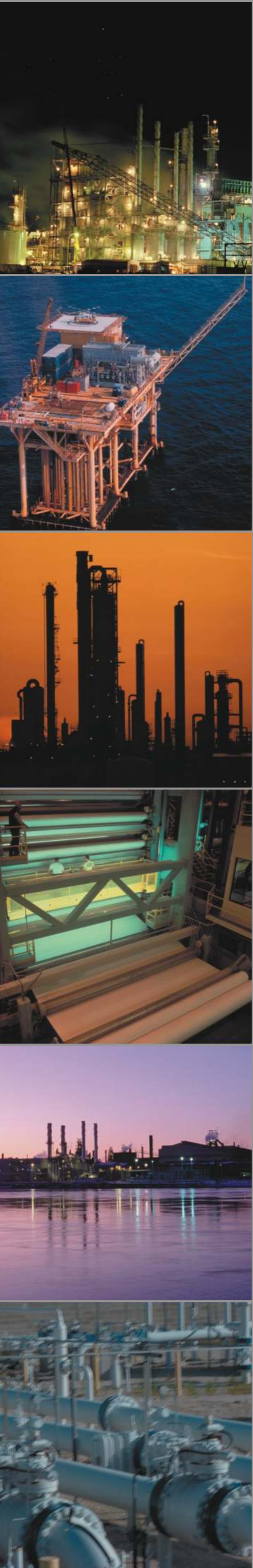

Risk Management Overview for Pipeline Projects

Executive Summary

Classical engineering design methods employ codes and standards to provide sufficient margins to assure successful performance. This approach is well proven for gas processing plants, compressor stations, and certain pipelines. However, some projects involve nontraditional risks because of incomplete information concerning design criteria or in-service conditions. Modern approaches to such situations can employ techniques of risk management to anticipate, prevent, and mitigate risks, and to improve profitability. In fact, risk management approaches can be successfully applied to pipelines that have been buried in the ground for decades, pipelines that are still on the drawing board, or pipelines that are currently under construction.

The traditional role of commercial risk management has been to recognize known hazards to the success of a project and to guide insurance purchases. However, some major risks of delays, economic losses, or failure of capital-intensive design and construction projects may well be uninsurable or only partially insurable. Modern engineering risk management methods, based on Quantitative Risk Assessments (QRA), provide a solid basis for anticipating, preventing, and mitigating both physical and economic risks. These engineering risk management methods have been practiced and refined for over 20 years. They were initially developed for use with high value/secret military systems and nuclear power plants. They are now being used to manage the risks of on-shore and off-shore piping systems and platforms, as well as many types of plants, including chemical, petroleum, and fossil power plants. Risk management methods are particularly effective when applied continually throughout the design, engineering, construction, and operation of such projects.

Risk Management Overview

Risk Management

Quantitative risk assessment is increasingly being used worldwide as a means of assuring that specific safety, environmental protection, and economic viability goals are met for novel engineering systems. Risk acceptance criteria that focus on environmental risks have been developed for various industries in Norway, the United States, the United Kingdom, and Canada, and are being considered by many more countries around the world. Further, risk management techniques are increasingly being employed to assess the impact of degradation materials on aging petroleum and chemical processing plants and in oil/gas platforms and pipelines. Not surprisingly, these techniques are also being used successfully to prioritize rehabilitation and maintenance activities.

Three fundamental types of risk are considered in a risk assessment:

- Risks of economic losses
- Risks to the environment
- Risks to personnel safety

In the early stages of a project, the risk is predominately economic (e.g., “What if we spend all this money on a detained design study and we determine that the project performance is uncertain, i.e., risky?”). As the project moves into the construction and operational phases, accidents, personnel safety, loss of production, and environmental risks increase relative to other risks. Towards the end of the economic life, the economic risks tend to be minimal and consist almost entirely of the costs associated with personnel and environmental hazards. Figure 1 depicts various process inputs during all stages of a project.

Risk can be mathematically characterized as the product of the probability of a given failure event and the consequences of that particular event (consequences can be expressed in terms of physical damage, personnel or other casualties, loss of production, or in monetary terms). A "high-risk" activity is typically one that either has a high probability of occurring (with limited consequences) or a low probability of occurring with significant consequences. For example, the failure of strainers in the cooling system of a gas processing plant would be an example of a high-probability/low-consequence event. However, the rupture of the pipeline and any resulting explosion and fire would be an example of a low-probability/high-consequence event. Note that even high- probability/low-consequence events, if they become common, can have high overall impact on economic risk, particularly when such events increase the probability of otherwise low-probability major events.

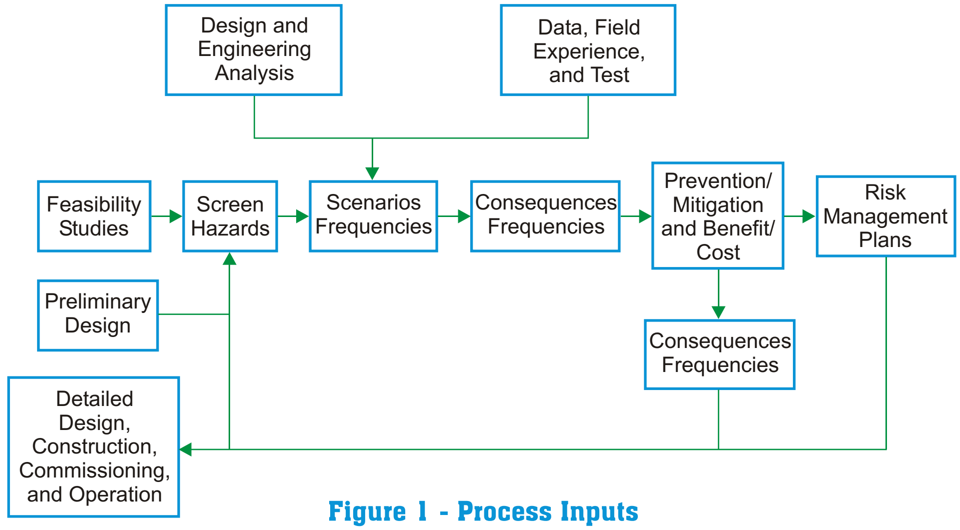

Figure 1 - Process Inputs

How Risk Assessment Results Are Used

Increasingly, risk assessment is used to support "no regrets" decision-making at all the stages of a project, from concept scoping to life style management of operations, maintenance, and replacement practices through to the end of useful life. **"No regrets" means that the decisions affecting the control of economic and safety-related risks make the best problem-solving use of all available information and resources.** The "regrets" situation that can be avoided, by using proper risk management techniques, is the common observation after major economic losses or accidents that : (1) the hazard was well recognized at some point in a project; and (2) in the absence of an accepted and systematic method for ranking the size of the risks, it was not assigned the appropriate level of importance. With proper risk management, all hazards should get the needed levels of attention for control, prevention, mitigation, and contingency planning.

Figure 2 is an overview of the language of risk. Figure 3 depicts the relationship between initiating events and scenarios. Figure 4 shows how we mathematically treat uncertainty in our state of knowledge.

What can happen?
How likely is that?
What are the consequences?

"AN" Answer	$< S_1\ \ell_1, X_1 >$
Set of Answers	$\{< S_1, \ell_1, X_1 >\}$
Complete Set	$\{< S_1, \ell_1, X_1 >\}_c$
"The" Risk =	$R = \{< S_1, \ell_1, X_1 >\}$

Defines S_c = "As Planned" Scenario

S_1 = "Risk Scenario"

H = Hazard = Set of S_1 Associated With Object/Operation

Figure 2 - Language of Risk

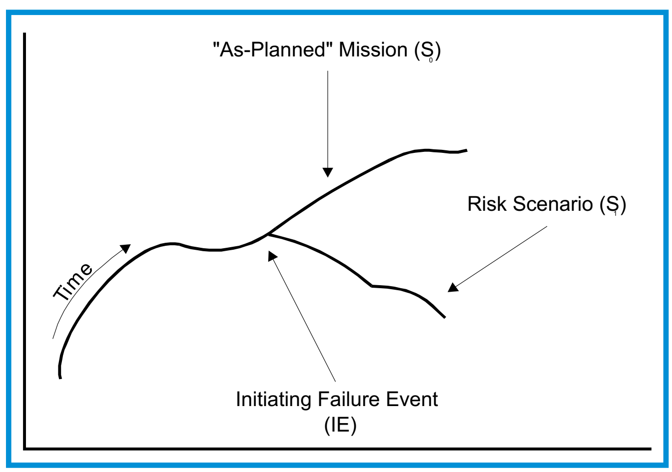

Figure 3 - Relationship Between Initiating Events and Scenarios

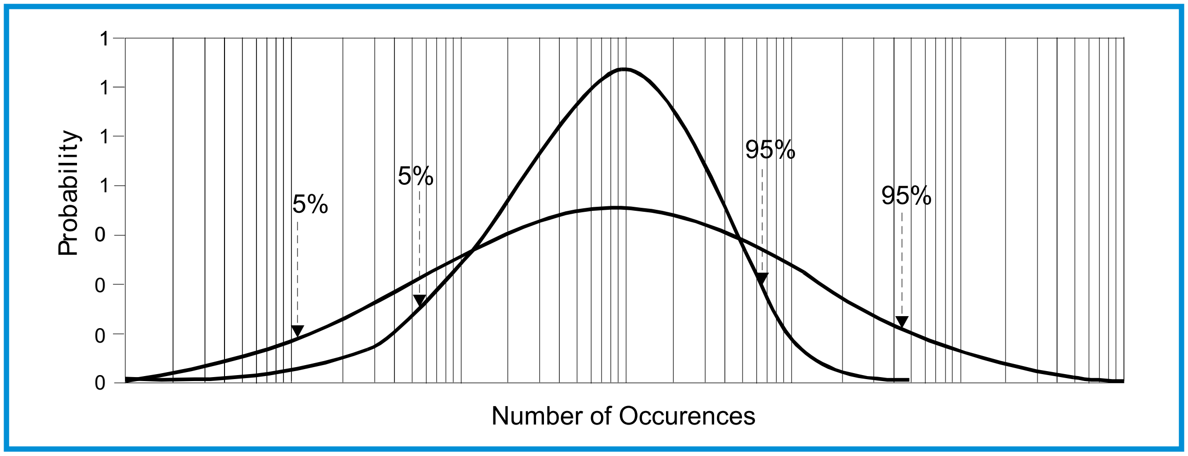

Figure 4 - How We Mathematically Treat Uncertainty in Our State of Knowledge

Risk Management for Existing Aging Pipelines

Risk Assessment in the Operational Phase

During the operational phase, the risks include:

- Loss of production
- Personnel safety (both on a day-to-day basis and in the event of a major accident involving loss of life)
- Environmental concerns due to a large-scale accident
- Risks introduced because of modifications to the pipeline (e.g., looping, branching, etc.) or the re-rating of the pipeline
- Risks introduced because of seasonal operational changes (e.g., line packing) or because of different contaminant levels resulting from contract carriage

Post-Construction Maintenance Phase

Once a pipeline is installed -- especially after years or even decades of operation – various other risk factors become important. These can include, for example:

- Material Degradation: Depending on the particular type of pipeline, this can include both low and high temperature types of degradation. Examples could include:
  - For Steel Piping: External and internal corrosion, including MIC (microbiologically influenced corrosion), coating disbondment, creep, graphitization
  - For Cast Iron Piping: Leakage at non-fused bell joints
  - For Plastic Piping: Bending and squeeze-off damage, embrittlement
- Growth of population centers above or in proximity to buried pipelines, increasing the likelihood of accidental impact damage
- Accumulation of freeze-thaw cycles

The risks inherent in these and other factors can be quantified and reduced through the use of techniques such as:

- Bayesian and other statistical analyses for probabilistic estimates of known and potential damage mechanisms
- Remaining useful life assessment and life cycle management
- Decision analysis for optimizing priorities and scopes of inspections and possible remedial actions

The result is optimized operations and maintenance (O&M) spending and enhanced pipeline reliability and safety with increased line lifetime.

Traditional Engineering Approach

The traditional engineering design process is generally viewed as the means by which a safe, cost-effective project is designed, constructed, and operated to meet intended performance and schedules. In this process, trade-offs are made between competing factors, such as cost and safety. For most types of structures, the acceptance levels in these trade-offs are based on an experience base of many years of successful operation. This experience base is often incorporated into design codes and standards, which evolve as the experience base shows that a given design element is either too safe (i.e., safety at a high cost) or not safe enough (i.e., failure experience). Technical uncertainties affect both the expected performance and the assurance of maintaining schedules for design, engineering, construction, and operational phases of a project.

However, when a unique engineering system is planned, there may not be adequate experience with similar systems on which to base the engineering design. Engineering management is left with little guidance in weighing the many trade-offs inherent in the design process (i.e., defining the acceptance criteria that lead to the appropriate factors of safety).

For those engineering projects that cannot be adequately defined on the basis of a past experience, risk assessment methodology can be used to optimally define a safe, reliable, and (in most cases) economic project.

Risk Management in the Design Phase

The consequences of a failure event during the design phase clearly will be entirely economic (the schedule slips and costs increase), although personnel safety and environmental concerns can also be raised. For example, the failure event that controls the main hazards during the design phase may be a design oversight that necessitates a redesign. Or, it may be a failure to convince financial organizations of the adequacy of the project's risk management plan. The principle failure events will change as the concerns shift from the project's economic risks to those directly affecting production, personnel, and the environment.

Risk Assessment in the Construction Phase

The construction phase introduces many types of potential hazards, including:

- Procurement problems (e.g., late deliveries due to material supply or production delays caused by shipping/manufacturing errors, inability to meet specifications, incoming inspection errors, and damage in storage or handling)
- Fabrication risks (e.g., welding quality deviations, excessive time cycles for welding and inspection, chronic equipment malfunctions, inspection deficiencies, and labor unrest or unavailability)
- Weather problems (e.g., storms disrupting the pipe placing operations)
- Emplacement risks (e.g., insufficient detail in the geotechnical survey, excessive sloping of the route, excessive spans, shifting due to subsidence or other factors)
- Personnel safety problems (e.g., accidents, injuries)
- Environmental design

How Risk Management Fits into the Design Process

It is apparent that the level and type of risk is constantly changing through time. However, risks associated with the operational phase also need to be considered during the design phase. Risk is best managed as part of an overall life cycle risk management program.

APTECH suggests a framework be developed for an overall life cycle risk management program. The known business and technical hazards, personnel errors, and potential for errors in design, specifications, procurement, fabrication, emplacement, and operations will be examined. The focus in developing this framework should be on economic factors. Consideration should be given to the higher levels of risks, including the effects of design changes, geotechnical surprises, extreme weather occurrences, seismic events, strikes, labor and material shortages, and exchange rate fluctuations.

It is important to note that it is difficult on some issues to quantify risk on an absolute scale (e.g., to be able to state the chance of an event happening and its expected cost). Even if this can be done, there are no generally-accepted guidelines on the acceptable level of risk (except for some very specific examples involving personnel risk under operating conditions). However, risk can be reliably determined on a relative basis. As long as the various risks are evaluated on the same basis, the use of relative risks allows the design team to optimize the use of resources. This means the design team can focus their resources on those factors that will provide the best cost/benefit ratio and produce a system with lowest overall risk.

Scoping Phase Uses

A feasability study for pipeline routing and operating conditions is an essential first step in a risk management program. This study provides a qualitative screening of known and evident hazards. This work will be followed by a preliminary (semi-quantitative) risk model to confirm that the principal hazards have been recognized and that reasonable extensions of known engineering, manufacturing, and construction practices can be used to limit and cope with these hazards. The qualitative ranking of the hazards at this stage sets the priority for the further detailing of the aspects of the design features that have the most leverage on risk control.

Figure 5 summarizes some of the typical sources of pipeline damage. Figure 6 provides statistics associated with these hazards. Figure 7 is an overview of a typical event scenario tree in which initiating events result in damage to a subsea pipeline and the consequences are defined by a downstream course of the tree.

Internal	External	Environmental	Deficiencies
Internal Corrosion	Dropped Objects	External Corrosion	Design Fault
Internal Erosion	Abrasion	Anode Depletion	Inadequate Specifications
Equipment Failure	Anchoring	Severe Storms	Material Defect
Operator Errors	Construction Operations	Earthquakes	Welding Defect
Stockage	Shipping Operations	Seabed Movement	Construction Fault
	Fishing Operations	Seabed Instability	
	Aircraft Operations	Liquefaction	
	Military Activity	Ice Bergs	
	Sabotage	Marine Growth	
		Frost Heave	

Figure 5 - Typical Sources of Pipeline Damage

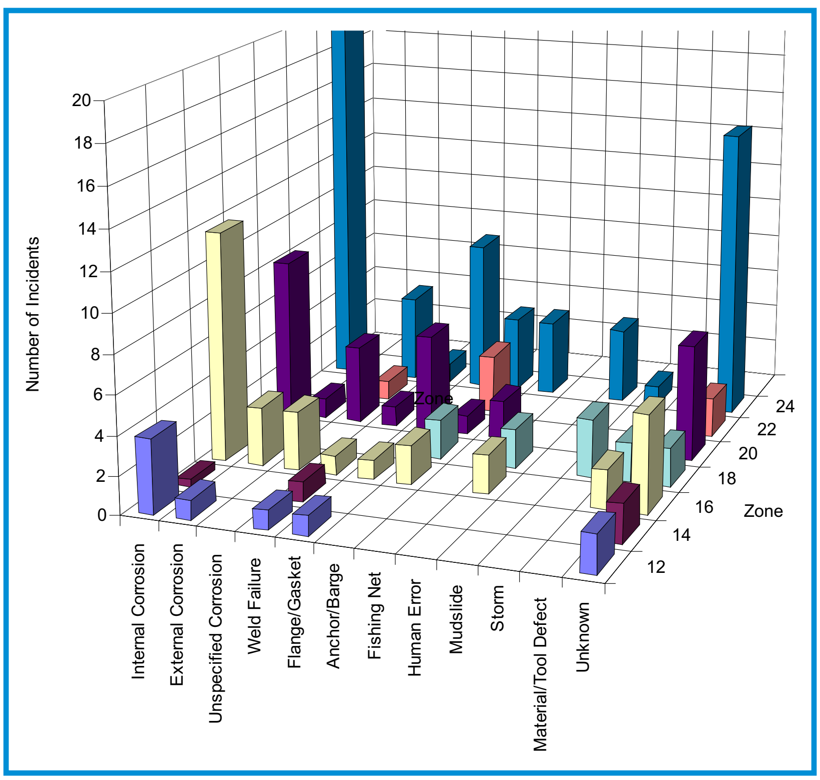

Figure 6 - Statistics Associated with Pipeline Hazards

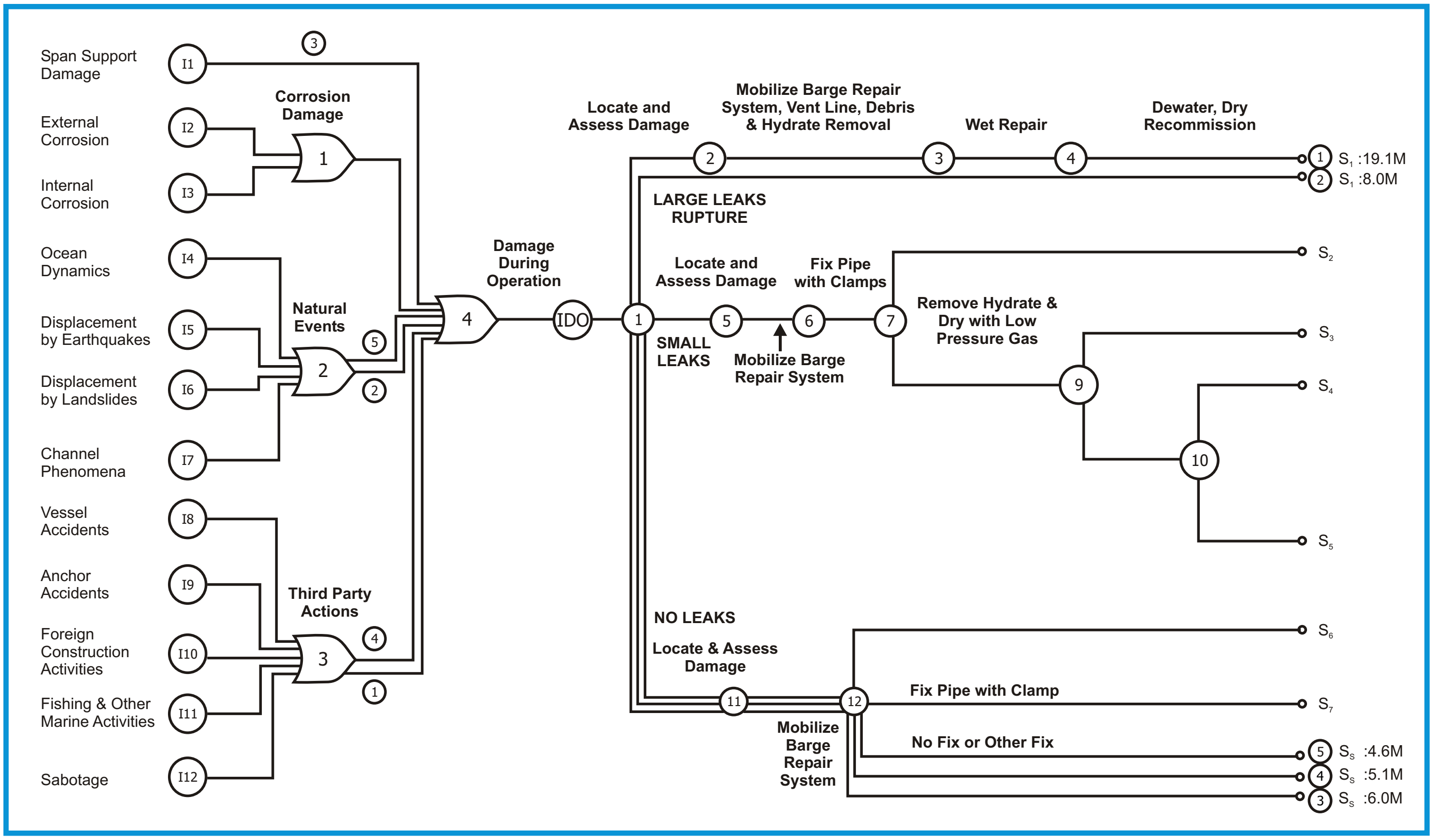

Figure 7 - Overview of a Typical Event Scenario Tree

Design Phase Uses

Incomplete handling of reasonable questions on the design basis and expected reliability performance of the system during the design phase can result in: (1) delays in getting project approvals; (2) delays in funding commitments; (3) delays in the start of manufacturing and construction; and (4) delays due to unanticipated requirements for design changes.

As the detailed design proceeds, risk models can be developed using "fault tree" methodology. Such models provide a framework for tabulating and ranking all of the significant hazards. A combination of generic reliability data and field experience, where applicable, can then be used to provide preliminary quantification and ranking of the various scenarios. These preliminary rankings are used as follows:

- To set priorities for the relative efforts applied to gathering improved reliability and field experience data
- To help define and prioritize engineering analysis tasks where design code experience is not fully applicable to define and control risks
- To define the goals and parameters for tests that can verify certain aspects of design, fabrication, construction, emplacement, or duty cycle that:
    - Have strong influence on the dominant hazards
    - Have elements of novelty or uncertainty not covered by adequate applicable field experience
    - Take account of realistic procedures for fabrication, inspection, and emplacement conditions

The ranking process assures that the best use is made of the available resources for design, analysis, and testing.

Construction Phase Uses

The principal hazard during the construction phase is again the economic effect of delays, but from a different set of controlling factors. Risk models can be developed to tabulate and quantify the relative risks of the known and anticipated hazards. These include, for example:

- Logistic Risks: The manufacturer does not meet material or dimensional specifications, or production rate is too slow for acceptable pipe, or delivery routes involve delays
- Field fabrication risks: The novel systems (e.g., for rapid field welding) do not regularly meet the target quality specifications, or are too slow, or inspection and rework are too slow
- Weather Risks: Excessive delays occur due to weather interruptions or due to repair/reinspeciton of damage incurred during severe weather
- Unexpected behavior of pipe during emplacement, for example due to insufficient detail in geotechnical contour surveys (e.g., shifting on slopes, unexpected spans, debris encounters)
- Accidents due to equipment failures, human errors, or unanticipated environmental conditions
- The qualitative and semi-qualitative ranking of these risks can be used to prioritize preventative and mitigating measures answering questions, such as:
  - What level of manufacturing capacity and back-up should be developed?
  - What levels of inventory of pipe are needed?
  - What level of spares and diagnostic systems should be provided for the fabrication and inspection equipment?

The money and effort applied to each of these should be in proportion to the risk reduction benefit by the risk assessment.

Summary of Risk Management

Risk management objectives and activities focus on technical and economic risks for both the short-term and long-term phases of a pipeline project. These objectives typically include:

- Establishing a basis for satisfying customers and financial organizations concerning the technical merit and risk control measures of a pipeline project
- Ensuring that the owners of the pipeline are not subjected to financial loss during pipeline design, construction, and operation

An added value of this approach is that risks to personnel and to the environment are likewise minimized.

Pipeline Experience

Clients	Projects
Investigation of COG Pipeline Leak	Investigation of COG Pipeline Leak
Alcoa of Australia	High Energy X-ray Inspections of Insulated Pipeline
Burnham & Brown	Investigation of Pipeline Pig Receiver Accident
Capello & McMann	Investigation of Cause of a Petroleum Pipeline Leak
Carrol, Burdick, and McDonough	Examination of Santa Fe Pipeline
Celanese LTD	Pipeline Integrity Management: Celanese Propylene Pipeline
Celeron Pipeline Corporation	Examination of Santa Fe Pipeline
Delta Wetlands	Pipeline Construction Cost Estimate
Fluor Engineer & Constructors	Fracture Evaluation of NW Alaska Pipeline
Fluor Daniel	Risk Analysis of Caspian Pipeline
Gonzales & Associates	Pipeline Failure Analysis
Law Offices of Dykema Gossett	Analysis of Pipeline Failure
Law Offices of Irwin Schwartz	Pipeline Rupture
Los Angeles Department of Water & Power	Surge Analysis of Fuel Oil Pipeline Facilities
McGowan Broz Engineers	GATZ Terminal Pipeline Life Assessment
Mirant Delta LLC	Metallurgical Evaluation of Ruptured Fuel Oil Pipeline
Nordman, Cormany, Hair & Compton	Crude Oil Pipeline Failure
Occidental Permian LTD	Oxy Pipeline RBI Program
Oman Oil Company	Oman_Indian Gas Pipeline Project
Standard Alaska Product	Analysis of Failed Gathering System Pipeline
The Aerospace Corporation	Evaluation of Oil Pipeline for Strategic Petroleum Reserve
Thelen, Reid & Priest	Water Pipeline Investigation
Todd & Weld	Analysis of Gas Pipeline
Walk Haydel & Associates	Fitness-for-Service Evaluation of Pipeline Girth Welds

Additional Information

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