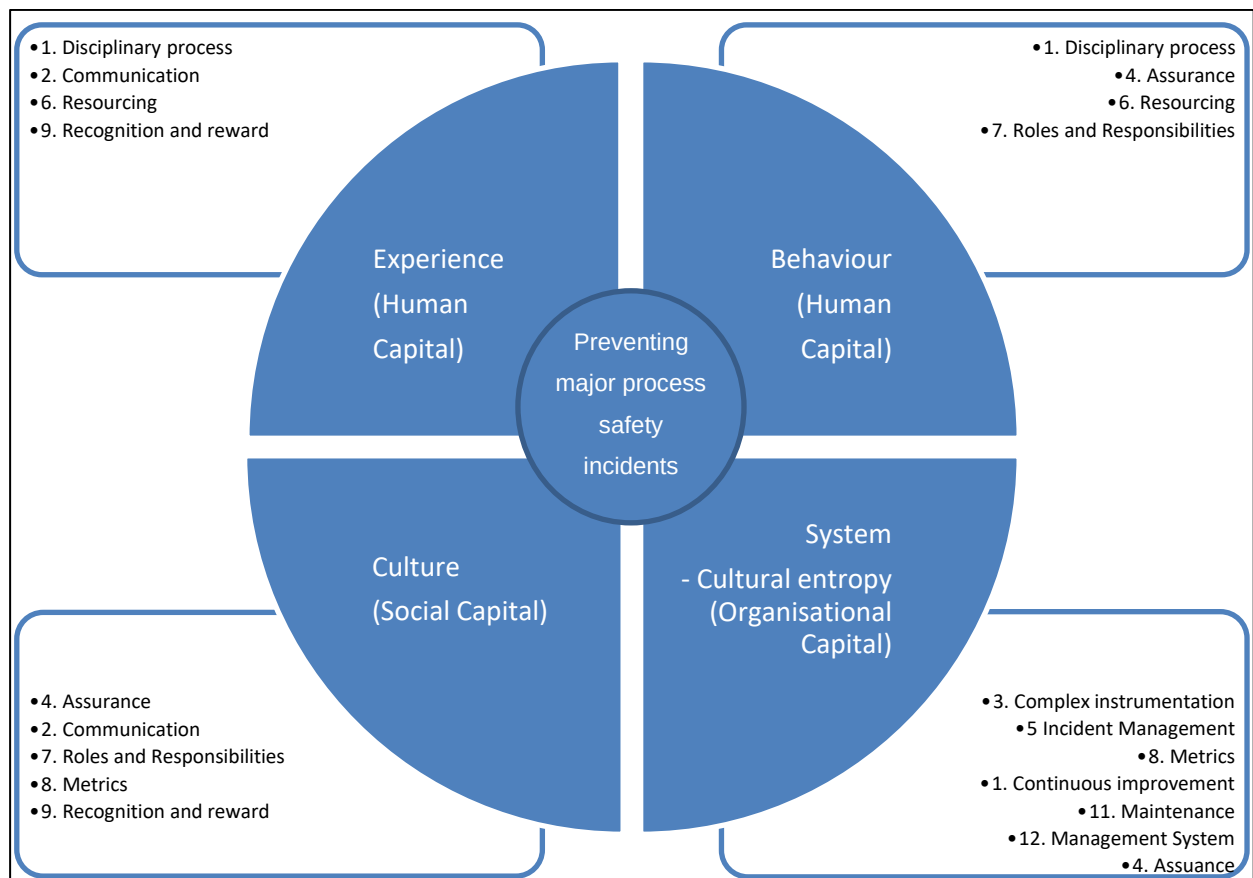


Figure 101. Adaptation of four quadrant and safety capital with process safety culture elements

From Figure 101, the system quadrant is composed of a central management system (maintenance and SHE) that also incorporates assurance and incident management. Integrity was considered to consist of asset and design. Asset integrity involves maintenance (mechanical, instrumentation and electrical) whilst design integrity involves complex instrumentation (digital control system with safety instrumented functions). Once the strategic intent is established, structure should follow. Hence resourcing of competent persons, roles and responsibilities, communication and the disciplinary process is included under people. Lastly performance

evaluation is a systematic and tangible approach to implement continuous improvement measures through metric assessment. Whilst sustainable performance can be achieved through recognition and reward systems. Many of these PSC elements have common themes, although interdependent, and they can be grouped together on a macro level. Upon review of Table 41, these PSC elements were consolidated into four pillars. Table 42 illustrates these four consolidated PSC culture pillars: [1] systems, [2] integrity, [3] people and [4] performance.

Table 42. Overview of Process Safety Culture Elements and Pillars

Process Safety Culture Elements	Consolidation into Pillars
Management System (Maintenance, SHE) [12]	Systems
Assurance [4]	
Incident Management [5]	
Maintenance [11]	Integrity
Complex instrumentation [3]	
Roles and Responsibilities [7]	People
Communication [2]	
Resourcing [6]	
Disciplinary process [1]	
Metrics [8]	Performance
Recognition and reward [9]	
Continuous Improvement [10]	

Drawing on the literature review from Chapter 5 and connecting the interdependencies of each PSC element (process safety climate attributes) within its respectively grouped pillar, even more relationships started to form. The Process safety culture (PSC) framework, as depicted in Figure 102, is a graphical representation that incorporates and indicates the relationships between all the PSC elements and pillars.

The performance pillar is comprised of three elements, namely: [1] metrics, [2] reward and recognition and [3] continuous improvement. Through active monitoring of metrics, positive process safety performance and climate can be acknowledged through reward and recognition programs. Substandard process safety performance can be addressed through continuous improvement to deliver on the expectations set. This entire process is iterative; hence it was represented by cogs, and it demands frequent reflection and introspection.

The people pillar was developed based on the structure follows strategy practices as previously mentioned in Section 5.8. It is composed of four elements, namely: [1] resourcing, [2] roles and responsibilities, [3] communication and the [4] disciplinary process. Once the chemical processing facility is resourced accordingly to strategy, their respective roles and responsibilities must be comprehensively and transparently established. The training and standard operating procedures as part of the existing PSM systems will assure that the roles and responsibilities is well incorporated. A communication program must be developed that includes various mediums and languages. The disciplinary process must also be clearly documented and consistently applied. The people pillar is more of a streamlined process and if executed correctly from inception, it should result in minor challenges down the line.

The integrity pillar incorporates maintenance and complex instrumentation. Diverse layers of protection with hard controls are required to significantly reduce or eradicate human factor failures. Asset integrity is key and accurate baselines with optimised maintenance strategies and reliability centred maintenance should be developed. These aspects should be aligned to the respective equipment risk identified. This pillar involves the delicate balance of high integrity safety instrumented systems and pro-active maintenance strategies that is suited for the risk profile of that specific chemical processing facility.

The systems pillar is comprised of a central management system taking the form of a digital solution. It includes the plant condition, assurance and incident management. Plant condition is further divided to include SHE, maintenance and reliability aspects. This collective system integrates the diverse elements to positively impact cultural entropy and safety capital.

Therefore, the PSC framework, Figure 102, is a holistic approach to process safety culture. It focuses on various aspects of process safety climate attributes which jointly contribute toward assessing and improving process safety culture in the chemical processing industry. It does not concentrate on influencing a positive process safety culture, but rather engineering a positive process safety culture practically and sustainably through systematic and continuous improvement focused initiatives. This model however has two dependencies: [1] existence of an active OSHA (or equivalent) PSM system and [2] it is actively driven by leadership. Building from the Systematic Safety Culture Enhance Process as seen in Section 2.9.2, Figure 72, essentially once safety culture expectations are established, the culture can be assessed, and enhancements recommended.

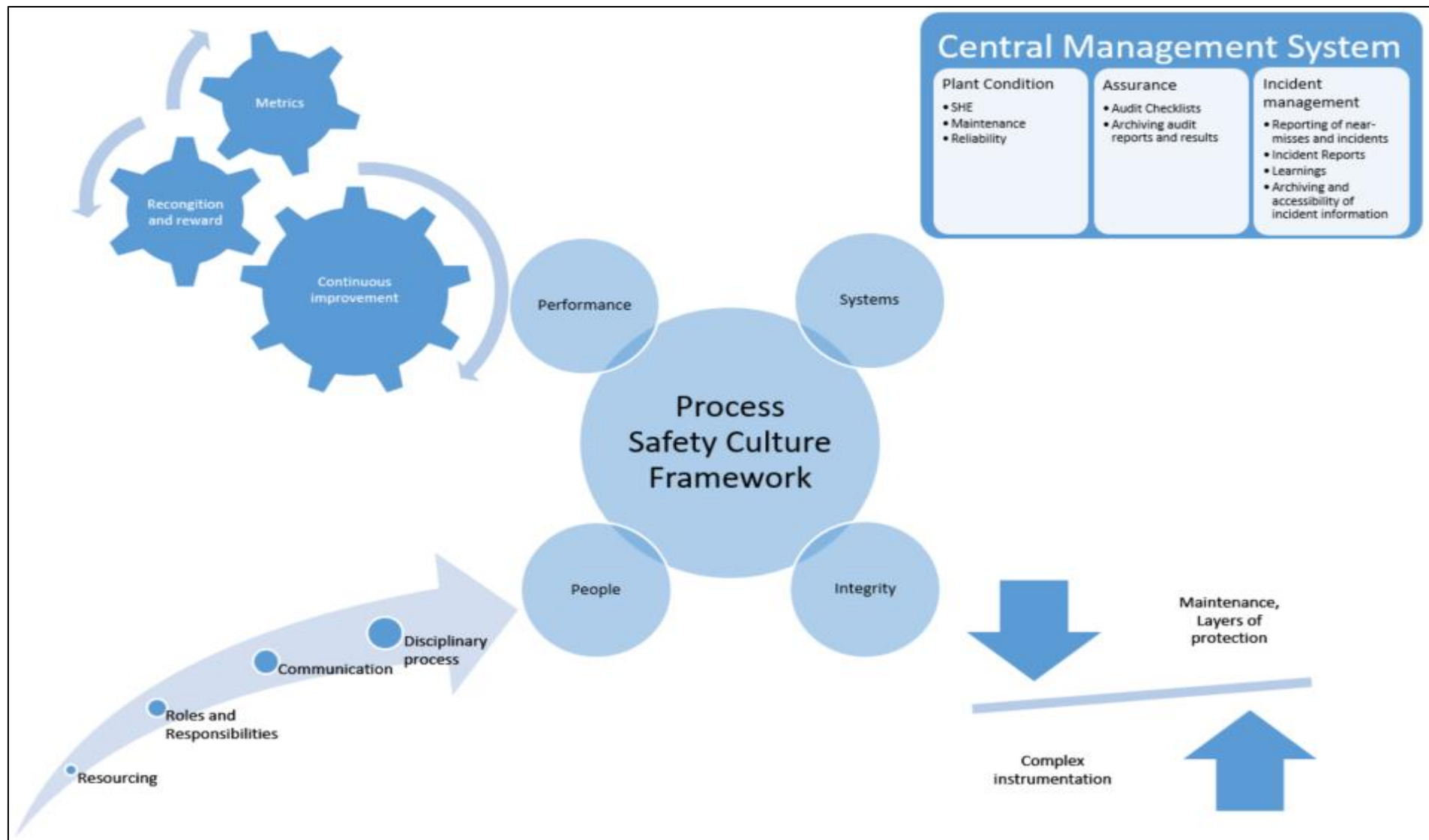


Figure 102. Process safety culture (PSC) framework Revision 0

However, the goals and targets need to be set based on the organisational factors, such as scale of operation, facility risk, geographical location and legislation. GAO (2012), Laitinen and Ruohomaki (1996) and Locke and Latham (1990) developed principles to effectively set goals and targets. Therefore, it is suggested that process safety culture goals and targets be derived considering their principles as listed below:

- SMART – specific, measurable, achievable, relevant and time-bound
- Compliance-based – focus process safety behaviours rather than just outcomes or rates
- Incremental – break down long term goals into a series of short-term goals with milestones
- Level-appropriate – set specific requirements for employee level
- Aligned – all process safety goals should complement one another (no conflicting or competing goals)

The next step will be to evaluate the current PSC landscape. The maturity of the PSC can then be judged. The type of PSC practiced will set the scene for where an organisation is, compared to where it wants to be. A Process safety culture (PSC) maturity chart was created, seen in Figure 103, as adapted from the MIRM maturity chart seen in Section 2.6, Figure 48. There are four basic elements which can indicate the process safety culture snapshot: [1] management system, [2] legal compliance, [3] equipment and process condition and [4] incident reporting, investigation and learning. Alternatively, more comprehensive maturity assessment tools can be used as developed by DEKRA (2019) and Behari (2019).

This is a very basic health overview of the process safety culture. Alternate mechanisms can be explored to assess a PSC, and surveys can greatly assist in pin-pointing specific failures. Cheung and Burch (2014), Forest (2012) and Arendt and Manton (2015) developed more comprehensive process safety culture assessments. It is recommended that these PSC assessments be reviewed and selected based on the nature of each chemical processing facility. Therefore, this study does not prescribe any specific assessment for PSC. A Process safety culture (PSC) framework implementation cycle was developed, as seen in Figure 104. This is a simplified implementation cycle which follows the plan, do, review and improve cycle due to its continuous improvement merits and sustainability attributes. It incorporates the three systematic approaches, by Arendt and Manton (2015), for realising process safety climate performance management. The success of this PSC model lies in its iterative nature and demands on-going efforts that are actively driven. For a more comprehensive approach, the Beukes (2015) seven phased changed implementation strategy is recommended, depicted in Section 2.6, Figure 52. Similarly, the review of barriers to realising sustainable process improvement by Hicks and Matthews (2010) is recommended, as depicted in Section 2.5, Figure 30.

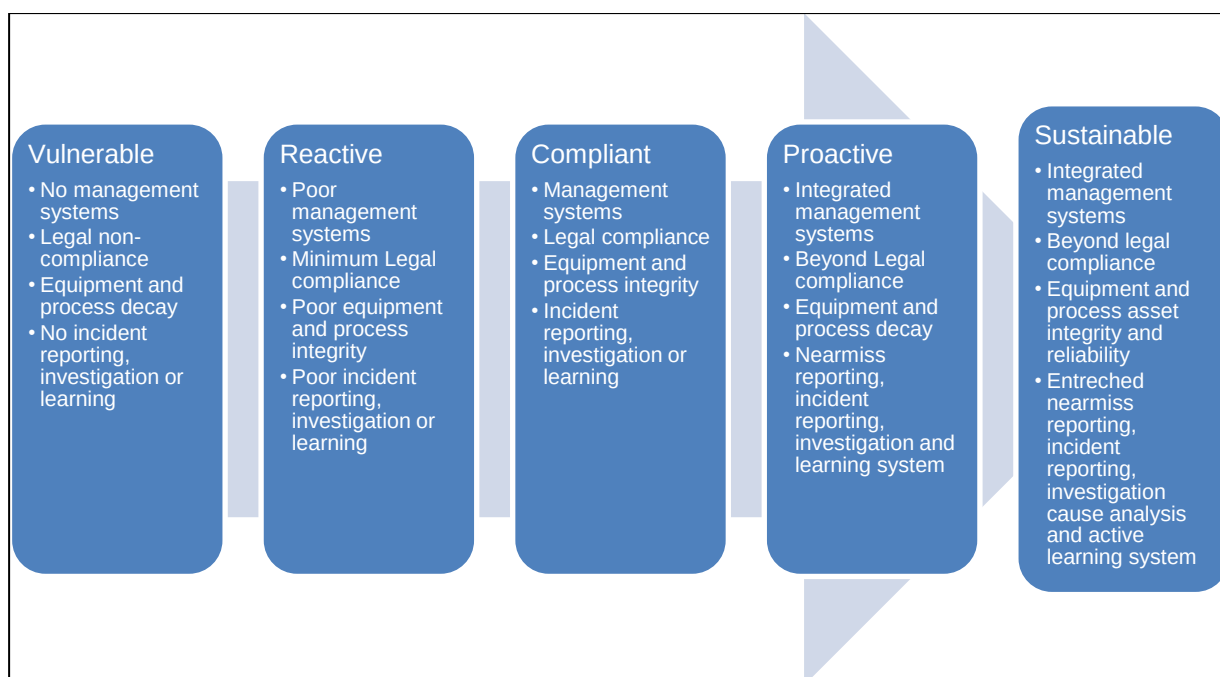


Figure 103. Basic Process Safety Culture (PSC) Maturity Scale

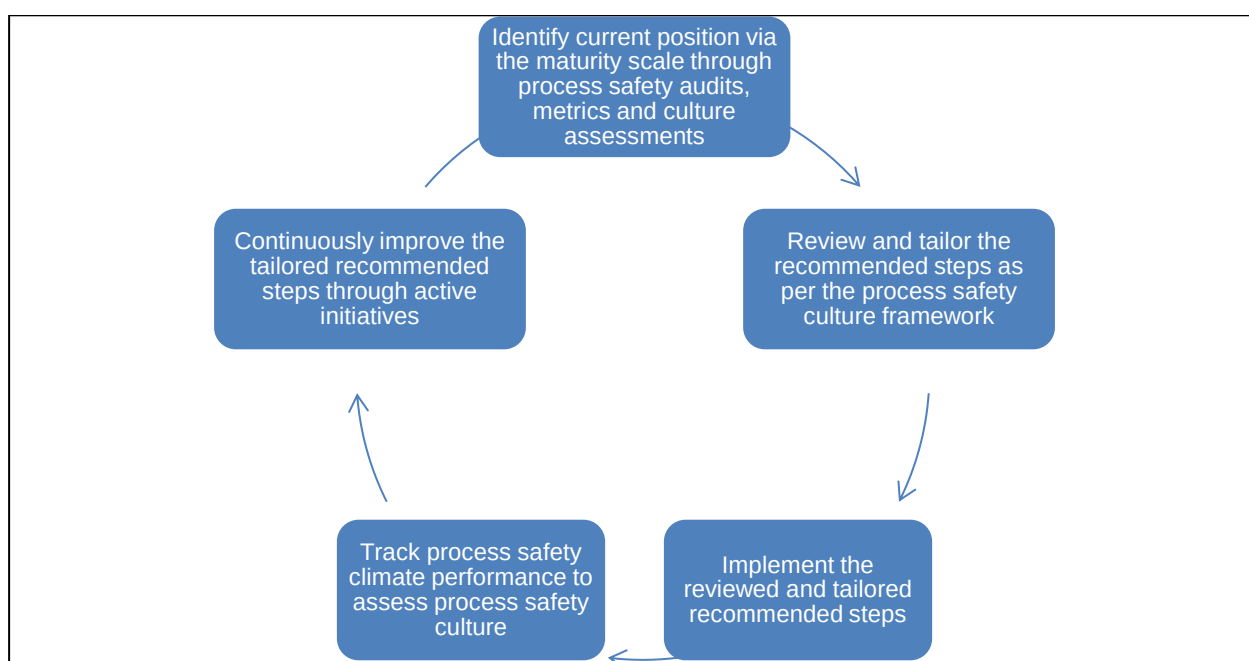


Figure 104. Process Safety Culture (PSC) Framework implementation cycle

The intended validation as described in Chapter 3, was to pilot the PSC framework at a chemical processing facility. Financial impact and each PSC elements' effective implementation were observed as the greatest challenges opposing validation. The rationale for this, was merely due to the considerable effort to first align the chemical processing facility to the ideal PSC element expectations as indicated in Section 5.13, Table 40.

Communication, roles and responsibilities, disciplinary, recognition and reward programs, metrics and continuous improvement programs may require substantial implementation periods, as it is more a tedious exercise to update these procedures and systems. These PSC elements were seen as more easily implementable, with little financial impact. After considering the design of an electronic central management system, procuring additional resources, complex instrumented systems and additional layers of protection, the time frame extension and financial implication was even greater. Many of these elements require significant facility downtime for installation and commissioning purposes.

It could be argued that these PSC elements could be implemented simultaneously, thereby reducing the pilot study duration. Unfortunately, there is much overlap with the discipline inputs, and more than likely the same resources would be required to participate in the implementation of more than one PSC element. Thus, overcommitted and subsequently exhausted resources would result in extended implementation cycles. The larger an organisation, the more effort, cost and time would be required to transition from the existing practices to the desired practices, and this is only the implementation phase. The real work commences once the PSC elements are effectively implemented as per the expectations previously outlined. Thereafter the PSC framework must be driven by leadership with specific measurable metrics, active monitoring and continuous improvement.

Establishing metrics and reporting in the central management system would be easily implementable. The basis for the new metrics could be provided by a chemical processing facility's past process safety metrics. With each monthly metric review by leadership, improvement plans could be developed and actioned. The effectiveness of this iterative process of active monitoring and continuous improvement would eventually culminate in the success of the PSC program. Therefore, prolonged lead times, as attributed by the challenges above, coupled with considerable financial impact, is this framework's greatest deficiency. The implementation phase was estimated to require 2 to 4 years and was largely dependent on the magnitude of the chemical processing facility. The pilot phase required leadership to actively drive the PSC framework. This was estimated to require at least a year of testing, in order to perform an adequate assessment of the PSC elements and the framework.

Thus, a total period, inclusive of implementation and field pilot testing, of between 3 to 5 years was estimated. The aforementioned estimations do not account for other factors and assumes that the organisation is only committed to the implementation of the PSC framework. Thus, the initial intended validation approach was not viable. An alternate approach was undertaken and the proposed PSC framework, shown in Figure 102, was critically reviewed by Subject Matter

Experts (SMEs) in the chemical processing industry and their feedback was incorporated. A total of ten SMEs were consulted, with combined experience in operations, engineering and process safety, exceeding 190 years. The SMEs are from three different provinces across South Africa, and are in roles across operations (production, maintenance), process engineering, behavioural transformation and process safety. Most of the SMEs consulted were very senior and instrumental in implementing (facilitating or guiding) process safety practices/programs at a chemical processing facility.

The SMEs also concur that the implementation of the PSC culture framework is quite challenging. It would be best suited for new chemical processing facility installations. For existing chemical processing facilities, a phased in approach over 5 years was thought to be more realistic with a journey toward PSC excellence. This estimation is also in line with the process safety initiative, CCPS Vision 2020 which commenced in 2013 (McCavit *et al.*, 2013). These SMEs also agree that the PSC framework is implementable and will yield positive PSC performance. However, this could not be quantified without practical validation.

Additional PSC and nuclear culture literature reviews were suggested by the SMEs, and this was incorporated into the study. Leadership and values were perceived as pivotal by these SMEs, which hinges on the success of a safety culture program, and this was missing in the framework. Although leadership commitment was indicated as one of the dependencies of this framework, it was not considered as adequate. Therefore, more guidance was requested on leadership expectations, similar to a “*how to guide*”. Similarly, leadership’s role was observed to be lost in the roles and responsibilities element. Hence the request to include another element focusing solely on this.

More guidance was also requested from the SMEs on the PSC element critical aspects. Although the information provided is graphical, it lacks the detail to assist in the effective development of the PSC elements. The proposed PSC framework and supporting approaches is spread over different figures and tables. A condensed overview of the methodology ideally summarised in one page was proposed. This facilitates the ease of understanding and in its simplicity can be shared across an organisation.

Figure 105 depicts the updated PSC framework which incorporated the aforementioned builds by the SMEs. The interdependencies were revisited and altered to better reflect their relationships. The four pillars and thirteen elements were included, along with a detailed overview of their associated critical aspects.

The major difference between the PSC framework revision 0 and revision 1, is the inclusion of the critical aspects of the now thirteen, previously twelve PSC elements. The additional PSC element is committed leadership, which although included, was diluted in the people pillar. This pivotal aspect's position was therefore elevated. The process flow diagram was also reviewed to better depict the relationships between the PSC pillars. This one-page high level overview greatly assists in summarising the PSC framework for ease of implementation as well as understanding.

A PSC assessment tool was also suggested to support this framework. Therefore, the PSC questionnaire was developed and tailored to the PSC framework, as seen in Annexure D, Table 50. Findings gathered from the PSC questionnaire will inform the implementation cycle in Figure 104. Thus, this will greatly complement the implementation of the framework and assist in pinpointing the framework's substandard process safety pillars.

Leadership expectations in the form of a "*how to guide*" was suggested to assist in practically executing the PSC framework. Therefore, a PSC roles and accountabilities guideline was developed, as seen in Annexure A, Table 43. Input was drawn from the Mindful Leadership with References to BP Texas City (Futuremedia, 2020) and Creating a Mindful Organisation (Futuremedia, 2020) training material by Professor A. Hopkins. Leadership was identified through all levels in a typical chemical processing business from the highest board member positions to the entry foremen level positions. The guideline also included all front-line operation personnel and other personnel with no direct reports, as process safety culture requires the participation from everyone in an organisation. Examples of other personnel include engineering, functional support and service providers. There were thus five levels of leadership. These levels included board member/executives, senior managers, plant managers, foremen and front-line operation personnel and other personnel.

Edward Schein said, "Leaders create cultures by what they systematically pay attention too." Therefore, eight key leadership expectations, as listed in Annexure A, Table 43, were devised incorporating the critical aspects of the thirteen PSC elements. These leadership expectations included policies and goals – directions, metrics and performance tracking, continuous improvement, incident investigation and learning, leadership commitment, competent resources, communication and rewards and disciplinary. The eight key leadership expectations were augmented for each of the leadership levels. Specific roles and accountabilities were tailored within the capacity and expectations for each leadership level.

These two additional tools [1] PSC questionnaire and [2] PSC roles and accountabilities guideline further enhances the PSC maturity chart, as seen in Figure 103, the PSC implementation cycle,

shown in Figure 104, and the PSC framework, seen in Figure 105. Through a systematic and iterative process as illustrated with the PSC implementation cycle in Figure 104, the process safety culture of a chemical processing facility can be practically and sustainably engineered.

Reflecting on Chapter 3 and the original intent of this study's research methodology, there were both positive and negative outcomes in relation to verification, validation and reliability. The verification approach consisted of four elements: [1] existing process safety frameworks, [2] chemical processing industry process safety culture approaches, [3] non-chemical industry safety culture approaches and [4] asset integrity safety culture approaches. The literature survey encompassed these elements, and much overlap was observed through different citations. Similarly, when the analysis was completed in Chapter 4, again much overlap was observed with respect to culture theme practices. Saturation of literature was thus observed.

Validation and reliability of a study is meant to confirm that the findings raised are truly representative of the area of study, thereby meeting the study's research aim and objectives. Therefore, it is very crucial that robust validation and reliability techniques are adopted. As discussed in Section 3.4, for this study, validation and reliability were to be addressed mainly through piloting the process safety culture framework at a sizeable chemical processing facility (>100000 man-hours per month, based on the author's experience). A typical period was considered to be between 1 to 2 years. The longer the field test duration the more accurate the reliability, given the other parameters remained the same. There was a failure in executing the intended validation and reliability approach. The duration of the implementation and pilot phases was only part of the challenge, with significant financial outlay being the other part.

Unfortunately, the major disadvantage of the PSC framework, although a holistic approach, it does require prerequisites. It takes the form of a chemical processing facility that is in a good financial position and is able to upgrade its safety instrumented systems, resource structure according to strategy and integrate SHE and maintenance digital solutions. Note that the PSC framework is coupled to the two dependencies as previously mentioned.

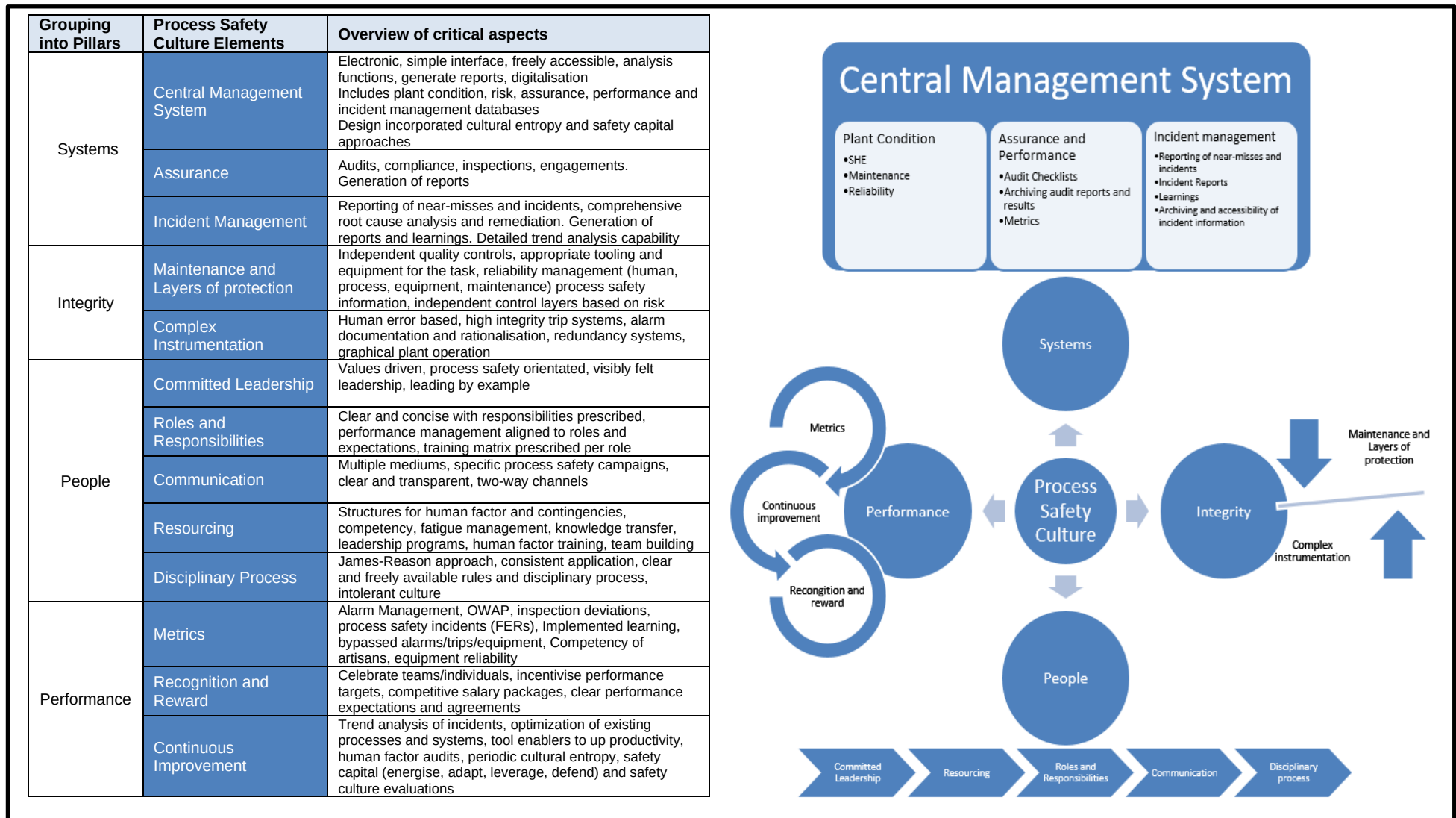


Figure 105. Process safety culture (PSC) framework Revision 1

CHAPTER 7 CONCLUSION

Industries where fire, explosion or releases (FERs) of hazardous chemicals may occur are overseen and prevented by a process safety management (PSM) system. For chemical processing process facilities, process safety hazards can affect both employees inside the plant and members of the public who reside nearby. Such events have the potential to cause catastrophes resulting in fatalities, process equipment/facility damage or detrimental environmental impacts.

A PSM system's main focus is to prevent the loss of life, and in doing so, other benefits are realised. By preventing the release of hazardous chemicals, the environment is also preserved. Equipment damage is the least severe consequence from a process safety incident, and this ultimately results in having a partial or no processing facility. This significantly hampers a company and its ability to satisfy customers, as it can no longer produce saleable chemicals. Hefty fines could be imposed on the company, dependant on the nature and significance of the consequences. These unforeseen and significant financial costs may cause a company to become insolvent, and as a result their employees lose their jobs. Therefore, effective PSM is rationalised as sound business principles for the socio-responsible and sustainable industries.

Despite governments and institutions promulgating comprehensive standards, legal prescriptions, guidance notes and best practices since 1992, major process safety incidents still occur today. It has been over 26 years since PSM legislation was conceived, yet we still experience major process safety incidents where significant loss of life occurs. Analysis of past process safety incidents reveals that inadequate process safety commitment, leadership, conduct of operations and poor organisational culture have been recurring.

Therefore, the research problem is that current PSM systems are deficient in addressing process safety culture in the chemical processing industry. As outlined in Chapter 1, this study endeavours to further understand how to improve and sustain process safety culture in the chemical processing industry. **The contribution to a new body of knowledge (BOK) sciences is to produce a practical and sustainable framework for improving process safety culture in the chemical processing industry.** The literature survey in Chapter 2, consisted of reviewing existing PSM systems and chemical company case studies, specifically understanding their process safety culture approaches. Occupational safety culture practices from diverse industries were investigated along with understanding the human mind and maintenance error to successfully leverage associated human factors. Other high-risk high-reliability industries with

catastrophic consequences were also evaluated. The nuclear and civil aviation industries were selected, and their safety culture approaches explored.

Delving into process safety culture systems revealed numerous human factor engineering practices and only a handful of process safety culture practices. Only two PSM systems included process safety culture, namely: [1] CCPS (2008) and [2] IOGP (2008). However, there is an abundance of occupational safety culture literature available. Approaches for occupational safety culture were mainly cited as well as psychological literature that provides guidance on positively influencing human behaviours. Human factor error also impacts asset integrity; hence this was incorporated into the literature survey.

High-risk high-reliability industries, specifically nuclear and civil aviation sectors, were also reviewed to provide an external view on safety culture approaches. There was also an abundance of safety culture literature available for these sectors. Thus, several safety culture approaches were uncovered, much of which resided in the occupational safety culture domain. **From the above, it is evident that our research problem exists, and that globally there is very limited guidelines into holistically managing process safety culture in the chemical processing industry.**

The employed research methodology, in pursuit of achieving the aim and objectives of this study, was discussed in Chapter 3. A qualitative mixed methods approach was selected, and comprehensive verification, validation and reliability techniques were reviewed. Theory building was highlighted as an additional literature survey required to assist in the development of the process safety culture framework. The aforementioned discussed practices were incorporated into this study's research methodology and is presented in Section 3.4, Table 26.

In Chapter 4, the literature surveyed was collated and analysed. Trends were observed and some themes were identified which featured repeatedly across the different process and occupational safety culture approaches in the diverse environments investigated. Shared themes were collectively grouped together to form parent themes. A process safety culture is inferred through process safety climate assessment. These parent themes are essentially process safety climate attributes, which form the foundational layer of a process safety culture framework. These parent themes are therefore process safety culture constructs. A total of nine process safety culture (PSC) constructs were derived as mapped out in Chapter 4, Table 33. In Section 5.13, Table 40, summarises these nine PSC constructs and their associated critical aspects.

The nine derived PSC constructs, as discussed in Chapters 4 and Chapter 5, were broadly reviewed for interdependencies and upon reflection ultimately expanded. The rationale behind

the expansion was purely due to the collectively grouped PSC constructs not being completely related to one another. Their independence necessitated their separation so that the PSC constructs was not diluted or lost. Three grouped PSC constructs were separated: [1] disciplinary process and communication, [2] resourcing and roles and responsibilities, [3] recognition and reward and metrics. The PSC constructs transformed into the PSC elements (process safety climate attributes) which collectively intertwine to develop the process safety culture framework. The original nine PSC constructs formed twelve final PSC elements as listed in Chapter 6, Table 41.

These twelve PSC elements were scrutinised against the human mind literature discussed in Section 2.7. Recommendations for exploring this literature was received by an experienced industrial psychologist Dr P. Calitz as introduced in Annexure C. The twelve PSC elements integrated and well represented the four quadrant focus areas. The four quadrant focus areas, safety capital principles and the PSC elements were adapted and overlapped, ultimately resulting in further grouping of the PSC elements into four pillars, as shown in Chapter 6, Table 42. The combination of all these concepts would culminate in achieving effective and sustainable process safety culture which ultimately prevents major process safety incident occurrences. The four PSC pillars are: [1] systems, [2] integrity, [3] people and [4] performance. In Chapter 6, Figure 102, is a graphical representation that incorporates and indicates the relationships between all the PSC elements and pillars, to form the PSC framework. Accompanying this also in Chapter 6, is a PSC implementation cycle, as shown in Figure 104, and the PSC maturity chart, as seen in Figure 103.

The intended validation as described in Chapter 3, was to pilot the PSC framework at a chemical processing facility. Financial impact and each PSC elements' effective implementation were observed as the greatest challenges opposing validation. The rationale for this, was merely due to the considerable effort to first align the chemical processing facility to the ideal process safety culture element expectations as indicated in Section 5.13, Table 40. The implementation phase was estimated to require 2 to 4 years and was largely dependent on the magnitude of the chemical processing facility. The pilot phase required leadership to actively drive the PSC framework. This was estimated to require at least a year of testing, in order to perform an adequate assessment of the PSC elements and the framework.

Thus, a total period, inclusive of implementation and field pilot testing, of between 3 to 5 years was estimated. The aforementioned estimations do not account for other factors and assumes that the organisation is only committed to the implementation of the PSC framework. Therefore, the initial intended validation approach was not viable. An alternate approach was undertaken, and the proposed PSC framework was critically reviewed by Subject Matter Experts (SMEs) in

the chemical processing industry and their feedback was incorporated. A total of ten SMEs were consulted, with combined experience in operations, engineering and process safety, exceeding 190 years. The SMEs are from three different provinces across South Africa, and are in roles across operations (production, maintenance), process engineering, behavioural transformation and process safety. Most of the SMEs consulted were very senior and instrumental in implementing (facilitating or guiding) process safety practices/programs at a chemical processing facility. Despite these challenges, after consultation with SMEs from operations, engineering and process safety at chemical processing facilities, they concur that the PSC framework is implementable and will yield positive process safety culture performance. However, this could not be quantified without field pilot tests.

In Chapter 6, Figure 105, depicts the updated PSC framework which incorporated the aforementioned builds by the SMEs. The interdependencies were revisited and altered to better reflect their relationships. The four pillars and thirteen elements were included, along with a detailed overview of their associated critical aspects. The major difference between the PSC framework revision 0 and revision 1, is the inclusion of the critical aspects of the now thirteen, previously twelve PSC elements. The additional PSC element is committed leadership, which although included, was diluted in the people pillar. The process flow diagram was also reviewed to better depict the relationships between the PSC pillars. This one-page high level overview greatly assists in summarising the PSC framework for ease of implementation as well as understanding.

A PSC assessment tool was also suggested to support this framework. Therefore, the PSC questionnaire was developed and tailored to the PSC framework, as seen in Annexure D, Table 50. Findings raised from the PSC questionnaire will inform the PSC implementation cycle in Chapter 6, Figure 104. Thus, this will greatly complement the implementation of the framework and assist in pin-pointing the framework's substandard process safety pillars. Leadership expectations in the form of a "*how to guide*" was suggested to assist in practically executing the PSC framework. Therefore, a PSC roles and accountabilities guideline was developed, as seen in Annexure A, Table 43. Input was drawn from the Mindful Leadership with References to BP Texas City (Futuremedia, 2020) and Creating a Mindful Organisation (Futuremedia, 2020) training material by Professor A. Hopkins. Leadership was identified through all levels in a typical chemical processing business from the highest board member positions to the entry foremen level positions. The guideline also included all front-line operation personnel and other personnel with no direct reports, as process safety culture requires the participation from everyone in an organisation. Examples of other personnel include engineering, functional support and service providers. There were thus five levels of leadership. These levels included board

member/executives, senior managers, plant managers, foremen and front-line operation personnel and other personnel.

These two additional tools [1] PSC questionnaire and [2] PSC roles and accountabilities guideline further enhances the PSC maturity chart (Chapter 6, Figure 103), the PSC implementation cycle (Chapter 6, Figure 104) and the PSC framework (Chapter 6, Figure 105). Through a systematic and iterative process as illustrated with the PSC implementation cycle in Chapter 6, Figure 104, the process safety culture of a chemical processing facility can be practically and sustainably engineered.

Reflecting on Chapter 3 and the original intent of this study's research methodology, there were both positive and negative outcomes in relation to verification, validation and reliability. In the literature survey much overlap was observed through different citations. Similarly, when the analysis was completed in Chapter 4, again much overlap was observed with respect to culture theme practices. Saturation of literature was thus observed. Unfortunately, the major disadvantage of the PSC framework, although a holistic approach, it does require prerequisites. It takes the form of a chemical processing facility that is in a good financial position and is able to upgrade its safety instrumented systems, resource structure according to strategy and integrate SHE and maintenance digital solutions. This model does have two dependencies: [1] existence of an active OSHA (or equivalent) PSM system and [2] it is actively driven by leadership.

However, the PSC framework focuses on assorted aspects which jointly contribute toward improving process safety culture in the chemical processing industry. It does not concentrate on influencing a positive process safety culture, but rather engineering a positive process safety culture practically and sustainably through systematic and continuous improvement focused initiatives.

In Chapter 1, the research hypotheses, aim and four objectives were stated, and their outcomes are discussed. This research study addressed the following two cases with a converse hypotheses:

H₁: There is a practical, sustainable and implementable process safety culture framework for the chemical processing industry. **H_{1.0}:** There is no practical, sustainable and implementable process safety culture framework for the chemical processing industry.

H₂: Implementation of a process safety culture framework will improve process safety incident case rates. **H_{2.0}:** Implementation of a process safety culture framework will not improve process safety incident case rates.

From the literature review in Section 2.2, of the investigated PSM systems, only two PSM systems included process safety culture. Only IOGP (2008) and CCPS (2008) PSM systems include such elements. These PSM systems are well acknowledged and practiced in the chemical processing industry. Several other guidelines or practice notes on process safety culture approaches were examined. Delving into this revealed numerous human factor engineering practices and only a handful of process safety culture practices. Chemical processing companies practising PSM were surveyed to understand their process safety culture practices. Large scale, international and well recognised chemical processing companies were selected: Shell, BP, Sasol and Chevron. Upon review, they all apply a risk-based approach closely following the CCPS (2008) Risk Based Process Safety systems. Process safety culture seemed to be governed by leadership and assurance programs. The observed process safety culture practices are comprehensively written, and they give guidance on implementation. **From the literature survey, it was also evident that our research problem exists, and that globally there is very limited guidelines into holistically managing process safety culture in the chemical processing industry.** Thus, there was merit in this study, to develop a practical and sustainable framework for improving process safety culture in the chemical processing industry. Therefore, based on this outcome, although very limited, it does appear that H_1 is applicable and there is a practical, sustainable and implementable process safety culture framework for the chemical processing industry.

The PSC framework requires significant financial outlay to effectively implement the process safety culture pillars, as well as necessitating two dependencies as previously mentioned. Despite the challenges experienced with the validation and reliability of the PSC framework, it has been theoretically reviewed, by experienced SMEs, to assure that it will improve process safety culture at a chemical processing facility, albeit unquantifiable. Therefore, based on these outcomes, it does appear that H_2 is partially applicable, and that implementation of the PSC framework will improve process safety incident case rates theoretically.

Research objectives were established to complement the two case hypotheses proposed. Three research objectives were proposed as discussed in Chapter 1. The outcome of each research objective was critically reviewed and discussed.

The first research objective to include a multi-disciplined and integrated process for managing the integrity and performance of hazardous operating processes. The research outcome included a literature review of asset management with respect to process safety culture, which was conducted in Section 2.8. In Chapter 4, Table 30 documents the analysis of this literature which was later incorporated into the PSC pillars forming the PSC framework. Therefore, this research objective was achieved.

The second research objective was to understand how high-risk high-reliability non-chemical processing industries maintain better incident case rates through improved safety cultures. The research outcome also took the form of a literature review. Similarly, a literature review of high-risk high-reliability non-chemical processing industries with respect to process safety culture was conducted in Section 2.9. The nuclear and civil aviation industries were specifically investigated. In Chapter 4, Table 31 and Table 32 documents the analysis of this literature which was later incorporated into the PSC pillars forming the PSC framework. Therefore, this research objective was achieved.

The third research objective was to validate the theory through empirical testing. The research outcome was that the PSC framework necessitates prerequisites prior to empirical testing. It takes the form of a chemical processing facility that is in a good financial position and is able to upgrade its safety instrumented systems, implement a resource structure according to strategy and integrate digital solutions incorporating SHE and maintenance programs. Also note that this framework must also be coupled to the two dependencies previously mentioned.

Unfortunately, practical validation of the PSC framework was not viable. Despite these challenges, after consultation with SMEs from operations, engineering, and process safety at chemical processing facilities, they concur that the PSC framework is implementable and will yield positive process safety culture performance. Unfortunately, this improvement could not be quantified without practical validation. Thus, theoretically the PSC framework was validated, however practical validation could not be completed as described above. Therefore, the third research objective was only partially achieved.

In the next chapter recommendations for further studies are proposed. These recommendations build on the current work conducted and complement the process safety culture field of investigation.

CHAPTER 8 RECOMMENDATIONS

In the last chapter, the hypotheses, aim and objectives study conclusions were discussed. With any study, there will be opportunities for further research and many avenues were uncovered. A total of four recommendations are proposed for future work as follows:

1. Pilot the process safety culture framework at a chemical processing facility.

Overview of future work: The PSC framework was only validated theoretically as previously discussed. Therefore, the validation process can be concluded by field testing the framework at a sizeable chemical processing facility (>100000 man-hours per month, based on author's experience). The greatest challenge remains to first establish the four PSC pillars as specified in Chapter 6, Figure 105, and then pilot the PSC framework. Improvement areas can be identified and incorporated into further revisions of the framework.

2. Adapt the process safety culture framework for industries outside of the chemical processing environment.

Overview of future work: From the literature analysis, common safety culture themes were apparent across the chemical and non-chemical processing environments. Therefore, the PSC framework, with a few adaptations, could be implemented in these non-chemical processing environments. Similarly, challenges as exhibited with piloting the framework at a chemical processing facility may be experienced.

3. Develop assurance programs for the each of the thirteen process safety culture elements.

Overview of future work: Frequent auditing against established criteria and requirements by experienced independent persons is the foundation of any assurance program. Integration of these programs into the PSC framework will optimise an audit program and improve the cultural entropy.

4. Develop a management system that incorporate SHE and Maintenance critical aspects as per Chapter 6, Figure 102.

Overview of future work: Many digital solutions exist for respective SHE and maintenance management systems. More so due to the software developers specialising in one or the other areas. Therefore, development of one central digital solution is recommended to optimise an organisation's cultural entropy. SMEs from SHE and Maintenance need to participate with software developers as this is imperative to the success of this recommendation.

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ANNEXURE A

Table 43. Process Safety Culture Roles and Accountabilities

Key Leadership Expectations	Board Members/Executives	Senior Managers	Plant Managers	Foremen	Front Line Operation Personnel and Other Personnel
Polices and Goals – Direction	Clearly state the importance of process safety culture in a high level vision statement and in supporting policy documents. Provide a clear vision of what process safety means to the organisation and define success milestones.	Drive the process safety culture polices and goals.	Enforce the process safety culture polices and goals.	Execute the process safety culture polices and goals.	Execute the process safety culture polices and goals.
Metrics and performance tracking	Select key group process safety culture indicators for reporting and performance tracking against specific targets.	Select key plant specific process safety culture indicators for reporting. Track performance of group and plant process safety indicators against specific targets.	Report on key process safety culture indicators and evaluate their performance against specific targets.	Report on key process safety culture indicators and evaluate their performance against specific targets.	Report on key process safety culture indicators and evaluate their performance against specific targets.
	Monthly monitoring of the process safety performance is central to ensuring business risks are being effectively managed. Focus on what is not going well.	Monthly monitoring of the process safety performance is central to ensuring business risks are being effectively managed. Focus on what is not going well.	Weekly monitoring of the process safety performance is central to ensuring business risks are being effectively managed. Focus on what is not going well.	Daily monitoring of the process safety performance is central to ensuring business risks are being effectively managed. Focus on what is not going well.	Always operate within safe operating limits and established operating procedures. Report challenges.

Key Leadership Expectations	Board Members/Executives	Senior Managers	Plant Managers	Foremen	Front Line Operation Personnel and Other Personnel
	Assure that risk studies, audits and management reviews are conducted in accordance with established schedules.	Ensure that risk studies, audits and management reviews are conducted in accordance with established schedules.	Drive compliance to completing risk studies, audits and management reviews within established schedules.	Execute or participate in risk studies, audits and management reviews within established schedules.	Participate in risk studies, audits and management reviews within established schedules.
		Drive timely resolution of process safety recommendations and concerns.	Ensure timely resolution of process safety recommendations and concerns.	Raise process safety recommendations.	Raise process safety recommendations.
Continuous Improvement	Drive process safety culture improvement plans to respond to patterns.	Drive process safety culture improvement plans to respond to patterns.	Develop Process safety culture improvement plans to respond to patterns.	Implement Process safety culture improvement plans to respond to patterns.	Implement Process safety culture improvement plans to respond to patterns.
	Assess periodic reviews of the group plant's process safety culture.	Assess periodic reviews of the group plant's process safety culture.	Assess/conduct periodic reviews of the plant's process safety culture.	Conduct periodic reviews of the plant's process safety culture.	
Incident Investigation and Learning	Assure group incident learnings and recommendations are communicated and implemented.	Assure group and internal incident learnings and recommendations are communicated. Assess the applicability of and drive the implementation of recommendations from these incident learnings.	Assure group and internal incident learnings and recommendations are communicated. Assess applicability and implement recommendations from these incident learnings.	Assure group and internal incident learnings and recommendations are communicated. Assess applicability and implement recommendations from these incident learnings.	Assess applicability and implement recommendations from these incident learnings.

Key Leadership Expectations	Board Members/Executives	Senior Managers	Plant Managers	Foremen	Front Line Operation Personnel and Other Personnel
			Drive the reporting and remediation of near-miss incidents.	Report all near-miss incidents and action corrective measures.	Report all near-miss incidents.
Leadership Commitment	Chair quarterly plant engagements and field verification with line leadership. Evaluate compliance and effectiveness to process safety practices.	Chair weekly plant engagements and field verification with line leadership. Evaluate compliance and effectiveness to process safety practices.	Chair weekly plant engagements and field verification with line leadership. Evaluate compliance and effectiveness to process safety practices.	Participate in weekly plant engagements and field verification with line leadership. Evaluate compliance and effectiveness to process safety practices.	Participate in weekly plant engagements and field verification with line leadership. Evaluate compliance and effectiveness to process safety practices.
Competent Resources	Drive a high value for process safety knowledge and expertise.	Establish a high value for process safety knowledge and expertise through training program requirements.	Attend the required process safety training programs. Ensure compliance to the frequency of these programs.	Attend the required process safety training programs. Ensure compliance to the frequency of these programs.	Attend the required process safety training programs. Ensure compliance to the frequency of these programs.
Communication	Communicate process safety expectations.	Drive a process safety communication plan.	Create a process safety communication plan.	Communicate as per the plan.	Participate as per the plan.
Rewards and Disciplinary	Allocate funding to reward programs.	Create and drive reward and recognition programs.	Ensure that process safety performance rewards and corrective actions are consistently applied.	Identify reward and recognition cases for escalation to management.	Identify reward and recognition cases for escalation to management.

ANNEXURE B

Table 44. Analysis of process safety culture approaches

Common safety culture elements	Various process safety culture approaches															
	CCPS, 2007	Kletz, 2003	Lowe and Kariuki, 2003	Mitchell, 2016	Halim and Mannan, 2018	Qi et al., 2012	Orr et al., 2013	EPSC, 2012	OECD, 2012	COMAH, 2019	Bridges and Tew, 2010	HSE, 2016	CSB, 2013	IOGP, 2008	Baker Panel, 2007	BP, 2010
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16
1. Strong leadership	X						X	X	X	X		X			X	
2. Open and effective communication	X					X				X	X		X			
3. Empowered individuals	X				X	X	X	X	X		X	X	X		X	
4. Establish a learning environment	X				X								X		X	
5. Continuous performance monitoring and improvement	X				X	X	X	X	X	X			X	X	X	X
6. Human error engineering		X	X	X			X				X	X		X		X
7. Risk awareness and management									X	X					X	X
8. Motivation											X		X			

Table 44. Analysis of process safety culture approaches (continued)

Common safety culture elements	Various process safety culture approaches			
	HSE, 2011	Roberts, 2012	Weick and Sutcliffe, 2007	Hudson et al., 1994
	Model 17	Model 18	Model 19	Model 20
1. Strong leadership	X	X	X	
2. Open and effective communication	X			X
3. Empowered individuals	X	X	X	
4. Establish a learning environment	X		X	X
5. Continuous performance monitoring and improvement	X	X	X	X
6. Human error engineering	X	X	X	X
7. Risk awareness and management	X	X	X	
8. Motivation	X	X		

Table 45. Analysis of chemical case study process safety culture approaches

Common safety culture elements	Various chemical case study process safety culture approaches			
	Sasol	BP	Shell	Chevron
	Model 1	Model 2	Model 3	Model 4
1. Process Safety Management System	X	X	X	X
2. Risk Based Safety Approach	X		X	X
3. Human behaviours and culture programs or elements		X		
4. Safety leadership programs or elements		X	X	
5. Focused on improved training programs	X	X	X	X
6. Specific human factor training		X		
7. Incident Investigation and Learning systems	X	X	X	X
8. Auditing systems	X		X	X
9. Emergency Response and management	X	X		X
10. High intolerance to rules and standards			X	

Table 46. Analysis of occupational safety culture approaches

Common safety culture elements	Various occupational safety culture approaches										
	Hudson, 2007	Ertuğrul, 2015	Reason, 1997	Geller, 2001	Cooper, 1999	Agnew, 2015	Hecker <i>et al.</i> , 2014	IET, 2017	IOSH, 2003	Mearns, 2017	Quayzin, 2012
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
1. An active safety information system which collects, analyses and records key incident causes and learnings		X	X	X	X			X	X		
2. Employees openly report all types of errors, mistakes and violations irrespective of how small or large			X	X		X			X		
3. Positive, transparent and open communication across all levels	X		X		X		X	X	X	X	
4. Agility of an organisation to respond to arising concerns			X								
5. Willingness and competence of employees to function and derive the correct conclusions with associated corrective actions			X	X	X	X					
6. Engaged, value driven and committed leadership from executive to senior to front line leadership	X	X			X		X	X	X	X	X
7. Well documented safety practices, policies and procedures	X	X			X		X		X		X
8. Safety driven goals, targets, performance monitoring and reward incentives					X	X			X		X
9. Consistent and clear disciplinary process						X			X		
10. Continuous improvement initiatives such as periodic culture surveys (maturity assessment)	X									X	

Table 46. Analysis of occupational safety culture approaches (continued)

Common safety culture elements	Various occupational safety culture approaches											NOPSEMA, 2013
	Cooper, 2016	Fleming and Scott, 2011	PSAN, 2002	University of Queensland, 2008	Vecchio-Sadus, 2007	Lardner <i>et al.</i> , 2011	Beukes, 2015	The State of Queensland, 2013	RMS, 2017	Parker <i>et al.</i> , 2006	SafeCare BC, 2015	
	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20	Model 21	Model 22	Model 23
1. An active safety information system which collects, analyses and records key incident causes and learnings		X	X							X	X	X
2. Employees openly report all types of errors, mistakes and violations irrespective of how small or large		X	X		X				X			
3. Positive, transparent and open communication across all levels					X	X					X	X
4. Agility of an organisation to respond to arising concerns			X									
5. Willingness and competence of employees to function and derive the correct conclusions with associated corrective actions										X		X
6. Engaged, value driven and committed leadership from executive to senior to front line leadership	X	X			X	X	X	X		X	X	X
7. Well documented safety practices, policies and procedures	X	X			X	X	X	X			X	
8. Safety driven goals, targets, performance monitoring and reward incentives	X						X	X		X	X	
9. Consistent and clear disciplinary process		X	X						X			
10. Continuous improvement initiatives such as periodic culture surveys (maturity assessment)	X			X			X	X		X	X	

Table 46. Analysis of occupational safety culture approaches (continued)

Common safety culture elements	Various occupational safety culture approaches				
	Schein, 1983	Verbele <i>et al.</i> , 1998	Zohar, 1980	Zohar and Hofmann (2012)	Guldenmund, 2010
	Model 24	Model 25	Model 26	Model 27	Model 28
1. An active safety information system which collects, analyses and records key incident causes and learnings					X
2. Employees openly report all types of errors, mistakes and violations irrespective of how small or large					X
3. Positive, transparent and open communication across all levels	X	X	X	X	X
4. Agility of an organisation to respond to arising concerns					X
5. Willingness and competence of employees to function and derive the correct conclusions with associated corrective actions					X
6. Engaged, value driven and committed leadership from executive to senior to front line leadership	X	X	X	X	X
7. Well documented safety practices, policies and procedures				X	X
8. Safety driven goals, targets, performance monitoring and reward incentives	X	X		X	X
9. Consistent and clear disciplinary process					
10. Continuous improvement initiatives such as periodic culture surveys (maturity assessment)					

Table 47. Analysis of asset integrity safety culture approaches

Common safety culture elements	Various asset integrity safety culture approaches									
	Dunn, 2003	Kusumawardhani and Markeset, 2015	Chandima Ratnayake and Markeset, 2010	Torres-Echeverria <i>et al.</i> , 2016	Kusumawardhani, 2016	Mahound, 2014	Reason and Hobbs, 2003	Khan, 2012	Emslie and Gibson, 2010	ATSB, 2008
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
1. Maintenance Management System	X		X	X	X	X	X	X	X	
2. Well-resourced and competent workforce					X		X			X
3. Quality Assurance	X			X		X	X			X
4. Process Safety Information - equipment data sheets, etc.		X			X	X	X			
5. Knowledge transfer		X			X		X			
6. Reliability Management	X		X	X			X	X	X	
7. Appropriate tooling and equipment										X

Table 48. Analysis of nuclear safety culture approaches

Common safety culture elements	Various nuclear safety culture approaches						
	Rzentkowski, 2016	IAEA, 2002	NPJ, 2012	Yates <i>et al.</i> , 2005	TEPOC and Chubu Electric Power	Parnas <i>et al.</i> , 1994	Fleming, 2017
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
1. Artefact, espoused value and basic assumption levels		X					
2. Optimization and Recognition	X		X				
3. Improve human error performance	X			X			
4. Continuous performance monitoring and improvement	X			X			X
5. Competent and well resources workforce				X			
6. Risk management program	X				X		X
7. Safety critical software quality control	X					X	
8. Committed and active leadership	X						X

Table 49. Analysis of civil aviation safety culture approaches

Common safety culture elements	Various civil aviation safety culture approaches										
	BARS, 2017	CANSO, 2008	ECAST, 2009	NLR, 2016	Dumitru and Boscoianu, 2015	Gill and Shergil, 2004	McDonal <i>et al.</i> , 2000	ICAO, 2013	Mearns <i>et al.</i> , 2009	ATSB, 2004	Shappell, 2000
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
1. Improve human error performance	X							X			
2. Dimensional Culture Management		X	X	X					X	X	
3. Training and Competency					X	X	X			X	
4. Improving Technical Execution	X	X	X	X	X	X	X	X			
5. Asset Integrity										X	
6. Human Factor Organisation Influences											X

ANNEXURE C

Background

Dr P. Calitz has a long career in social psychology spanning 37 years. Social psychology is also known as sociology which focuses on social action and on the interrelation of social structure and culture with personality, values and mind. He has worked for many large international companies and has gained extensive business experience. He obtained a Doctor of Philosophy in Business Sociology from North-West University in 1994.

Experience

Senior Organisational Development Consultant	(2015 – present)
Organisational Development Specialist	(2011-2015)
Human Resource manager	(2005-2010)
Manager: Learning and Development	(1999-2004)
Manager: Labour Relations and Employee Wellness	(1992-1998)
Human Resources Business Partner	(1987-1991)
Recruit Officer	(1985-1986)
Remuneration specialist	(1983-1984)

ANNEXURE D

Table 50. Process Safety Culture Questionnaire

Pillar	Process Safety Culture Element	Critical aspect assessment		Yes	No
1. Systems	1.1. Central Management System	1.1.1.	Are there electronic systems designed to effectively manage maintenance and SHE?		
		1.1.2.	Is the electronic system easily accessible and does it provide a user-friendly and simple interface?		
		1.1.3.	Are Plant Condition, Risk, Assurance, Performance and Incident Management databases integrated?		
		1.1.4.	Does it allow analysis capability and report generation?		
		1.1.5.	Design incorporated cultural entropy and safety capital approaches?		
	1.2. Assurance	1.2.1.	Does the assurance program include first, second and third-party audits?		
		1.2.2.	Does leadership conduct planned and frequent audits across the facility? (e.g. Plant, control rooms, workshops)		
		1.2.3.	Are assurance deviations discussed and shared?		
		1.2.4.	Are assurance corrective actions tracked and discussed?		
	1.3. Incident Management	1.3.1.	Are near-misses and incidents reported and investigated?		
		1.3.2.	Are employees trained and do they understand the key investigation roles?		
		1.3.3.	Are quality investigations completed? (E.g. Assess root causes and corrective actions)		
		1.3.4.	Are actions tracked and learnings shared?		
		1.3.5.	Trend analysis on near-misses/incidents discussed, and corrective actions implemented?		
	Total out of 14 questions				
2. Integrity	2.1. Maintenance and Layers of protection	2.1.1.	Are there independent quality controls? (e.g. Quality control plans with levels of verification, equipment welding, joint integrity, pump/compressor protocols)		
		2.1.2.	Are there appropriate tools and equipment prescribed to aid in executing the task?		
		2.1.3.	Is reliability performance (human, process, equipment, maintenance) discussed and corrective actions tracked?		
		2.1.4.	Are there independent control layers based on risk? (e.g. Layers of protection analysis)		

Pillar	Process Safety Culture Element	Critical aspect assessment		Yes	No
	2.2. Complex Instrumentation	2.2.1.	Are processes evaluated to reduce the probability of human-error?		
		2.2.2.	Are SIL rated instruments installed as per SIL study recommendations based on plant risks identified?		
		2.2.3.	Are alarm documentation and rationalisation studies updated?		
		2.2.4.	Are the plant digital control systems evaluated to reduce the probability of human-error?		
	Total out of 8 questions				
3. People	3.1. Committed Leadership	3.1.1.	Does leadership drive values and lead by example?		
		3.1.2.	Are leaders process safety orientated and is this visible? (e.g. interactions, meetings and decisions)		
		3.1.3.	Are process safety concerns or suggestions from employees acted upon by leadership?		
		3.1.4.	During high pressure production and/or maintenance scenarios, do leaders abandon process safety practices?		
		3.1.5.	Do leaders acts or expressions contradict process safety procedures or practices?		
		3.1.6.	Do leaders prioritise production over process safety?		
	3.2. Roles and Responsibilities	3.2.1.	Do leaders have clear and concise process safety responsibilities?		
		3.2.2.	Is process safety performance management aligned to roles and expectations?		
		3.2.3.	Are process safety training programs well defined?		
		3.2.4.	Are the process safety competency practices effective?		
		3.2.5.	Are leaders periodically assessed to improve process safety leadership?		
	3.3. Communication	3.3.1.	Is a comprehensive and focused process safety communication plan available (e.g. scheduling of messages, location of messages, trusted messenger, appealing information, personalized messages and real life examples)?		
		3.3.2.	Are multiple communication mediums used (e.g. multi-lingual, video, verbal, live and posters)?		
		3.3.3.	Do employees and leaders frequently (daily) and effectively converse on process safety?		
	3.4. Resourcing	3.4.1.	Do organisational structures incorporate design elements to reduce human-error?		

Pillar	Process Safety Culture Element	Critical aspect assessment		Yes	No
		3.4.2.	Are human factor prevention practices applied to procedures and processes?		
		3.4.3.	Is fatigue effectively managed?		
		3.4.4.	Are the knowledge transfer and succession planning programs well managed?		
		3.4.5.	Are the human factor error prevention training programs effective?		
		3.4.6.	Are there team building sessions to promote healthy working environments?		
	3.5. Disciplinary Process	3.5.1.	Are the consequence management practices based on or similar to the James-Reason approach?		
		3.5.2.	Is the disciplinary process clearly defined, consistently followed and transparent?		
		3.5.3.	Are disciplinary cases indicative of an intolerant culture? (assess the insignificant errors, which hinder a learning environment)		
	Total out of 23 questions				
4. Performance	4.1. Metrics	4.1.1.	Are the alarm rates within internationally accepted targets?		
		4.1.2.	Are OWAP deviations identified and promptly rectified?		
		4.1.3.	Are inspection deviations identified and promptly rectified?		
		4.1.4.	Is there appreciable annual reduction in the severity of process safety incidents?		
		4.1.5.	Are internal/external learning shared with recommendations being actioned?		
		4.1.6.	Are alarms/trips/equipment bypassed for prolonged periods (>2 days)?		
		4.1.7.	Are the required training program schedules effectively managed?		
		4.1.8.	Are the competency of artisans well distributed across shifts to enable effective knowledge transfer?		
		4.1.9.	Is there appreciable annual reduction in the number of bad actor equipment?		
	4.2. Recognition and Reward	4.2.1.	Is the recognition and reward process clearly defined and consistently applied?		
		4.2.2.	Are the incentives designed to positively impact process safety?		
		4.2.3.	Are salary packages per role competitively based?		

Pillar	Process Safety Culture Element	Critical aspect assessment		Yes	No
		4.2.4.	Are performance expectations clearly defined?		
		4.2.5.	Do performance agreements include process safety expectations?		
	4.3. Continuous Improvement	4.3.1.	Is the process safety incident analysis discussed frequently (monthly) and improvement areas actioned by leadership?		
		4.3.2.	Are metrics discussed frequently (monthly) and improvement areas actioned by leadership?		
		4.3.3.	Are systems and processes analysed at least annually to identify cultural entropy and safety capital (energise, adapt, leverage, defend) improvement areas?		
		4.3.4.	Are process safety culture and human factor audits conducted at least annually to identify improvement areas?		
	Total out of 18 questions				
Overall	Total out of 63 questions				