Development and Customisation of Integrated Pipeline Integrity Management System

Main author
Mohd Nazmi bin Mohd Ali Napiah
Principal Engineer (Pipeline Integrity)
PETRONAS Gas Berhad
Malaysia
1.0 Abstract

PETRONAS Gas Berhad (PGB), a subsidiary of Malaysia’s national oil and gas corporation, PETROLIAM Nasional Berhad (PETRONAS), processes, transports and supplies natural gas and utilities to petrochemical plants. PGB through its operating division, Transmission Operations Division (TOD) currently operates and maintains the nation’s 2,554 km of high pressure on-shore gas pipelines ranging from NPS 2 up to NPS 48. TOD has been operating the pipelines for more than 24 years and has kept good track record with regard to pipeline safety.

Recognising the value of a risk based approach to pipeline integrity management program, in 2002 PGB implemented a customised and fully integrated Pipeline Risk and Integrity Management System (PRIMS) which included software modules for:

- Data management;
- Semi-quantitative risk assessment;
- Risk control cost benefit analyses;
- Defect Assessment;
- Corrosion growth modeling; and
- Reporting.

As part of this development and customisation project, a benchmarking study was performed, PGB’s pipeline integrity programs were also compared with a broad group of international pipeline operators. This study compared the relative ranking position of PGB pre- and post-implementation of PRIMS. It demonstrated that implementation of PRIMS places PGB in a select group of first quartile international pipeline operators, with respect to the implementation of pipeline integrity management best practices. This paper describes the functionalities of PRIMS system and how it has benefited PGB, which have been realised to date from its implementation.
PRIMS was first implemented in 2002 on 886 km of pipelines, focusing on PGB’s PGU and liquid onshore transmission pipelines. Realising the benefits and importance of PRIMS, the implementation has been extended to the entire 2,554 km, which includes both onshore and offshore pipelines. The implementation has thus far resulted in improvements in overall integrity management activities that minimises risk of pipeline failure while optimising maintenance cost.
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Table 2 – Improvement can be seen from implementation of PRIMS i.e. no leak, ILI and integrity planning are risk-based etc.

Figure 3 – Reduction in maintenance spending pre- and post-PRIMS implementation

PRIMS comprises of interactive modules that enable PGB to implement a data management system following the specifications of the Pipeline Open Database (POD) Model, perform semi-quantitative risk assessment for prioritisation of integrity assessments, followed by post-assessment analysis and cost benefit analysis to optimise preventive and mitigation actions. Overall, PRIMS can be used as a system to produce; monitor and update integrity management plans. These modules are developed in consistent with the requirements of API 1160 for liquid pipelines, and ASME B31G and B31.8S for gas pipelines. Details of each module will be discussed in the proceeding paper.

2.0 Introduction

2.1 Pipeline Integrity Benchmarking Study

As explained in the abstract section, the benchmarking study was performed to gauge the level of implementation of pipeline integrity management in PETRONAS Gas Berhad (PGB) as compared to other operators in the world. The benchmarking study inclusive of the following steps:
i. Selection of peers  
ii. Agreement on the integrity action items to be studied and to assign individual weightage  
iii. Establishing/review integrity questionnaires based on the action items  
iv. Submission of questionnaires to peers  
v. Analysing of the answers and preparing report

Peers were selected based on certain criteria i.e. type and volume of product, length of pipeline, size of organisation and willingness to share information with others. In PGB’s case, peers were selected from around the world i.e. North America, South America, Europe, Asia, South East Asia and Australia. In total, nineteen (19) pipeline operators representing every continent participated in the benchmarking study and valuable inputs were gathered from them for the sole purpose of the study.

We can say that the integrity action items are the key indicator for the successful of the benchmarking study. The consultant and PGB’s team had several discussions in order to come up with integrity action items that could yield meaningful and effective results from the study. Basically, the integrity action items are based upon what constitute the main areas or activities pertaining to managing integrity of a pipeline section. As a result, nine integrity action items were agreed to be focused upon. They are:

i. Risk assessment methodology  
ii. In-line inspection policy  
iii. Corrosion assessment methodology  
iv. Third-party damage prevention  
v. Corrosion prevention  
vi. Leak detection  
vii. Repair method  
viii. Integrity planning  
ix. Failure history

The above items may not be all inclusive but PGB felt that at that point of time they were sufficient enough to meet the objectives of the benchmarking exercise.

Weightage needs to be assigned to each of the item to indicate the relative importance of each item in managing pipeline integrity. In doing so, specific
question was asked i.e. Are the actions/activities in integrity action (i) more important than those in integrity action (ii), (iii), … (ix) in order to avoid any leak/rupture? Consequently, an overall percentage weight contribution for each integrity action item is obtained.

![Figure 4 – Relative weightages for the nine integrity action items](image)

As depicted in Figure 4, integrity actions that are ‘prevention’ in nature received the most percentage weight. This is due to the fact that preventive actions are the ‘first defense’ mechanism to avoid any unwanted incident or accident onto a pipeline system.

Total of ninety-nine (99) questionnaire were established to cover the nine integrity actions. As much as possible, the questionnaire should be comprehensive and pipeline operator specific making sure that answering the questionnaire could be done in short time and without much of hassle. The questionnaire should also maximise ‘Yes’ and ‘No’ and checklist type of questions, and avoid elaborative ones.

Once the questionnaire had been reviewed and agreed, they were sent across to the selected peers and answers were analysed to determine the ranking of participating companies.

3.0 Integrated Pipeline Integrity Management System – Pipeline Risk and Integrity Management System (PRIMS)
3.1 Database management module

The core of PRIMS system is the database. It is developed using the industry standard data model, PODS that can directly be integrated with other third party GIS and database systems as other information becomes available. Running on SQL Server, the database can be accessed by multi-user at different locations at the same time for optimal data manipulation and verifications using PRIMS as the interface. Through the interface, PGB can add, modify, and update new pipeline data at any time, and from anywhere with easy access to the reliable network connection. Modules that were built within PRIMS interact with the database and serve as storage/placeholders for pipeline data. PRIMS pulls all relevant data; integrate them in accordance to the specifications that were built within the system, and will later be used to perform assessment on each individual pipeline or the entire PGB’s system.

Data gathering is an ongoing effort. A “satisfactory” database is built over time and as pipeline data become available or changes, the database needs to be updated accordingly. In order to ensure the integrity of data is not jeopardised unintentionally, several levels of security have been implemented. The data are editable by users with the required security clearance, while other normal users of the PRIMS system will need to have permissions to view data and perform assessments but with limitations on changing the pipeline data. This capability allows all level of PGB’s personnel to have access to the data as needed while monitoring and maintaining the integrity of data.

The ASME B31.8S and API 1160 subscribe to managing integrity of gas and liquid pipelines via risk-based approach. In doing that, critical data and information need to be collected, verified and integrated to ascertain its credibility to be used for performing risk assessment, defect assessment, corrosion growth and determination of re-inspection interval as well as reviewing the mitigation measures to reduce the risk.

As depicted in Figure 5, the critical data are as follows:

i. Basic pipeline data that can be extracted from ‘accurate’ as-built drawings and construction documents.

ii. Historical failure data need to be collected as an input to risk assessment particularly in determining and calculating the probability of failure.
iii. Cost data basically are data pertaining to cost of performing inspection and repair activities as well as for mitigation measures. The cost data will be used to calculate the cost benefit analysis for selecting the appropriate mitigation measures to reduce pipeline risk.

iv. Inspection data i.e. ILI, cathodic protection, coating survey, excavations are the ‘heart’ of the PRIMS. Without it risk-based integrity management for a pipeline cannot be realised.

3.2 Semi-quantitative risk assessment module

PRIMS utilises semi-quantitative approach for pipeline risk assessment. Quantified data includes pipeline attributes relating to design, construction, operating pressure, damage/failure histories, in-line inspection, close internal potential survey, and others while qualitative data tends to be more subjective in nature depending on the person making the judgment. Threats considered in the risk assessment are:

- External corrosion
- Internal corrosion;
- Constructions error;
- Fatigue;
- Stress corrosion cracking;
- Third party intrusion;
- Geotechnical problem;
- Sabotage and pilferage;
- Off-pipe equipment failure; and
- Incorrect operations i.e. operator error

The general formulation of risk is defined as follows:

**Total Risk = Probability of Failure x Consequence of Failure**

The consequences considered included:
- Public risk (principally safety),
- Environmental effects,
- Customer impact,
- Financial impact, and
- Cost of failure

The above risk assessment method is customised specifically to meet the requirements and standards of PGB’s pipeline system. As part of the customisations, a score is assigned to each category of data based on statistical analysis, industry’s best practise and engineering judgment (Subject Matter Experts – SME’s). Higher score indicates higher risk. The scores are combined to calculate the probability and consequence of failure for each individual pipeline and overall to give an associated risk number. Using these scores, the relative influence of each of the failure causes is considered and the impact/consequences of these failures are measured. Built in PRIMS is the capability to extract information from inline inspection results, CIPS and other assessment’s results and apply in the risk assessment calculations.
3.3 Cost benefit analysis module

PRIMS allows PGB to perform cost benefit analysis/What-if scenarios to strategise and optimise the preventive and mitigative actions. It provides the flexibility to perform the analysis at the segment or pipeline level. Integrating the cost data and
the risk assessment methodology, the risk reduction per Ringgit Malaysia (RM) spent is calculated to obtain the highest benefit per RM ratio; as defined below.

\[
(CostRatio)_i = \left( \frac{Risk\ Reduction}{RM\ /\ Spent} \right)_i
\]

where \(i\) denotes the repair method mitigation action or prevention action of a specific threat.

Given that integrity management plan is a continuous process, PGB has implemented within PRIMS the facility to track changes via the Risk Tracking tool. This tool allows PGB to perform evaluations to track the reduction in the risk score for a specific interval by feeding additional information into the system when information becomes available and/or when mitigation/prevention actions have been undertaken. Comparisons can be made between risk charts to show the risk reduction due to specific actions taken; as shown in Figure 8.

Figure 8 – Risk tracking after performing cost benefit/what if analysis

### 3.4 Defect assessment module

Upon performing integrity assessment; by means of inline inspection, direct assessment, hydrostatic testing and/or other assessment methods, these newly available information can be feedback into PRIMS. Assessment then can be
carried out on the results found using the ASME B31G or Modified B31G/RSTRENG or Detailed RSTRENG method for metal loss defects. A standard industry acceptance criterion is used to identify locations where existing dents may threaten the integrity of the pipeline. Criteria define in BS7910 Level 1 is used to assess crack in PRIMS.

The assessment results can then be used to determine the locations where repairs are required and further plan for mitigative/preventive actions as an on-going integrity management plans. Where repairs are required, PRIMS has the facility to generate excavation sheet serves as a handy reference material during the repair job. Upon completing the necessary repair according to the industry acceptable methods, PRIMS allows PGB to feed field information back into the system, indicate that the defect has been remediate and assessed and should not be threatening the integrity of the pipeline.

![Defect Assessment Module](image)

**Figure 9** – Assessment of metal loss, manufacturing, dent, crack and lamination can be conducted via the Defect Assessment Module

### 3.5 Corrosion growth module

As part of its integrity assessment planning, PGB has performed inline inspections in the past to determine areas where corrosion may occur and the severity of these defects can be assessed. Further to the Defect Assessment module, PRIMS is equipped with Corrosion Growth Module that provides the ability to calculate the
corrosion growth rate for external and internal corrosion using the following theoretical models:

- Full life rate – external/internal corrosion
- Half life rate – internal corrosion
- De Waard and Milliams rates – internal corrosion

Knowing the need and benefits of verifying corrosion threat, it is part of PGB’s integrity program to perform field excavations to validate the in-line inspection results. In any event that “huge” discrepancy is found and a higher/lower corrosion rate is determined, PRIMS provides PGB the capability to apply these corrosion rates to perform corrosion growth on all other corrosion defects detected by the in-line inspection. By this means, the re-inspection interval can be maximised. Additionally, the ability to determine and predict the remaining strength of corrosion defects allows PGB to establish corrosion management program that allows us to better define and plan future rehabilitation and operation regimes.

Figure 10 – Corrosion growth module showing the essentials parameters and Information

3.6 Reporting module
The above module has been customised for PGB to produce excavation sheets and management reports based on corporate requirements. The aim of these reports is to minimise the amount of time spent on documentations while ensuring that operations and maintenance programs are communicated effectively at any given management level.

The “Query” function built within PRIMS allows extraction of information pertaining to a pipeline at an ease of a touch. Query/filtering of the database can be carried out when there is a need to evaluate a subset of data pertaining to specific pipelines. Overall, this allows PGB to gather and integrate different data together with minimum time required.

4.0 Conclusion

PGB has developed an Integrated Pipeline Integrity Management System called PRIMS that has the capability to act as a database storage/management; and performs semi-quantitative pipeline risk assessment, defect assessment for critical pipeline defects and produces repair plan, corrosion growth analysis to determine re-inspection and future repair plan, and reporting module to produce low level as well as high level management reporting. With implementation of PRIMS, PGB sees the improvement in its integrity management program as well as its operation and maintenance. It clearly shows that PGB’s PRIMS helps PGB, the management and its staffs manage the pipelines better maintaining the highest pipeline reliability while at the same time optimising cost of pipeline inspection and maintenance accordingly.

5.0 References

1. Risk and Integrity Management System (RIMS).
2. Risk Integrity Management System’s (RIMS) Risk Assessment Methodology.
4. Duraid Alkazraji; “Phase 1 Benchmarking Study of the 2,400 km PGB’s Transmission and Lateral Pipeline”.