IMPORTANCE OF A GEOGRAPHIC INFORMATION SYSTEM FOR THE DEVELOPMENT OF A PIPELINE INTEGRITY PLAN

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1. INTRODUCTION

In Argentina, Transportadora de Gas del Sur (TGS) operates and maintains a pipeline system whose extension is over 7,400 km, and through which it transports more than 60% of the natural gas volume used in the country.

The first pipeline was constructed in 1965, and to this day the system has continued growing as a consequence of the importance of natural gas in the energy matrix of the country.

One of the main problems we face as operators of the system is the deterioration that affects buried pipelines, due to the passage of time and the impact of a variety of agents affecting their integrity. Thus, the need arises to define an Integrity Plan, aimed at recognizing, locating and subsequently repairing sensitive points in the system, so as to minimize incident risks which, through the application of the best maintenance techniques, may extend the service life of the facilities and the preservation of assets. This, in turn, will help ensure consistent gas supply to the clients and the consideration of the environmental and economic aspects of the business.

As the causes that have an impact on the integrity of a buried system are varied, so is the information required to plan the tasks of: prevention, inspection, mitigation, and repair. All this information comes from a variety of sources, some of which are included in the following list:

- Construction data: Materials and design.
- Specific field surveys: soils, potentials, defects.
- Information related to rights of way: roads, rivers, lakes, entry and exit conditions.
- Operations Data
- Incident data.
- Satellite imagery.
- Land registry data.
- Structural Integrity Data

It should be taken into account that the reference systems used in pipelines for localization vary according to the origin of the data:

<table>
<thead>
<tr>
<th>Gas Pipeline</th>
<th>Length (km)</th>
<th>Diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Martin</td>
<td>3407</td>
<td>76.2</td>
</tr>
<tr>
<td>NEUBA I</td>
<td>1240</td>
<td>60.96 - 76.20</td>
</tr>
<tr>
<td>NEUBA II</td>
<td>1665</td>
<td>91.44 - 76.20</td>
</tr>
<tr>
<td>Regional</td>
<td>1107</td>
<td>20.32 - 60.96</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7419 km</strong></td>
<td></td>
</tr>
</tbody>
</table>

Gas Pipeline System

Figure 1
- GPS Coordinates (latitude, longitude, elevation)
- ILI odometer readings (meters, feet)
- Constructed continuous measure (similar to odometer in the absence of such)
- Milepost (miles or kilometers)
- Engineering Station (e.g. 136+40)
- Surface reference

The need to integrate all the information in a common database and the definition of a point of study which was readily available for consultation led to the implementation of a Geographic Information System (GIS). Geographic location through the x and z coordinates is the linking variable among the different data sources, as this is a specific characteristic of each of the elements that make up the system and of any event affecting it.

By having an integrated database and a common reference system for all the sources, it is possible to:
- Perform a spatial representation of information originating from different tools and correlate their conclusions, thus enhancing the results from each separate report.
- Import documents, photographs, and satellite images, thus simplifying the location of specific points and the determination of the reasons for their occurrence.
- Develop new analysis tasks.
- In case of an event, it can be quickly located through the description of a geographic characteristic, whether its milepost is known or not.
- Improve the discovery and identification of parameters related to risk assessments.
- Filter, organize, and perform searches of the information according to specific requirements.
- Correlate the information with other information systems that include geographic variables. The possibility of integrating all the information in a GIS is undoubtedly the key to achieve an efficient management of the Integrity Plan established for our system.

2. CLASSIFICATION OF THREATS TO INTEGRITY

The “Pipeline Research Committee International” (PRCI) has analyzed gas pipeline incidents and classified them in 22 main causes: Each of these causes represent a threat to the integrity of the pipeline, and thus must be identified in order to determine if the system is subject to any of them, in which case the threat must be assessed and managed.

One of the causes reported by the operators is labeled: “unknown”. The remaining 21 threats have been classified in 9 major categories according to type of failure, nature, and growth characteristics. At a latter stage, the classification focuses on three types of flaws which are related to the time factor.

a) Time Dependent
   1) External Corrosion (1)
   2) Internal Corrosion (2)
   3) Stress Corrosion Cracking (3)

b) Stable
   4) Manufacturing Related Defects
      Defective pipe seam (4)
      Defective pipe (5)
   5) Welding/Fabrication Related
      Defective pipe girth weld (6)
      Defective fabrication weld (7)
      Wrinkle bend or buckle (8)
      Stripped threads/broken pipe/coupling failure (9)
   6) Equipment
      Gasket O-ring failure (10)
      Control/Relief equipment malfunction (11)
      Seal/pump packing failure (12)
      Miscellaneous (13)

c) Time Independent
   7) Third Party/ Mechanical Damage
      Damage inflicted by first, second, or third parties (instantaneous / immediate failure) (14)
      Previously damaged pipe (delayed failure mode) (15)
Vandalism (16)
8) Incorrect Operations
   Incorrect operational procedure (17)
9) Weather Related and Outside Force
   Cold weather (18)
   Lightning (19)
   Heavy rains or floods (20)
   Earth Movements (21)

The natural combination of threats (e.g., more than one threat occurring simultaneously at the same pipeline section) should also be taken into account at the development stage of the integrity plan. An example of such an interaction would be a pipe with localized corrosion that crosses a populated area and that suffers third-party damage.

Historically, metal fatigue has not posed a significant risk for gas pipelines. Nonetheless, if there have been significant changes in operative procedures and pressure and/or temperature variations are detected, fatigue should be taken into account as an additional factor, i.e., pressure-cycle and temperature-variation fatigue.

3. INTEGRITY MANAGEMENT PROGRAM

An integrity plan describes the process applied to evaluate and mitigate the risks posed by the previously described threats, so as to reduce: the number and consequences of accidents.

Figure 2 shows the framework for an Integrity Plan, as established by the supplement to the ASME B31.8 standard.

![Framework for an Integrity Management Program](image-url)
Integrity Management is a complex and interactive process involving the collection, monitoring and assessment of information. The stages described in Figure 2 show a sequence of activities and a significant flow and interaction of information throughout the different steps. Thus, the data collection and risk assessment stages are closely related.

3.1. Reasons for an Integrity Plan

Integrity Plans are required for a variety of reasons:

- **Accounting and Safety:** There are a number of reasons for which an operator needs to prevent pipeline deterioration and failure: To protect individuals and the environment, to comply with legal and regulatory requirements, to conform to current standards and to ensure the gas supply. All these parameters change through time (population increase, compliance with quality standards, cathodic protection, operative conditions). Therefore, a routine review of the entire system is a requirement.

- **Cost-Effectiveness:** Every year, the operators face the problem of asset deterioration. On the other hand, the passage of time increases the probability of failures; therefore, the program needs to be increasingly adjusted.

- **Insufficient Background:** Older lines are poorly documented, a fact which does not prevent them from having excellent safety levels.

- **Increase in capacity:** In order to reduce operation costs, operators normally attempt to increase the transport capacity and working life of their pipelines beyond their design values.

Therefore, there are many advantages to be obtained from an updated integrity plan:

- Ongoing review of the structural status of the pipeline.
- Review of design and operating conditions.
- Confirmation that the current operations are conducted in a safe manner.
- Opportunities to take action before failures occur.
- Inventory of the accuracy of features to satisfy regulatory reporting
- Confirmation of future operations for stockholders, clients, and general public.

4. INTEGRATING INFORMATION WITHIN A GIS

A GIS (Geographic Information System) is a computing system that has the capability of assembling, saving, handling, and displaying geographically referenced information. It combines layers of varied information about an area, in order to provide a better understanding of that site’s specific characteristics. The information layers to be combined depend on the desired purpose.

The GIS provides spatial analysis and visualization of the pipeline and its surrounding area. This spatial mechanism integrates inspection and positioning data with layers of spatial information about the pipeline and its environment, such as topography, population densities and aerial photos, in both planimetric map and profile views.

As we can see, a GIS can make use of information from different sources. The key requirement for the data source is that the location of the variables be known through its x, y and z coordinates (longitude, latitude and elevation.) A requirement to include a variable in the GIS is that it should be possible to locate it spatially.

The following figure shows the type of information included in our database which is available through the GIS. This information allows us to perform the following type of query to the system: Show all the defects at a depth below 40%, with a cathodic potential more positive than –850 mV OFF, and a soil resistivity of <10,000 ohms. The GIS provides an ideal platform for this type of complex queries.
Effectively, the GIS produces smart maps, a system that retains all the spatial relations of the data.

A field survey team equipped with GPS (Global Positioning System) units captured the coordinates for the pipe characteristics on the ground, such as: Valves, scraper traps, vents, river crossings, water, and roads. When entered into the GIS, all this information enabled the geopositioning of the pipe's layout and the incorporation of the data. Through the use of data capture tools, a variety of information was entered into the GIS: encroachment data, MAOP, coatings, cathodic protection, sleeves, etc.

A GIS also provides conversion of information not originally mapped into digital format, for later reorganization and use. Satellite images are an example; once incorporated into the database they can be used both to produce a map and to distinguish single points of interest, thus allowing to accentuate the spatial relationship among the objects that are being mapped. An example of this is the relationship between two information layers such as: gas pipelines and satellite images, through which it is possible to determine the number of household units in the proximity of the pipeline. A combination of photographs and satellite images at different resolutions was included into the GIS; the choice was determined by population density:

- **First Stage: Aerial Photogrammetry Survey.** Second Stage: Ikonos satellite images (at a 1.5 mt/pixel resolution), performed for populated and semi-populated areas. This information provides the exact location of facilities in the proximity of our installations which may pose a risk, and helps determine the consequences of an unexpected event.
- **Multispectral Landsat TM Satellite images (at a 30 mt/pixel resolution) and SPOT images (at a 10 mt/pixel resolution) for remote locations.** Both are very useful for the determination of cartographic characteristics, soil usage, hydrography, roads, and layout of the pipeline and of other systems.

All these images are compressed and incorporated into the system in MrSid format, which significantly reduces the file size without affecting picture definition.

Projection is a key component of map drawing. A projection is a mathematical process to transfer three-dimensional earth curvature information into a two-dimensional surface, such as a sheet of paper or a computer screen. Different maps use different projections, as each projection is destined to a specific use. GIS's enable the handling of records in such a way that they can be quickly adapted to the proper projection.

Another important function of the GIS is the possibility of monitoring a visible variable through time in a satellite image. By comparing satellite images it is possible to analyze changes in a river's course in the vicinity of our pipelines, or the number of new household units between two periods of study (in our case, comparing images from the years 1998 and 2001).

### 4.1. Integrating GIS with Risk Assessment

The risk assessment is an analytical process through which an operator determines the types of adverse elements or conditions that may have an impact on pipeline integrity. It also determines the possibility or probability of an event that may cause a loss of integrity. This analytical process includes design, construction, operation, maintenance, testing and inspection information related to the pipeline system. The risk program serves the purpose of identifying the most significant risk areas in which the operator is required to develop an effective mitigation / prevention and detection plan.

TGS has implemented a Risk Assessment Model called IAP (Integrity Assessment Program) for its entire pipeline system. This program determines a pipeline's global risk as the product of two main factors: The **probability** of occurrence of an adverse event (e.g., external corrosion damage) and the **consequences** of an event (e.g., houses in the proximity of the pipeline).

The IAP establishes a comparison of each variable with the corresponding value of the attribute and the significance of the risk assigned by the user in the algorithm, thus determining the contribution to the risk of that variable. The partial contributions from each variable are added to obtain a final risk score.

To avoid duplicating the database required to estimate the risk variables, an interface was developed to capture the required information from the GIS to be fed into the IAP. In turn, the results obtained through that interface were entered into the GIS database. Therefore, the system uses a single database which is enhanced by the results from the IAP.
4.2. Integrating GIS with Soil Model

TGS performed a complete soil survey, whose data and conclusions were incorporated into the GIS.

The study comprised two stages: The first stage was oriented toward the establishment of a relationship between the geologic-morphologic-edaphologic information and the possible susceptibility of gas pipelines to the impact of the medium (soil) properties. In order to do this, a geomorphologic regional interpretation was conducted at the areas of influence of the various pipelines, taking into account the hydrologic and climatic characteristics of each area. Soil Charts were used to associate each landscape unit to the soil characteristics, its properties, analytical data, etc., and the degree of erosion, salinity, alkalinity, and drainage deficiencies. The study developed a geologic-morphologic risk model to characterize the various gas pipeline sections.

The second stage implied the determination of a Corrosion Rate for the soils, based on the determination of physical and chemical parameters (pH, resistivity, Eh, water percentage, sulfates, chlorides, carbonates, alkaline elements, etc) at selected sites which were considered critical in relation to the prior assessment. To do this, it was necessary to obtain field samples, on-site soil measurements, and laboratory analyses, and to develop a specific model in order to assess and identify those areas which were more sensitive to physicochemical corrosion and its correlation to the distribution of corrosion failures in gas pipelines.

4.3. Integrating GIS with SCC Model

The J.E. Marr Associates staff developed a SCC susceptibility model adapted to the gas pipeline system of TGS. This model incorporates two basic hypotheses: The existence of a pipe with a propensity to develop SCC and loss of coating bonding.

The areas which the model identifies as showing a higher probability of SCC are entered into the GIS database and assigned priority for assessment in relation to their proximity to population centers.

4.4. GIS in the INTRANET

All the company personnel can access the data entered into the GIS through a tool developed for the Web. Users can browse the entire system and perform queries. They can select a device or a pipe section, and zoom in or out through user-friendly commands. Satellite images are also available for consultation.

There are many projects for information queries, which have been designated with the following labels:

- Facilities
  This project includes information related to the surface facilities along the gas pipeline system (valves, plants, scrapper traps, etc.), which can be identified through a set of symbols.
- Completed Works
  The project describes the integrity tasks performed on the gas pipelines, such as repairs, replacements and pipe descents, re-coatings, etc.
- Planned Works
  The project details the future integrity tasks to be performed on the gas pipeline, such as re-coatings, loop construction, instrumentation passages, etc.
- Surveys
  The project specifies the surveys performed for gas pipeline integrity monitoring, and produces reports on the monitoring results.

  It contains information about:
  1. Internal Inspection
  2. On/Off Potentials
  3. GIS/DCVG
  4. Risk Assessment
  5. SCC Model
  6. GPS Survey
  7. Soil Models

- Cartography / Buenos Aires Ring
  The project contains topographic and demographic data, and satellite images of the areas affected by the pipelines, at two different resolutions:
    - 15 mts. for the entire layout of the pipe (Landsat type)
- 1 mt. for the area designated as the Greater Buenos Aires Supply Ring (Ikonos Type)

- Measurements
  This project displays operating data for flow rate, pressure and temperature, taken at compressor and regulator plants, and at delivery and injection points monitored by the Measuring System.

- Line Diagrams
  The project generates a unifilar diagram that includes database information, is user-defined, and can be printed through the Visio software.

5. EVOLUTION OF INTEGRITY PLANS DEVELOPMENT AT TGS

Until 1992, the transportation and distribution of natural gas was the sole responsibility of Gas del Estado, a State company owned by the Argentine government.

The information about pipeline construction, including technical data of the pipes and existing facilities, was manually sketched in very long maps that could be pasted together. The addition or replacement of an installation implied that the affected map had to be re-drawn. With the coming of the PC, many databases that included information from those maps were developed. The main problem arose when a modification was done and it was necessary to update both data sources (maps and databases) separately because they were not synchronized. For this reason, pipeline integrity studies were scarce and inaccurate.

In 1993, a short time after TGS took charge of the southern transport system, the need arose to develop the first pipeline integrity plans. Due to the lack of investment in the years before the privatization, the risk factor to control was external corrosion, therefore the developed plan addressed the following issues.

- Definition of an Internal Inspection Program
- Definition of an inspection tool
- Possible pipeline replacement / repair program

The available information was scarce: It comprised the latest internal inspections conducted by Gas del Estado, inspections conducted with MFL low resolution tools, and measurements of On cathodic protection potentials obtained in 1992. By correlating this information it was possible to make the above mentioned decisions.

During 1994 and 1995, the first MFL internal inspection using high resolution tools was conducted over the entire system, which was immediately followed by a flaw repair stage where the criteria established by the ASME B31G standard were applied. Additionally, natural potentials and Off km potentials were measured, which entailed the upgrading of the software and equipment used for this task.

In 1996, a re-coating plan was developed for an extension of approximately 240 km. The plan was implemented between 1997 and 2001. The concentration per km of remaining failures from the first run of internal inspections and the On, Off, and Natural Potentials were taken as a basis for the plan.

In the years 1997 and 1998, the second internal inspection run of the system was conducted. At this point, a new element for analysis was added, that is, the flaw comparison between the two internal inspections, which afforded the opportunity to perform specific corrosion growth studies.

In 1999, the company began the construction of a database to complete and improve the Integrity Plan. The availability of all the data in a single information system allowed us to enhance our assessment capabilities and to improve our preventive and predictive maintenance plans. Prior to this we had to define which information was required inside the database and which were the sources to obtain that information.

5.1 TGS’ Current Integrity Plan

Knowing the status of an entire pipeline implies monitoring and measuring many variables which are related to each of the risk categories that affect pipes.

The first step for data collection consisted of the identification of the required data sources to develop the integrity plan, and their incorporation into a common database. As established by the supplement to the ASME B31.8 standard, those sources can be categorized in three separate classes.

- Design, Materials, and Construction Records: The design information is used to identify design pressures and other data, such as diameter and thickness. The materials information should include the steel grade, seam type, welding procedure type, coating type, pipe manufacturer, quality certifications, etc.
Right of Way Records: Used to identify the pipe’s location. This information is essential to determine the areas which may be affected by the pipeline, it establishes patrolling programs, and measures taken to prevent third-party damages.

Operational, Inspection, Maintenance, and Repairs Records: Operation and Control Procedure data are used to identify maximum working pressures and temperatures, and their variation through time. Maintenance records are used to determine the efficiency of the anticorrosion protection system. Line inspections are used to identify: Corroded sections, dents, cracks, and other flaws. The repairs records identify problems in the past that may recur in the future. These records are also used to identify the specific location where these problems have been eliminated from the system.

Records to determine pipe sections that may affect sensitive areas or high-consequence zones: This information is used to develop impact zones along the pipeline.

Incident and Risk Reports

The type of data required depends on the type of flaw and the failure model that is expected. Nonetheless, it is necessary to consider not only the expected failure models but also the potential but so far inexistent failure models.

Therefore, if we consider external corrosion, the key variables that should be collected and included in the database are:
- Soil Type
- Pipeline Temperature
- Soil PH
- Cathodic Protection System used.
- ON, Off, and Natural potentials data, and their evolution through time.
- Various coating types of the pipeline
- Coating condition
- Pipeline age
- Coating age
- Potential interferences that other metallic structures may induce on the cathodic protection system
- Data from specific cathodic protection surveys: CIS, depolarization of the pipeline, coating conditions, corrosion coupons, DCVG, etc.
- Internal inspection data regarding external metal loss. In our case, two complete runs of the whole system.
- Location of active corrosion areas
- Monitoring of rectifiers
- Potential for MIC
- Level Curves
- Jobs performed on the system, such as: Coating replacement, repair of flaws, installation of new rectifier equipment, installation of deep anodes.
- Flaw history

In the case of internal corrosion, the following data are required:
- Gas composition
- Sulphide percentage and water content
- H2S, carbon dioxide and monoxide values.
- Gas temperature
- Pipeline age
- Level Curves
- Sweep frequency of cleaning scraper
- Sweep results of cleaning tools
- Internal inspection data regarding external metal loss.
- Flaw history

For third-party damage, the database requires the following information:
- Nearby constructions
- Nearby farming activities
- Control of Third-party work on the pipeline.
- Inspection patrol frequency
- Public communication program
- Special pipeline protection: guniting, gabions, and others.
- Pipeline obstruction
- Pipeline tensile strength
- Nominal pipe thickness
- Conditions of the trail
- Demarcation of the pipeline
- Internal inspection data in relation to dents

When considering earth movements, the following parameters should be known and included in the database:
- Soil Type
- Water crossings: flow rate, position changes through time.
- Pipeline cover
- Girth weld conditions
- Pipeline descent data
- Flaw history

As regards materials, the following data are required:
- Seam type
- Manufacturing Date of pipe
- Manufacturer hydraulic test
- Internal inspection data in relation to materials defects
- Pipeline tensile strength
- Transition temperature
- Pressure cycles

As regards SCC (Stress Corrosion Cracking) or HIC (Hydrogen Induced Cracking), there is a variety of elements that should be known for decision-making:
- Soil Type
- Soil composition
- Soil drainage
- Low Points
- Pipeline Temperature
- Coating type
- Coating condition
- Pipeline pressure cycles
- Gas temperature
- Pipeline tensile strength
- Transition temperature
- Cathodic protection data
- Condition of rectifiers
- Site resistivity
- Hydraulic tests
- Data from test wells to determine the presence of cracking
- Internal inspection data related to crack detection

The entire volume of technical, operational, regulatory, design, inspection, monitoring, environmental and soil variables, and land registry information described in this section must be properly correlated in order to improve the decision-making process as regards pipeline integrity. Therefore, the decision was made to collect, generate (if required), and update this impressive amount of data, in order to tabulate them and incorporate them into a common database.

The Integrity Plan was developed as a result of an initial collection of existent data and a further risk assessment performed with the available information.

In the future, the data list that was defined in the initial process may change according to emerging requirements related to:
- The need for better understanding of the threats that may affect the pipeline’s integrity.
- The need to modify the threat prevention and/or mitigation program.

5.2 Relevance of a GIS for an Integrity Plan

A GIS is not a tool or a system that provides decisions automatically; it is rather a query and analysis tool that creates data maps in relation to the decision process undertaken.

This means that the key advantage that a GIS provides is undoubtedly the improvement in the management of available information and, therefore, of available resources. “Better information leads to better decision-making.” As we can see, an integrity plan handles a great number of variables that must be analyzed separately and as a set in order to make the right decisions.
The main advantages are:
- Current and accurate pipeline geoposition and landbase data.
- Integrated and Organized Data
- Current Pipeline Reports
- Practical, cost–effective solution
- Meets the requirements of 49 CFR 195
- The improvements in decision–making are: excavation decisions, repairs planning, implementation decisions, and emergency response.
- Accuracy to satisfy regulatory reporting
- Risk analysis can be estimated by means of well–maintained and accurate data
- Integration of multiple inline inspections
- Facilitation of corrosion growth modeling

6. CONCLUSIONS

As gas pipeline design provides for ample safety margins, the failure rate of these systems is low. Nevertheless, as any other engineering structure, they can fail, mainly due to the fact that buried pipes eventually suffer the effect of a variety of agents that have an impact on their integrity.

Every operator strives to provide consistent safety and reliability throughout the system, avoiding adverse effects on the environment, the employees, or the clients. This is the reason for the existence of the Pipeline Integrity Program.

In order to know the condition of an entire pipeline system it is necessary to collect and monitor a great number of variables. Those variables usually originate from a variety of measuring systems, which in turn apply different processes to determine a specific point in the pipeline system. Examples of this diversity are CIS and ILI information. The correlation of these two types of information is no simple task.

Our solution to this problem entails the implementation of a GIS, which through the use of geographic coordinates (information added through a GPS unit), enables the correlation of information by means of the x, y, and z coordinates.

Additionally, we enhanced the existing information by incorporating information from other sources.
- Satellite images: Landsat, Spot, and Ikonos.
- Soil Models
- Road Maps
- Hydrographic Maps
- SCC (Stress Corrosion Cracking) Models.

Having huge amounts of data does not necessarily mean that the information is useful and that the operator knows what is going on in the pipeline. Data should be structured and organized properly to facilitate its use. This is another essential task that the GIS performs for TGS: storing, organizing, and handling information in an efficient and user-friendly manner.

By using the GIS it is possible to conduct topical mappings, logical searches, integration with geographic data, and risk scenario simulations, thus creating new analysis tools.

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