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The Evaluation of Process Safety Management Effectiveness in the Oil and Gas Sector: Case of Sonatrach, Algeria

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by

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A Thesis Submitted in Partial Fulfillment of the Requirements of the Degree of Master of Science in Environmental Sustainability, Health and Safety Management

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Abstract

Over the last decade the process sector has experienced unprecedented process incidents that are due to a combination of organizational, technical, and cultural deficiencies. Thus, Process Safety Management (PSM) has become a subject of great interest for process companies, governments, and professional associations. In fact, many researchers have questioned the effectiveness of PSM programs in process companies and discussed the features of a quality PSM program. Indeed, a review of the literature reveals several PSM issues in this sector internationally, which are mainly about organizational safety culture, maintenance and operational integrity of processes, PSM performance measurement, employee training, and knowledge management.

The purpose of this research is to assess the maturity of PSM at Sonatrach, the Algerian public-owned oil and gas company, by evaluating the effectiveness of its PSM program as a part of the overall EHS management system through assessment of the key characteristics of a functional PSM program at Sonatrach, and how this is indicative of the state of PSM in developing countries. Given the results, this work provides recommendations for an appropriate path forward for Sonatrach to fully implement and improve PSM beyond adoption of standards. An explanatory mixed research approach was selected to investigate the state of PSM programs at Sonatrach facilities. It consisted of an online survey administered to a sample of twenty-two EHS specialists followed by six interviews with EHS specialists working at different Sonatrach facilities.

The results showed that Sonatrach encounters issues, in addition to the ones mentioned above, in the organizational structure of the company, the PSM documentation, human integrity, legal compliance, and checking and reviewing of the PSM program performance. This research concludes with recommendations that would address these issues in order to establish a robust PSM program within Sonatrach facilities and in the process sector in general.

Keywords

Process Safety Management

Environmental Health and Safety Management

Sonatrach

Algeria

Dedication

To the memory of my grandfather Mahmoud;

To my father Mohammed Tahar and mother Fatima;

To my wife Samiha and my son Adam;

To all my family;

I dedicate this work.

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Table of Contents

List of Tables

List of Figures

List of Acronyms

ANSI: American National Standards Institute

Btu: British Thermal Unit

EHS: Environmental Health and Safety

EIV: Emergency Isolation Valves

HTHA: High Temperature Hydrogen Attack

ISOM: Isomerization

LOTO: Lock Out Tag Out

PDA: Propane De-Asphalting

PHA: Process Hazard Analysis

Chapter 1: Introduction

Following the catastrophic accident in Bhopal, India on December 3, 1984 and the Piper Alpha disaster in the North Sea on July 6, 1988, both of which involved uncontrolled releases of dangerous materials, safety in the process industry became a subject of great importance for governments and professional organizations. Many countries promulgated regulations in an effort to enhance the safety of processes and industrial plants. For example, the European Union amended the so-called Seveso I Directive (adopted for the first time in 1976, few months after a catastrophic accident in a chemical plant at Seveso, Italy) twice in 1987 and 1988 to include into its scope facilities that store dangerous substances (European Commission 2015).

In the United States, a report was issued by the Environmental Protection Agency (EPA) in 1989 about the Acute Hazardous Events database reported more than 11, 000 events in eight years (Mason 2001). As a result, the government adopted Section 112 in the Clean Air Act Amendments of 1990 which dealt with catastrophic releases. On February 24, 1992, the Occupational Health and Safety Administration (OSHA) passed the Process Safety Management of Highly Hazardous Chemicals standard (29 CFR 1910.119). This regulation aimed to prevent accidental releases of highly hazardous chemicals in the process industry, and to protect employees and the nearby community from exposure to those hazards (US OSHA 2000).

Since the implementation of the PSM of Highly Hazardous Chemicals standard by processing companies does not guarantee the safety of processes alone, OSHA recognizes that "an effective PSM program requires a systematic approach to evaluating the whole chemical process" (OSHA 1994). Indeed, major process accidents did not cease to occur even after the requirements of the aforesaid standard became effective (e.g. Sierra Chemical Company accident in 1998 at Mustang, NV, Union Carbide Corp. accident in 1999 at Hahville, LA, and First

Chemical Corp. explosion at Pascgoula, MS in 2003). Therefore, an agreement in the sector was implicitly and gradually formed about the need to go beyond legal compliance with process safety regulations to a preventive posture where process incidents are prevented.

With the emergence of management systems standards in the EHS field by the end of 1990s, companies in the process industry tended to incorporate some principals and elements of those standards such as the Plan- Do- Check- Act approach in PSM in effort to prevent process incidents and maintain a continuous improvement in process safety performance. However, the sector started to experience unprecedented disasters where organizational, cultural, and technical failures contribute simultaneously in the occurrence of incidents. Table 1 summarizes the root causes of some process incidents in the oil and gas sector based on the US Chemical Safety Investigation Board (CSB) completed investigation reports published online. These mishaps happened in the United States over the last decade, and resulted in fire or explosions.

Accident name	**Nature**	**Root causes**		
		Technical	Organizational	Cultural
Giant Industries Refinery explosions & fire, 2004	Uncontrolled release of pressurized Alkylate	Frequent seal-related failures in the pumps due to corrosion	Substandard maintenance practices, inadequate management of change on process design, ineffective LOTO program	Reactive mindset of management; Behavioral issues of operators (safety shortcuts)
Valero Refinery Propane Fire, 2007	Uncontrolled release and ignition of liquid propane from PDA unit	Uncontrolled propane mix freezing hazard; No EIV in place	Incomplete PSI; failures to revise and implement PHA; gaps in standards and codes	Operators not involved in the 2006 PHA review process
Tesoro Anacortes Refinery, 2010	Uncontrolled release and ignition of hydrogen and naphtha from a ruptured heat exchanger	HTHA mechanism	Hazardous non routine work, ineffective PHA and inspection	Complacency of technical experts

Table 1. Root causes of some process incidents in the oil and gas sector (US CSB 2015a)

Such undesirable events lead to one conclusion: that the process sector is still struggling to implement an effective PSM program that ensures process integrity. Moreover, these developments increased the discussion among professionals and researchers about the way companies are managing their process safety and the extent of PSM program integration within the overall EHS management system, since the development in personal safety performance was not followed with a progress in process safety performance.

1.1 Background:

1.1.1 Process Safety Management (PSM)

US OSHA defined Process Safety Management (PSM) as "the proactive identification, evaluation and mitigation or prevention of chemical releases that occur as a result of failures in processes, procedures, or equipment" (US OSHA 29 CFR 1910.119 Appendix C 1992). In the United States and Europe, companies that run processes covered by at least one of the PSM regulations have to comply with the provisions of those regulations and implement a program for the management of process safety. While the OSHA PSM of Highly Hazardous Chemicals standard came to protect workplace safety including the safety of operators, subcontractors, and visitors inside the facility, the purpose of EPA Risk Management Plan (CAA Section 112 r) is to ensure the safety of the community surrounding the plant (EPA 2013). The uniform PSM program prescribed by EPA and OSHA regulations aimed to guarantee the minimum level of process safety performance in U.S. plants. However, this command and control approach did not achieve all of its intended outcomes in preventing or mitigating process incidents. In fact, the U.S. CSB has been criticizing the OSHA PSM standard and requested major changes on the standard about broadening its scope, amending the list and concentrations of regulated chemicals in order to cope with reactive chemicals hazards (Simmons et al. 2009; CSB 2013).

The Center of Chemical Process Safety (CCSP) presented a broader definition and scope for the PSM program, and considered it as “A program or activity involving the application of management principles and analytical techniques to ensure the safety of chemical process facilities” (CCPS 1995). In fact, this approach enables companies to manage process safety as an integrated subsystem of the overall EHS management system. Hence, PSM is included in the planning, implementation, checking, and review of the EHS management system.

1.1.2 Organizational safety culture

The concept of safety culture emerged after the nuclear disaster of Chernobyl on April 26, 1986, which “was the most severe in the history of the nuclear power industry, causing a huge release of radio nuclides over large areas of Belarus, Ukraine, and the Russian Federation” (IAEA 2015). The findings of the International Nuclear Safety Advisory Group (INSAG) pointed to the lack of safety culture as the root cause behind the deviation from testing procedures of turbo generators in Unit 4 and other major deficiencies in the design and operation of the plant (IAEA 1992). Since then, many definitions have been given to safety culture based on the perspective of researchers. Discussion has been mainly about the nature of safety culture: whether it is an output variable related to the organizational culture and safety performance, or an aspect of the organizational culture. The International Atomic Energy Agency, along with many other researchers, consider safety culture as an aspect of an organization’s culture and defined it as “that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive attention warranted by their significance” (IAEA 1992). In the same vein, Hale (2000) depicted safety culture as “the attitudes, beliefs and perceptions shared by natural groups as defining norms and values, which determine how they act and react in relation to risks and risk control systems.”

Furthermore, Ciavarelli and Crowson (2004) provided a similar broad definition of safety culture (as cited in Mannan et al. 2013, 1425), which meant for them "an organization's shared attitudes, values, norms, and beliefs about safety, including attitudes about danger, risk, and the proper conduct of hazardous operations."

Many studies considered safety culture as a multidimensional concept. Parker et al. (2006) supported this perspective since safety culture literature emphasizes the value of safety-related attitudes and the activities of managers. In fact, researchers suggested several elements as important dimensions of safety culture. Filho et al. (2010) outlined the most frequently cited safety culture dimensions in literature, which are information, organizational learning, employee involvement, internal safety communication, and management commitment. These dimensions are interrelated and their effective functioning is a prerequisite for the success of organizational safety culture (Kilaparthi 2014).

With regard to the information dimension, it concerns the system used within an organization to report safety information such as incidents and near misses, safety performance, etc. Kilaparthi (2014) discussed the importance of the information dimension and argued that it "brings attention towards right flow and distribution of information to the right people from the right source. Right flow of information is necessary to avoid any kind of miscommunication and taking rights actions at the right time." Organizational learning deals with the way the organization exploits the information resulting from accidents or near misses and how it is communicated to employees or other external parties.

Employee involvement concerns their participation in the management of EHS. In an organization with a good safety culture, employees are more engaged in EHS activities like accident investigations, risk assessments, safety committees, etc. Moreover, they are empowered to stop operations whenever an unsafe condition arises and report it openly to the management. Mannan et al. (2013) added "Best-in-Class management seeks to maximize employee engagement with safety by treating workers fairly, encouraging employee participation in the safety systems, and providing open lines of communication across the organization." In practice, employee involvement is a requirement in many national and international standards like ANSI/Z10, OHSAS 18001, EMAS III, and ISO 14001, as well as laws and regulations such as the Process Safety Management of Highly Hazardous Chemicals standard (29 CFR 1910.119) and the European Directive 2012/18/EU (i.e. SEVESO III Directive).

Internal safety communication is one of the crucial elements of a good safety culture. A two-way flow of safety information should circulate between the top and bottom levels of organization. According to Mannan et al. (2013), the information flow from the board of directors down to the shop floor is about safety policies, goals, and expectations of an organization. Whereas, the feedback flow is about EHS performance, and represents the information flow from the shop floor and rising to the board of directors. To ensure that the message from the top level of the organization is well received by those working on the shop floor, Mannan et al. (2013) suggested that the definition of roles and responsibilities for the middle levels of the organization (e.g. senior managers, middle managers, and frontline supervisors) in terms of receiving and communicating the safety message. In addition, the existence of open communication channels to forward the feedback of employees about EHS management to the upper levels of the organization is required for the effectiveness of safety communication.

Management commitment is the most important element for the effective performance of the other safety culture dimensions and for the establishment of a good safety culture as well.

Commitment to safety improvement in the workplace should be through the visible recognition of the management that safety is a core value for the business and not just a cost of operation or production. In organizations that have a good safety culture, their top management commitment toward safety is often translated with their leadership by example, setting clear safety goals and policies and allocating resources to achieve them, striving to maintain an open and trustful environment for communication with employees, integration of risk management in the overall decision making process, etc.

For companies in the process sector, special attention should be given to the safety culture as it can affect both the personal safety and process safety performance (Mannan et al. 2013). This infers that the maturity of the organizational safety culture would have an influence on the effectiveness of the PSM program. For instance, safety culture has a strong influence on employee participation in process safety activities, the effectiveness of process maintenance and inspections, the implementation of best operating practices for processes, etc. In fact, major global accidents in the oil and gas or even nuclear sectors such as the Piper Alpha disaster in 1988, the Bhopal disaster in 1984, the BP Texas City refinery explosion in 2005, etc. occurred because of poor organizational safety culture. Therefore, safety culture became the current wave of evolution in the process safety management, as discussed in the Chapter 2.

1.1.3 Oil and gas sector

The oil and gas sector is one of the main sources of energy internationally, and the most profitable industry for many countries and multinational companies. The international consumption of oil and other petroleum liquids was estimated at 179 quadrillion Btu in 2010, and is projected to exceed 197 quadrillion Btu by 2020 (U.S. EIA 2014a). This important demand is met by an increased production of oil, gas, and other derivatives. In 2011, the total world production of petroleum and other liquids was 87.8 million barrels per day, and will increase to 97.6 million barrels per day in 2020, as projected in the 2014 International Energy Outlook (U.S. EIA 2014b).

However, the production of oil and gas involves many complex, costly, and hazardous activities that require a well-founded decision before investing in the sector. Activities in this sector can be grouped under four different categories: exploration, oil extraction, refining, and transporting and marketing of oil and its derivatives (Schneider et al. 2011).

In the exploration stage, companies try to locate regions where formations bearing hydrocarbons deposits would be promising for production and investment. For this, they use different tools and methods such as geologic, geochemical, geophysical, and survey methods. Recent advancements in technology like three-dimensional (3D) and four-dimensional (4D) seismic imaging help in increasing the accuracy in locating and estimating the volume of onshore and offshore hydrocarbon deposits. The evaluation of the promising deposits can be completed after drilling exploratory wells. Very important data can be obtained such as the properties and extent of deposits, characteristics of formations, etc. (Hilyard 2012).

The oil extraction phase starts after the exploration results yield the existence of interesting deposits and predict that economic profits would be made. To get crude oil to the surface, oil wells are drilled from the beginning until well completion. Usually, the crude oil produced from multiple wells is collected and sent through pipelines to production sites for separation and processing (U.S. EPA 2000).

The refining stage of crude oil consists of many operations such as distillation, conversion, treatment, formulating and blending, and other products recovery and waste treatment (OSHA 1999). At the end of refining, different products can be derived from crude oil, which are grouped in three main categories: fuels (e.g. gasoline, liquefied petroleum gas, kerosene, etc.), finished nonfuel products (e.g. solvents, lubricating oils, greases, etc.), and chemical industry feedstock (e.g. naphtha, ethane, propane, etc.) (Schneider et al. 2011). These products are transported and commercialized to the end-users like industrials or fuel stations, which concludes the last stage of petroleum production activities.

The aforementioned activities pose significant hazards to the environment, employees' and community health and safety, and the safety of facilities themselves. Accidents that occurred in the sector over decades were due to the nature and quantities of chemicals and products used and the complexity of processes, along with poor control over risks like chemical, pressure, and mechanical hazards, and resulted in tremendous human and material losses as well as environmental damage. Such undesirable events jeopardized the business of many oil and gas companies and tarnished their reputation and image. An example of these mishaps is the Chevron Richmond Refinery fire that occurred on August 6, 2012. The corrosion of a 52-inch long pipe led to its rupture and caused the leakage of flammable hydrocarbon fluid in Crude Unit # 04. According to the US CSB, the released material "partially vaporized into a large vapor cloud that engulfed 19 Chevron employees and ignited," (US CSB 2015b). The ignition of that material resulted in a plume of vapor, particulates, and smoke that covered the nearby areas. Although no injuries were recorded among employees, the local community in Richmond, California, was significantly affected: "Approximately 15,000 people from the surrounding area sought medical treatment due to the release" (US CSB 2015b). The investigation report outlined key issues in Chevron's PSM programs (e.g. poor inspection program, lack of knowledge about process hazards among employees, lack of management commitment, etc.) and emergency response (e.g. failure to follow the OSHA Hazardous Waste Operations and Emergency

Response standard, poor communication, no emergency protocol at Chevron at the day of incident), in addition to deficiencies in mechanical integrity industry and leak evaluation and response industry standards (like API 570, API RP 571, and API RP 574). Interestingly, the report highlighted safety culture shortcomings that contributed to this process incident such as reluctance of employees to use their stop-work authority, a decision-making system that allowed operations to continue while the release of flammable material occurred, and substandard equipment maintenance practices.

Process safety management has gained the interest of industry and academia over the last decades as major incidents did not cease despite recent developments in process design, knowledge, and standards. On June 5, 2014, when the US CSB presented its final investigation finding about the Blow Out Preventer (BOP) failure during the Deepwater Horizon disaster in the Gulf of Mexico on April 20, 2010, Investigator MacKenzie stated, "Although there have been regulatory improvements since the accident, the effective management of safety critical elements has yet to be established. *This results in potential safety gaps in U.S. offshore operations and leaves open the possibility of another similar catastrophic accident*" (US CSB 2014).

1.1.4 PSM in the oil and gas sector in Algeria

Over the last decade, the Algerian oil and gas sector has experienced catastrophic incidents that led to human losses and material damage. On January 19, 2004, an explosion flattened a Liquefied Natural Gas (LNG) plant owned and operated by the national hydrocarbon company Sonatrach in Skikda, 500 km east of the capital, Algiers. This tragic accident that resulted in 30 deaths and more than 70 injuries was considered the most significant accident in the history of the process industry in Algeria since the 1970s. It also raised inquiries about the safety of LNG plants internationally, especially in the US, as the media reported the concerns of the citizens in cities proposed to have new LNG terminals (Romero 2004). The investigation findings revealed that a faulty boiler was behind the massive explosion, and highlighted several failures in terms of PSM mainly about mechanical integrity and preventive maintenance, employee training, and process hazard management (Sakhri Larnene 2012).

Due to the catastrophic consequences of that major accident, on December 25, 2004, the government passed Act 04-20 on the prevention of major risks and disaster management in the context of sustainable development, and was followed later by Executive Decree 06-198 of May 31, 2006 which stipulated the provisions applicable on classified installations.

The promulgation of these laws and regulations did not prevent the occurrence of other accidents either at the same refinery or at other facilities. Chetouh and Hamzi (2014) analyzed the accidents that occurred at the same plant between 2002 and 2013. Their study illustrated that 34 accidents took place after the famous one of January 2004, and three of them happened in the same year. It is important to note that many other significant accidents occurred in other sites in the south of Algeria over the last decade. However, due to the lack of published data and records about them, it is difficult to provide further details about their circumstances.

The recent attack on the Tiguentourine gas plant in In Aminas, located 1300 km southeast of the capital Algiers and fewer than 80 km from the Libyan border, has proven another aspect of weakness in the organizational resilience of Sonatrach and its associates operating at that site, British Petroleum, and Statoil. On January 16, 2013, an armed group attacked the plant in the desert of Algeria and held hundreds of employees of different nationalities hostages. After four days of encirclement, the intervention of Algerian troops to free the hostages and secure the plant ended with dramatic results: the number of deaths reached at least 37 foreign hostages in addition to the 29 militants (Reuters 2013). Furthermore, the plant had significant damage due to the blasts and fire that occurred at the moment of military intervention.

The investigation conducted by Statoil about this accident confirmed the failure of internal and external controls to secure people and assets. Moreover, the investigators also shed light on major gaps in security risk management, which would have helped the attackers to take control on the plant (Statoil 2013). The failure to resist the security threat was because of the isolation in the function of the inner security (internal security) and outer security (Algerian Army) protection layers of the facility. In fact, the inner security layer was weak and designed based on the assumption that the outer security layers would be capable of detecting and reacting to any security threats. Thus, the investigators found that "At In Aminas, inner physical security measures were not constructed to withstand or delay an armed assault and certainly not an attack of this scale" (Statoil 2013). Furthermore and over years, the joint venture plant built full reliance on the outer security layers (armed forces) to protect the plant and no scenarios were developed for the situations where this layer fails to detect or resist an attack. Moreover, the joint venture plant never received complete details about the capabilities of these armed forces although they were part of the security plans. Finally, the investigation report urged Statoil to strengthen its security measures and culture when it comes to doing business in unstable and complex environments (Statoil 2013). The findings of Statoil investigation match the statement of Bajpai and Gupta (2005) who asserted that terrorists target facilities with less security measures where they can cause significant damage.

This accident raised again concerns about the level of security maintained at each of the oil and gas plants in the country. In order to improve its resilience against external perturbation (security threats), Sonatrach and its partners conducted a review of their security plans and strengthened security measures through the presence of military units nearby the major oil and gas plants in the south, re-conducting a background security check program on all the employees, and reinforcement of security controls on the movement of expats in remote oilfields in the south, just to name few.

The above sequence of accidents in Sonatrach over the last decade illustrates that the company took a step forward in the management of process safety by expanding the PSM program to include the external security of facilities. The focus of Sonatrach was about the improvement of process safety controls at all the facilities after the Skikda's disaster of 2004, shifted to strengthen the external security measures of facilities in the aftermath of Tiguentourine attack of 2013. This step has been widely adopted by process companies especially after the 9/11 in the US in 2001, where organizations started to incorporate security risks in the management of process safety (Bajpai and Gupta 2005; Bajpai and Gupta 2007; Reniers and Amyotte 2012). Indeed, Reniers and Amyotte (2012) argued that process companies assumed that security threats would be unlikely to happen. However, this perception changed after the 9/11 events where security risks are managed due to the significant economic and material damage associated with them.

1.2 Research Objectives

Since the aforementioned incidents seem grounded in ineffective PSM, this work will attempt to assess the maturity of PSM at Sonatrach by evaluating:

1- The effectiveness of Sonatrach's PSM program as a part of the overall EHS management system through assessment of the key characteristics of a functional PSM program at Sonatrach, and

1- a. How this is indicative of the state of PSM in developing countries.

2- Given the results, provide recommendations for an appropriate path forward for Sonatrach to fully implement and improve PSM beyond adoption of standards.

1.3 Significance of the study

Despite the technological advancement in process design and operation, companies in the process sector could not cope with the frequent process incidents over the last decade. These incidents, which resulted in significant losses for companies, triggered the discussion again about the qualities of an effective PSM program, and led to initiating a review in academia about the past, current, and future of process safety in the 21st century. Researchers have focused lately on reviewing the current challenges related to PSM in the process industry and recommended future directions for improvement of PSM performance in the sector. However, there is a significant gap in knowledge and many questions remain unanswered. For the MKO Process Safety Center (2011), “the effects of this knowledge gap are evident; even today, reliable data for examples on failure rates are scare.” Hence, this work aims to contribute to the current efforts in understanding what impedes process companies from improving their process safety performance.

Furthermore, an overview on the existing literature shows that most of the research and scientific symposia concerns European and U.S. companies with little existence of research about process safety in developing countries, where a majority of processing, especially chemically related or high hazardous processing occurs. Therefore, this work will bridge this gap through the collection and analysis of real-world data from companies.

1.4 Definitions

1.4.1 Process

According to the CCSP (2015), a process is "A broad term that includes the equipment and technology needed for petrochemical production, including reactors, tanks, piping, boilers, cooling towers, refrigeration systems, etc."

1.4.2 PSM metrics

PSM metrics have been of great interest for safety professionals and researchers since the last decade. There was a debate among professionals about the quality and number of metrics to be adopted by each plant or facility. A work led by the American Institute of Chemical Engineers in collaboration with representatives of process industry companies, regulators, and researchers resulted in the development of guidelines for the definition and use of leading and lagging metrics for PSM (CCPS 2009). The CCPS (2009) presented a PSM metric as "a standard of measurement or indicator of process safety management efficiency or performance." A similar effort was made by the Health and Safety Executive of the United Kingdom to recommend an approach for the development of PSM indicators by senior managers and safety professionals in the chemical and major hazard industries (UK HSE 2006a).

1.4.3 Leading and lagging indicators

The CCSP (2015) defined leading indicators as "Process-oriented metrics, such as the degree of implementation or conformance to policies and procedures that support the PSM program management system and has the capability of predicting performance." Whereas, lagging indicators are defined to be "Outcome-oriented metrics, such as incident rates, downtime, quality defects, or other measures of past performance."

To identify and distinguish between the two types of indicators, the U.S. API (2010) adopted the Heinrich model of 1931 (i.e. accident-pyramid) to define leading and lagging indicators, and argued that “It is believed that a similar predictive relationship exists between lower and higher consequence events that relate to process safety. Indicators that are predictive are considered leading indicators and may be used to identify a weakness that can be corrected before a higher consequence event occurs” (API 2010). The Heinrich model suggests that there is a relationship between personal safety events with higher and lower effects. In other words, an incident that occurs with severe consequences would be preceded by many events with less severity.

The U.S. API (2010) defined four types of performance indicators: Tier 1, Tier 2, Tier 3, and Tier 4). Tier 1 performance indicators count the rate of Tier 1 process safety events that include any event that involves an uncontrolled or unplanned release of process material, which results in a fire or an explosion that costs the company more than 25,000 USD as a direct cost, a fatality or injury of an operator or a subcontractor employee leading to days away from work, hospital admission of a third party employee, “an officially declared community evacuation or community shelter-in-place,” etc. (API 2010). Tier 2 performance indicators count the rate of loss of primary containment (LOPC) events with lesser consequences (Tier 2 events) such as a recordable injury of an employee, contractor or subcontractor, a fire or explosion that costs greater than or equal to $2,500 as direct cost, a release of material greater than the threshold quantities provided in the severity chart of Tier 2 events in any one-hour period, etc. (API 2010). With regard to Tier 3 performance indicators, they measure Tier 3 events that represent any excursion of Safe Operating Limits (SOL) that took place in a specific period of time (API 2010). The last type of performance indicators are Tier 4 ones that “represent performance of individual components of the barrier system and are comprised of operating discipline and management system performance" (API 2010).

The aforementioned standard considered Tier 4 performance indicators, which are about operating discipline and management system performance, at the bottom of the pyramid as the most leading indicator. They would be used as predictors of shortcomings that would lead or contribute to the occurrence of future process incidents with higher or lower consequences (Tier 1 and Tier 2 process safety events). In addition, Tier 4 indicators (leading indicators) would be useful for internal use of the facility to identify learning opportunities and improve safety management performance.

At the top of the pyramid, Tier 1 performance indicators are the most lagging indicators that serve to count process safety events characterized by loss of process containment with high consequences. These lagging indicators in addition to Tier 2 indicators, would provide an idea about the past PSM performance of the company. Both leading and lagging indicators would help process companies assess and improve their PSM performance. De Rademaeker et al. (2014) depicted "To sustainably maintain and continuously improve process safety culture, it is at the same time essential that process safety performance indicators, both lagging and leading, are meaningful and easy to understand for the entire organization from shift workers, plant engineers, and plant managers to top management."

1.5 Structure of the work

The remainder of this work is structured as follows: the next chapter outlines the findings of literature review about the effectiveness of PSM and current PSM issues the process sector. The methodology of research is discussed in the third chapter. The results and analysis of collected data is the subject of the fourth chapter. Finally, this work ends with general conclusions and suggested recommendations for improvement and future research.

Chapter 2: Literature Review

This chapter goes through the literature and describes what the best-in-class PSM program looks like. Then, the evolution of PSM in the process industry and the current PSM issues in the sector are illustrated.

2.1 Quality PSM program

Motivated by the frequent occurrence of major accidents in the process industry, several studies have questioned the effectiveness of PSM programs implemented by companies in the sector. Indeed, the investigation reports, published by the U.S. CSB over the last decade, show that serious process accidents still occur in the process sector. Moreover, Louvar (2008) reported that 50% of accidents occurred in facilities covered by the PSM standard. Researchers in the field of process safety have attempted to define the features of a quality PSM program. The following characteristics were found to be the most common ones cited in research.

2.1.1 Safety culture and positive attitude

Safety culture, a subset of the organizational culture, is the underlying background for the safety performance of any company. Therefore, having a good safety culture would prevent the occurrence of an important number of incidents. Safety culture improvement got special attention after the major disasters in the sector in the late 1980s and the early 1990s such as the Bhopal and Seveso disasters. Many companies have undergone an assessment for their safety culture after major accidents in the sector. However, they were challenged in defining a good safety culture. To overcome this shortcoming, Olive et al. (2006) defined the characteristics of and steps to build a good safety culture in the chemical industry. Furthermore, Knegtering and Pasman (2009) reviewed three of the major accidents that occurred in the last decade, and concluded that “a holistic approach of leadership, empowerment and participation, with continual alertness of top management, a dedicated reliability and safety attitude trickling down through the organization," are essential to improve safety performance.

2.1.2 PSM performance measurement

The measurement of PSM performance is a crucial step toward the continuous improvement of PSM performance. Researchers asserted that an effective PSM program should entail PSM indicators to measure the program's performance. For instance, Arendt (2006) argued that the effectiveness of a PSM program is depending upon PSM performance and PSM efficiency. Therefore, process companies have to adopt leading and lagging PSM indicators as part of the overall EHS management system indicators. Mannan (2005) stated that proactive or leading indicators are suitable for the monitoring of some items like achievement of objectives, compliance with procedures and standards, auditing effectiveness, and state of documentation. Meanwhile, reactive measures (lagging indicators) can be used in the monitoring of injuries, material losses and damages, plant deteriorations, and incidents. However, the process industry has struggled to select and adopt the best lagging and leading indicators to drive continuous improvement of PSM. Kadri et al. (2014) argued that near miss indicators related to process engineering design along with API Tier 3 (i.e. challenges to safety systems) indicators would be the best ones, so far, to provide an insight on potential occurrence of process safety events. The U.S. API (2010) stressed that "Selecting appropriate indicators using unbiased and broad-based input will lead to a high-performing program" Moreover, the standard presented high-level guidelines on the selection of leading and lagging indicators through the use of past incidents investigation findings to identify safety controls failures, use of PHA and risk assessment to identify high potential events, and any lessons learned from the industry about successful indicators.

2.1.3 Integration of PSM program into the overall EHS management system

A PSM program would not attain its desired outcomes unless it is fully integrated into the overall EHS management system of the company. This integration concerns the planning, implementation, checking, and reviewing of the PSM program as part of the EHS management system. As Louvar (2008) explained, "PSM implementation and utilization processes can be significantly improved with some additional practices, for example, PSM should be integrated in an effective management system that enhances success."

2.1.4 Training, education, competency, and continuous learning

Training and competency of process employees are not only legal requirements for process companies, but are among the characteristics of a quality PSM program. Companies have to ensure that their employees are fully trained and competent to perform process operations and maintenance, in compliance with the operating procedures. In fact, employees have to enjoy a minimum level of education in chemistry, engineering, and other fields. Mannan (2004) made a distinction between training and education and noted that education means a broad body of knowledge; meanwhile, training refers to the necessary knowledge and tools for a specific operation or task. With regard to process employees' education, Lovar (2008), for instance, argued that process engineers have to master the fundamentals of chemical reactivity, inherent safety controls, and chemical process safety (i.e. flammability, deflagration, etc.), just to cite a few elements, in order to protect the integrity of processes.

Moreover, companies with a quality PSM program should have a learning system that allows a feedback flow of information from normal and abnormal situations and incorporate it into the design, operation, and maintenance of processes, in order to continuously improve the PSM performance. Costella et al. (2009) explained that companies have "to emphasize understanding normal work rather than just learning from incidents, in order to learn and to disseminate successful working strategies." Additionally, Mannan et al. (2013) considered that capture and implementation of lessons learned from incidents is one of the attributes of best-in-class organizations, and there is no good reason for them to ignore those lessons. Learning from incidents requires in the first place having an effective process that ensures thorough and comprehensive incident investigations along with a transparent and well-implemented reporting system for incidents and near misses.

2.1.5 Robust document management system

The management of PSM documentation necessitates having a reliable system in place for the appropriate storage, retrieval, and accessibility to process documents by process employees. One of the features of an effective PSM program is the control of PSM reports and technical documentation such as process maintenance reports, operating procedures, equipment manuals and drawings, process operation and condition, etc. King (2013) suggested that "The technical evidence of a strong PSM program will include a robust document management system where all the PSM-related reports and procedures reside, and which is readily available to those personnel that need access to the information."

2.1.6 Top management commitment and leadership

While the commitment and leadership of top management in process companies are vital prerequisites for establishing a positive safety culture, they are also of importance for an effective PSM program. King (2013) asserted, "If management is about doing things the right way, leadership is about doing the right things. Both are necessary for sustained growth and continuing success. Excellence in process safety requires good management and effective leadership." Indeed, top management of companies must lead by example: The safe actions and positive attitude of top management spreads among employees the commitment of the company to establish a safe work environment (Mannan et al. 2013). In fact, positive attitude and commitment of top management were also looked at by Knegtering and Pasman (2009), as one of the principals for a holistic approach to manage process safety, in addition to process reliability, employee participation, measurement metrics, etc.

2.1.7 Stakeholder engagement/communication

Researchers deemed the active engagement of internal and external stakeholders in PSM as a sign of a quality PSM program. Process employees and contractors are the main internal stakeholders for a PSM program. Their engagement should be reflected in participation in process safety activities, such as process risk management, incident investigation, procedures development and revision, training sessions, inspection and audits, etc. However, Mannan et al. (2013) related the active engagement of internal stakeholders with the fair treatment of employees, encouragement to participate in safety management, and opening communication channels between the upper and lower levels of the organization. By the same token, King (2013) recommended the involvement of external stakeholders who may have an interest in process safety like legal and local authorities, local community members, organizations, etc. in different PSM activities.

As for communication, researchers asserted that an effective and timely communication with internal and external stakeholders is an attribute of companies that have an effective PSM program. In their study about critical communication interfaces between PSM stakeholders, Kelly and Berger (2006) argued "a well-functioning process safety program depends on maintaining successful communication interfaces between each involved employee or stakeholder and the many other employees or stakeholders that person must interact with."

Internal PSM communication covers many elements of the PSM program such as process operations, abnormal situations, risks and safeguards, employees' suggestions, etc. as well as any revisions or changes to these elements. In addition, external communication with local communities ought to be an integrated part of the overall communication strategy of the company. Community outreach can be carried out via arranging open meetings with the community, awareness and training about process risks and emergency plans, and online means of communication, in order to capture the expectations and concerns of the local community, help them understand what risks they are exposed to, and what they have to do in case of emergency situations where the effects go beyond the facility premises. Moreover, a best-in-class PSM program maintains reliable communication links with other external stakeholders like legal authorities, professional groups, competitors, etc. in order to ensure a sustainable process safety performance.

2.1.8 Preparedness/early warning/detection and anticipation

With the emergence of the resilience concepts and principals, preparedness, detection, and anticipation became attributes of a highly resilient process. Therefore, a PSM program has to ensure that processes can detect and anticipate any deviation from normal operating conditions to abnormal situations. Dinh et al. (2012) stated, "If the system has the ability to detect disturbances and manipulate operating variables accordingly (a function of a process control system), it is likely to stay in the normal state." This target requires highly reliable equipment along with monitoring actions on the process condition.

Although efforts should be dedicated to preventive measures, companies must also take into consideration their preparedness for emergency situations. An effective PSM program pays attention to the effectiveness and efficiency of activities like drills and simulation exercises about the most potential incident scenarios. These activities enable companies to evaluate where they stand in terms of preparedness to respond to any emergency situation, and draw conclusions for further improvement in their efficiency.

2.1.9 Flexibility

One of the attributes of a resilient process is flexibility. A flexible process implies its ability to detect, adapt, and react to any external disturbances. These disturbances could be natural (e.g. earthquakes and hurricanes), human-made (e.g. terrorist acts, sabotage), or technological (e.g. effects of deflagrations or fires in neighbor plants). These latter disturbances occurred several times in the history of the process industry, in cases where process plants were clustered together within a specific area like production terminals. A quality PSM program must guarantee that processes are flexible and can absorb such disturbances. It is worthwhile to note that this attribute has nothing to do with incident prevention but with recovery from those disturbances. In this context, Dinh et al. (2012) noted that, "Resilience engineering helps to recover system states after incidents happen rather than prevent incidents from occurring. Incident prevention is a subject of study in other process safety areas (e.g., risk assessment)." Costella et al. (2009) went beyond process flexibility and addressed the organizational flexibility in general as a feature for the EHS management system. They argued that, "work system design must be flexible, recognizing that variability management is as important as variability reduction. In fact, design should support the natural human strategies for coping with hazards, rather than enforce a particular strategy." However, this approach would allow deviation from safe practices and best operating procedures, thus incidents may occur.

2.1.10 Awareness of system status

A company with an effective PSM program should be able to track the actual status of processes and predict future changes that may affect these changes. This feature can be fulfilled through effective and timely activities like process inspections, audits, and maintenance activities.

2.2 Evolution of PSM in the process industry

Before establishing a quality PSM program in the process sector, PSM went through different development stages over the last fifty years. Those developments were mainly driven by technological and engineering advancements, major incidents, and emerging legal requirements and standards. The process sector started its first steps toward process integrity in the 1960s via the improvement of materials and equipment reliability. While the sector was focused on further enhancements of technical aspects of process operations and design, the Flixborough disaster in England on June 1, 1974, shifted the focus of industry to human errors and factors. Indeed, this incident occurred due to the failure of chemical engineers to manage a plant modification properly. This disaster gave rise to risk analysis methodologies like Hazard Operability (HAZOP) in the management of process operations risks. During the 1980s, process companies became much more aware of the importance of human reliability (i.e. of process operators, engineers, and maintenance personnel) in the PSM as experience showed that technical reliability was not enough to attain the full integrity of processes. Therefore, written procedures on human behaviors for process maintenance and operation were developed (Pasman and Suter 2004).

However, the process sector awoke after other major accidents like the Bhopal disaster in 1984, the Chernobyl nuclear disaster in 1986, and later the Piper Alpha explosion in 1988, which brought the attention of governments and process companies to the importance of management attitude and commitment and organizational safety culture in general for the PSM. Consequently, new PSM regulations were adopted or amended in Europe (i.e. Seveso Directive I amended on 1987 and 1988) and in the United States (i.e. Section 112 (r) of the 1990 Clean Air Act Amendments, and OSHA PSM of Highly Hazardous Chemicals regulation in 1992). These regulations put process facilities under the scrutiny of regulatory agencies.

With the emergence of management system standards in 1990s, there was a new tendency to adopt a systematic approach in the PSM. This advancement was revivified with the acknowledgment by process companies of the importance of successful EHS management in business. National and international standards about functional safety like ANSI/ISA-84.01 on safety instrumented functions of 1996 and IEC 61508 standard on functional safety of electrical/electronic/programmable electronic safety-related systems of 1998 became common and widely adopted in the process industry.

At the beginning of the twenty-first century, discussion about the role of organizational safety culture in implementing an effective PSM program was again triggered with the occurrence of BP Texas City refinery mishap in 2005, although the safety culture concept had been known since the 1980s after the Chernobyl nuclear disaster. Based on the Baker Report (known also as BP US Refineries Independent Safety Review Panel), the process industry should move a step forward in incorporating leading indicators that measure the effectiveness of leadership and safety culture practices in the measurement of PSM performance (UK HSE 2007). In this context, the U.S CCPS published its guidelines for process safety metrics in 2009. Pasman and Suter (2004) summarized in Figure 1 the evolution of safety performance since 1960s in the process industry.

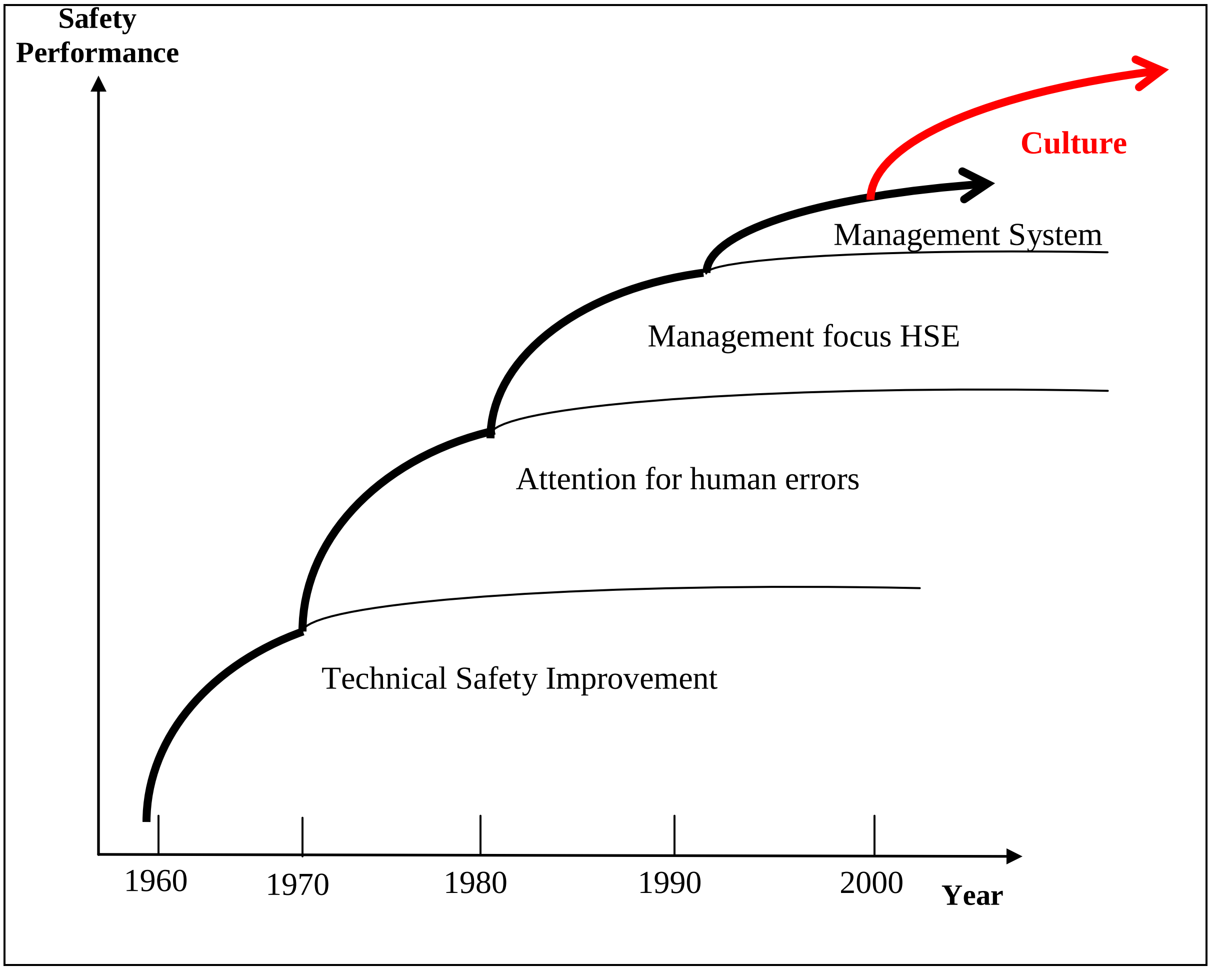

Figure 1. Process safety evolution since 1960s (Pasman and Suter 2004)

2.3 Process Safety Management Issues in the Process Sector

After five decades, process companies still struggle to establish quality PSM programs, and have been facing common issues in their PSM programs. In the following section, a literature review will shed light on the most reported issues in the last decade internationally that impede companies from having an outstanding PSM program.

2.3.1 Process safety performance measurement

Companies in the sector have for a long time settled for the use of OSHA rates of illness and injury as measures of their process safety performance, and ignored the use of leading indicators (Qi et al. 2012; Mannan et al. 2010). For instance, in the aftermath of the BP refinery explosion at Texas City in 2005, the U.S. CSB (2007) revealed “Reliance on the low personal injury rate at Texas City as a safety indicator failed to provide a true picture of process safety performance and the health of the safety culture.” This was behind the request of the U.S. CSB to the U.S. API to develop new performance indicators specific to process safety management. The Baker report recommended adopting leading indicators of process safety management by BP and all other companies in the sector (BP 2007).

Following the Baker report, the U.S CCSP developed Process Safety Leading and Lagging Metrics at the end of 2007, in order to be used in benchmarking process safety performance among companies. These guidelines were updated later and aligned with the API standard, so definitions of Tier events would be similar and companies can use either of them. The API issued its ANSI/API Recommended Practice 754 in April 2010, which defined new process safety event metrics (Tier 1, Tier 2, Tier 3, and Tier 4 performance indicators). However, this standard remains voluntary and companies may choose not to disseminate publically their statistics annually.

Even though the CSB aimed to bring the focus of companies toward process safety risks, some of the API process safety indicators remain lagging, and there is a need to set additional leading indicators beyond Tier 4 indicators (i.e. performance indicators). Indeed, Ardent (2006) stated that, “an increasing number of companies are experimenting and/or learning from adopting PSM leading indicators of performance.” Furthermore, the evaluation of ANSI/API Recommended Practice 754 indicators conducted by Mendeloff et al. (2013) showed that only large companies would be able to distinguish between Tier 1 and Tier 2 events, but would struggle to benchmark the indicators relevant to those events.

Finally, near misses have been ignored for a long time despite their importance as early warnings of potential unforeseen failures in process safety. Many companies in the process industry did not establish a near misses reporting system that facilitates their tracking and analysis (Knegtering and Pasman 2009).

2.3.2 Training, competency, and continuous learning

In view of the rapid development in process technologies and the increasing complexity of processes, many researchers reported a lack of awareness among employees about the new risks related to those processes or operations. In their study about the challenges and needs for process safety in the new millennium, Qi et al. (2012) reported: “process installations have become even more complex today than ever before. Process control and safeguarding equipment are more complex, thereby increasing newer risk which is often unforeseen.” This lack of awareness was behind many accidents in the sector, among other causes. Indeed, Bullemer et al. (2011) investigated the root causes of 32 accidents that occurred in the US and non-US facilities, in which failures in procedure execution during abnormal situations were detected. The researchers found that root causes like failure to detect an abnormal condition, failure to detect an abnormal situation, lack of awareness of process or of equipment hazards, or lack of understanding of the impact of actions were common among those accidents.

Furthermore, companies in the sector have been facing tremendous pitfalls maintaining a satisfactory level of knowledge and training among employees. One of the reasons for this is high turnover rates and retirement among employees in the process sector, which contributed to the “erosion of knowledge and experience” (Knegtering and Pasman 2009; De Rademaeker et al. 2014). In fact, Parry et al. (2007) predicted that 50% of employees in the sector would retire over the next ten years, while companies do not have qualified and trained replacements. One year later, Hargreaves (2008) estimated that 80% of personnel in the petroleum sector would retire in the next decade while the sector failed to attract young, educated personnel. In their study about the PSM performance of small and medium enterprises in China, Zhao et al. (2013) found that knowledge management was one of the key shortcomings of the PSM programs in this type of organization, and recommended an effective transfer of knowledge among the stakeholders and SMEs in the process industry.

With regard to learning systems, De Rademaeker et al. (2014) applauded the remarkable progress in the sector from understanding how accidents manifest to thinking about preventing them, through the implementation of inherent safety practices and focusing on safety culture. However, most of the process companies do not yet have a learning system that ensures a timely implementation and sharing of lessons learned with other interested parties of lessons learned from incidents (MKOPSC 2012; Qi et al. 2012; Mannan et al. 2010; Knegtering and Pasman 2009). Pasman (2009) analyzed this particular issue and found that there is a deficiency in the use of recorded information from incident investigation in the operational control of processes. In addition, he affirmed that, “Much information is lost by not finding the root causes of accidents, and not analyzing the latent conditions and the effect on safety barriers.” Consequently, a good number of accidents in the sector could be prevented if the recommendations from accident investigation were shared and adopted by all the actors in the process industry.

A practical example of this observation is the series of explosions and fires on December 11, 2005, at Buncefield oil storage and transfer depot at Hemel Hempstead in the United Kingdom. This disaster, which occurred in the fifth largest storage terminal in the United Kingdom, resulted in catastrophic impacts and losses. The U.K. HSE investigated this mishap and found that there was an ignition of gasoline coming from an overfilled tank (HSE 2007). Annex 5 of the initial investigation report outlined six accidents similar in nature and root causes to the Buncefield one, which occurred in the world between 1962 and 1999 (HSE 2006b). Although the implementation of recommendations from these accidents would prevent or at least mitigate the effects of the Buncefield disaster, obviously the sector struggles to learn from experiences, and accidents continue to take place worldwide. Therefore, an emphasis was given by researchers to the establishment of a learning system that feeds all the process stakeholders (designers, legislators, professional associations) with the necessary information in order to improve operational control of processes by companies, and enhance inherent safety design practices by process manufacturers (Pasman 2008).

2.3.3 Robust documentation system

Process operating procedures have been one of the most reported areas of weakness by many companies. For instance, the complexity of procedures, their number and accessibility are among the major concerns of employees in the sector (Høivik 2008; Shirali et al. 2012).

2.3.4 Top management commitment and leadership

Management commitment and leadership are one of the main internal drivers for an outstanding safety culture, and one of the pillars for a quality PSM program. However, researchers found that a lack of management commitment prevails in many process companies. In this context, Kilparthi (2014) asserted that top management of well-known oil and gas companies have paid less attention to the promotion of strong safety culture and core values within their organization for a long time. Høivik et al. (2009) confirmed this fact in their study about EHS culture in the Norwegian oil and gas sector. The interviewed employees were worried about the commitment of their management toward EHS management, and looked forward to “a visible manager who spoke to people and showed interest in motivating for HSE, understanding HSE challenges and giving HSE credibility."

Contrary to the advancement in knowledge about process risks over the last decades, top management of many companies do not take into account risk assessment outcomes in decision-making process. Information about risks is either simply ignored or neglected under other financial and market pressures like cost cutting, downsizing, and competition. Therefore, those decisions would expose processes and/or operations to higher levels of risks (Shirali et al. 2012; MKOPSC 2012; De Rademaeker et al. 2014). In addition to this pitfall and due to the same reasons cited above, the top management of these companies keeps the mindset of driving maximum efficiency and decreasing the operation time. This limited focus on the optimization of process function and production would result in cutting edges of safety barriers (Shirali et al. 2012; MKOPSC 2012; Qi et al. 2012).

2.3.5 Stakeholder engagement/communication

Although employee participation in PSM is one of the requirements of many PSM regulations, the sector is still lagging in achieving a higher and active employee involvement in the management of process safety. In the framework of a research project led by the U.K. HSE about safety climate assessment in offshore environments, Cox and Cheyne (2000) found that "a large number of employees felt that they were not involved in, or informed of, safety initiatives," and only a small number of them participate in safety programs and activities. In the same context, Kilaparthi (2014) stated that this element was one of the drawbacks to establish a strong safety culture in the Norwegian oil and gas sector. This issue can be viewed as a symptom of management failure to create a positive safety culture, which is necessary for an effective PSM program. As Mannan et al. (2013) explained, "Best-in-Class management seeks to maximize employee engagement with safety by treating workers fairly, encouraging employee participation in the safety systems, and providing open lines of communication across the organization."

Another facet of the aforementioned shortcomings is the ineffective communication or lack of communication between employees and their management. In view of the internal communication model illustrated by Mannan et al. (2013), it is obvious that the distance between the different levels of a company would cut the flow of information about EHS goals and policies from the top management down to the floor shop and the feedback flow about EHS management from the floor shop up to the top management. In addition to internal communication problems, community outreach would know more challenges in the long term. As populations around facilities continue to grow and become highly exposed to risks, companies would see external pressures to be more socially responsible and enhance their external communication strategy. The MKO Process Safety Center (2012) argued that land planning and plant sitting would be an area to focus on, and recommended to facilitate dialog between industrials and communities about controversial ideas such as "risks" vs. "market and economy," especially for existing facilities.

2.3.6 Preparedness/early warning/detection and anticipation

With the increased complexity of processes, human reliability has emerged as an area of improvement in an effort to reduce human errors especially during abnormal situations. Along with what Bullemer et al. (2011) found, accidents in the sector have been linked to a failure of human component (cognitive limits) and process deviation from normal situation.

2.3.7 Flexibility

The complexity of new processes enhanced the process control and safeguarding and enabled improving the quality of products, flexibility, and safety. However and as many researchers asserted, this advancement is not a warranty for a fully safe process. The sector is increasingly witnessing unpredictable risks, which are aggravated by other organizational and human factors (Qi et al. 2012; MKOPSC 2012; Knegtering and Pasman 2009).

2.3.8 Awareness of system status

The tendency towards outsourcing maintenance activities to small, specialized companies has become a norm instead of exception. This practice has resulted in additional issues about subcontractor safety management and loss of quality communication between process operations and maintenance teams (Qi et al. 2012). Companies undertaking this practice lack placing controls on the competency, knowledge, and quality of work procedures followed by subcontractor employees. Therefore, maintenance integrity of the process would be ruined.

To summarize, Figure 2 is adapted from Schneider (2014), and represents a visual map for the PSM program in the process industry according to the Plan- Do- Check- Act approach, where the different elements of the PSM program and the discussed PSM issues in the sector are highlighted. Steps in orange represent the areas where the sector faces issues. The orange dashed arrow is a gap in reporting between companies and process designers.

At the planning phase, process companies face problems with the organizational safety culture, which affect the overall PSM program. Influenced by industry and market, the organizational culture of process companies is still behind in terms of internal communication, employee participation in PSM, and most importantly the management attitude that encourages the tradeoff between production and process safety. It is believed that both functional and maintenance integrity are dependent on the human integrity which is in turn influenced by the organizational safety culture and training issues (i.e. erosion of human capital knowledge and experience, and lack of employee awareness about process risks).

At the implementation stage, maintenance integrity is mainly affected by the outsourcing of maintenance activities to third-party companies, which engenders communication issues between the subcontractor and process employees. With regard to operational integrity, it is mostly compromised by the business mindset of management that pushes the process production up to the operational limits in an environment where the human component is not fully competent to operate complicated processes.

In terms of PSM performance measurement, companies in the process sector started to adopt PSM metrics along with personal safety ones. However, most companies still rely heavily on lagging metrics and need to move forward by setting additional PSM leading metrics. Furthermore, near misses are not tracked and analyzed by most of the companies, although they can be predictors of potential process incidents.

In the checking and corrective action phase, the lack of reporting of process safety experiences (i.e. operational issues, process safety incidents and near misses, etc.) to process designers, in order to continuously improve the inherent safety design practices is emphasized. The missing input from process designers would contribute to the PSM program through the enhancement of the functional integrity of processes, thus achieving the asset integrity goal.

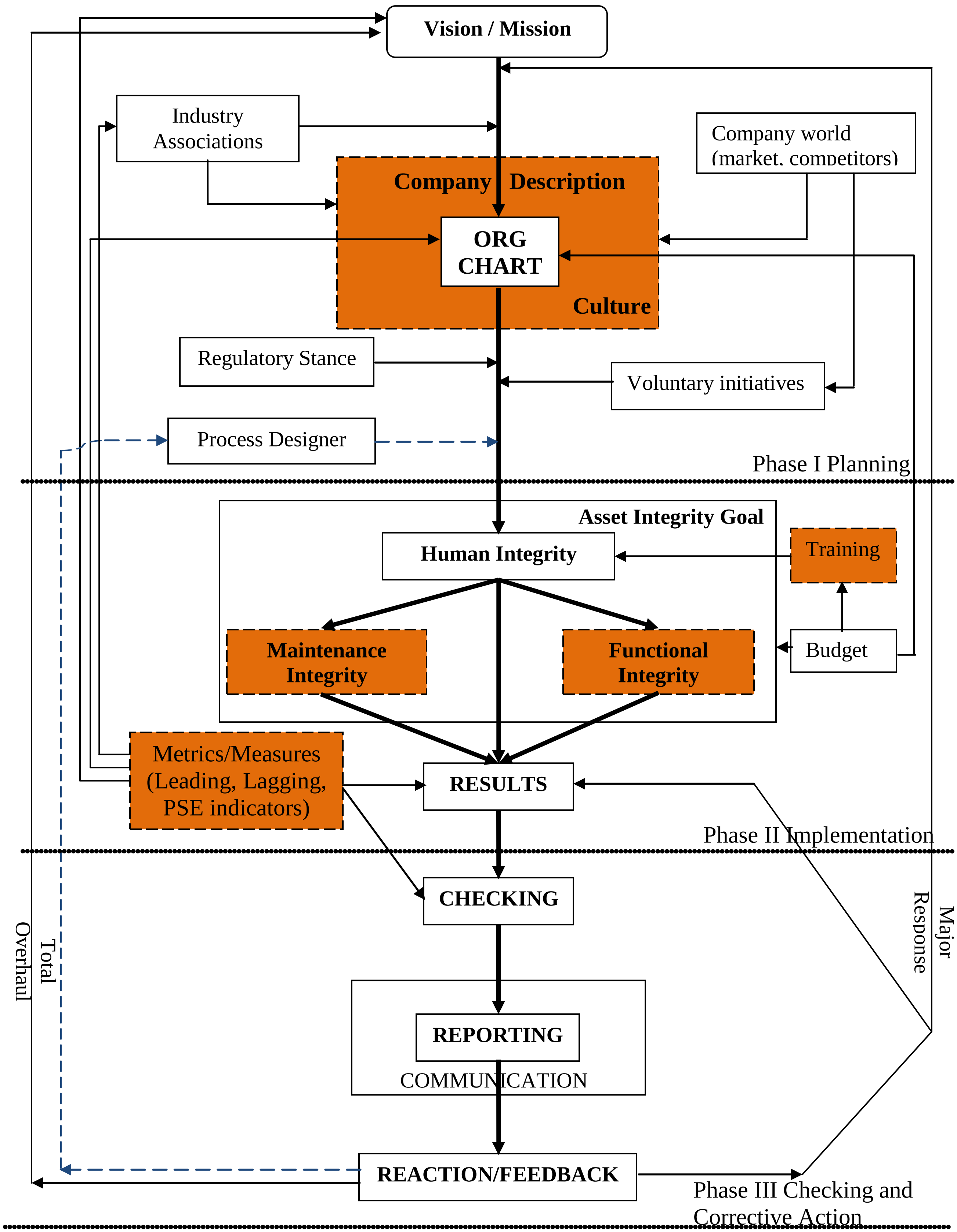

Figure 2. PSM program map in the process industry (Adapted from Schneider 2014)

In conclusion, this chapter outlined the characteristics of a quality PSM program and current PSM issues in the process industry. The sector faces safety culture and organizational issues along with unprecedented challenges related to the changes in technology and industry. Finally, a PSM program map was presented to illustrate the discussed issues in the sector.

The next chapter will introduce the research methodology followed in this study to collect data, and will set the stage for the fourth chapter, where the research results are presented and discussed.

Chapter 3: Research Methodology

This work aims to evaluate the integration of PSM program with the overall EHS management system of Sonatrach through the evaluation of Sonatrach's PSM program effectiveness and a comparison of the current PSM program with the state of PSM within the overall processing sector internationally. To conduct this research, a mixed research method that consisted of quantitative and qualitative research tools, was followed. This chapter outlines the data collection procedure, research participants, and data analysis approach.

3.1 Research design

The research on the data about the Algerian oil and gas sector showed that there is little data about PSM in the sector. Therefore, an explanatory sequential mixed method was selected. This type of approaches is suitable for situations where there is a little or no data about the research subject. An explanatory sequential mixed method is a type of mixed research methods that starts with quantitative data collection and analysis, and followed up with qualitative data collection and interpretation. While the quantitative method helps in understanding the extent of existence or implementation of research variables, the qualitative method provides clarifications about the collected data from the quantitative method. Creswell (2013) explained that, "the overall intent of this design is to have the qualitative data explain in more detail the initial quantitative results." For this research a survey tool was designed to collect quantitative data, and one-to-one interviews were conducted to collect qualitative data that builds on the results of the survey.

3.1.1 Survey

An online survey was designed to evaluate the effectiveness of a PSM program based on the characteristics of a quality PSM program that were discussed in Chapter 2. Each characteristic was associated with a set of indicators that reflect the extent of implementation of the relevant characteristic in a PSM program. Each indicator had in turn a metric or metrics to allow its measurement. The survey questions were crafted to allow the collection of quantitative data from participants, which will allow capturing the metrics of each indicator. Appendix 1 of this research presents the survey questions that were sent to the participants.

3.1.2 Interviews

One-to-one interviews were held with EHS specialists working for Sonatrach. Interview questions, which are outlined in Appendix 2, were open-ended, and aimed to obtain further details and explanation about the survey results. The collected responses were transcribed and analyzed to identify constructs about PSM and EHS management at Sonatrach.

3.2 Research Participants

3.2.1 Survey

After designing the survey tool and translating it into French, a call for participation in the survey was sent to twenty-two EHS specialists working at different facilities of Sonatrach. Each facility was represented with one participant. The participants hold positions at different levels of the EHS department (e.g., technicians, engineers, supervisors, etc.) with key roles in PSM at their respective facilities, and all have more than three years of professional experience. To ensure the anonymity of participants, survey questions asked only for general information that identifies their facility in terms of main product, the headcount, and the yearly throughput. Facilities were identified in this work with letters and a brief description of processing activities and the region where the facility is located.

3.2.2 Interviews

One-to-one interviews were conducted with EHS professionals working at different facilities and levels of the organization. Figure 3 shows the location of these facilities on the map of Algeria. Interviewees were selected based on their experience, which exceeds five years, and all have direct duties related to the PSM in their respective facilities. Interviewees were:

- An EHS principal inspector working at the Unit and Engineering Service at the divisional level of the region of Hassi Messaoud. This service plays a coordinating and supervising role in all the facilities in the region.
- An EHS engineer working at the Unit and Engineering Service at the divisional level of the region of Hassi Messaoud.
- An EHS engineer working at the Joint Venture (i.e. Sonatrach, British Petroleum, and Statoil) facility in In Aminas.
- An EHS inspector working at a refinery in Skikda.
- An EHS technician in the prevention section at a crude oil facility in the region of Hassi Messaoud.
- An EHS technician in the intervention section at a gas facility in the region of Hassi R'mel.

It is believed that this interview set comprises the major actors in PSM at Sonatrach.

Figure 3. The location of Sonatrach facilities on the map of Algeria

To ensure the anonymity of the participants, pseudonyms were used throughout this work because some of the interviewees fear the reaction of the top management in case they are identified. In view of the number of facilities in the region and the headcount of EHS specialists holding the same titles at the different regions, it is believed that the above details about the participants would not jeopardize their anonymity.

Interviews were focused on the PSM and EHS management in Sonatrach facilities in the region of Hassi Messaoud mainly because:

1- It is the oldest and one of the largest oil and gas fields in Algeria with 1500 oil and gas wells by the end of 2014.

2- There is a significant number of facilities in place (3 refineries, 4 processing facilities, 7 satellite units, and 2 stations of water injection), and

3- It has a plurality of final products with PSM requirements (oil, gas, condensate, and other oil and gas derivatives).

In conclusion, the research methodology followed in this work was the explanatory mixed method that facilitated the collection of quality data from different location and levels of Sonatrach. It helped in understanding the current status of PSM program and EHS management system of the company via an online survey and interviews held with EHS specialists working mainly in one of the largest and most important oil and gas fields in Algeria.

The next chapter will present the results of the online survey and interviews, followed by a discussion about PSM and EHS management in Sonatrach.

Chapter 4: Results and Discussion

In the previous chapter, the research methodology used to collect data was outlined. It consisted of a survey followed by interviews with EHS specialists working for Sonatrach. Sonatrach was selected because of its important production capacities and the high number of process plants it owns and runs in Algeria. Furthermore, it was the largest oil and gas producer in Algeria and Africa and the third international exporter of liquefied petroleum gas and the fifth international exporter of gas in 2013 with a turnover of more than 63 billion USD (Sonatrach 2015). In this chapter, the results of data collection will be presented and discussed.

4.1 Survey Results:

The preliminary analysis of survey results showed that ten out of twenty-two subjects had participated in the survey, which represented a participation rate of 45%. After the elimination of incomplete responses, four responses which represented four different facilities were taken. Table 2 outlines the description of facilities considered in this work:

Facility	Main Product	Annual Throughput	Headcount	Nature of Activity
Facility A	Gas	108,000 m^3	1,500	Gas production
Facility B	Oil	30,000,000 m^3	57	Crude oil compression
Facility C	Gas	21,900,000,000 m^3	42	Gas compression
Facility D	Oil derivates	16.5 million tons	1,500	Crude oil refining

Table 2. Description of facilities considered in the analysis

The four facilities considered in this work showed some similarities in terms of processes involved in their activities, thus the nature of potential risks. The production and compression of important volumes of crude oil or gas require operating big-size exchangers, compressors, turbines, storage tanks, etc. under high temperatures and pressures. These types of operations are hazardous and present high risks like fire, explosion, pressure, and chemical risks due to the number of employees exposed to the hazards and the nature and the quantities of processed materials (i.e. flammable, corrosive, and toxic). Therefore, process safety would be the core focus of management in the facilities.

Facility A and facility D would be considered large plants with intensive production of natural gas and processing of crude oil, but they differed in their annual throughput due to the difference in the markets of the final products from each facility. Natural gas from facility A is transported to another collecting station in the region of Hassi R'mel in order to be combined with the product of similar facilities before its exportation to Italy, Spain, and export terminals. However, facility D is the largest refinery in the country, and it fulfills the national demand on oil derivatives like kerosene, benzene, plastics, etc. and an important percentage of its product is also exported.

Meanwhile, facility B and facility C represented two small remote plants where oil and gas are collected from wells or other large plants, then compressed and transported through pipelines to other locations. This type of activity translates the high annual throughput of each of those facilities, with limited headcount for operating and monitoring purposes only.

The responses of participants to the survey questions were clustered in sections and are presented below in tables. Due to the lack of data, some metrics without input by all the facilities were not presented individually. Other metrics with singular input were discussed. This shortcoming, along with the small size of the sample, would influence the accuracy of analysis and prevent performing further statistical analysis. However, it will still be possible to draw some observations from the available data.

4.1.1 PSM Performance measurement

The two metrics considered for PSM performance measurement in Table 3 would give an idea about the importance of PSM performance measurement for Sonatrach's top management. Interest in process safety has to start first with adopting PSM performance metrics, then capturing them in a timely manner.

The questions of this section were provided in section 2 of the survey: process safety management indicators (See Appendix 1). For the percentage of PSM-related metrics, questions were about the number of EHS metrics which are PSM-related and the overall number of EHS metrics adopted at each facility. The second metric about the deadline of reporting PSM-related metrics aimed to evaluate the delays in capturing PSM metric beyond the scheduled timeframe.

Facility	**Metric**	
	Percentage of PSM-related metrics	Deadline of reporting PSM-related metrics
A	34 %	More than two weeks but less than a month
B	0 %	/*
C	0 %	/*
D	0 %	/*

(*) data was not provided by the participants.

Table 3. Survey results about PSM Performance measurement

Except for facility A where an important number of PSM indicators were considered, facilities B, C, and D did not adopt any PSM performance indicators as part of the overall EHS indicators. This finding led to look for further details about the quality of PSM performance measurement in Sonatrach facilities. For the delays in capturing PSM metrics, it was obviously not possible to provide such data by the participants since no PSM indicators were in place.

4.1.2- Integration with EHS management system:

The three metrics in Table 4 were among others included in the survey that aimed to evaluate the extent of integration of PSM activities with the overall EHS activities like audits, training, risk assessments, job definition, etc. The data provided in Table 4 about the percentage of EHS training hours spent on PSM were based on the responses on questions of section 7 of the survey about the total hours spent per year for each employee in overall EHS training and on EHS training related to PSM. Meanwhile the percentage of employees with PSM roles defined in their job description was calculated based on the answers on a question in section 4 of the survey about the number employees who have PSM roles in their job description and the last question of section 1 about the headcount of operating employees at each facility. For the last metric in Table 4 about the percentage of process risk assessments reviews completion per year, the percentage was calculated based on the answers on section 9 of the survey about the total number of process risk assessment reviews scheduled per year, and the number of process risks assessment performed per year.

Facility	**Metric**		
	Percentage of EHS training hours spent on PSM	Percentage of employees with PSM roles defined in their job description	Percentage of process risk assessments reviews completion per year
A	50 %	25 %	23%
B	15 %	62 %	/*
C	10 %	60 %	/*
D	25 %	35 %	/*

(*) data was not provided by the participants.

Table 4. Survey results about the PSM program integration with the EHS management system

The above data revealed a strong negative correlation between the size of the facilities and the integration of PSM roles in job descriptions (r=-0.97). In addition, there was a strong negative correlation between the integration of PSM roles in job descriptions and the integration of PSM training in the overall training programs (r=-0.91). In other words, although facilities B, C, and D had a significant number of their employees in charge of process safety roles as part of their jobs, employees would have spent less time in PSM training compared to the overall training hours. This would infer that the management of Sonatrach had less focus on PSM training, although this element is among the main pillars of a quality PSM program. Data for the completion of process risk assessment reviews was not available for facilities B, C, and D. For facility A, a low rate of completion was reported (23 %).

4.1.3- Training and competency:

The metrics of this section were presented to evaluate the performance of Sonatrach in terms of PSM training and competency of personnel mainly in terms of: the availability of resources for training, the effectiveness of training, and the effectiveness of competency evaluation programs. However, only the two latter measures could be reported in Table 5. Answers on the first two questions of section 7 of the survey allowed the calculation of the rate of competency assessment completion based on the number of total employees who completed their competency evaluation on process operations and the rate of PSM training completion among employees from the total number of employees who completed their PSM training in each facility.

Facility	**Metric**	
	Rate of competency assessment completion	Rate of PSM training completion
A	20 %	15 %
B	9 %	48 %
C	0 %	5 %
D	60 %	70 %

Table 5 Survey results about training and competency

The data in Table 5 shows a strong positive correlation between the size of the facilities in terms of headcount and the completion rate of employees' competency (r=0.77), and a moderate positive correlation between the training effectiveness and the size of facilities (r=0.31). This result may imply that large plants get more access to resources to train their employees compared to small ones even though they belong to the same company. Nevertheless, this conclusion would not be confirmed unless one analyzes further the training process and the organizational structure of the company.

4.1.4- Document management system:

Documentation is an important part of the PSM program. For example and besides being an attribute of an effective PSM program, the U.S PSM regulations and standards like OSHA PSM 29 CFR 1910.119 requires the plant owner to develop, revise, and retain written process safety information and operating procedures, and make them available for employees and regulatory authorities. Therefore, the metrics of this section aimed to measure the performance of Sonatrach in terms of process documents control (i.e. in term of accuracy, completeness, storage, and retrieval of records), however answers on four metrics only were provided by the four facilities and reported in Table 6.

For the metrics of Table 6 on records control that were based on the previous year audit findings, they were captured from responses on the questions of section 10 of the survey about the total number of audit findings on inaccurate records, incomplete records, inability to retrieve records, improper storage of records, and the total number of audit findings that were raised in the previous year. Whereas, the first question of section 3 of the survey asked the participants to estimate the percentage of obsolete documents in use in their respective facilities. Their responses were reported under the obsolete documents in use metric in Table 6. The frequency of procedures review/update metric represented the responses on the second and last question of section 3 of the survey about the process safety documents management where the participants estimated the delays in reviewing or updating process operating procedures in each facility based on the estimation of participants.

Metric	Facility			
	A	B	C	D
Audit findings about inaccurate or incomplete records	3 %	0 %	0 %	/*
Obsolete documents in use	21-40 %	1-20 %	1-20 %	/*
Frequency of procedures review/update	Delay of a month or more but less than a quarter	Delay of a semester or more	Delay of a semester or more	No delay
Audits findings about inability or delays in retrieving records	10 %	0 %	0 %	0 %
Audits findings about improper storage of records	0 %	0 %	0 %	0 %

(*) data was not provided by the participants.

Table 6. Survey results about document management system

Audits on EHS management system conducted in the four facilities did not raise almost any findings about document management. Except facilities A and D where procedures were reviewed or updated in a timely manner, facilities B and C showed long delays in reviewing the operating procedures with moderate percentage of obsolete documents in use. In view of the importance of documentation for PSM, questions about the efficiency of the document management system in these two facilities (B and C) should be raised.

4.1.5 Top management commitment

Top management commitment was one of the areas of focus in this survey as it would inform about the overall safety culture in the company, thus the EHS management system and PSM. Unfortunately, only one metric about the attendance of top management to the management review meetings was reported from facility A. Table 7 presents the survey results about management commitment to PSM in the four facilities.

The questions in section 5 of the survey about the total number of management meetings held at each facility and on the number of those meetings attended by top management were used to capture the top management attendance in management review metric reported in Table 7. Furthermore, the respondents answered the last question of section 5 through the estimation of the average response time on process safety suggestions from their reception till their resolution, as mentioned in Table 7 under the average response time to the resolution of process safety suggestion metric. For the last metric in Table 7, it was captured using answers on two questions of section 4 of the survey about the total number of employees' suggestions about PSM submitted every year, and the number of accepted suggestions by the top management of each facility.

Metric	**Facility**			
	A	B	C	D
Top management attendance in management review meetings	100 %	/*	/*	/*
Average response time to the resolution of process safety suggestion (CCPS 2009)	Less than a week	Less than a week	More than two weeks but less than a month	Less than a week
Percentage of accepted employees' suggestions (CCPS 2009)	35 %	67 %	80 %	72 %

(*) data was not provided by the participants.

Table 7. Survey results about top management commitment

The collected data in Table 7 did not help to draw any conclusions about the attendance of top management to the management review meetings in facilities B, C, and D. However, it is assumed that top management was committed to participating in those meetings and opening communication channels between the top and lower levels of the company, in view of their positive performance with regard to the resolution of employees' suggestions about process safety. The average response time to those suggestions did not exceed one week in facilities A, B, and D, and was less than a month in facility C.

4.1.6 Stakeholder engagement, and communication

Internal and external stakeholders' engagement in PSM and communication are interrelated elements that are crucial for the success of any PSM program. In the context of this work, internal stakeholders for the four facilities are the employees and subcontractors, and external stakeholders are mainly the regulatory authorities, local community, insurance providers, and clients. Therefore, the metrics were about the evaluation of employees' participation in PSM activities, and about the evaluation of the legal stance of facilities as a measure of the involvement of regulatory authorities in the PSM. With regard to local community outreach, metrics were about the effectiveness of communication means and events between facilities and communities in surrounding areas and awareness of these communities about the nature of process hazards they are exposed to. Table 8 summarizes the reported results from the four facilities. For the first metric about percentage of operating employees involved in PHA, investigation, and procedures development or review, it was captured from the responses on the questions of section 4 of the survey about the number of employees involved annually in process hazard analysis, accident investigation teams, the development of operating procedures, and in the review of operating procedures. Concerning the second metric about the percentage of reduction in the number of citations from the Algerian regulatory institutions about PSM nonconformance, the participants answered two questions of section 12 of the survey about legal compliance that were about the number of citations received from regulatory institutions this year and in the last year. The last metric in Table 8 reported the answers of participants on the eighth question of section 6 of the survey: community outreach and communication.

Metric	**Facility**			
	A	B	C	D
Percentage of operating employees involved in PHA, investigation, and procedures development or review.	45 %	42 %	30 %	40 %
Percentage of reduction in the number of citations from the Algerian regulatory institutions about PSM nonconformance.	40 %	0 %	/*	0 %
Frequency of updating communication plan	/*	Once per year	/*	Once per year

(*) data was not provided by the participants.

Table 8. Survey results about stakeholder engagement, and communication

The data showed high rates of employees' involvement in PSM activities in all the facilities. This performance may be linked to the PSM training completion in each facility, as there was a moderate positive correlation between the PSM training completion and the employees involvement in PSM activities (r=0.384). But other concerns arise from the collected data, as the employees' engagement in PSM activities did not correlate with the number of employees with PSM roles. In fact, there was a strong negative correlation between these two variables (r=-0.598). Therefore, further details about employees' engagement in PSM are needed to answer these concerns. Moreover, data about the law enforcement actions against these facilities would be helpful to understand their legal stance over the last five years. However, the collected data did not provide much insight in this area. Finally, and with regard to community outreach, facilities B and D reported that an update of their communication plan takes place once per year. This timeframe would imply the existence of open communication channels with local communities. The unavailability of data for facilities A and C is due to their location: both of them reported that they are located in remote areas where no local community is surrounding them.

4.1.7- Emergency Preparedness /Early warning/detection and anticipation:

The type of hazards associated with the activities in the oil and gas sector necessitates a permanent preparedness to cope with any hazardous deviation in process operations. This feature is also related to the awareness of PSM program status (including process mechanical integrity), as the anticipation and detection of hazardous situations require a permanent awareness of process status. Metrics were about the effectiveness and efficiency of drills and simulations, maintenance effectiveness, and emergency response training. The reported results are presented in Table 9.

The percentage of emergency response plan (ERP) training completion among employees metric in Table 9 was calculated from the answers of participants on the last question of section 7 of the survey number of employees who have been trained on ERPs. The capture of the percentage of drills/ simulations completion metric was done based on the responses on the questions of section 15 of the survey about the total number of drills/simulation scheduled and performed per year. For the percentage of maintenance tasks/ inspections completion, the answers on the questions of section 13 of the survey about the number of process maintenance tasks scheduled and performed per year allowed capturing this metric.

Facility	**Metric**		
	Percentage of ERP training completion	Percentage of drills/ simulations completion	Percentage of maintenance tasks/ inspections completion
A	15 %	100 %	90 %
B	48 %	100 %	95 %
C	30 %	100 %	92 %
D	70 %	100 %	90 %

Table 9. Survey results about preparedness / early warning/ detection and anticipation

The data presents a strong positive correlation between the size of facilities and the emergency response plans training completion (r=0.726). Furthermore, all the facilities reported a rate of drills completion of 100% and a percentage over 90% in terms of maintenance effectiveness. The data would suggest that the four facilities paid special attention to their preparedness for emergency situations through training, drills, and timely process maintenance activities. This observation would be interpreted by the importance given by Sonatrach to the continuity of process operation and production of oil, gas, and oil derivatives in general, knowing that oil and gas production is the main source of income for the country.

4.1.8- Flexibility:

Flexibility is one of the features of resilient organizations or processes. It measures the capacity to handle external perturbations or deviations from operating procedures that can lead to hazardous situations. Table 10 shows the results of the organizational resiliency questions (section 11) of the survey. The participants were requested to rate the ability of their respective facilities to detect, adapt to, and react to external perturbations or deviations.

Facility	**Metric**		
	Facility's ability to detect perturbation	Facility's ability to adapt perturbations	Facility's ability to react perturbations
A	1-20 %	1-20 %	1-20 %
B	21-40 %	21-40 %	21-40 %
C	1-20 %	1-20 %	1-20 %
D	41-60 %	41-60 %	41-60 %

Table 10 Survey results about the flexibility of PSM

All of the four participants estimated that their facilities had low resiliency levels, and none of them provided a definition of organizational resilience as it is perceived by their management. Thus, concerns would arise about the ability of these facilities to detect, adapt to, or react to external perturbations.

4.1.9 Awareness of system status

Awareness of system or process status can be achieved through some PSM activities like audits, inspections, and preventive maintenance. The metrics selected for the auditing, inspection, or maintenance activities would inform about the effectiveness and efficiency of these elements in keeping the management aware of the status of processes and the performance of the PSM program.

The questions of section 10 of the survey on the total number of planned and performed audits and the number of raised and closed audit findings facilitated capturing of both the percentage of audits completion and the audit findings closure metrics presented in Table 11. The percentage of maintenance tasks on process that failed to reveal failures was reported from the last question of section 13 about the number of maintenance tasks that did not discover failures on process equipment compared to the total number of performed process maintenance tasks that was presented in the precedent question in the same section.

Facility	**Metric**		
	Percentage of audits completion	Percentage of audit findings closure	Percentage of maintenance tasks on process that failed to reveal failures
A	100 %	/*	2 %
B	100 %	100 %	/*
C	100 %	65 %	/*
D	100 %	70 %	/*

(*) data was not provided by the participants.

Table 11. Survey results about the awareness of system status

Table 11 introduces the participants' responses, which were only on the questions related to PSM auditing and maintenance activities. Facilities reported positive performance in regard to audits effectiveness and completion. However, additional explanations are deemed necessary about the nature of conducted audits (i.e. internal, external) and their frequency, before drawing any conclusions about the auditing activity and the awareness of the PSM program status in general. Furthermore, facility A reported high maintenance efficiency, as only 2% of maintenance tasks failed to discover failures in their processes. The rest of the facilities (B, C, and D) did not provide any response about this metric.

Due to the small size of the sample, and need for further explanation and confirmation of findings such as ongoing EHS programs made earlier, six interviews were conducted with EHS specialists working for the same company, Sonatrach, but at different locations and levels. These interviews aimed to gain a better understanding about PSM performance at Sonatrach. The following section will discuss the interview themes drawn from the analysis of transcribed interviews.

4. 2 Interview Results:

The interviewees provided detailed information and clarifications about the PSM program of Sonatrach and how it is integrated with the overall EHS management system. The analysis of interview transcripts allowed for the conclusion of some common themes among the majority of facilities, which are presented underneath in detail.

- *PSM performance measurement*

The interviewees from facilities D, E, F, and H asserted that their facilities adopted only three lagging health and safety metrics for the measurement of EHS performance, and no process safety indicators were taken into account. The lagging metrics are captured at the end of each month and sent to the corporate office in Algiers. In this context, Mr. Ali (EHS engineer at facility E) stated, "Every month, we report the EHS statistics and metrics of our plant to the EHS department at the corporate level at Algiers. We capture three indicators which are the incident frequency rate, the incident severity rate, and the number of accidents." Concerning the communication of these metrics within the plant, he added: "At the end of the year, we communicate all those indicators and other statistics to all the employees via posters and announcements at workplaces, commons, and residential blocks." Moreover, the interviewees raised one more idea about EHS and PSM performance measurement. They confirmed that the majority of employees do not know what are the EHS objectives or targets of the company. This situation would impede Sonatrach's ability to improve its EHS performance in the future.

On the other side at facility A, PSM leading and lagging indicators like the rate of inspection completion, the number of near misses, and the rate of completion of technical audits were adopted as part of the overall EHS indicators. The EHS department communicates them on a monthly basis to all the employees working at the facility. "We consider the involvement of employees in achieving EHS objectives as a goal," explained Mr. Ismail (EHS engineer at facility A).

- *Integration of PSM with the overall safety management system*

All the interviewees at all sites highlighted the integration of PSM with the EHS management system of the company. Several departments are involved in PSM as an integrated part of their function such as exploitation, methods, maintenance, and EHS departments. Furthermore, PSM activities like process inspections, maintenance, and audits are managed concurrently with other EHS activities and programs. An example of this integration would be the internal and external EHS audits carried out at each facility. These audits cover their technical aspects, process integrity, and safety in addition to the other aspects of the EHS management system. Mr. Ianis (an EHS inspector at facility D) added, “Usually when the external auditors of certifying bodies come to perform a follow-up audit at our facility, they audit every single aspect of processes as part of the health and safety management system in place like personal training on PSM, maintenance efficiency and performance, equipment integrity and safety systems of processes, etc. They reveal between 30% and 35% of findings about PSM out of the total findings every year.”

- *Training, competency, and continuous learning*

Since all the facilities belong to the same public-owned group, Sonatrach, they follow the same procedure for the management of employee training. All the employees in charge of operating processes receive training on process operation and maintenance at the Algerian Petroleum Institute, a training institution that is part of the Group Sonatrach. However, a limited number of them get trained every year on process safety subjects like process hazard identification, and risk assessment. Lack of training for EHS staff was also highlighted by most of the interviewees. “Many EHS personnel working at intervention sections are not trained on the operation of sophisticated firefighting equipment, which were purchased recently by the company," explained Mr. Farid (EHS intervention technician at facility G). With regard to competency assessment of operating employees, all the interviewees confirmed the existence of a system in place for the periodic assessment of skills and knowledge of operating employees.

Our interviews revealed, however, significant deficiencies in the management of lessons learned from process incidents and/or safety drills and simulations. The majority of facilities do not share lessons learned from incidents that happened on their premises, as they fear the top management reaction. Mr. Ahmed (EHS prevention technician at facility F) said, "Whenever an incident occurs, the plant director reminds us not to send any safety alerts to the regional office or corporate offices to avoid further problems and questions from officers at the middle and top level of the company. So, no one knows about many incidents that took place in our plant except our employees." In addition, many incidents are not subject to full investigation as per the provisions of an internal procedure. According to this procedure, incidents have to be fully investigated only if the involved employee is given a work leave for 21 days or more. Otherwise, a simple report that explains the incident is prepared and forwarded to the upper level of the EHS function.

Concerning the lessons learned from drills, Mr. Ianis (EHS inspector at facility D) stated, "We conduct between four and twelve drills and simulations per year about process accidents in our plant in coordination with the public firefighting department and other local authorities. At the end of each exercise, we draw recommendations for improvements in terms of tactics and logistics of intervention in case of accidents. But we have never shared them with other facilities with similar activities. It would be weird if someone among us suggests this, as no one is used to thinking about that. All what we care about is the safety of our plant." Similar statements were shared by other interviewees who implicitly agreed on a weakness in this area. Mr. Ahmed (EHS prevention technician at facility F) said, “Every year, the EHS department prepares a drills plan. Usually, the intervention section performs them but we never know what recommendations or concerns they have or even share them with other facilities. They think that this is an internal matter of the intervention section and our section (prevention one) has nothing to do with them.”

Furthermore, all the interviewees noticed that since 2008, there has been a large wave of early retirement among the operating employees who typically accumulated more than thirty years of experience. This poorly managed shift in human resources resulted in a significant loss of knowledge and a failure to retain the necessary learning in the majority of facilities. Mr. Omar (EHS principal inspector at facility E), illustrated the effect of this loss in learning due personnel retirement on the EHS performance of the region: “Since five years, we started to notice an increase in the frequency of some incidents (like strained twists, injuries, etc.) among new employees when operating equipment or some devices that were not a source of frequent incidents before that. These incidents were due to the lack of experience, mentoring, and training of newly hired crews.”

- *Robust Documentation system*

A major problem in the control of documents and records related to process equipment and installations was raised by most of the interviewees in many facilities. For instance, Mr. Ahmed (EHS prevention technician at facility F) illustrated: “Whenever there are excavation works inside the plant, we become worried if the excavator would hit an underground pipe or cable because no department in our facility has the maps of the underground electric cables and pipes.” In addition, Mr. Ali (an EHS engineer at facility E) disclosed, “A few months ago, a maintenance team requested a permit from our department to calibrate a safety valve placed on an old pressurized vessel. They used to calibrate the valve to start off whenever the pressure inside the vessel reaches 38 bars. Whereas, the operating pressure of the vessel is usually around 29 bars, and the manufacturer specifications recommend calibrating the valve at 30 bars. For years no one knew at what pressure the valve should be set to start off, because all the technical documents of that installation and other equipment were lost."

One last point was raised in facility D about the use of technical documents and equipment manuals. Many references are not used properly because of the language barrier. Equipment manuals and technical documents are written in English, which is less common as other languages in Algeria.

- *Top management commitment and leadership*

Top management commitment and leadership is one of the prominent issues in many of the facilities. Except facilities A and F where managers carry out roundabouts on a weekly basis and show their commitment to safety, the interviewees from facilities D, E, and G assumed that their management is invisible and does not lead by example or open communication channels with employees about EHS issues. In these later facilities, managers perform inspections and roundabouts only when there is an incident or exceptional circumstances (e.g. complete process shutdown, startup of new process, etc.). Mr. Omar (an EHS principal inspector at facility E) reported the same situation in many facilities in the region, and assumed that the only commitment of top management would be found on the company EHS policy. However in practice, middle level managers and supervisors still have the old mindset and consider the EHS function as a barrier against achieving operational objectives and increased production. He added, "Our EHS performance will not know any improvement as long as we keep reporting to the operations function at the top level of the company, instead of assigning a senior officer responsible for EHS management."

Moreover, all the interviewees from facilities D, E, F, and G had no idea about the EHS management review meetings as they were never been held in their facilities or at the regional level. They assumed that these meetings would be held at the corporate level because of the centralized structure of EHS function at Sonatrach. Facility A was the exception, as it had its own EHS management system and organizational structure. So, management review meetings took place twice per year over the last decade.

- *Stakeholder engagement/communication*

With regard to internal stakeholders' engagement in PSM, the interviewees from facilities E, F, and G noted that the employees' involvement was limited to PSM incidents investigation as witnesses or as members of investigation teams. In addition, the same interviewees asserted the absence of a stop-work authority system or any formal system to communicate the employees' suggestions about EHS concerns to their facility management. Furthermore, the employees of those facilities in addition to facility D do not participate actively in the development and/or revision of operating procedures; however, their suggestions are sometimes taken into account like in facility D. For facility A, the interviewee confirmed that the participation of employees in the PSM program is viewed as a sign of a healthy safety culture. Therefore goals are set for this purpose and metrics are adopted to track the facility's performance in this area.

External stakeholders for EHS management and PSM at Sonatrach are mainly clients; public authorities (like Labor Inspection Office, District Environmental Department, and District Security Commission); insurance providers; and any local communities surrounding the plants. All the interviewees in the five facilities (A, D, E, F, and G) confirmed that over the last five years, they had one inspection visit at the most by the District Security Commission or District

Environmental Department. For instance Mr. Omar (EHS principal inspector at facility E) said, "Over fifteen years of work here, I had never seen officials from any public authority inspecting our PSM or our compliance with EHS regulations." This lack of law enforcement by public authorities weakened their engagement in PSM at all the plants of Sonatrach.

For the communication with local communities, interviewees from facilities A, E, F, and G stated that there is no external communication plans or events with them. They said it is simply because our plants are located in remote areas in the desert or inside industrial zones away from cities, although these last may be affected in case a significant process incident happens.

- *Preparedness/early warning/detection and anticipation*

All the interviewees asserted that emergency response plans exist at their facilities and are revised as needed. However concerning resources, they pointed out the limited number of employees in the intervention sections that are in charge of handling process mishaps when they occur. In facilities E, F, and G, the problem of physical ability of an important number of intervention employees was considered critical since they had become old and can no longer meet the physical demand of the position.

Furthermore, the interview participants confirmed that almost all the processes were equipped with sophisticated detection, emergency shutdown, and automatic firefighting systems, following the provisions of insurance providers. Periodic maintenance activities of processes are done by a third party on a timely manner at all the facilities. For facilities E, F, and G, process maintenance services are usually provided by a specialized unit of maintenance that belongs to Sonatrach as well. Whereas, some plants like facility D maintain contracts with the process manufacturer to secure the maintenance services for the purchased equipment.

- *Flexibility*

The interviewees in all the facilities assumed that their facilities would be able to detect and react to a security threat. Mr. Farid (EHS intervention technician at facility G) added, “As of the first quarter of 2013, the security personnel in our facility became armed all the time and supported with gendarmerie elements (a military institution in charge of police duties).Whereas in the past, few of them only were armed during night shifts only and there was no presence of any public security forces.” This would be explained with the strategic position of the oil and gas sector in Algeria, as it is the main source of income for the country. Therefore, the security of oil and gas plants would be one of the highest priorities for the Algerian government. However, the interviewees in facilities D, E, F, and G were not sure about the ability of processes and other installations to resist an industrial perturbation (blast, fire, etc.) occurring in a neighboring facility and going beyond its premises. In this context, Mr. Ahmed (EHS prevention technician at facility F) explained, “In the aftermath of the terrorist attack of Tiguentourine on January 16, 2013 (discussed in the background section of Chapter 1), our security measures against any security threat were strengthened since a military troop was placed nearby our facility to secure all the facilities in the area. However, I do not think we have measures at our level to resist a thermal flow or an overpressure coming toward our processes and storage tanks, as a result of a fire or explosion in a nearby facility.”

- *Awareness of system status*

In facilities D, E, F, and G, internal audits were conducted once or twice per year at the most by a team of EHS auditors from the corporate office at Algiers and the EHS department at the regional level, just before the external one became due. For facility A, audits were planned and conducted throughout the year before and after any external audits. The PSM findings in facilities D, E, F, and G were about 30 to 45% of the overall EHS audit findings. This significant percentage of findings could be due to two main reasons: either the PSM program was disintegrated from the EHS management system or due to the quality of audits. Meanwhile, other PSM activities like process maintenance activities and inspections were carried out regularly. For the latter ones, they were included as part of the overall EHS inspections, which are performed on a bi-weekly basis.

4.3 Discussion

From the above results, facility A could be considered as an outlier compared to the other facilities included in this study, in view of the provided responses about PSM compared to the other facilities. It is argued that facility A enjoys a better safety culture than the rest of facilities that were the subject of the interviews.

In addition to the PSM issues in the process industry, illustrated in Chapter 2, and based on the themes identified from interviews, Sonatrach found to be facing additional problems in several areas.

The top management of Sonatrach shows a lack of commitment and leadership toward PSM and EHS management in general, although they engaged in a certification process to get ISO 14001 certification. The organizational structure of Sonatrach inhibits the EHS department from achieving its outcomes and limits its influence, as the EHS function is not reporting to a senior EHS officer at the top level of the company. Placing EHS function under the responsibility of production departments is a unique issue that was not reported by experts or researchers as a concurrent issue in the process sector. In addition, there was a negative perception about the commitment of top management toward EHS management. The interviews revealed that top management commitment is announced only in the EHS policy of the company. However, the EHS function is always seen as a barrier for production and operations.

The lack of commitment from top management is reflected also in the definition of goals and PSM indicators of performance. In addition to the complete reliance on lagging personal safety indicators as measures for process safety performance, the EHS department of Sonatrach did not set goals to manage its EHS systems, including the PSM program. In the same vein, top management did not set a minimum level of PSM performance for all their plants to maintain. Furthermore, Sonatrach lacks an effective system for the control of documents and records. Missing operating procedures, technical drawings, and documentation for most of the process equipment and installation is among the common issues within the organization. Although the survey results showed that audits did not raise any findings about records retrieval or accuracy, the scope of audits and quality of auditing process have to be reviewed to cope with this issue. Moreover and due to its poor safety culture, incidents and lessons learned from incidents were not being investigated properly and shared among the facilities of Sonatrach. Thus, it is believed that Sonatrach loses a crucial opportunity to learn new lessons and avoid the reoccurrence of similar incidents at the same facility since there is a deficiency in the incidents investigation system.

The aforementioned deficits in PSM had a direct repercussion on the engagement of some stakeholders in PSM. Sonatrach employees, who represent the main internal stakeholders for EHS management, are not involved in PSM activities like hazard identification, risk management, procedures development, etc., whereas, insurance providers are the main external stakeholders for EHS management that have a tangible influence on PSM through the prescription of process safety requirements and auditing plants. For the regulatory stance, the company does not know where it stands in terms of compliance with EHS regulations and laws. The responsibility for this failure is shared between Sonatrach and regulatory enforcement authorities. These latter ones (regulatory enforcement authorities) exert only limited efforts to inspect public and private companies in many sectors to ensure legal compliance.

On the other hand, it is believed that other companies in the sector would have limited influence on the safety culture of Sonatrach. This conclusion can be proven from the significant difference in maturity and performance of EHS management among Sonatrach facilities and other joint venture plants of Sonatrach with BP, Statoil, Total, etc. These joint venture plants are managed as per the international standards, but Sonatrach did not take advantage of these arrangements to improve the safety culture within its own facilities. This observation could be further analyzed in a future work to understand the drawbacks preventing Sonatrach from taking this opportunity.

In terms of preparedness, early warning, detection, and anticipation, it was found that Sonatrach encounters the same issues as other companies in the sector internationally, in addition to experiencing a remarkable shortage in human resources for the intervention section at many plants. Most of the employees took retirement or are old and do not have the physical ability to continue to working in this section.

Finally, and although they were performed in the majority of Sonatrach facilities, the planning of internal audits seems to be done from a reactive perspective. Internal audits are completed once per year just before the due date of the external audit. Furthermore, it is clear from the collected data that the auditing process lacked effectiveness. The findings revealed that Sonatrach had deficiencies in relation to PSM document control, whereas the survey data affirmed that no findings related to the PSM documents completeness, recording, storage, or retrieval were raised in most of the facilities.

Moreover, many plants cannot secure the necessary spare parts for the maintenance of process installations. The reasons for this vary between financial, bureaucratic, and practical considerations. Most of the process equipment has been in service for thirty to forty years, and manufacturers have stopped producing spare parts for old models and the cost of spare parts is very high. Under these circumstances, troubleshooting became a norm in many facilities.

In order to illustrate the findings of this research, Figure 4 which is adapted from Schneider (2014), represents the PSM program map of Sonatrach. This map illustrates PSM issues in the sector in addition to the identified issues in Sonatrach facilities. Steps in red represent the areas where the company faces issues. The red dashed arrows are gaps in reporting and communication within the organization or with external stakeholders.

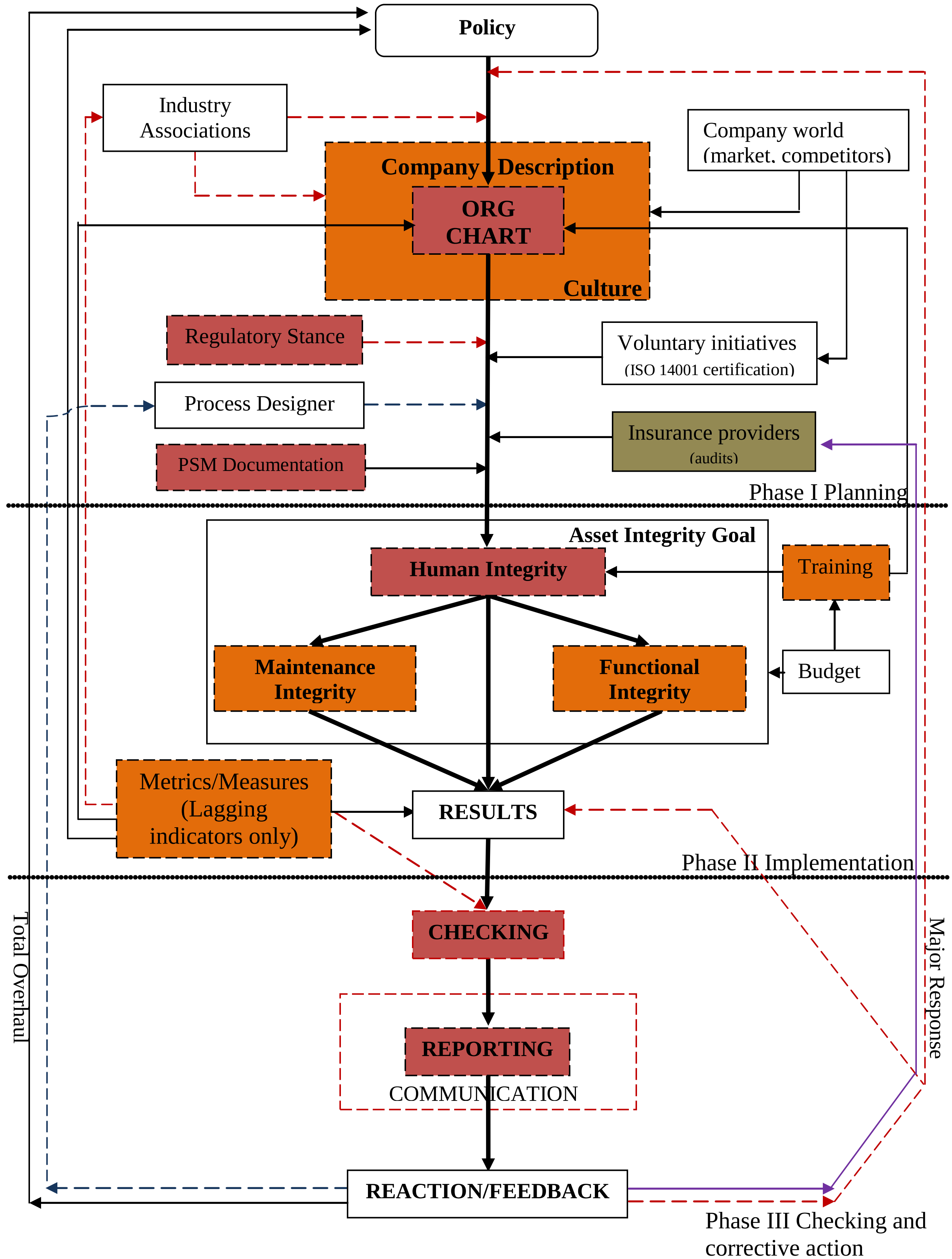

Figure 4. The PSM program map of Sonatrach (adapted from Schneider 2014)

To conclude, this chapter discussed the data collection results, and analyzed the survey and interviews outcomes regarding PSM in Sonatrach facilities. The discussion of these results showed some unique issues at Sonatrach in addition to those reviewed in Chapter 2. Sonatrach encounters significant cultural issues that affect the performance of its current PSM program and its integration within the overall EHS management system. A map of the PSM program of Sonatrach is presented based on the findings of this work. The following chapter will conclude the work and recommend future extensions to this research.

Chapter 5: General Conclusions

5.1 Research summary and recommendations

The process sector has made significant progress in terms of PSM. Companies in the sector have become able to understand how process incidents manifest, and shifted to the proactive management of process hazards in order to prevent the occurrence of these incidents. This development in controlling process hazards has been the result of enhancements in the process design and advancements in science and engineering fields. Nevertheless, the sector failed to achieve full safety of processes and prevent the occurrence of incidents. Major unprecedented accidents are still hitting plants internationally, leading to severe human and material losses. These accidents are the result of a combination of cultural, organizational, and technical issues in the EHS management and PSM in particular. In this work, the most common issues related to the EHS management and PSM in the sector that were reported in literature over the last six years, were reviewed. Finally, a map of PSM program in the process industry was created, and reflects all the issues identified above.

This work subscribes to the ongoing efforts to explore issues in PSM in developing countries, as the majority of studies concern facilities located in developed countries with little focus on companies in the process sector established in developing countries where the majority of high hazardous work occurs. Research focused on the effectiveness of PSM programs at Sonatrach, the Algerian oil and gas public company, which is the largest company in this sector in Africa. In view of its size, production capacities, and location, this company was considered as a typical one in Africa to conduct this research on it.

The research methodology followed in this work consisted of a mixed method of quantitative and qualitative tools. An online survey was designed to evaluate the effectiveness of the PSM program and its integration with the overall EHS management system. The questionnaire was then tested, and sent to twenty-two EHS specialists working in different facilities of Sonatrach, including its joint ventures with other international companies. The analysis of results, six weeks after launching the survey, showed a need for further development of responses by the EHS department of Sonatrach, due to the limited size of our sample and incompleteness of received responses. Subsequently, a set of interviews was held with other EHS specialists working for Sonatrach at different facilities and levels of the organization that showed additional issues that Sonatrach faces in terms EHS management and PSM, in addition to the ones the sector encounters internationally, as reviewed in Chapter 2.

Conclusion 1: Lack of top management commitment, leadership, and communication

Severe safety cultural issues in Sonatrach facilities were identified and related to lack of top management commitment, leadership, and communication. It is believed that Sonatrach's safety culture represents an inattentive culture prevailing in the sector internationally that resulted from top management, and can have catastrophic impacts and implications. To address these issues, a thorough review and reform of the organizational safety culture should be the urgent task to complete before tackling other issues. Having the positive commitment of top management and leadership is the foundation for establishing a good safety culture. This will pave the way for redressing of the following issues in PSM or EHS management system.

Conclusion 2: Absence of PSM performance measurement

The findings present some PSM issues unique to Sonatrach like absence of PSM performance measurement, and ambiguous or nonexistent EHS goals for all the company. In addition, Sonatrach lacks an internal standard for an effective PSM that states the minimum PSM performance to be maintained by all the facilities and subsidiaries. This standard would help the company establish for a continuous improvement in their PSM performance and prioritize areas of action at each facility. Sorting out these issues requires first a commitment by the top management toward prevention of incidents and injuries. Therefore, it is believed that these issues should be addressed after fixing the ones related to cultural issues. After that, EHS goals (including PSM ones) should be defined, and EHS and PSM leading and lagging indicators have to be established using audit results and previous EHS statistics. Benchmarking with competitors and other leading companies in the sector would facilitate the selection of performance indicators and areas of focus.

Conclusion 3: Ineffective document management system

This work revealed the ineffective control of process documents and records and a deficient incident investigation process. These issues cannot be fixed unless the previous ones are thoroughly investigated and properly addressed. However for the control of process documents, the resolution of this shortcoming requires a deep audit of the PSM program and EHS management system in general, in order to identify gaps in document management and bridge them. But before that, it would be efficient to take advantage of information technology tools and establish an internal online platform that links all the facilities together and serves as the host for all PSM documents. With regard to the incident investigation process, Sonatrach should establish a reporting system for near misses that allows the investigation of near misses and incidents.

Conclusion 4: Deficiency in regulatory enforcement by public authorities

Finally, findings have proven a significant deficiency in regulatory enforcement by public authorities. For this reason, Algerian authorities are strongly encouraged to update the existing laws and regulations related to occupational health and safety, and promulgate new regulations to cover PSM in the process industry. These legal tenets ought to be enforced by competent institutions in order to ensure an acceptable level of safety performance in the process industry. Furthermore, it is recommended that competent institutions develop a matrix for societal risk assessment to be used as a guideline by companies in the process industry for the management of process risks, and land use planning of future plants. Indeed, Algeria like most developing countries, is still lagging in terms of EHS regulations that ensure the safety of people, and maintain the minimum level of process integrity performance at all the sites. Thus, leveraging the experience of developed countries in PSM and adapting it to the Algerian context would facilitate bridging this gap.

It is worthwhile to note that these findings were only linked to facilities where Sonatrach is the only owner and operator of processes. Joint venture facilities with international oil and gas companies were the exception, and tend to follow international standards in terms of PSM.

In general, the process industry needs to take further steps to acquire control of the emerging PSM issues. Among these actions, companies should establish an effective learning system that allows a harmonized flow of information about process experience among process users, designers, and other interested parties to prevent the reoccurrence of incidents, and enhance inherent process design practices. Furthermore, each company should adopt a succession plan for its human capital in order to retain minimum knowledge and expertise among employees and achieve a better human integrity. Finally, top management of companies in the sector are compelled to take further steps to integrate EHS management into decision making by considering the input from process risk analysis along with the financial and operational input when making decisions, and boost their commitment toward proper and robust PSM.

5.2 Research limitations

As any academic work, this research has some limitations; in this case, this is due to the small size of the final sample considered for analysis. Furthermore, the incompleteness of survey responses prevented conducting further statistical analysis about the statistical significance of responses and uncertainties in participants' answers. This incompleteness was due to the unavailability of data at the level of participants, who work for a company that faces internal communication challenges, and demonstrates fears of open communication.

Moreover, the translation of the survey from English to French may have caused a minor loss in the meaning of some terms, although the French version was also verified by another competent bilingual EHS specialist.

Finally and due to the unavailability of published data about PSM from Algerian authorities or Sonatrach, a challenge in corroborating and confirming some facts provided by interviewees with other external sources was faced. Therefore, this work considered only the most frequent issues in common among facilities, as they were reported by interviewees.

5.3 Future work:

This work can be improved by considering a larger sample of facilities for analysis, and developing a composite indicator that allows comparisons between the current performance levels in the sector with the scored level of each facility. It is an important first step in measuring the effectiveness of PSM in non-first-world countries and provides insight into the challenges of appropriate PSM beyond policy.

Future research would investigate the huge difference in safety culture and EHS management among facilities and joint ventures with first-world partners, to explore the root causes for not adopting the same best practices about EHS management within all facilities.

Finally, conducting this research on a process company in another developing country would be another extension for this work. This extension would give insight into similarities in PSM in developing countries and an understanding of where they stand in terms of PSM compared to developed countries.

This work indicates the idea that policy creation on an international scale must be adapted and implemented locally, and that local context (culture) largely drives success in PSM. Therefore, a much more mature safety culture is the upcoming challenge for third-world countries to desire to achieve a better EHS and PSM performance in the process industry.

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Appendix 1. Survey questions about PSM in Sonatrach

1. General Information:

This section helps us understand the context of your facility, and asks for general information that identifies it from other facilities.

What is the main product of your facility?	Gas	Oil	Oil derivates
What is the annual throughput of your facility?			
What is the operating budget of your facility?			
What is the total employee headcount of your facility?			
What is the headcount of operating employees? By “operating employees” we mean those who are at the lower level of the organization and have duties related to process activities?			

2. Process Safety Management Indicators:

The questions of this section ask about adoption and capture of process safety management indicators within your facility.

How many Environmental, Health and Safety indicators have your facility adopted last year?							
Among the overall Environmental, Health and Safety indicators, how many process safety management indicators have your facility adopted last year?							
How long is the average delay in capturing Process Safety Management indicators?	A semester or more	A quarter or more but less than semester	A month or more but less than a quarter	More than two weeks but less than a month	Between a week and two weeks	Less than a week	No delays

3. Process Safety Documents Management:

The following section is about the management of process safety documents (forms, procedures, technical drawings, etc.) in terms of reviewing and update.

How do you rate the percentage of obsolete documents in use out of the total number of documents?	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

How long is the average delay in procedures review?	A semester or more	A quarter or more but less than semester	A month or more but less than a quarter	More than two weeks but less than a month	Between a week and two weeks	Less than a week	No delays
How long is the average delay in procedures update?	A semester or more	A quarter or more but less than semester	A month or more but less than a quarter	More than two weeks but less than a month	Between a week and two weeks	Less than a week	No delays

4. Employees Participation

The following questions are about the involvement of employees in the management of process safety. We mean by “operating employees” those who are at the lower level of the organization and have duties related to process activities (operations and maintenance)

How many employees have process safety management roles in their job description?	

Is there a program for employees to communicate their suggestion about process safety matters to the facility management?	Yes			No		
If yes, how many suggestions on average submitted annually?						
How many suggestions on average accepted annually?						
How many operating employees are involved annually in process hazard analysis?						
How many operating employees are involved annually in accident investigation teams?						
How many operating employees are involved annually in the development of operating procedures?						
How many operating employees are involved annually in the review of operating procedures?						
5. Top Management Commitment: The questions below are about the commitment of top management of your facility toward process safety. By "Top management" we mean the senior officers who are responsible for managing the business and running the facility (including process activities) like Base manager, Operations manager, Production manager, etc.						
Does your facility have a plan for walk-rounds?	Yes			No		
If yes, how many walk-rounds are planned on average per year?						
How many walk-rounds are performed by the top management of your facility per year?						
How many management review meetings are held per year in your facility?						
How many management review meetings are attended by the top management of your facility?						
How do you rate the average response time on process safety suggestions from their reception till their resolution?	A semester or more	A quarter or more but less than semester	A month or more but less than a quarter	More than two weeks but less than a month	Between a week and two weeks	Less than a week
6. Community Outreach and Communication: The following questions aim to assess the extent to which your facility communicates with the nearby community. Please note that if your answers on the first two questions are both "NO", then you may skip this section.						
Is your facility located in an urban area?	Yes			No		

Is your facility located in a suburban area?	Yes			No		
If yes, does your facility have a plan for open meetings with the community?	Yes			No		
If yes, How many open meetings with the community are planned for the year?						
How many open meetings are actually held with the community each year?						
What is the average number of inquiries submitted to the top management of the facility per year?						
What is the average number of completed commitments toward the community?						
In the event of an accident, what is the total number of community members who would be potentially affected?						
What is the average number of community members who were trained on Emergency Response Plans by the company per year?						
What is the average number of community members who are aware of emergency response scenarios?						
Does your facility have a communication plan with the community?	Yes			No		
If yes, what is the frequency of updating your facility communication plan?	Once in more than three years	Once in three years	Once every two years	Once a year	Less than once a year	
How long on average is the delay to respond on community inquiries comparing to the planned timeframes?	Three months or more	Two months or more but less than three months	A month or more but less than two months	More than two weeks but less than a month	Two weeks or less	No delays at all
7. Training, Education, and Competency This section aims to get an idea about process safety training and competency of employees in your facility.						
Is there a system for employees' competency assessment on process safety management in your facility?	Yes			No		
If yes, how many employees have completed their competency assessment on process safety management?						
Does the training plan of your facility include training on process safety management?	Yes			No		
If yes, how many employees have completed training on process safety management?						
What are the total hours spent per year for each employee in: a. EHS training?						

b. Process safety management training?		
What is the average budget allocated for the training of employees in your facility per year?		
How many employees have been trained on Emergency Response Plans?		
8. Continuous Learning The questions of this section are about sharing and implementation of learnt lessons (also called safety alerts) from process safety experiences (near misses, accidents) that happened in your facility, other company facilities, or in the industry.		
How many learnt lessons (Safety Alerts) shared by other companies with your facility per year?		
How many learnt lessons (Safety Alerts) recommendations from process safety experiences have been implemented per year in your facility?		
9. Risk Assessment and Process Safety Information, This section is about Risk Assessments performed for process activities and Process Safety Information. We mean by "Process Safety Information" a compilation of written information about "the hazards of the highly hazardous chemicals used or produced by the process, information on the technology of the process, and information on the equipment in the process."(U.S OSHA, 2000)		
What is the total number of risk assessments on process activities conducted in your facility?		
Is there a procedure for reviewing risk assessments on process activities conducted in your facility?	Yes	No
If yes, how many risk assessments on process activities reviewed per year in your facility?		
Does your facility have a plan for reviewing process safety information?	Yes	No
If yes, how many process safety information reviews are planned in your facility per year?		
How many process safety information reviews conducted in your facility per year?		
10. Audits and Inspections: This section is about process safety management audits conducted in your facility. The questions are about audits planning and types of findings		
Does your facility conduct process safety management audits separately from the overall Environmental Health and Safety management system audit?	Yes	No
If yes, how many process safety management audits are planned per year?		
How many process safety management audits		

are completed per year?											
How many findings on process safety management per year have been raised?											
How many closed findings on process safety management per year?											
Are there any process safety audit findings that are repeating for two years in a row?	Yes					No					
If yes, how many process safety audit findings have repeated for two years in a row?											
How many audit findings per year on: a. delays in retrieving records?											
b. inability to retrieve records?											
c. improper storage of records?											
d. inaccurate records?											
e. incomplete records?											
11. Organizational Resilience: This section assesses the organizational resilience of your facility. In this context, We mean by “Organizational Resilience” the ability of an organization to detect, adapt, and react on a timely manner to an external disturbance that would affect process activities.											
How do you rate the ability of your facility to detect any external disturbances that would affect process activities?	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
How do you rate the ability of your facility to react in timely manner to external disturbances affecting process activities?	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
How do you rate the ability of your facility to adapt to external disturbances affecting process activities?	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
What is the definition of organizational resilience, as perceived in your facility?	*[Type your answer here]*										
12. Legal Compliance This section aims to understand where your facility stands in terms of compliance with applicable regulations related to process activities.											
Do regulating agencies conduct periodic inspections about process activities in your facility?	Yes					No					
If yes, over the last five years, how many inspections related to process activities have been conducted by regulating agencies in your facility?											
How many citations has your facility received about the process safety management from regulatory agencies in											

last year?		
How many citations has your facility received about the process safety management from regulatory agencies this year?		
What is the average cost of fines from regulating agencies received by your facility for noncompliance with process safety management regulations over the last five years?		
What is the average cost of fines from regulating agencies received your facility for noncompliance with process safety management regulations last year?		
13. Process Maintenance Activities The questions of this section are about the planning and efficiency of process maintenance activities in your facility.		
Does your facility have a plan for preventive maintenance tasks on process equipment?	Yes	No
If yes, what is the total number of planned preventive maintenance tasks on process equipment per year?		
How many preventive maintenance tasks on process equipment are completed per year?		
How many maintenance tasks that did not discover failures on process equipment?		
14. Safety Systems This section is about the function and periodic inspection of safety systems that monitor and protect the process.		
What is the average number of safety critical instruments that monitor process condition in your facility?		
Are there any safety critical instruments that failed to indicate process conditions last year?	Yes	No
If yes, how many safety critical instruments that failed to indicate process conditions last year?		
How many safety systems activations (valves, reliefs, etc) were recorded last year due to equipment failures?		
How many safety systems activations (valves, reliefs, etc) were recorded resulting in complete shutdown of the process last year due to equipment failures?		
Does your facility conduct periodic test of process safety systems?	Yes	No
If yes, how many process safety systems that did not function properly to the desired		

performance standard when tested in the last periodic test?		
15. Safety Drills This is the last Section! The following questions are about drills planning and outcomes in your facility.		
How many safety drills were planned last year?		
How many drills were conducted last year?		
Does your facility review Emergency Response Plans after conducting drills?	Yes	No
If yes, how many reviews have been performed last year resulting in changes on Emergency Response Plans?		
How many changes in Emergency Response Plans tactics have been introduced following the conducted drills in your facility last year?		
How many changes in Emergency Response Plans logistics have been introduced following the conducted drills in your facility last year?		

Appendix 2. Interview questions

1- PSM Performance Measurement:

- How does your plant follow the performance of process safety management?
- What type of indicators did your facility adopt for your PSM?
- Are the employees of your plant aware of the existing indicators?
- What is the frequency of sharing the reported indicators with the facility employees?

2- Integration of PSM with EHS:

- Besides the EHS specialists, who is else in your facility is responsible on PSM?
- What is the scope of EHS audits in your facility?

3- Training, Education, Competency, And Continuous Learning:

- What type of PSM training do your employees and contractor employees receive as part of the overall EHS training?
- How do you assess the competency of employees in terms of process operation and maintenance?
- Do you share or receive any safety alerts from other facilities related to PSM?

4- Document Management System:

- Briefly describe the process of revising or updating operating procedures (who initiates the process, how it is prepared, tested, approved, and communicated?)
- Are the employees ‘suggestions taken into account?
- Do you think it takes a long time to complete the update or review of procedures?
- Did you experience any incidents or recorded non conformances due to a documentation problem?

5- **Top Management Commitment and Leadership:**

- Do your managers perform or participate in roundabouts in your facility?
- How do your managers communicate with employees about process safety subjects?

6- **Stakeholder Engagement/ Communication:**

- What type of PSM-related activities are employees or their representatives involved?
- How do you evaluate the status of your plant in terms of compliance with EHS laws and regulations? If not known, what is the frequency of inspections by regulatory institutions (inspections by labor inspection, department of environment, security committee of the District)?

7- **Preparedness /Early Warning/Detection And Anticipation:**

- Describe the drills plan and activities in your plant (who plans them, who participates, material means availability, learnt lessons are implemented and shared)?
- How do you evaluate the ability of your processes to detect serious failures, malfunction, or abnormal conditions?
- How do you evaluate the effectiveness and efficiency of your process maintenance activities?

8- **Flexibility:**

- In case of external perturbation on your process, do you think your facility is able to detect, react, and adapt appropriately in a timely manner?

9- **Awareness of system status:**

- What are the PSM activities that keep you aware of the status of your process?