PART I

DESIGN
1

PIPELINE INTEGRITY MANAGEMENT SYSTEMS (PIMS)

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1.1 INTRODUCTION

Effective management of pipeline system integrity is essential for safe and reliable pipeline operation. Pipeline integrity management systems (PIMS) provide the overarching, integrated framework for effective pipeline asset management. Significant failures in both gas and liquid pipelines have made global headlines. Although pipelines are statistically very safe and reliable, pipeline failures have resulted in fatalities, environmental damage, and an erosion of public confidence in the pipeline industry. Some examples of catastrophic pipeline failures that resulted in fatalities include the sweet gas line rupture in Carlsbad, New Mexico, in 2000, the gasoline pipeline failure in Bellingham, Washington, in 1999, and the gas line rupture in San Bruno, California, in 2010. Failures in oil pipelines such as the Kalamazoo River oil spill in 2010, the Red Deer River spill in 2012, and the Mayflower, Arkansas, spill in 2013 also generated significant public concern regarding environmental impacts. Failure investigations have identified that the significant contributing factors to the cause and the size of pipeline releases are directly related to flaws in the company’s management systems. As such, an effective PIMS is critical to prevent failures. Additional information on pipeline failures and causes is publicly available on websites such as Pipeline and Hazardous Materials Administration (PHMSA), the U.S. National Transportation Safety Board (NTSB), and Alberta Energy Regulator (AER).

Pipeline integrity management requirements and expectations have been continuously evolving and will continue to change in the future. There is no single correct “formula” for developing an integrity management system; however, this chapter outlines the fundamental basics of an effective management system that have been successfully integrated in companies across the world. Industry groups such as International Association of Oil and Gas Producers [1] and the American Petroleum Institute (API) [2] have developed guidance documents that can be used as additional references for developing management systems. This chapter covers downstream, midstream, and upstream oil and gas pipelines. Pipelines have different operating practices and different consequences of failure; however, the fundamental principles of an effective integrity management system apply to all pipeline operations.

Although this chapter focuses on PIMS, it is important to note that the pipeline industry is shifting toward safety management systems (SMS), which are more comprehensive than traditional PIMS. For example, SMS emphasize safety culture and process safety management more than conventional PIMS. Significant changes are expected within CSA Z662 Section 3.0 Safety Loss Management to reflect the transition to SMS principles. API Recommended Practice 1173—Pipeline Safety Management System Requirements [2] (Draft Version 11.2 issued in June 2014) is an example of an industry SMS document. The reader is encouraged to review and understand the latest industry and regulatory documents pertaining to both SMS and PIMS. SMS are outside the scope of this chapter; however, PIMS and SMS are closely linked and the principles governing PIMS development can be extended to SMS.
1.2 LESSONS LEARNED AND THE EVOLUTION OF PIPELINE INTEGRITY

In the early days of the oil and gas pipeline industry, integrity-related activities such as coating application, cathodic protection, corrosion inhibition, and weld inspection were implemented in response to pipeline failures and incidents. As the pipelines have aged and the size and complexity of pipeline networks have grown, the impact of pipeline failures has increased. More specifically, there is more public awareness and concern regarding pipeline failures. In response, the industry improved prevention, mitigation, monitoring, and inspection technologies for pipeline hazards. For example, coatings have improved, in-line inspection (ILI) was developed (and has since evolved dramatically), corrosion inhibitors have become much more effective, and alternative materials to carbon steels, such as spoolable composites, were developed.

In addition to improving technology, companies started utilizing risk assessments to focus and prioritize integrity management-related activities. Risk assessments provide a more structured and analytical approach to identify and address pipeline integrity issues.

As a result of the combined efforts of technology improvements and risk assessment application, the number of failures in the North American pipeline industry declined significantly. For example, the upstream pipeline failure rate in Alberta declined from 5.0 failures per 1000 km of pipelines in 1990 to 1.5 failures per 1000 km by 2012 [3].

The regulators and the oil and gas industry agree that technological improvements and risk management are positive changes that are reducing the number of failures; however, they also understand that these advancements alone are not sufficient to address all pipeline hazards. Integrity management systems provide a more encompassing and integrated approach to addressing pipeline risks. At the June 2013 National Energy Board (NEB) Pipeline Safety Forum, the NEB paper “Emerging issues in oil and gas industry safety management” listed three key aspects that must be in place for an effective management system. This paper states that the management system must be:

- Consistently applied
  “The system elements are applied consistently across operational programs (worker safety, asset integrity, damage prevention, environmental protection, and emergency management), facilities and geographic regions.”
- Highly integrated
  “There are multiple interdependencies between management system elements and so the management system is designed to share information and intelligence to promote better decisions.”
- Assign accountability
  “All officers and employees have a role in meeting the safety, security and environmental protection goals of the organization. These responsibilities must be clearly assigned and communicated. Performance must be measured and improvement required.”

Pipeline failure incident investigations provide important insight into why an effective management system is necessary. The examples below are summarized from pipeline investigations published on regulatory or industry websites describing contributing factors to major pipeline failures:

- Lack of training and competency: examples include operator error that led to overpressurization of a system, inadequate inspector training that led to construction-related failures, and incorrect ILI analysis that misinterpreted a defect signal.
- Lack of effective change management: examples include production changes that altered corrosion rates, staffing changes that resulted in critical tasks incomplete or communicated improperly, and material substitution that resulted in an unsuitable material being used incorrectly in the wrong environment.
- Lack of records: improper or missing/lost documentation.
- Lack of understanding hazards: a lack of understanding of potential hazards resulting in an unaccounted for corrosion mechanism that resulted in pipeline failure, and an incorrect assumption of pipeline condition (the pipeline was assumed to be “dry” but rather the pipeline catastrophically ruptured due to internal corrosion).

As explained above, pipeline failures commonly link to management system failures. Developing and implementing an effective PIMS requires significant, albeit critical, work to prevent pipeline failures due to ineffective management systems. The success of PIMS requires the integration of a company vision, a well-developed structure, and a company safety culture supported by process management. The following sections will define and outline the core structure of an effective PIMS.

1.3 WHAT IS A PIMS?

The principles of asset integrity management apply to a wide range of industries, including power generation, aircraft, nuclear, pharmaceutical, transportation, and defense. Common asset management system principles apply to any system with physical assets that are core to achieving the company’s business objectives.
There are many industry documents, standards, and recommended practices that describe asset integrity management systems. One standard that is frequently used as a guideline document for asset management is the Publicly Available Specification (PAS) 55 [4], which is administered by the British Standards Institution (BSI). This standard was developed by the Institute of Asset Management and has been adopted by utility, transportation, mining, process, and manufacturing industries worldwide. PAS 55 has been incorporated by the International Organization for Standardization (ISO) and has been updated as the ISO 55000 Asset Management series of standards [5].

In PAS 55-1:2008 [4], asset management is described as

Systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan.

An organizational strategic plan is described as

Overall long-term plan for the organization that is derived from and embodies its vision, mission, values, business polices, stakeholder requirements, objectives and the management of its risks.

Figure 1.1 demonstrates the interdependencies of company vision/strategic plan, the management system structure, and the company culture. All three elements are required for success.

In the oil and gas industry, assets can include pipelines, pressure equipment, piping, and tanks. Integrity management systems can be developed for the conventional oil and gas assets mentioned, and can also extend to rotating equipment, electrical, and structural systems.

The purpose of pipeline integrity management is the effective execution, documentation, and communication of the technical work throughout the pipeline life cycle, and PIMS provides the framework (structured and integrated system elements) to execute effective pipeline integrity management. The technical programs can include, but are not limited to, quality control and inspection, cathodic protection, ILI, chemical inhibition, coating selection, excavation (dig) programs, corrosion monitoring, and river block valve maintenance. These are the activities that require plans, programs, processes, and procedures to be managed, scheduled, executed, tracked, documented, communicated, and reported.

There are multiple interdependencies between the many functions within an organization. Effective integrity management requires the cultural aspects of understanding, communication, and collaboration between operations, engineering, management, finance, and safety—in fact, almost every function within an organization through business unit integration. A great technical program may fail for one of the following reasons: people are not trained and competent, change is not effectively managed, key information, records, and documents cannot be found, and roles and responsibilities are not clearly defined.

1.4 REGULATORY REQUIREMENTS

The codes, standards, and regulations that govern the pipeline industry continue to change in response to lessons learned from industry failures. These regulatory documents

![FIGURE 1.1 PIMS: vision, structure, and culture.](image-url)
provide a defined basis that is used by industry to determine pipeline integrity requirements. It is important to realize that regulatory changes take time and typically lag public expectations and industry practices of progressive companies.

Companies often fall into the trap of building their integrity management systems to meet, but not exceed, regulatory requirements. In the 2013 NEB Safety Forum, Jeff Weise, Associate Deputy Director of PHMSA, commented to the audience that “regulatory requirements are ‘the floor’ on which you stand and meeting regulatory requirements is nothing to be proud of.” He emphasized that companies need to be proud of their safety and performance achievements, not of meeting minimum requirements. If you are only meeting regulations, then you are already well behind the industry leaders and good integrity management practices.

Regulatory requirements fall into two very different categories. The specific and prescriptive “shall and must” aspects of regulations provide clearly defined minimum requirements. For example, the AER Pipeline Rule that “the licensee of a pipeline that crosses water or unstable ground shall at least once annually inspect the pipeline right of way” is easy to understand and apply. The minimum compliance is therefore one right of way (ROW) inspection a year; however, an effective and comprehensive approach to risk management suggests that companies conduct ROW inspections at an appropriate frequency for their operating conditions. The “appropriate frequency” can be quarterly or monthly, and in some cases, operators perform daily aerial surveillance to mitigate risk.

The second category of regulatory requirements is more general and requires interpretation. Regulations regarding management systems require each company to interpret the intent and incorporation of the stated requirement. For example, the management systems requirement for management of change (MOC) is only prescriptive in the sense that MOC is required. Each company must determine what specifically is required to ensure MOC exists in their organization, including documenting, communicating, and archiving MOC documentation such as the MOC process or completed MOC forms. Logically, MOC for a small upstream company may be simpler than MOC for a major transmission pipeline company.

Regulations for management systems, on the other hand, are more general and require each company to interpret how to meet the intent of the stated requirement. For example, a regulatory audit investigates a company’s document and records management system. The audit may determine that “yes, there is a document and records management system and it meets the audit requirements.” However, this conclusion does not mean that the company has an effective system that ensures all critical records, documents, and information are verified and are readily accessible for use in supporting risk assessment, fitness for service, MOC, and other important processes. From a process maturity perspective, an adequate system is a long way from a more mature “competent” or “excellent” system.

A maturity grid approach can be used to determine a system’s relative state. A maturity grid is a description of the characteristics/criteria of the company operating at various levels of maturity; for example, maturity levels may include Innocence, Awareness, Understanding, Competence, and Excellence. This is a qualitative assessment technique that can provide an effective way of communicating and illustrating the current state of the management system as well as the future state that the management system aims to achieve. This approach has been used in many industries and a good example can be found in the book “Uptime: Strategies for Excellence in Maintenance Management” [6]. There can be a staged approach to achieving the desired level. For example, a company may wish to first achieve Understanding and then implement a plan to progress to Competence or Excellence.

It is important for each company to evaluate major incidents and review their own programs for weaknesses and deficiencies. Canadian and U.S. regulatory and industry bodies (such as the NTSB, AER, NEB, and PHMSA) will include interim directives, current incident investigation reports, and other communications on industry lessons learned. It may also be beneficial to consider regulations and industry practices that are not mandatory in the regulatory regime in which your company operates. Other pipeline or industry regulations and practices may be in a more advanced state or may contain useful approaches to more comprehensive integrity management systems. As previously mentioned, the API Recommended Practice 1173 addresses process safety management and safety culture in more detail than this chapter provides, and the reader is encouraged to review this document for additional information.

1.5 CORE STRUCTURE AND PIMS ELEMENTS

All pipeline companies have some degree of a PIMS in place; however, the PIMS elements typically are not fully integrated between business units and/or not effectively executed. So, what does a fully integrated and effectively executed PIMS look like? As mentioned in Section 1.1, there is no single “right” PIMS; however, the purpose of this chapter is to introduce a method to effectively structure and develop a PIMS.

A complex, interdependent system such as a PIMS can be difficult to describe and illustrate. One common way to represent a dynamic PIMS is using a Plan–Do–Check–Act (PDCA) cycle. The PDCA cycle can be drawn and interpreted in many ways and the reader is encouraged to customize the approach used here to meet their own needs. The PDCA cycle shown in Figure 1.2 has been adapted and
modified from PAS 55-1:2008 [4]. PAS 55 describes the importance of strategic planning (Plan), program enable and execution (Do), assurance and verification (Check), and management reviews (Act). In this chapter, we will examine each of these sections in terms of what they mean and present ideas for development.

The center circle in Figure 1.2 represents the ongoing PDCA cycle that must be in place to keep the integrity management system functioning to mitigate both asset and business risks. For clarification purposes, the primary inputs into the ongoing integrity management cycle are illustrated as arrows feeding into the circle. The PDCA cycle inputs include the following:

- New asset design–fabrication–construction–commissioning that tie in the asset life cycle.
- Improvement opportunities from outside the company to illustrate adopting industry lessons, new technology, and new concepts.
- Inputs that can impact asset integrity planning such as changes in company objectives, significant regulatory changes, new acquisitions, and so on.

**Plan:** strategic and operational plans

Planning sets risk reduction direction, incorporates new ideas and technologies, supports process improvement, and ensures appropriate resources are available.

**Do:** execute

This includes both processes that:  
- are common corporate processes such as MOC and training that provide the structure and skills to support core life cycle activities;  
- support core life cycle technical activities that address pipeline hazards in design, operations, and maintenance through to abandonment.

**Check:** assurance and verification

Processes to verify the effectiveness of the integrity management system.

**Act:** management review

Providing input for planning and strategic decisions.

**FIGURE 1.2** Integrity management Plan–Do–Check–Act cycle.
1.6 PIMS FUNCTION MAP

A function map, such as that shown in Figure 1.3, is another method that can illustrate the PIMS core elements. The intent of Figure 1.3 is to provide an overview of common elements; as such, it must be customized for each company. The same four elements of Figure 1.2 (Plan–Do–Check–Act) are incorporated into Figure 1.3. Function maps are particularly useful for structuring and organizing the systems a company uses to execute asset management activities.

1.7 PLAN: STRATEGIC AND OPERATIONAL

Figure 1.4 shows an expanded function map for the Plan element. Operational planning for integrity programs includes both annual activities and longer term strategic plans. In addition, operational planning often coincides with the annual budget cycle. An annual budget is created for ILI and excavations (digs), cathodic protection, risk assessments, scheduled training, facilities programs, and line replacements.

Strategic planning is a more comprehensive exercise and must incorporate lessons learned from management reviews as well as changes in corporate objectives and plans for new major projects or acquisitions. Strategic planning includes considering new concepts and ideas, addressing long-term risk reduction, and ensuring new major initiatives are properly planned and resourced. Strategic planning is about stepping back and ensuring there is a long-term focus on sustaining and improving integrity programs.

Strategic planning should also include the assessment of new technology, participating in joint industry projects, and funding research and development projects. In addition, technologies, ideas, and concepts from outside the oil and gas industry may provide a long-term benefit to the organization.

A strategic plan is more comprehensive than a 1-year annual budget cycle. Strategic plans often forecast multiple years in advance to plan the progressive advancement of key initiatives to improve pipeline integrity programs. For example, if a company’s goal is to move from Innocence to Excellence (using a process maturity perspective) for information management, strategic planning would outline a multiyear approach and achievable targets to progressively

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**FIGURE 1.3** Pipeline integrity management system (PIMS) function map.

**FIGURE 1.4** Plan function map.
advance the information management system at a manageable pace. Another example of strategic planning is the divestiture of low-value but high-risk pipeline assets.

1.8 DO: EXECUTE

The Do cycle shown in Figure 1.3 has three main components, which are expanded in Figure 1.5. The Do section includes the core life cycle technical activities that address pipeline hazards, documentation, and communication.

Risk management is a key element of integrity management and determines how pipeline risks are assessed and controlled by the organization. Risk management is a comprehensive framework of principles, processes, and procedures to ensure the safety and integrity of pipelines and facilities.

The ISO 31000:2009 [7] standard for risk management provides principles, framework, and a process for managing risk that can be applied to pipeline integrity. Risk management is not a stand-alone activity that is separate from the main activities and processes of the organization; rather, risk management is a part of management’s responsibilities and an integral part of all organizational processes, including strategic planning and all project and change management processes.

Risk management includes identifying threats, hazards, and/or degradation mechanisms that could lead to failure, characterizing risks, prioritizing actions, and executing risk control from design and construction through mitigation, monitoring, and inspection programs.

An effective risk management process will include the following:

- Process management to ensure effective execution and integration of the processes and supporting activities throughout the organization.

- A common understanding and effective communication between operations, engineering, maintenance, asset integrity, and other groups regarding their respective roles, responsibilities, and contributions to achieving safe and reliable operations.

- Defined physical and operational threats that could result in product release that could potentially have serious safety, environmental, production, or regulatory impacts.

- Processes to assess risks and guarantee that the appropriate prioritized controls are in place to reduce the likelihood of a release and to limit the consequence if a release occurs.

- Defined requirements to assess and continuously improve the risk management process through internal reviews, incident investigations, and the use of key performance indicators (KPIs). This may include developing metrics and defining categories (bounds) to indicate performance levels.

Enable processes are those that provide the support structure for pipeline integrity work. They are the common management processes that are used to guide and support the work activities, and they are applicable to all aspects of the company’s business. Examples include MOC, training and competency programs, and information management.

The effective execution of these processes is essential for a successful PIMS. These processes need to be in place to ensure that the knowledge, skills, and tools are available to manage risk and support the life cycle elements. As previously mentioned, failures still occur in companies that have corrosion controls and inspection programs in place; however, important hazards are still missed or are not properly addressed, so their risk management programs are ineffective for all relevant hazards. Examples of significant contributing factors to pipeline failures include a lack of training and

![FIGURE 1.5 Do (execute) function map: risk management, enable, and life cycle.](image-url)
knowledge, inadequate documentation and records management, and poorly applied MOC.

Life cycle processes of a management system include the technical processes and activities that are required to effectively execute integrity programs and activities. Life cycle processes are the technical core of pipeline integrity activities, and include the technologies and activities that are directly applied to the pipeline to prevent failures. For pipeline integrity, the activities and tasks can be broadly grouped into design and construction, maintenance (mitigation, monitoring, and inspection activities), assessment, and abandonment.

Design and construction includes materials selection, life cycle design, fabrication inspection, construction quality control, and commissioning that must be completed before a pipeline (new and repaired) is transferred to operations. Integrity issues that are “built” into a pipeline (such as weld seam defects, poorly applied coatings, construction dents, and incapability with ILI tools) either create additional hazards to manage during operation or limit the ability of operations to manage hazards. A well-thought-out life cycle design and the elimination/reduction of fabrication and construction defects can significantly improve pipeline safety and reliability.

Maintenance life cycle processes include mitigation (cathodic protection and chemical inhibition), monitoring (corrosion coupons and slope stability), and inspection (ILI, direct assessment, and ROW surveillance). These are the primary operation activities to address and control potential pipeline hazards such as external and internal corrosion, geotechnical hazards, and cracks.

Assessment processes are in place to ensure all hazards are understood and addressed, fitness for service methodology is applied to pipeline defects, and sound engineering judgment is used to make good decisions based on operation, monitoring, and inspection data.

Discontinue and abandonment processes are required to ensure end-of-life programs are in place and any residual hazards due to a pipeline are addressed.

1.9 CHECK: ASSURANCE AND VERIFICATION

The next element in the PDCA cycle is the Check (assurance and verification) step. This element includes external audits, internal reviews or assessments, incident investigation, and research and development. This also includes external inputs such as new technologies, industry lessons learned, involvement in joint industry projects (JIPs), and participating in industry task forces. Figure 1.6 outlines the expanded function map for the Check element.

The Check part of the PDCA cycle is critical, but often not well executed. During a review of major incidents, the NEB determined that capturing lessons learned and implementing learnings is an area often overlooked. The quote below is from NEB Safety Forum 2013 paper titled “Emerging issues in oil and gas industry safety management”:

The assessment indicted that while most organizations involved in the accidents had management systems or programs developed, they were not effectively implemented or reviewed on a regular basis to ensure adequacy and effectiveness.

A well-thought-out internal review process can be a useful way to assess the internal process and program effectiveness. The internal review process should include both the traditional audit check (“are we doing what we say we are doing”) and a way of measuring or quantifying effectiveness. The highest value obtained from an internal assessment will be a measure of program effectiveness and recommendations for improvements. A maturity grid or other assessment models can be used to support the assessment of effectiveness.

1.10 ACT: MANAGEMENT REVIEW

The “Act” portion of the Plan–Do–Check–Act cycle is shown in Figure 1.7. The management review is an assessment of the outcomes of pipeline integrity work, including

FIGURE 1.6 Check: assurance and verification.

FIGURE 1.7 Act: management review.
performance measures, audit and review results, reviews of major projects, outcomes from participation in industry task groups, and evaluation of important company and industry lessons learned. Management reviews can be conducted annually or as a more frequent, less formal, assessment.

Many companies have a dashboard summary report for senior management. The objective of a dashboard is to succinctly communicate a few key metrics that represent the ongoing performance of the pipeline integrity program and represent a “status or progress gauge.” The metrics or performance measures incorporated in a dashboard are often tied to a company’s specific safety, reliability, and production targets.

Management reviews often include high-level assessments such as a summary of the “top 5 risks.” This allows the most significant risks to the company to be understood and addressed at senior level in the organization. Addressing these risks can become part of the company’s strategic plan.

Management assessments provide direction for future activities. This direction can be expectations for process changes, audit improvements, and training requirements. The outcomes of the management reviews can be used to determine changes required or additional resources to support integrity programs or as inputs into longer term strategic plans.

1.11 CULTURE

The processes, procedures, skills, knowledge, and technologies required for pipeline integrity management are only one part of an effective PIMS; the other critical aspect is a process safety culture. Safety can be considered in two ways: occupational safety that addresses personal safety issues such as “slips, trips, and falls” and process safety that addresses preventing releases of any substance (ruptures and leaks) that could lead to injury/fatality and/or environmental damage. Process safety started in the chemical process industry after a series of serious equipment-related failures that resulted in numerous fatalities such as the Bhopal, India, disaster. Process safety includes both the mechanical integrity of the equipment and the safety culture required to ensure that the structure and company culture are aligned.

The importance of a safety culture is emphasized in CSA Z662 Safety Loss Management [8] and in API Recommended Practice 1173 [2]. As detailed in Section 1.1, the pipeline industry has had far too many major failures resulting in public fatalities (Carlsbad, Sand Bruno) and environmental damage (Kalamazoo, Red Deer River) [9]. Pipeline operators have been adopting process safety and cultural change into their overall approach to pipeline integrity management, with the goal to minimize, and ultimately eliminate, pipeline failures.

This overview of PIMS provides the framework and ties together the supporting processes and procedures to provide the overall structure to ensure pipelines are designed, built, operated, and maintained in a way that achieves pipeline safety and reliability. The functions described in the PIMS include the roles, responsibilities, and accountabilities that, when fully understood and implemented, can drive culture change.

1.12 SUMMARY

To be effective, a PIMS must be fully integrated within a company’s core business functions. The multiple interdependencies within an organization regarding integrity management need to be defined and understood. Operations, engineering, asset integrity, and many other groups have essential roles in achieving safe and reliable operations. The responsibilities and accountabilities must be clearly assigned and communicated.

In addition to role clarity between departments, the PIMS elements must be applied consistently across all operational departments, facilities, and geographic regions. The risks associated with lower value assets need to be understood and managed with the same diligence as high-value assets. The elements of integrity management should have the same focus and attention as the company’s commitment to personal safety and production targets.

The PIMS is a comprehensive, continually improving and evolving system that is essential to achieve safe and reliable operations. The PIMS does not need to be overly complex or heavily dependent on processes—it is fundamentally a simple system intended to effectively manage risks and assets. If companies create too much structure and implement complex controls, the system can become bogged down and rendered ineffective. PIMS can be successful if the interdependencies and relationships of the elements shown in Figure 1.2 are understood, the processes are in place to support these elements, and the roles and responsibilities are defined. The system requires regular reviews, assessments, and improvements to ensure it will continue to be effective and, as a result, both the company and the pipeline industry will change for the better.

REFERENCES


