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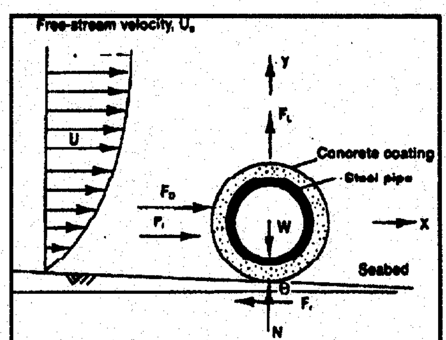
# FEASIBILITY STUDY OF DEVELOPMENT OF A COMPUTERIZED MARINE *PIPELINE INSPECTION, MAINTENANCE, AND PERFORMANCE INFORMATION SYSTEM* *"PIMPIS"*

**Report to**

**Exxon Production Research Company**
**Houston, Texas**

**and**

**U. S. Minerals Management Service**
**Technology Assessment and Research Branch**
**Herndon, Virginia**




**By**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**UNIVERSITY OF CALIFORNIA AT BERKELEY**


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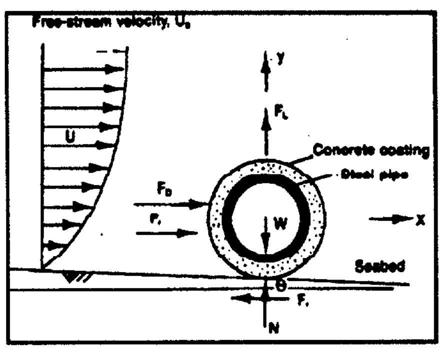


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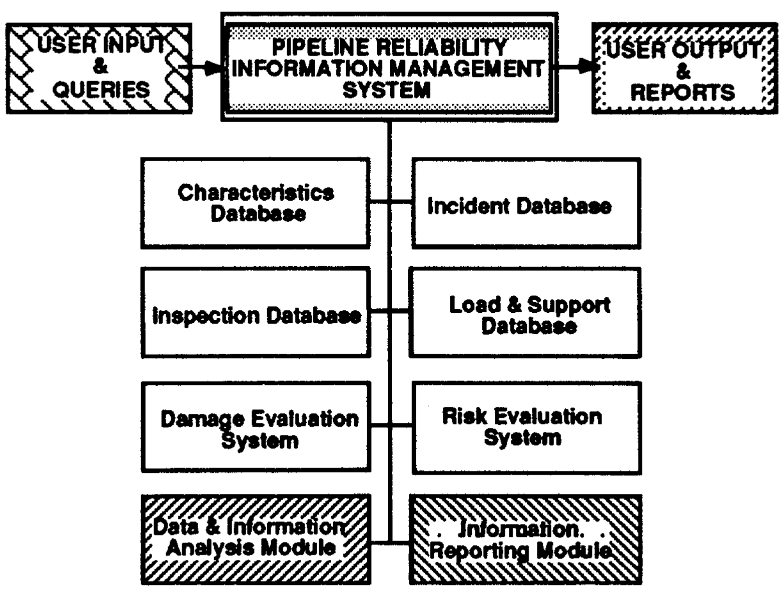
# SUMMARY


The objective of this study was to document and demonstrate the feasibility of developing a computerized Pipeline Inspection, Maintenance, and Performance Information System (PIMPIS) that can form the basis for an industry - government wide database and decision making system for marine pipelines, and provide the greatest assistance to all involved in tracking the life-cycle performance of marine pipelines, including owners, engineering contractors, operators, inspectors, and regulatory authorities.

To fulfill this objective, PIMPIS was organized to have the following primary functions:

- provide pipeline population data
- identify potential hazards
- provide estimates of the incident occurrence frequency
- provide estimates of the achieved safety levels
- provide pipeline operational data
- provide pipeline inspection, maintenance and repair data
- provide load data
- assess the pipeline integrity upon feature detection
- determine remedial measures upon assessment

PIMPIS is composed of a pipeline characteristics database, an incident database, an inspection database, a load - support database, a damage evaluation system, and a risk evaluation system. Three key modules have the function of managing information input and output from PIMPIS, performing the necessary analyses and producing standardized written, tabular, and graphical output. The structure of PIMPIS is summarized in the following figure:


**The structure of PIMPIS**

The pipeline characteristics database contains details of all the pipelines installed in the Gulf of Mexico, and as the system is further developed, pipeline characteristics in other offshore areas. The pipeline characteristics database includes information such as pipeline engineering, manufacturing and construction data. It also provides the population data on pipelines in a given area such as the number of pipelines, length, and operating experience.

The incident database contains a description of each reported pipeline incident. It provides estimates of the likely incident occurrence frequency, and estimates of the safety levels achieved in the operation of pipelines. It is noted that an extensive marine pipeline incident database has been complied by the Marine Technology Development Group (MTDG) at the University of California at Berkeley (UCB) sponsored by the Minerals Management Services (MMS) [Woodson, 1990]. This database has been further developed by the Minerals Management Service office located in New Orleans, Louisiana.

The inspection database contains a description of each defect or operational fault detected during on-line inspection, and subsequent remedial actions. It is used for fitness-for-purpose assessment of an individual pipeline, as well as for evaluation of existing pipelines in general. To make PIMPIS a truly valuable industry - government wide database and decision making system, it is very important to obtain reliable inspection and repair data for the existing marine pipelines.

The load and support database contains information about operational, environmental and accidental loads, including the operating and testing pressure records for each pipeline, long-term distributions of wave and current in various blocks of the Gulf of Mexico (and other areas as PIMPIS is developed), and accidental impact loads from the third parties. Geotechnical information on soil conditions along the route of the pipeline are included together with information on the installed and current burial conditions.

The damage evaluation system contains necessary criteria for evaluating pipeline integrity upon damage or change in service using inputs from various databases within PIMPIS.

The reliability evaluation system module contains the information necessary to characterize the reliability of the pipeline in a given area for a proposed service. This includes information from the foregoing modules and in particular information on loading and support conditions (all sources of stresses induced in the pipeline) and information on the capacity characteristics [Sotberg, 1990]. Pipeline reliability is evaluated in both qualitative and quantitative terms [Sotberg, 1990; American Gas Association, 1994]. The AGA (American Gas Association) qualitative system has been developed specifically for the prioritization of pipeline maintenance and identification of high risk areas for pipelines [Marine Board, 1994].

The reporting module provide systems for responding to user queries via standardized written, tabular, and graphical formats. The analysis module provides the necessary computational algorithms for all of the other systems and modules within PIMPIS.

The Information Management System (IMS) provides the overall logic for PIMPIS interfacing with the other eight modules.

A graphical interface would be developed to facilitate data input, analysis, and evaluations. Knowledge Base - Expert Systems, Neural Networks, and Fuzzy Set technologies would be developed as a part of the "Soft Computing" requirements of these developments. One such system has been developed by the American Gas Association to define in soft computing terms the relative pipeline risk. Risk is defined as the product of the probability of failure and the consequences of the failure. Probability factors include coating type, cathodic protection, stress corrosion cracking, pipe condition, coating condition, wall thickness, soil type, leak history , and other items. Consequence factors include location and propagation of ductile and brittle fracture.

Each factor is assigned a weighted number defined in the algorithm instructions to correspond with a level of probability or consequence. This number is then integrated into the algorithm to calculate the risk index [American Gas Association, 1994].

Based on this feasibility study, it is recommended that the development of PIMPIS should be divided into the following phases:

**Phase 1: Continued data collection from pipeline operators, regulatory authorities and inspectors** (the extent of this effort would depend on the progress achieved by the MMS in developing a comprehensive pipeline information and integrity database)

**Phase 2: Compilation of individual databases and development of the PIMPIS system** (the extent of this effort would depend on the progress achieved by the UCB MTDG in developing similar integrity information systems for commercial ships and platforms)

**Phase 3: Development of a graphical interface to link individual databases and system** (the extent of this effort would depend on the progress achieved by the UCB MTDG in developing similar integrity information systems for commercial ships and platforms)

**Phase 4: Verification and completion**

# 1.0 INTRODUCTION

## 1.1 BACKGROUND

Marine pipelines are major transportation systems in oil and gas fields. The consequences of pipeline failures may not only result in heavy economical losses due to system shut-downs and repairs, but also constitute serious hazards to the environment due to loss of containment of the transported oil or other chemicals. It is thus important that marine pipelines are designed and operated safely [Jones, Davis, Tauzin, 1991].

As a result of a National Research Council, National Academy of Engineering, Marine Board study sponsored by the Minerals Management Services (MMS), a project was completed by the Marine Technology Development Group (MTDG) at the University of California at Berkeley (UCB) on the failure of marine pipelines. This project resulted in development of a first-generation computer database on failures of marine pipelines in the Gulf of Mexico [Woodson, 1990]. In the Woodson database, over 1000 offshore pipeline failures in the Gulf of Mexico Offshore waters were included. The MMS has continued development and refinement of this database [Alvarado, 1993].

During Hurricane Andrew (1993), 396 incidents on marine pipelines were reported [Alvarado, 1993]. It was found that the causes of failures were mainly due to overload from currents and waves, strength degradation, mechanical failures, dragging anchors, collisions from mobile drilling units, and human error. Many of these failures could have been avoided if an advanced industry - government wide database and decision making system had been available to all parties involved in tracking the life-cycle performance of marine pipelines.

In 1991, the MMS sponsored an International Workshop on Offshore Pipeline Safety in New Orleans. The proceedings of this workshop [Morris ed., 1991] provide one of the most comprehensive documents available on the reliability of marine pipelines. The proceedings address design, integrity assessment, monitoring, performance, and repair considerations. A key issue addressed is the need for development of a comprehensive industry - government wide computer database to archive information on the inspection, maintenance, and performance of marine pipelines. This same key issue has been identified in the study being performed for the MMS by the Marine Board [1994].

Development of a pipeline reliability database for North Sea pipelines has been initiated [Hokstad, 1989]. This development has included development of algorithms to characterize the reliability of pipelines for a proposed service [Sotberg, 1990].

During the time period of these developments, the UCB MTDG has performed several projects that have addressed development of computer databases for the inspection, maintenance, and performance of marine structures. Two extensive databases have been developed that address cracking and corrosion problems in tankers. A Repair Management System (RMS) has been developed that interfaces with these databases and provides information to assist decisions on inspections (when, where, how) and repair (when, alternatives) [Bea, 1993]. A graphical interface has been developed to facilitate data input, analysis, and evaluations. Knowledge Base - Expert Systems, Neural Networks, and Fuzzy Set technologies have been explored as a part of the "Soft Computing" requirements of these developments.

In addition, a computer database Ship Structural Integrity Information System (SSIIS) has been developed to enable the "life-cycle" tracking of commercial ship structures to ensure their adequate "quality" (serviceability, capacity, durability, compatibility). SSIIS embodies many of the same attributes that have been defined in PIMPIS. SSIIS will enable all of the parties concerned with the quality of ship structures to perform evaluations and report developments. One of the prime objectives of SSIIS is communications between the concerned regulatory agencies (e.g., U. S. Coast Guard), the classification societies (e.g., American Bureau of Shipping), the ship owners and operators, and the ship builders and repair yards.

In 1991, the Marine Board proposed a study of the safety of marine pipelines to the Office of Pipeline Safety (OPS) of the Department of Transportation and to the U. S. Minerals Management Service (MMS). This proposal was approved by the OPS and MMS and a study initiated in April 1992. In 1994, the Marine Board Committee on the Safety of Marine Pipelines issued a comprehensive report that contained the following key recommendations:

> *"...the regulatory agencies involved develop a common safety data base, covering both state and federal waters, and periodically review their data requirements. The focus should be on collecting, archiving, analyzing, and reporting safety data with the intent of improving design and operating regulations. The extended database should include the information needed for risk and cost-benefit analysis. MMS, which has the greatest test experience and resources in data gathering, should coordinate this effort."*

> *"...safety regulations be based on sound risk analyses and cost-benefit analyses. Specifically, regulatory agencies should agree on a consistent risk management strategy for setting priorities about human safety criteria, and about the use of cost-benefit analysis for the reduction of property and environmental damage. A zone-based risk analysis model, based on the zonation approach....should be developed on the basis of currently available information and then be regularly updated, to help determine whether regulations should be revised, strengthened, or relaxed and to assist in establishing priorities for the operational use of resources by both government and industry for enhancing pipeline safety (such as inspection coverage and frequency, use of intern al inspection devices, and establishment of burial depths for areas having high erosion rates)."*

> *"...MMS should coordinate an effort by appropriate federal and state regulatory agencies and industry to establish a system through which leaks detected by third parties can be reported to a single agency or notification center with continuous coverage around the clock. This one central location should have a comprehensive data base permitting easy identification of the operator of any marine transmission or production line based on the reported sighting location. All maritime entities should be encouraged to use this single reporting center. Pipeline operators, in turn, should have 24-hour telephone numbers of a means of immediately contacting all other pipeline and platform operators who must take action."*

Based on these developments, it is apparent that the time has come to develop a computerized Pipeline Inspection, Maintenance, and Performance Information System (PIMPIS) that can form the basis for an industry - government wide database on marine pipelines. This database will provide the greatest assistance to all parties involved in tracking the life-cycle performance of marine pipelines, by taking advantage of the latest developments in "Knowledge-Based Systems" and "Soft Computing Systems".

## 1.2 OBJECTIVE AND SCOPE OF STUDY

The objective of this study was to document and demonstrate the feasibility of developing a computerized Pipeline Inspection, Maintenance, and Performance Information System (PIMPIS) that can form the basis for an industry - government wide database and decision making system for marine pipelines.

The primary tasks of this study were:

- to define the features that should be provided in PIMPIS, which will include marine pipeline engineering, manufacturing and construction, testing, operation, maintenance, inspection, monitoring, and repair data.

- to define the functions that should be provided in PIMPIS, which will provide the greatest assistance to all involved in tracking the life-cycle performance of marine pipelines, including owners, engineering contractors, operators, inspectors, and regulatory authorities.

## 1.3 ACKNOWLEDGMENTS

This research was performed as part of a post-doctoral research program at the Department of Naval Architecture and Offshore Engineering, University of California at Berkeley. The Principal Investigator was Dr. Guoyang Jiao. This research was performed under the supervision of and with the assistance of Professor Robert Bea.

This research was made possible by research funds provided by the U. S. Minerals Management Service and by Exxon Production Research Company. Special appreciation is expressed to Mr. Charles Smith (Manager, Offshore Technology and Research Program) and Mr. Alex Alvarado (Supervisor, Pipeline Unit, Gulf of Mexico Region) of the U. S. Minerals Management Service, and to Dr. Edward Clukey of Exxon Production Research Company for the assistance and direction they provided during this research.

# 2.0 DESCRIPTION OF PIMPIS

## 2.1 General

A computerized Pipeline Inspection, Maintenance, and Performance Information System (PIMPIS) is to form the basis for an industry - government wide database on marine pipelines. This database will provide the greatest assistance to all parties involved in tracking the life-cycle performance of marine pipelines, by taking advantage of the latest developments in "Knowledge-Based Systems" and "Soft Computing Systems".

## 2.2 Structure

PIMPIS is composed of a pipeline database, an incident database, an inspection database, a load database, and a damage evaluation system. The structure of PIMPIS is illustrated in Figure 2.1

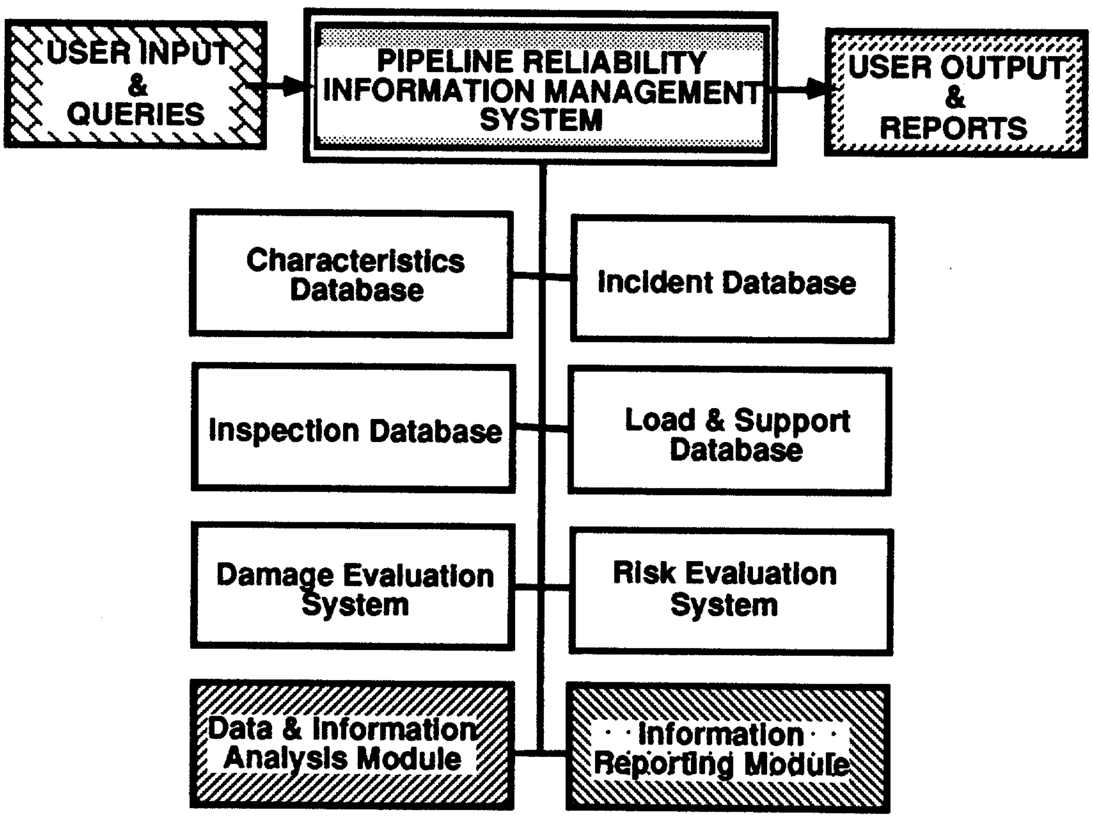



**Figure 2.1 - Structure of Pipeline Inspection, Maintenance, and Performance Information System (PIMPIS)**

Each primary component of PIMPIS is described in the following paragraphs.

User Input & Query

The PIMPIS user defines the nature of the interface with PIMPIS (to input information or to develop output information), and the types of queries that are desired (types of data analyses, graphical output, standardized reporting formats).

Information Management System

Defines which of the PIMPIS modules will be accessed, how they will be accessed, how input information will be validated, and the types of analyses that will be performed.

User Output & Reporting

Tabular, graphical and standardized paper and electronic reporting user reporting.

Pipeline Characteristics Database

The pipeline characteristics database contains details of all the pipelines installed in the Gulf of Mexico, including pipeline engineering, manufacturing and construction data. It also provides the population data such as the number of pipelines, length, and operating experience.

Incident Database

The incident database contains a description of each reported pipeline incident. It provides estimates of the likely incident occurrence frequency, and estimates of the safety levels achieved in the operation of pipelines.

Inspection Database

The inspection database contains a description of each defect or operational fault detected during on-line inspection, and subsequent remedial actions. It is used for fitness-for-purpose assessment of an individual pipeline, as well as for evaluation of existing pipelines in general.

Load and Support Database

The load database contains information about operational, environmental and accidental loads, including the operating and testing pressure records for each pipeline, long-term distributions of wave and current in various blocks of the Gulf of Mexico, and accidental impact loads from the third parties. Geotechnical information on soil conditions along the route of the pipeline are included together with information on the installed and current burial conditions.

Damage Evaluation System

This system contains necessary criteria for evaluating pipeline integrity upon damage using inputs from various databases within PIMPIS.

A graphical interface will be developed to facilitate data input, analysis, and evaluations. Knowledge Base - Expert Systems, Neural Networks, and Fuzzy Set technologies should be developed as a part of the "Soft Computing" requirements of these developments.

Risk Evaluation System

Given information on the characteristics of the pipeline, its present condition, the nature of any previous incidences with either this pipeline or similar pipelines, information on the pipeline loadings and support conditions, a risk analysis is performed to determine the likelihood associated with loss of serviceability of the pipeline for its proposed service. This information is integrated into a comprehensive pipeline risk exposure system to define the priorities for future inspection, monitoring, maintenance, and analysis efforts. The risk analysis is performed in both qualitative and quantitative terms. The qualitative method is intended to prioritize pipelines for maintenance and rehabilitation and to identify high risk pipeline "corridors" [American Gas Association, 1994].

The reliability evaluation system module contains the information necessary to characterize the reliability of the pipeline in a given area for a proposed service. This includes information from the foregoing modules and in particular information on loading and support conditions (all sources of stresses induced in the pipeline) and information on the capacity characteristics [Sotberg, 1990]. Pipeline reliability is evaluated in both qualitative and quantitative terms [Sotberg, 1990; American Gas Association, 1994]. The AGA (American Gas Association) qualitative system has been developed specifically for the prioritization of pipeline maintenance and identification of high risk areas for pipelines [Marine Board, 1994].

Analysis Module

This module defines the algorithms and types of analyses that will be performed. These analyses could be either analyses of data in the database to determine trends or analyses of information in the database to determine future performance characteristics.

Reporting Module

This module contains the written, tabular, and graphical information reporting routines.

## 2.3 Descriptions

PIMPIS can be used to:

- provide pipeline population data (e. g. hazardous and non-hazardous areas)
- identify potential hazards
- provide estimates of the incident occurrence frequency
- provide estimates of the achieved safety levels
- provide pipeline operational data
- provide pipeline inspection, maintenance and repair data
- provide load data
- assess the pipeline integrity upon feature detection
- determine remedial measures upon assessment

The pipeline population data, typically in terms of the number of pipelines, miles and in-service years of pipelines, may be obtained from the pipeline database for all the pipelines or a specific class of pipelines, as summarized in Table 2.1.

Table 2.1: Pipeline database

| Population data | Classification |
|---|---|
| Total number<br>Total miles<br>Total operating years<br>... | Overall<br>Type: steel lines, flexible<br>Content: oil, gas, ...<br>Size: 2", 4", ..., 40", ...<br>Age:<br>... |

The incident database contains a description of each reported pipeline incident, including cause, location, pipeline condition at the time of incident detection, consequences of incident, etc., as presented in Table 2.2.

Table 2.2: Incident database

| Causes | Classification |
|---|---|
| Impact<br>Corrosion<br><br>Structural/material<br>Natural hazard<br>Mechanical<br>Human error | Number of incidents<br><br>Location: riser, safety zone,<br><br>Pipeline condition: temporary, operating,<br><br>Consequence: leak, pollution |

The major hazards to pipelines, their likely occurrence frequencies, and the pipeline safety levels achieved in operation, are provided by estimating the incident rate, based on the pipeline database and incident database. Table 2.3 summarizes typical pipeline groupings and frequency units used in comparing the significance of reported incidents.

Table 2.3: Incident rate

| Grouping | Frequency |
|---|---|
| Overall<br>By line types<br>By size<br>By age<br>By operating pressure<br>By cause<br>By content types<br>By locations<br>By extent of pollution | per year<br>per mile<br>per pipeline<br>per year per mile<br>per year per pipeline<br>per year per safety zone<br>... |

The inspection database contains information of each defect or operational fault detected during on-line inspection, and subsequent remedial actions, as illustrated in Table 2.4. It provides input for fitness-for-purpose assessment of an individual pipeline, as well as for evaluation of existing pipelines in general.

Table 2.4: Inspection database

| Feature | Description | Sampling |
|---|---|---|
| Buckle<br>Impact damage<br>Crack<br>Corrosion<br>Coating damage<br>Spanning<br>Sea bed modification<br>Pipeline movement<br>... | Inspection/detection method<br>Time to inspection<br>Remedial actions<br>... | Number<br>Size<br>Distribution<br>... |

The load database contains information about functional, environmental and accidental loads, including the operating and testing pressure records for each pipeline, long-term distributions of wave and current in various blocks of the Gulf of Mexico, and accidental impact loads from the third parties. A description of the load database is given in Table 2.5.

Table 2.5: Load database

| Load type | Recording |
|---|---|
| Functional:<br>- maximum operating pressure<br>- pressure fluctuations<br>- other<br><br>Environmental:<br>- waves<br>- current<br>- other<br><br>Accidental:<br>- third party impact<br>- other | Magnitude<br>Frequency/cycles<br>Long-term statistics<br>Short-term statistics<br>... |

The damage evaluation system is a decision making system based on inputs from the pipeline database, inspection database and load database. As shown in Table 2.6, it contains a set of limit state criteria or protective measures for evaluation of the acceptability of detected features, based on which, remedial actions may be taken accordingly.

Table 2.6: Damage Evaluation System

| Feature | Load | Limit state criterion | Remedial action |
|---|---|---|---|
| Buckle | Functional | Buckling/collapse | Following inspection<br>Repair |
| Dent | Functional | Fracture/fatigue<br>Collapse/ovalization | Replacement<br>... |
| Crack | Functional/Environmental | Fracture/fatigue | |
| Corrosion | Functional | Bursting | |
| Impact | Accidental | Leak/rupture/collapse | |

Given information on the characteristics of the pipeline, its present condition, the nature of any previous incidences with either this pipeline or similar pipelines, information on the pipeline loadings and support conditions, the risk evaluation system develops qualitative and quantitative assessments to determine the likelihoods associated with loss of serviceability of the pipeline for its proposed service. This information is integrated into a comprehensive pipeline risk exposure system to define the priorities for future inspection, monitoring, maintenance, and analysis efforts. The risk analysis is performed in both qualitative and quantitative terms. The qualitative method is intended to prioritize pipelines for maintenance and rehabilitation and to identify high risk pipeline "corridors" [American Gas Association, 1994].

The reliability evaluation system module contains the information necessary to characterize the reliability of the pipeline in a given area for a proposed service. This includes information from the foregoing modules and in particular information on loading and support conditions (all sources of stresses induced in the pipeline) and information on the capacity characteristics [Sotberg, 1990]. Pipeline reliability is evaluated in both qualitative and quantitative terms [Sotberg, 1990; American Gas Association, 1994]. The AGA (American Gas Association) qualitative system has been developed specifically for the prioritization of pipeline maintenance and identification of high risk areas for pipelines [Marine Board, 1994].

The Analysis Module defines the algorithms and types of analyses that will be performed by PIMPIS. These analyses could be either analyses of data in the database to determine trends or analyses of information in the database to determine future performance characteristics.

The Reporting Module contains the standardized written, tabular, and graphical information reporting routines that are used to respond to user input and queries.

More detailed descriptions of each component of the database are presented in the following Chapters of this report.

# 3.0 PIPELINE CHARACTERISTICS DATABASE

The pipeline database contains details of all the pipelines installed in the Gulf of Mexico. It is to provide the population data including

- total number of pipelines
- total length
- total operating experience, in years, in km-years, or in pipeline-years

Further population data is useful by classifying pipelines in terms of

- line types (steel lines, flexible)
- size (large, medium, or small diameter)
- content (oil, gas, or others)
- maximum operating pressure

The structure of the pipeline database is as shown in Table 3.1.

Table 3.1: Pipeline database

| Population data | Classification |
|---|---|
| Total number<br>Total miles<br>Total operating years<br>... | Overall<br>Type: steel lines, flexible<br>Content: oil, gas, ...<br>Size: 2", 4", ..., 40", ...<br>Age:<br>... |

## 3.1 Compilation of the Pipeline Database

In compiling the pipeline database, the following information needs to be included:

NAME:

- name or ID number

TYPE:

- steel lines vs. flexible
- trunk export pipeline
- inter field pipeline
- infield pipeline
- flowline
- loading line

LOCATION:

- block number (from/to)
- start point and end point

OPERATOR:

LENGTH:

- a pipeline extends from the pig trap and associated pipe work and valves, and including all pipe work and fittings on the main flow path and all branches on the main flow up to and including the first valve on each branch. Where a pipeline does not have a pig trap the first valve above water level is the termination point.

SIZE:

- nominal steel thickness
- nominal steel outer diameter
- nominal overall diameter

SPECIFICATION:

- for steel pipelines: steel grade (APL 5L steel, etc.)
- for flexible flowlines: coflexip, pag-o-flex, dunlop, duplex, hose, etc.

CONTENTS:

- gas
- oil
- mixture of oil and gas
- condensate
- injection water
- other chemicals including methanol, glycol, etc.

COATINGS:

- concrete coating and thickness
- thermal coating and thickness
- corrosion coating

PROTECTION:

- trenched/buried
- corrosion allowance/corrosion anode

PRESSURE CONTROL:

- maximum operating pressure
- design pressure
- pressure surge (transient pressure)
- hydro-testing pressure
- set pressures of the pressure regulating and safety system

WATER DEPTHS:

MILESTONES:

- date installed
- date tested
- date commissioned
- date abandoned

## 3.2 Sources of Data

Sources for compilation of the Gulf of Mexico pipeline database are mainly

- regulatory authorities
- pipeline operators

There are about 20,000 miles of pipeline approved in the Outer Continental Shelf (OCS) in the Gulf of Mexico, Pearcy (1993). Figure 3.1 shows statistics from 1984 - 1991. Miles of pipelines installed in the Gulf of Mexico OCS region in the period of 1950 to 1991 is shown in Figure 3.2.

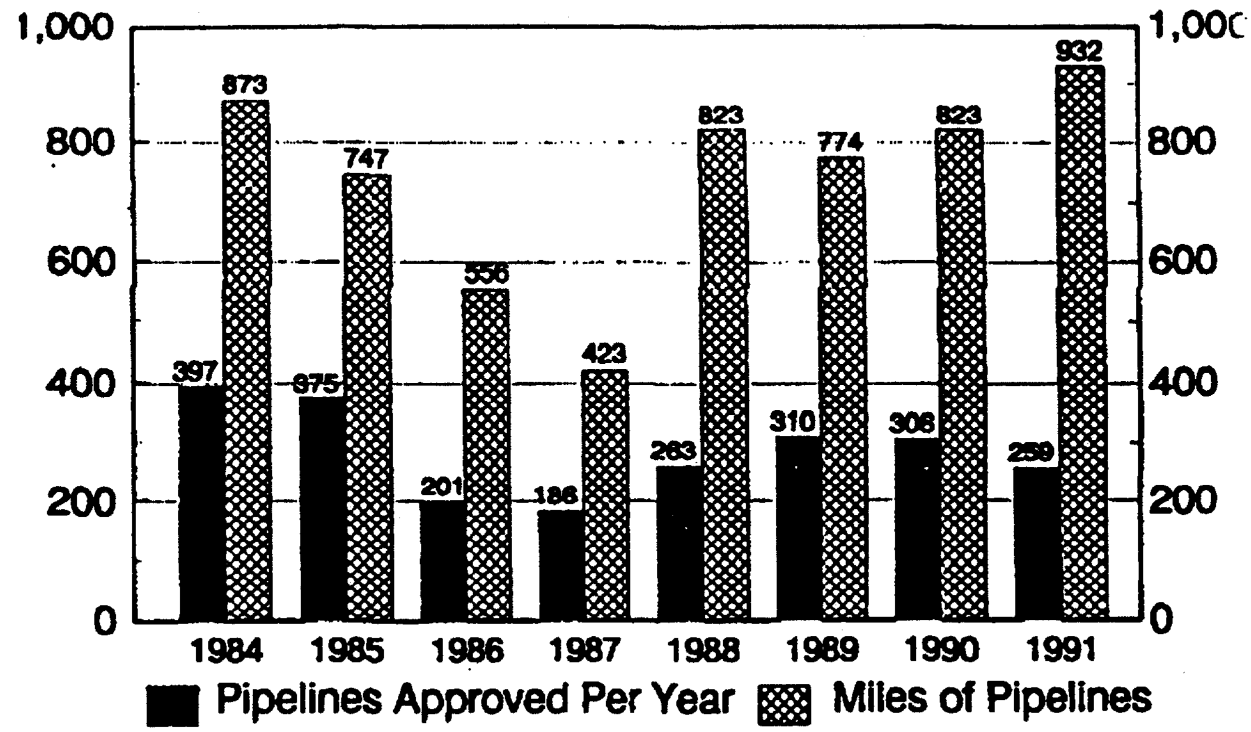



Figure 3.1: Approved and total pipeline miles, Gulf of Mexico OCS region, Pearcy (1991)

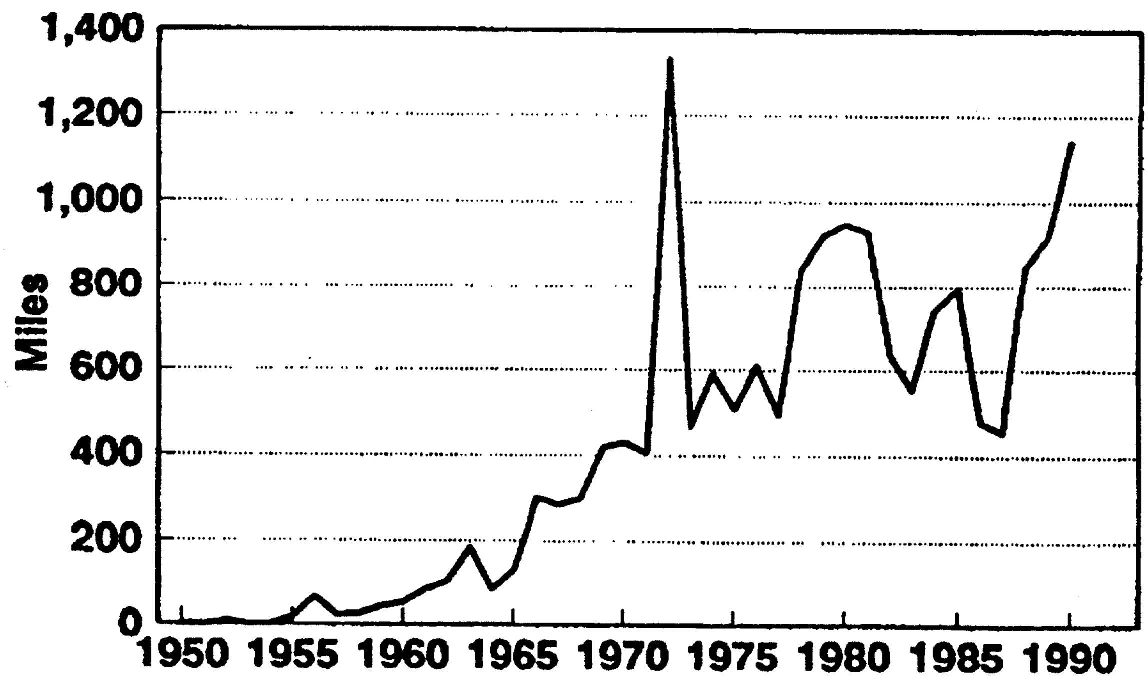



Figure 3.2: Pipeline miles installed per year, Gulf of Mexico OCS region, Pearcy (1991)

# 4.0 INCIDENT DATABASE

The incident database contains a description of each reported incident and data on the pipeline or line affected. An incident may be defined as an occurrence which directly results or threatens to results in lack of serviceability of a pipeline.

The incident database, together with the pipeline database, can be used to identify potential hazards and provide estimates of the likely incident occurrence frequency for an individual pipeline. It also provides estimates of the safety levels achieved in the operation of pipelines, which can be used in the context of comparative risk assessment.

The structure of the incident database is given in the following Table 4.1.

Table 4.1: Incident database

| Causes | Classification |
|---|---|
| Impact | Number of incidents |
| Corrosion | Location: riser, safety zone, ... |
| Structural/material | Pipeline condition: temporary, operating, ... |
| Natural hazard | Consequence: leak, pollution, ... |
| Mechanical | ... |
| Human error | |

## 4.1 Compilation of the Incident Database

In compiling the incident database, the following information needs to be included:

NAME OF PIPELINE

DATE OF INCIDENT FOUND

LOCATION OF INCIDENT ON THE PIPELINE

- platform
- riser
- safety zone 1 (more than 500 m away from the platform)
- safety zone 2 (500 m or less from the platform)
- on shore approach zone

PIPELINE STATUS AT TIME OF INCIDENT FOUND

- construction
- hydro-testing
- before commissioning
- during commissioning
- operational
- shut down

WATER DEPTH AT INCIDENT LOCATION

OPERATING PRESSURE AT TIME OF INCIDENT FOUND

CAUSES AND DESCRIPTION OF DAMAGE

Construction:

- laying
- trenching
- lifting and handling
- repair
- mechanical failure

Fitting (end fitting, connector, valve, hydrocouple, flange, tee, etc.):

- mechanical failure
- leak
- material failure

Impact:

- supply/standby/construction vessel impact on risers
- dropped object
- dropped/hook/dragged anchor
- fishing trawl gears
- submarines
- sunk vessels

Corrosion:

- internal: erosion, at weld
- external: anode failure, coating failure, etc.

Natural hazard:

- storm/hurricane
- vibration in current
- sea bed modification (scouring, sand waves, liquefaction)
- fire/explosion
- earthquake

Maintenance/repair:

Structural/material:

- buckling/collapse
- fatigue/fracture of girth and longitudinal weld defects
- overload/rapture
- aging/wear of flexible pipes
- steel out of specification,

Human and Organization errors:

- initiating events
- contributing events
- propagating events

## 4.2 Sources of Data

Sources for compilation of the incident database for marine pipelines in the Gulf of Mexico include:

Woodson Pipeline Failure Database

The Woodson database [Woodson, 1990] with over 1000 offshore pipeline failures in the Gulf of Mexico Offshore waters, was compiled from combined records from the following sources:

- Department of Transportation Office of Pipeline Safety
- U. S. Coast Guard National Response Center
- Department of Interior Minerals Management Services
- Literature

Hurricane Andrew Pipeline Damage Database

This database contains 396 incidents caused by Hurricane Andrew. It is a supplement to the Woodson database.

Other Sources

- Battelle economic study (1984)
- Mandke (1990a, 1990b)
- Further information from regulatory authorities and operators

# 5.0 INSPECTION DATABASE

The inspection database provides a detailed description of pipeline in-service defects or operational faults associated with:

- pipeline geometry
- wall thickness
- presence of cracking
- burial in the sea bed

These defects or operational faults are critical to the pipeline integrity.

The structure of the inspection database is presented in Table 5.1.

Table 5.1: Inspection database

| Feature | Description | Sampling |
|---|---|---|
| Buckle<br>Impact damage<br>Crack<br>Corrosion<br>Coating damage<br>Spanning<br>Sea bed modification<br>Pipeline movement<br>... | Inspection/detection method<br>Time to inspection<br>Remedial actions<br>... | Number<br>Size<br>Distribution<br>... |

## 5.1 Compilation of Inspection Database

In compiling the inspection database, the following information needs to be included:

<u>NAME OF PIPELINE</u>

<u>METHOD OF INSPECTION</u>

- Pressure teasing
- Internal Non-destructive teasing
- External surveillance

<u>DATE OF DEFECT FOUND</u>

<u>TYPE AND DIMENSION OF DEFECT</u>:

Dent:

- plain dent
- seam weld in dent
- crack-like defect in dent

Wrinkle/buckle:

- local buckling
- cross-sectional flattening of the pipe wall
- a combination

Gouging/spalling:

Corrosion:

- shallow general corrosion
- localized corrosion pitting
- plateau corrosion

Cracking:

- lamination
- circumferential girth weld defects
- longitudinal seam weld defects
- stress corrosion cracks (SCC)
- sulfide stress corrosion cracks (SSCC)
- hydrogen induced cracks (HIC)

Loss of burial:

- weight coating damage
- scouring
- sea bed liquefaction
- sand wave movement

REMEDIAL ACTION UPON DAMAGE DETECTION

- repair of damage
- replacement of the damaged pipe section
- scheduled time for a following inspection

## 5.2 Inspection Techniques

Methods for pipeline inspection can be classified into three types:

- Pressure testing
- Internal inspection
- External surveillance

Pressure testing is performed before the pipeline is to be commissioned. It aims to removal critical defects and material fault. However, no information is obtained regarding surviving defects. Pressure testing may also be performed on aging pipelines if the pipeline is to be requalified or uprated.

Internal inspection is typically performed using intelligent pigging. This is non-destructive testing (NDT). Conventional NDT methods include:

- Ultrasonics
- Magnetic Particles
- X-Ray
- Eddy Current

For internal inspection on pipelines, more sophisticated techniques have to be employed, Shannon and Knott (1985), Jackson (1992).

External surveillance methods include [Shell, 1991]:

- Helicopter
- Sidescan sonar
- Scanning sonar
- Diver
- Remotely operated vehicles (ROV)
- CP potential survey
- Magnetometer
- Gradiometer

The corrosion control survey methods include [Weldon and Kroon, 1991]:

- Towed vehicle/trailing wire survey
- ROV assisted remote electrode survey
- ROV assisted trailing wire
- Electric field gradient survey

## 5.3 Sources of Data

The sources of data may be from

- Pipeline operators/owners
- Pipeline inspection contractors
- Pipeline regulatory authorities

It has to be expected to be a very difficult task to collect existing inspection, maintenance and repair data for marine pipelines. In the literature, hardly anything can be found. Pipeline operators/owners usually regard such information as highly confidential. While pipeline inspection contractors do have valuable information and data obtained from on-line inspection, they are nevertheless restricted to the confidentiality requirements imposed by the clients. Regulatory authorities usually keep a good track of the pipeline incident data, but they do not necessarily receive all the inspection data, in particular, those features which do not require any remedial actions.

Hence, cooperation from various parties is the key element in data collection. A key to cooperation is the provision of positive incentives for achieving adequate reliability of marine pipelines.

# 6.0 LOAD & SUPPORT CONDITIONS DATABASE

The load database contains information about functional (operational), environmental and accidental loads, including the operating and testing pressure records for each pipeline, long-term distributions of wave and current in various blocks of the Gulf of Mexico, and accidental impact loads from the third parties. The description of the load database is given in Table 6.1.

Table 6.1: Load database

| Load type | Recording |
|---|---|
| Functional:<br>- maximum operating pressure<br>- pressure fluctuations<br>- other<br><br>Environmental:<br>- waves<br>- current<br>- other<br><br>Accidental:<br>- third party impact<br>- other | Magnitude<br>Frequency/cycles<br>Long-term statistics<br>Short-term statistics<br>... |

## 6.1 Functional/Operational Loads

The most fundamental operational load is the internal pressure load. The internal pressure history with time needs to be included in the database, which should contain the following information:

- hydro-testing pressure
- normal operating pressure
- normal pressure fluctuation
- incidental pressure
- shut-down

Other functional loads include:

- external pressure load
- bending moment
- residual pulling force
- thermal force

## 6.2 Environmental Loads

Environmental loads are mainly due to:

- waves
- current

In some cases, there can be important environmental loadings due to movements of the sea floor. These movements can be associated with chiefly vertical diaperic activity associated with "mud lumps" adjacent to river deltas, "mud slides" associated with down-slope movements of weak soils (generally triggered by storm waves), "collapse depressions" associated with de-gassing of the sea floor sediments, and fault movements associated with earthquake activity.

Both short-term and Long-term distributions of waves and current in various blocks of the Gulf of Mexico need to be included in the database.

For current, its direction relative to the as-laid pipeline is important for free span dynamics.

## 6.3 Accidental Loads

Accidental loads are caused by impacts from the third parties including:

- vessels
- anchors
- fishing trawl gears
- dropped objects

The database should contain the magnitude and probability of occurrence associated with different impact scenarios.

## 6.4 Support Conditions

Pipeline support conditions should be described along the pipeline route including the following:

- geotechnical properties
- spans
- cover / burial depths

# 7.0 DAMAGE EVALUATION SYSTEM

The damage evaluation system is a decision making system based on inputs from the pipeline database, inspection database and load database. As shown in Table 7.1, it contains a set of limit state criteria or protective measures for evaluation of the acceptability of detected features, based on which, remedial actions may be taken accordingly.

Table 7.1: Damage Evaluation System

| Feature | Load | Limit state criterion | Remedial action |
|---|---|---|---|
| Buckle | Functional | Buckling/collapse | Following inspection<br>Repair |
| Dent | Functional | Fracture/fatigue<br>Collapse/ovalization | Replacement<br>... |
| Crack | Functional/Environmental | Fracture/fatigue | |
| Corrosion | Functional | Bursting/leak | |
| Impact | Accidental | Leak/rupture/collapse | |

## 7.1 Buckling Evaluation

Buckling damage refers to local buckling, cross-sectional flattening of the pipe wall, or a combination.

Pipeline industry experience has shown that the onset of a small amplitude buckle does not pose an immediate threat of failure [Stephens et al., 1991]. However, the onset of buckling is a precursor to failure.

Critical buckling assessment should take into account the interaction of bending, pressure and axial forces.

<u>Pure Bending</u>

Review and comparison of various assessment methods can be found in, e.g., Ellinas et al. (1989), Fowler (1990) and Stephens et al. (1991). Existing criteria for "extreme fiber bending compressive strains" include:

- Classical Elastic, Reddy (1979)
- Sherman (1983)
- Murphey and Langner (1985)
- Gresnigt (1986)
- Norman Wells Pipeline, Nixon et al. (1984)
- Alyeska Pipeline, Simmons and Alto (1988)
- Damage state criterion, Stephen et al. (1991)

A comparison of the above cited buckling criteria is illustrated in Figure 7.1. Comparisons of experimental data and buckling criteria are shown in Figures 7.2 - 7.4. Further details may be found in Stephens et al. (1991).

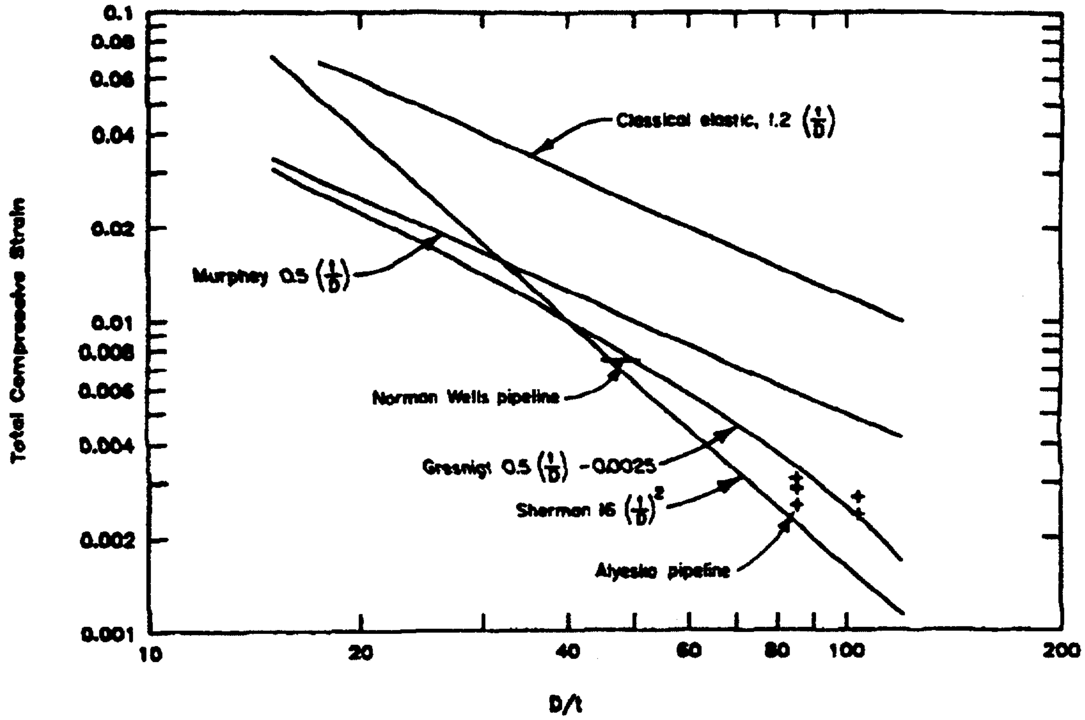



Figure 7.1: Comparison of buckling criteria

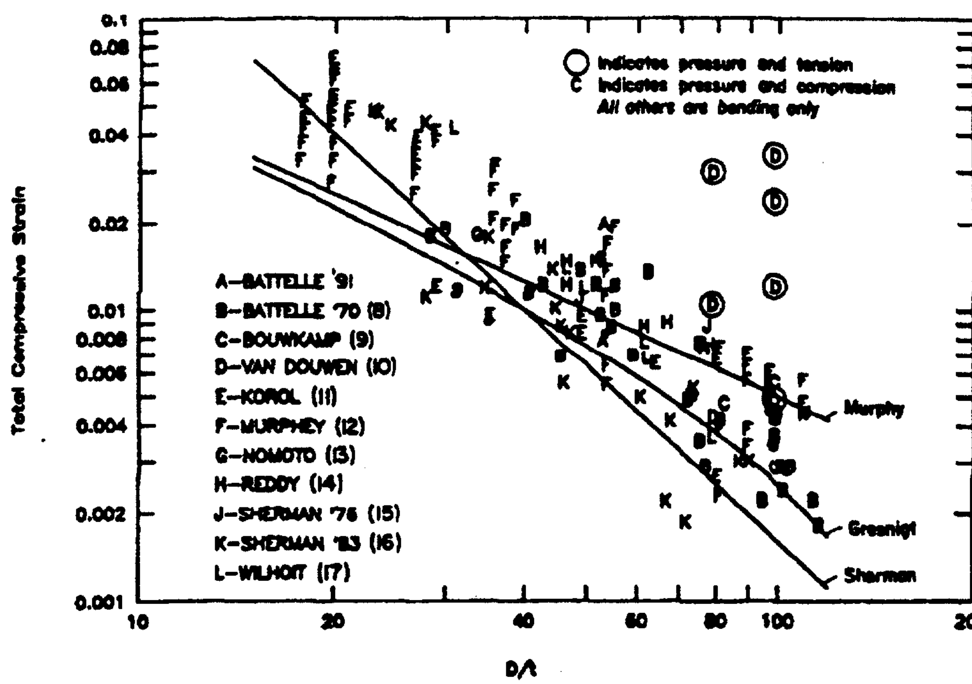



Figure 7.2: Comparison of experimental data and buckling criteria

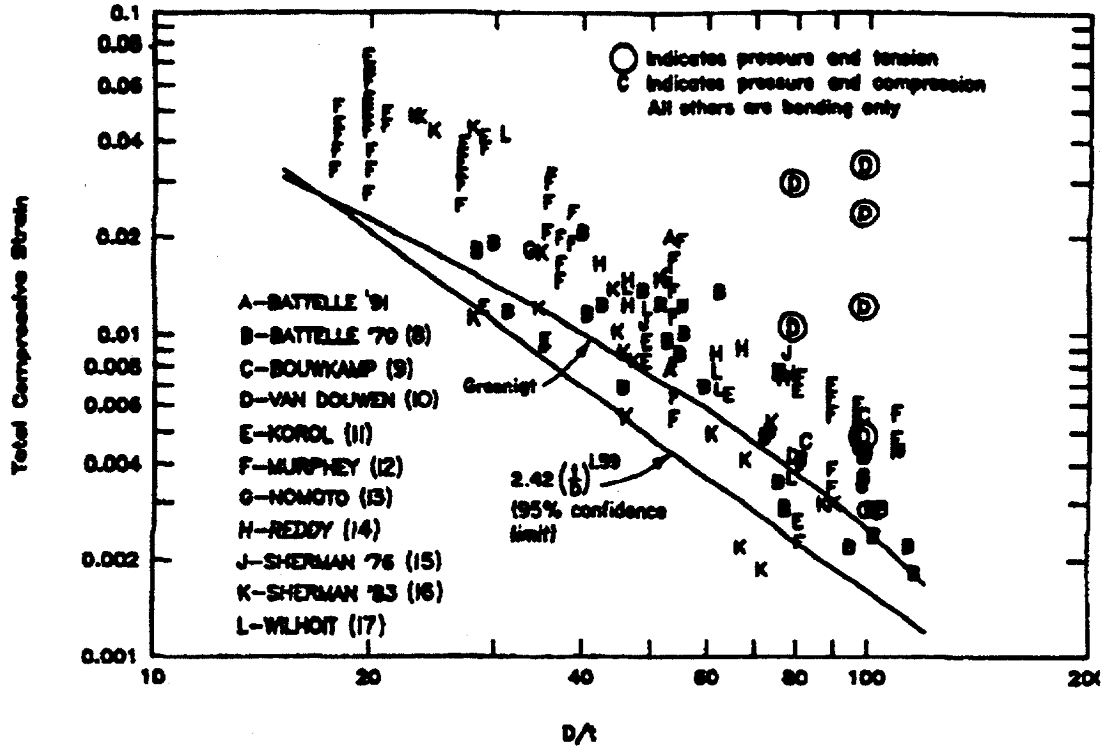



Figure 7.3: Comparison of experimental data and damage state and Gresnigt criteria

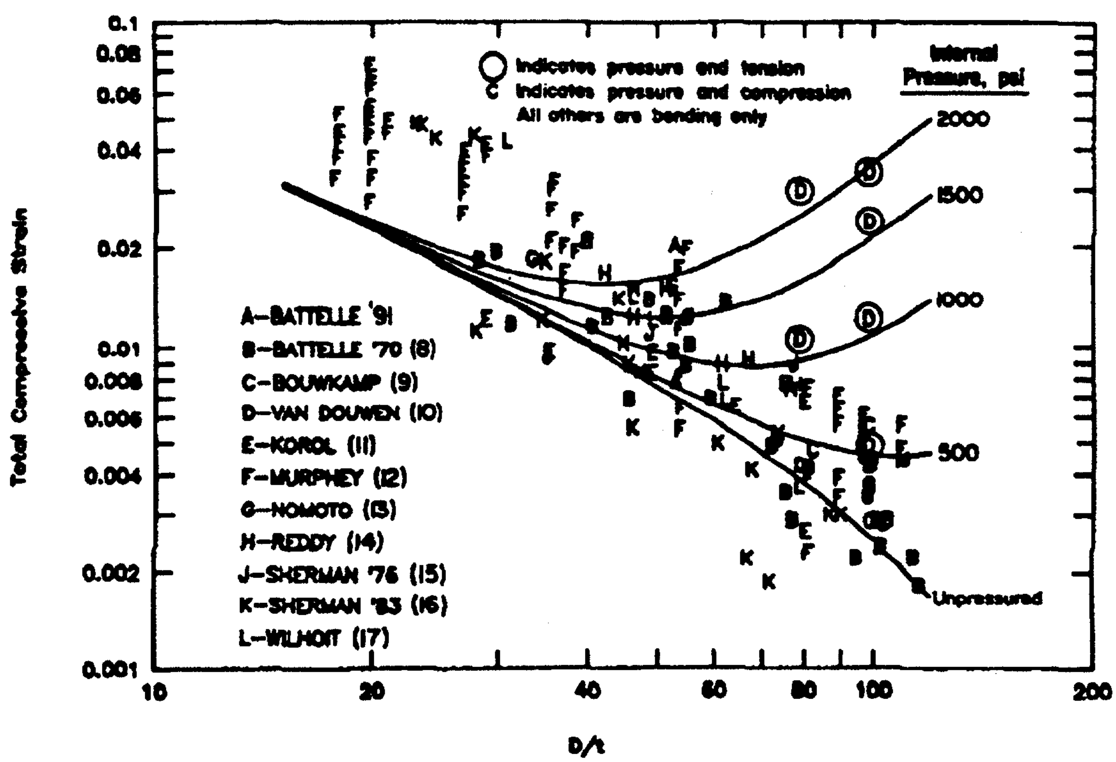



Figure 7.4: Gresnigt criterion with internal pressure

Bending, Pressure and Axial Force

The bending capacity is reduced when external pressure and axial force are present. A generally applied interaction equation is of the following form:
in which E is the applied bending strain, $E_b$ is the buckling bending strain, p is the applied external pressure, $p_c$ is the collapse pressure, and

- a = ß = 2/3 [Jones and McConnell, 1984]
- a = ß = 1 [Murphey and Langner, 1985; BS 8010, 1993]
- a = 1+300t/D, ß=1 [Moan et al., 1992]

The effect of axial force may be accounted for by correcting the yield pressure, which is a key parameter in determining the collapse pressure, see, e.g., Flower (1990) and Murphey and Langner (1985).
Instead of a simple interaction equation, advanced computer programs are also available from e.g., Kyriakides (1990) and Gresnigt (1986).

Recommendation

Due to significant differences among the existing buckling criteria, and also due to the fact that currently there is no general agreement regarding the selection of the "best" model, it is then necessary to define the most rational dent evaluation criteria/procedures in PIMPIS.

## 7.2 Dent Evaluation

A dent in a pipeline causes a high stress concentration in the base of the dent. This stress concentration will not reduce the burst strength of a dent. Plain smooth dents of depth up to 8% pipe diameter [Eiber, 1981] and possibly 24% [Jones, 1982] are found to have little effect on the burst strength of linepipe.

Under cyclic loading, the local stress concentration in the dented area results in a significant reduction of fatigue life [Fowler et al., 1992; Fowler, 1993].

As the pipe ovality at the dented area is proportional to the dent depth, a dent may significantly reduce the pipe buckling and collapse capacity. Besides, an excessively ovalized pipe section caused by denting may prevent a pig from passing through, thus lead to the lack of serviceability of the pipeline.

If a defect, such as V-notch, gouge or weld defect, happens to exist in a dent, the combination of defect and dent results in a significant reduction in the pipe burst strength [Hopkins and Cairns, 1981].

## 7.3 Fatigue Evaluation

An S-N curve is presented by Fowler et al. (1992) and Fowler (1993) for fatigue assessment, which is of the following form:

$$N = C / S^{3.74}$$

where N is the number of cycles to failure, C is equal to 2 $10^6$ cycles, and S is the dent alternating stress depending upon the diameter to thickness ratio (D/t) and the dent depth to diameter ratio (d/D).

This S-N curve is the appropriate power from the equation for the API - X' curve. Figure 7.5 presents a comparison of API X and X' curves and Department of Energy (DOE) B curve.

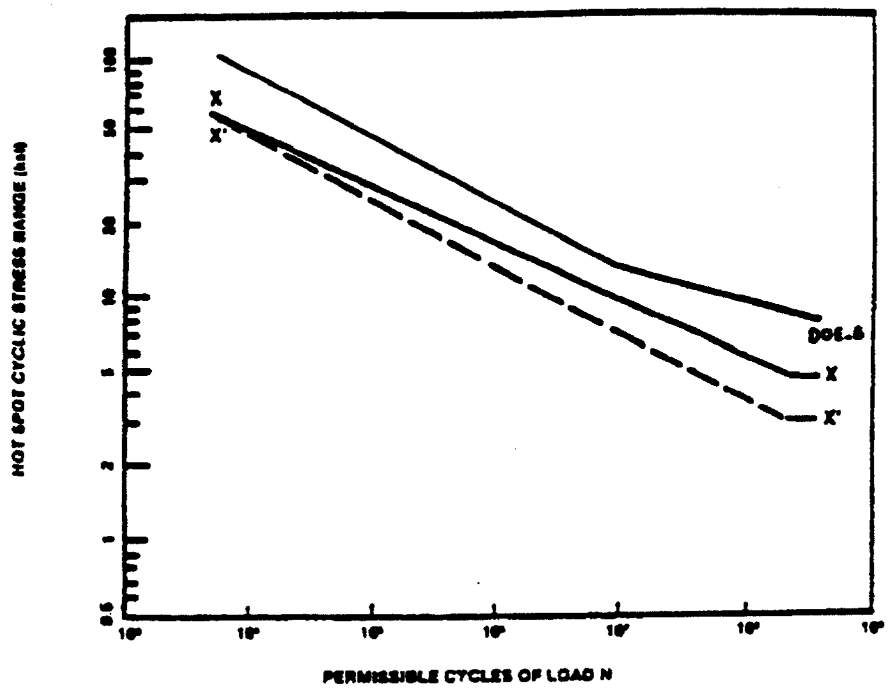



**Figure 7.5: Fatigue S-N curves**

## 7.4 Fracture Evaluation

The most commonly applied analytical models for fracture assessment regarding denting damage are developed by

- Battelle, see e.g., Kiefner et al (1973) and Maxey (1974)
- British Gas, see e.g., Hopkins and Cairns (1981) and Muntinga and Koning (1990)

Considering a critical combination of dent and defect, the British Gas equation is widely regarded as the best analytical model available [Muntinga and Koning, 1990].

<u>Recommendation</u>

Fatigue and fracture models for denting assessment should be included in PIMPIS. Due to large uncertainties involved in the above assessment models, a better alternative is to make finite element analysis for improved prediction of the stress concentration factor (SCF) in the dented/defected area.

Buckling/collapse due to denting may be assessed in connection with the buckle assessment, as outlined in Section 7.1. Unserviceability due to excessive ovalization may be assessed according to Murphey and Langner (1985).

## 7.5 Evaluation of Crack-like Defects

Crack-like defects are very critical from a fracture mechanics point of view. The consequences of defect failure are loss of containment by means of

- stable fatigue crack growth to leak
- unstable fracture

Types of crack-like defects include:

- weld defects
- V-notches
- stress corrosion cracks (SCC)
- hydrogen induced cracks (HIC)

SCC and HIC are generally rare in offshore pipelines [Jones, 1990]. V-notches are the most critical in combination with dents, which can be assessed in accordance with Section 7.2. For seamless pipelines, weld defects refer to circumferential girth weld defects. For large diameter pipelines, longitudinal seam weld defects may also exist. However, seam weld defects are generally well controlled during fabrication and testing, and proved to be harmless through the-fitness-for-purpose assessment [Jones, 1990].

Critical circumferential girth weld defects are typically associated with free spans. Failure mechanism of such defects is unstable fracture under a combination of:

- fatigue crack growth under cyclic stresses due to current-induced vortex shedding
- over-stress caused by the free span geometry

An applicable assessment is proposed by Jiao et al. (1992) and Jiao (1993) as follows:

- Fracture assessment is according to the standardized PD 6493 (1991), in which the level 2 method is appropriate, as shown in Figure 7.6.

Crack size for fracture assessment is calculated using the Paris equation:

$$da / dN = C (\Delta K)^m \qquad \Delta K > \Delta K_{th}$$

in which a is the defect depth, N is the number of stress cycles, C and m are crack growth constants, $\Delta K$ is the stress intensity factor range, and $\Delta K_{th}$ is the threshold stress intensity factor range, below which there is no crack growth.

The stress analysis here involves free span modeling and long-term current statistics.

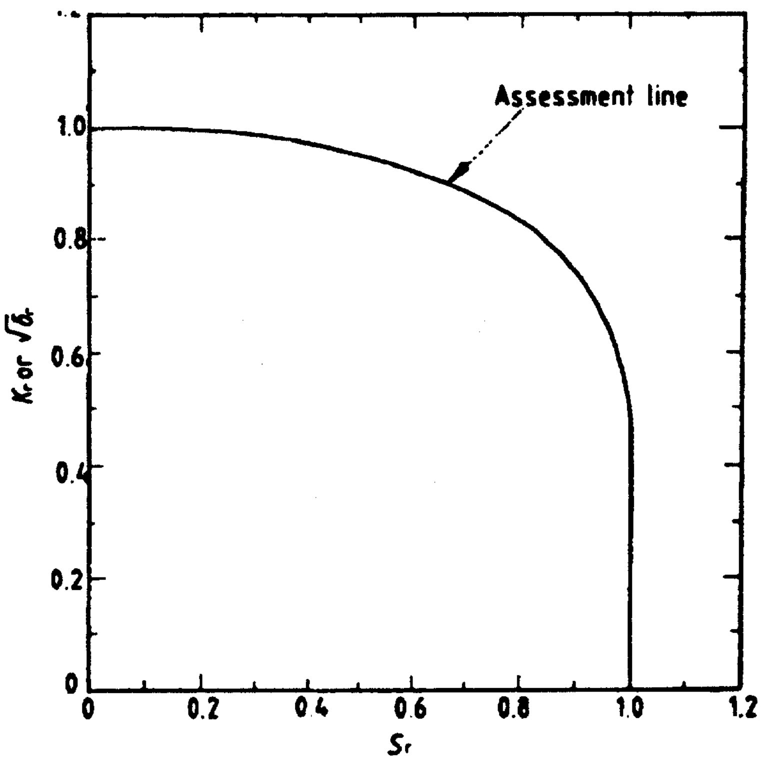



**Figure 7.6: Level 2 failure assessment diagram [PD 6493, 1991]**

## 7.6 Corrosion Evaluation

Metal loss in gas and oil transmission pipelines due to corrosion causes most failures in the Gulf of Mexico [Mandke, 1990a,1990; Marine Board, 1994].

Internal corrosion is commonly linked to a change in the pipeline operating conditions [Palmer, 1991]. The change in internal fluid composition or temperature can alter and remove protective layers of corrosion product which have built up on the pipe surface, leading to an increase in the corrosion rate. As future lines are required to operate at temperatures of 180 degrees F and beyond, there is greater uncertainty over material performance and hence the integrity of the line.

External corrosion reflects the combined breakdown of the pipeline external coating and the cathodic protection system in response to chemical and biological effects, and to soil stresses.

More specifically, the following types of corrosion are encountered:

- general loss of wall thickness
- general or localized corrosion at low points (often associated with water)
- generalized pitting
- localized pitting, particularly at bends and valves

The strength of a corroded pipe may be calculated based on a semi-empirical fracture mechanics relationship, commonly referred to as the NG-18 surface-flaw equation, see, e.g., Bubenik et al. (1992). The assessment equation is given by:

$$\sigma_{H,f} = \sigma_f \, [1 - A / Ao] / [1 - (A / Ao) / M_t]$$

in which $\sigma_{H,f}$ is the hoop stress at failure, $\sigma_f$ is the material flow stress, $M_t$ is the Folias factor, Folias (1964), A is the area of the corrosion defect in the longitudinal plane through the wall thickness, and $A_0$ is the original cross sectional area of the pipe at the defect which is equal to the corrosion length (L) multiplied by the wall thickness (t). Such a corrosion profile is illustrated in Figure 7.7.

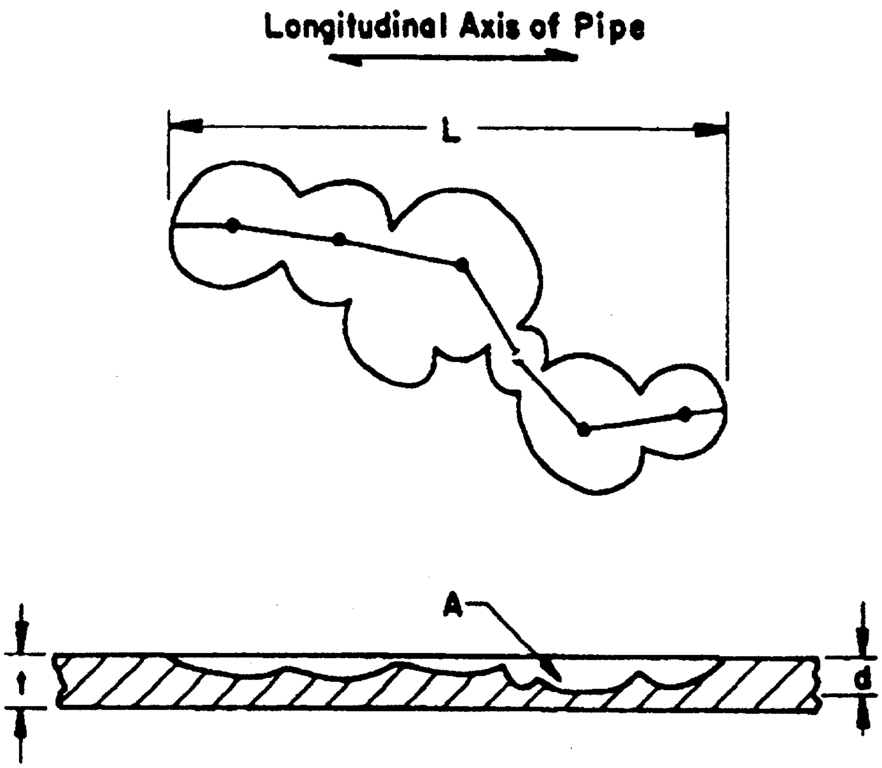



**Figure 7.7: Corrosion profile assumed in the B31G method**

The ASME B31G manual (1986) simplifies the above equation by approximating the defect shape as a parabola. A modified B31G criterion is presented in Vieth and Kiefner (1992).

## 7.5 Other Safety Measures

In cases when insufficient structural capacity is expected, other safety measures, such as additional protection methods, are widely applied in the design of marine pipelines. These measures, in particular those given in the following, as according to McKeehan and Kyriakides (1991), should be included in the damage evaluation system:

- worldwide trenching practices regarding the influence of depth, diameter and damage mode on required trench depth and/or backfill.

- the effectiveness of valve protection devices and the influence of angle, type of structure and embedment.

- span correction practices with a comparison of one-time verse annual maintenance.

# 8.0 RISK EVALUATION SYSTEM

## 8.1 Qualitative and Quantitative Risk Assessments

Risk is defined as the product of the likelihood of loss of serviceability (or "failure", Pf) of a pipeline (or pipeline system) and the consequences associated with the loss of serviceability (Cf). Loss of serviceability can be expressed in terms of leaks developing in the pipeline (e.g., due to corrosion, fatigue) or in complete rupture of the pipeline (e.g. due to anchor dragging, mudslide loading, or dropped objects. The consequences associated with the loss of serviceability range from those associated with property and productivity ("on-site") to those associated with injuries to personnel and the environment.

The likelihood of loss of serviceability can be expressed in terms of the loadings or displacements imposed on the pipeline (S) and the capacity of the pipeline to sustain those loadings or displacements (R). Given that the loadings and capacity of the pipeline can be characterized adequately with Lognormal distributions, then:

$$Pf = 1 - \Phi \{[\ln (R_{50} / S_{50})] / \sigma\}$$

where $\Phi$ is the standard cumulative Normal distribution for the quantity {.}, $R_{50}$ is the median (or 50-th %-tile capacity, $S_{50}$ is the median maximum loading or displacement, and $\sigma$ is the standard deviation of the pipeline loading (S) and capacity (R) (or total uncertainty in the pipeline loading and capacity). The uncertainty in the pipeline loading and capacity can be determined as:

$$\sigma^2 = \sigma_R{}^2 + \sigma_S{}^2$$

In the case of loss of serviceability due to fatigue or repeated loadings, the likelihood of loss of serviceability is expressed in terms of the pipeline service period, Ts, and the time to development of a significant through-wall crack, Tf:

$$Pf = 1 - \Phi \{[\ln (Tf_{50} / Ts_{50})] / \sigma\}$$

In the case of Normally distributed loadings and capacities:

$$Pf = 1 - \Phi \{[\ln (R_m / S_m)] / \sigma\}$$

where Rm and Sm are the median (or mean) capacities and loadings and $\sigma$ is the standard deviation of the loadings and capacity. Other types of distributions of loadings and capacities can be modeled by fitting the "tail" of the Normal or Lognormal distribution to the particular distribution. More advanced numerical analysis methods can be used if required [Sotberg, 1990].

Thus, with only four quantities (two to describe the central tendencies of the loadings and capacity, and two to describe the uncertainties in the loadings and capacity), one is able to make reasonable estimates of the likelihood or likelihoods associated with loss of serviceability.

There are two complimentary approaches to developing evaluations or assessments of pipeline risks. The first is qualitative. The second is quantitative. Qualitative methods rely on ranking or rating schemes similar to those used in academic course grading and determination of the grade point average. Numerical grades (e.g. a 4 - point grading system with 4 points for outstanding performance and 0 points for unsatisfactory performance) are assigned to the key characteristics that determine the loadings, capacities, and likelihoods of failure. Weightings similar to those associated with the numbers of "hours" assigned to a particular course are used to combine the grading. The sum of the products of the course grading and the course hours divided by the course hours indicates the overall grade point average (GPA). The GPA gives an indication of the likelihoods associated with loss of serviceability of the pipeline. A similar GPA scheme can be utilized to formulate the costs associated with loss of serviceability of the pipeline. Qualitative risk analyses are generally calibrated or verified by comparisons with the performance of existing pipeline systems and / or by comparisons with quantitative evaluations.

Given information on the characteristics of the pipeline, its present condition, the nature of any previous incidences with either this pipeline or similar pipelines, information on the pipeline loadings and support conditions, a qualitative risk analysis can be performed to determine the likelihood associated with loss of serviceability of the pipeline for its proposed service. This information is integrated into a comprehensive pipeline risk exposure system to define the priorities for future inspection, monitoring, maintenance, and analysis efforts. The qualitative method is intended to prioritize pipelines for maintenance and rehabilitation and to identify high risk pipeline "corridors" [American Gas Association (AGA), 1994].

The AGA probability factors include coating type, cathodic protection, stress corrosion cracking, pipe condition, coating condition, wall thickness, soil type, leak history , and other items. Consequence factors include location and propagation of ductile and brittle fracture. Each factor is assigned a weighted number defined in the algorithm instructions to correspond with a level of probability or consequence. This number is then integrated into the algorithm to calculate the risk index [American Gas Association, 1994].

The reliability evaluation system module contains the information necessary to characterize the reliability of the pipeline in a given area for a proposed service. This includes information from the foregoing modules and in particular information on loading and support conditions (all sources of stresses induced in the pipeline) and information on the capacity characteristics [Sotberg, 1990]. Pipeline reliability is evaluated in both qualitative and quantitative terms [Sotberg, 1990; American Gas Association, 1994]. The AGA (American Gas Association) qualitative system has been developed specifically for the prioritization of pipeline maintenance and identification of high risk areas for pipelines [Marine Board, 1994].

The risk analysis module utilizes information from all of the other modules and systems within PIMPIS. Of particular importance is the information integrated within the Characteristics, Inspection, Loadings - Support, and Damage Evaluation Modules.

## 8.2 Consequence Assessments

Evaluations of consequences associated with loss of pipeline serviceability should address both "on-site" and "off-site" aspects. Consequences should address:

- property losses
- productivity losses
- injuries to personnel
- injuries to the environment

Evaluations of the geographic locations of high likelihoods of "demands" from sources such as anchors, drilling rig and boat activities, and natural geologic activities such as mudslides and beach front migrations, coupled with assessments of the locations associated with potentially high consequences of loss of serviceability can be used to identify pipeline "high risk corridors." These locations then become the locations in which special methods are used to either control the demands or improve and maintain the capacity characteristics of the pipelines.

Quantitative evaluations of consequences can be expressed in a wide variety of ways. The metric or unit used to express consequences should be one that best expresses the nature or impacts of the consequences and that can be measured or reasonably estimated.

## 8.3 Risk Analysis Module

The reliability evaluation system module contains the information necessary to characterize the reliability of the pipeline in a given area for a proposed service. This includes information from the other PIMPIS modules. Pipeline reliability is evaluated in both qualitative and quantitative terms [Sotberg, 1990; American Gas Association, 1994]. The AGA (American Gas Association) qualitative system has been developed specifically for the prioritization of pipeline maintenance and identification of high risk areas for pipelines [Marine Board, 1994].

Given information on the characteristics of the pipeline, its present condition, the nature of any previous incidences with either this pipeline or similar pipelines, information on the pipeline loadings and support conditions, a risk analysis is performed to determine the likelihood associated with loss of serviceability of the pipeline for its proposed service. This information is integrated into a comprehensive pipeline risk exposure system to define the priorities for future inspection, monitoring, maintenance, and analysis efforts. The risk analysis is performed in both qualitative and quantitative terms. The qualitative method is intended to prioritize pipelines for maintenance and rehabilitation and to identify high risk pipeline "corridors" [American Gas Association, 1994].

The reliability evaluation system module contains the information necessary to characterize the reliability of the pipeline in a given area for a proposed service. This includes information from the foregoing modules and in particular information on loading and support conditions (all sources of stresses induced in the pipeline) and information on the capacity characteristics [Sotberg, 1990]. Pipeline reliability is evaluated in both qualitative and quantitative terms [Sotberg, 1990; American Gas Association, 1994]. The AGA (American Gas Association) qualitative system has been developed specifically for the prioritization of pipeline maintenance and identification of high risk areas for pipelines [Marine Board, 1994].

# 9.0 INFORMATION MANAGEMENT SYSTEM, ANALYSIS & REPORTING MODULES

## 9.1 Information Management System

The Information Management System (IMS) is the central coordination module for PIMPIS. It receives direction on queries and input information from the user and provides written, tabular and graphical outputs in response to user directions. The IMS acts to coordinate and provide verification of information that is input by the PIMPIS users to the various modules. The IMS provides access to information in the multiple databases incorporated in PIMPIS.

## 9.2 Analysis Module

This module defines the algorithms and types of analyses that will be performed in response to user queries and directions. These analyses could be either analyses of data in the database to determine trends or analyses of information in the database to determine future performance characteristics.

## 9.3 Reporting Module

The reporting module provides a central definition point for how information is input into the various databases and modules that comprise PIMPIS. Data verification routines would be provided to help assure that correct information is properly input into the various modules.

One of the most important aspects of PIMPIS is communications. The objective is to provide the multiple users of PIMPIS with timely and accurate information relating to the integrity of marine pipelines. Standardized written, tabular, and graphical routines would be integrated within the reporting module so that these communications could be facilitated.

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