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Pipeline Data Analysis to make suitable decisions in the integrity of pipelines

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Abstract

A Pipeline Integrity Management System (PIMS) is a crucial to ensure the safety of the public, protection of the environment and the reliable and cost effective transportation in pipelines in accordance with API 1160, Managing System Integrity for Hazardous Liquid Pipelines and the PD 8010 part 4, Steel pipelines on land and subsea - code of practice for integrity management. The keynote of the PIMS is to develop a Geographic Information Systems (GIS) to facilitate data integration and further assessments.

The purpose of this paper is to present two study cases where a proper data analysis give an operator the opportunity of making suitable decisions to maintain their assets and prioritize their investments.

The first case of study relates how combining different sources of data helped us to identify cathodically unprotected locations or external corrosion areas using an internal risk model and the methodology described in “Pipeline Risk Management Manual. Ideas, techniques and resources, W. Kent Muhlbauer, 2004, WKM Consultancy, Texas, USA”.

The second case explains a successful vulnerability analysis to detect illegal tappings on pipelines. Pipeline thefts have been reported as a major integrity issue as they increase the likelihood of having a loss of containment in High Consequence Areas (HCA). This assessment was carried out in different sections of the pipeline network through multivalent analysis based on geographic information and previous experiences, what has allowed the company to predict the location of new potential sabotages.

Key words: Pipeline Integrity Management System, PIMS, Geographic Information Systems, GIS, Illegal Tapping, Vulnerable Analysis, High Consequence Area, HCA

1. Introduction

A Pipeline Integrity Management System (PIMS) guarantees the safety of people, protection of the environment and safe and efficient transport of products. This PIMS facilitates appropriate and timely actions on the part of the pipeline to assure that the pipeline system is continually operated in a manner that minimizes risks to the public, the employees, the environment, or the customers. Furthermore, this PIMS provides a comprehensive and structured framework for assessment of pipeline condition, likely threats, risks assessment and mitigation actions to ensure safe and incident free operation of the pipeline system.

This system includes risk assessment plans and assessments of integrity, repair and remediation, re-assessment, risk prevention and mitigation and management of change. There are multiple ways to develop a PIMS, although it is highly recommended to do it in accordance with international standard such as API (American Petroleum Institute) 1160-2013 - Managing System Integrity for Hazardous Liquid Pipelines and good practices.

A key part of the PIMS is how to save and analysis the available information. Hence, it is necessary to create a database of pipeline segments which contains all the key information to carry out accurate assessments. This database must be maintained by graphic files contained in a Geographic Information System (GIS) to ease later analysis and create remediation plans to keep the pipeline fitness-for-service.

The following studies are a direct application of this analysis over the pipelines and has been performed by Argongra in collaboration with CLH-PS.

2. Identifying the risks

The risk model identifies all the variables, for each of the different threats, related to the likelihood and the consequence of failure. The findings of the analysis will justify diverse action plans and the allocation of priorities, resources and targets related to risk management.

2.1. Risk Analysis

The risk analysis integrates the information available on the threats to pipelines and the respective consequences of failure. Risk is defined as the likelihood of failure multiplied by the consequence of failure.

$$R = L_f * C_f$$

2.2. Assessment Methods

There are two commonly used methods for calculating the risk of leaks in pipelines. These are the qualitative and the quantitative methods.

<u>Qualitative Method</u>

This method uses categories for input and output values. The categories can be defined as low, medium-low, medium, medium-high and high, or in numerical terms, assigning them values of 1, 2, 3, 4 or 5. The input values or categories are processed systematically to determine the output categories (low, medium or high) or the output numerical values, which technically continue to be qualitative, despite being numerical.

Quantitative Method

This method uses numerical input and output values that express the likelihood of a failure occurring in the pipeline during a defined period of time.

Advantages and Disadvantages

The below table lists some of the advantages and disadvantages of these 2 approaches used in the calculation of the risk of a leak in the pipeline.

	Qualitative Method	Quantitative Method
Advantages	It is easier to engage people who are not experts. It is also easier to reach a consensus.	The accuracy tends to increase over time, as the company builds on past data and gains experience. The risk can be expressed in high level terms, such as: Monetary values and likelihoods expressed as percentages.
Disadvantages	The results of the analysis depend on the degree of experience of the members of the risk management team created. In addition, it is hard to justify preventive measures as there is no basis for a cost-benefit analysis.	The calculations can be complex. The processes needed to reach good results and consensus may be time-consuming.

Table 1. Advantages and disadvantages of qualitative and quantitative risk analysis

2.3. Results of the Risk Assessment

One common way of presenting and analysing the results is through the use of a matrix. Qualitative and quantitative assessment matrixes are shown below.

Likelihood Consequence	Unlikely	Possible	Likely	Highly Likely	Very Likely
Critical	Tolerable Risk	Average Risk	High Risk	High Risk	Very High Risk
Severe	Tolerable Risk	Average Risk	Average Risk	High Risk	High Risk
Moderate	Tolerable Risk	Tolerable Risk	Average Risk	Average Risk	High Risk
Slight	Low Risk	Tolerable Risk	Tolerable Risk	Average Risk	Average Risk
Irrelevant	Low Risk	Low Risk	Tolerable Risk	Tolerable Risk	Tolerable Risk

Table 2. Qualitative Risk Matrix

Consequence / Likelihood	1,000 €	10,000 €	100,000 €	1,000,000 €	10,000,000 €	100,000,000 €
1						
0.1						
0.01						
0.001						
0.0001						

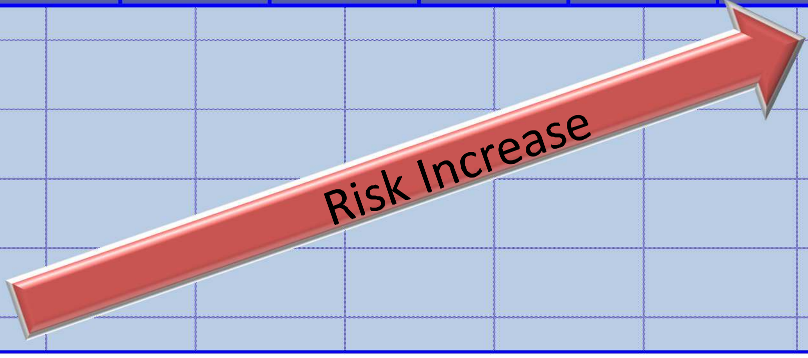

Table 3. Quantitative Risk Matrix

Every pipeline in CLH-PS is risk assessed by an internal model where the anomalies are classified in a qualitive 5x5 matrix to prioritize the action plans based on likelihood and consequence via a risk assessment plan. A risk assessment plan is a plan that aims to identify any likelihood of failure and the consequences thereof, with the respective failure variables. The risk analysis is conducted as often as needed, based on the most significant changes that affect the risk factors as regards risk rating and classification.

The model is customized to consider different sources of information to make a proper assessment such as the general intrinsic characteristics of the pipeline (year, steel grade, type of coating, MAOP, etc.), the potential threats of the pipeline (type of corrosion, third party damage, fabrication defects, etc.) along with integrity surveys (Cathodic Protection routine values, In-line inspections, coating surveys, CIPS measurements, depth of cover data, etc.) and the consequences that a failure could mean in the different High Consequence Areas (HCAs).

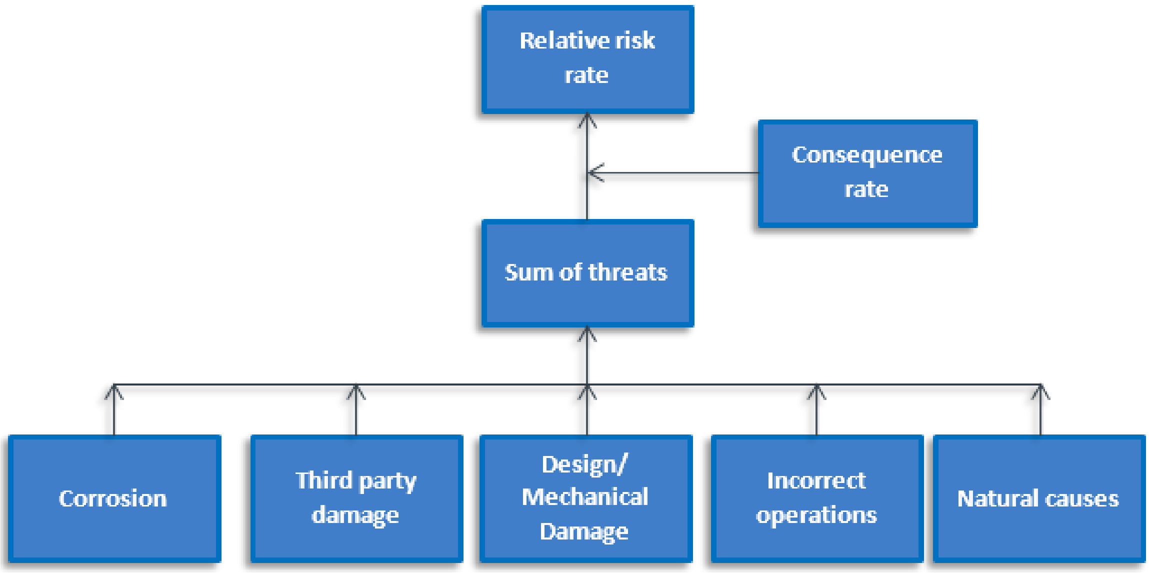

Figure 1. Variables included in the risk algorithm

All of this information is geographically represented to help the analysis using the Corporative GIS developed by Argongra and accessible to the key players in the company at all times via a web service.

3. Case Study 1.

3.1. **Findings**

The first case study combines the analysis of different integrity sources to determinate the root cause of an increase of the corrosion in an area of a pipeline.

In the case study, we were analysing a 108.4 km pipeline predominantly coated with coal tar or asphalt enamel built in the 1950's. The last In-line inspection done in February 2018 gave similar results compared to the previous one in 2012. However, there were some new anomalies with an external corrosion lower than 30% loss of wall thickness that appeared in a determined area.

Reviewing the rest of the available integrity information from the last and previous inspections in that area, the main information was as follows:

- Cathodic Protection routine monitoring. TRs are at least checked monthly via remote monitoring. The closest TRs are 17.8 and 15.4 km away from the area. Some variations have been identified during the last 5 years but no none of them were considered as major. TPs in the area are not controlled via remote monitoring, so they are inspected once a year. Values identified an increase in 2015 and the last off values were recorded over 1,200 mV.
- Induced Alternating Current. The corrosion likelihood in the area was recorded as negligible because the alternating current density referred to a 1 cm^2 bare surface was lower than 30 A/m^2.
- Close Interval Potential Survey (CIPS). The whole network is inspected under the 5-year plan of surveys. Again, it was found a slight overprotection in the area where compared with the previous inspection with "off values" over 1,200 mV.
- Coating survey (DCVG). The whole network is inspected under the 5-year plan of surveys. No major changes were detected between inspections. In both cases, some defects were found. In most of the pipeline is likely to find significant coating damages due to the age of it.
- Depth of cover. The whole network is inspected under the 5-year plan of surveys. No major changes were detected being the pipeline 0.8 m underground as average.

In the next figure, it is possible to see all the integrity values in the same layer where the anomalies were detected.

Figure 2. Integrity values over the section

According to the internal risk model, initially, none of the anomalies of the area required to be inspected as they were allocated in the tolerable risk area:

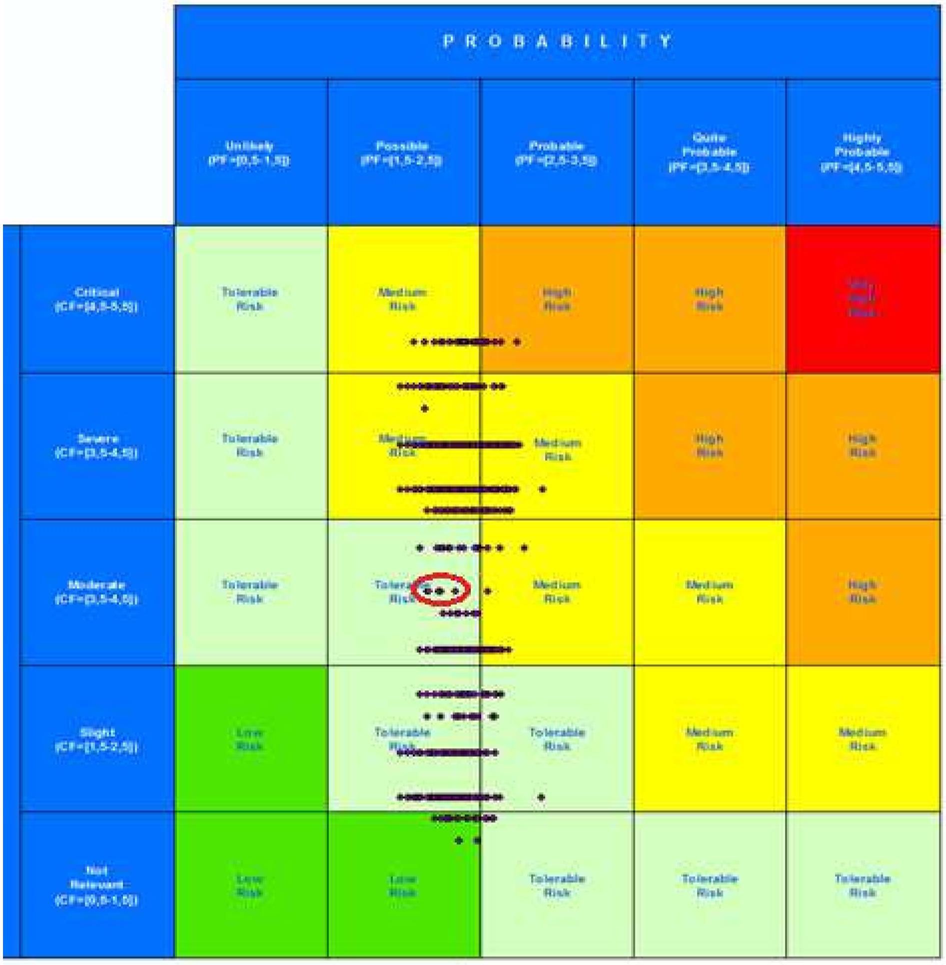

Figure 3. Initial risk matrix of the pipeline

Therefore, these anomalies were not included to be investigated in the In-Line Inspection Plan. However, in March 2018, due to a third-party infringement in the area it was noted that some unrecorded water services were buried close to the pipeline. When the levels of the CP were recorded over the pipeline, some fluctuation was detected when the TRs were switching on/off so it was decided to undertake further investigations of the CP in the area to determinate the cause of this. A PCM was carried out in April 2018 in order to identify a possible location of the CP defects or drain in the area. The results confirmed that a large CP current consumer (buried bond) was involved nearby the In-Line Inspection defects. As consequence of this finding, in July 2018, it was decided to excavate the pipeline to remove the potential bonding between the lines. A mechanically connected bond cable to pipeline connection was found, the connection type is unclear, believed to be a non-conventional type of cable connection. On inspection of the foreign bond cable it was found that 11.1A DC current was following in the bond. It was decided to contact the CP Engineer from the water services to disconnect the TRs that could affect the system from the foreign source. As in the figure below, it was identified that the cross-country pipeline was not protected and the previous reading were misleading the real situation:

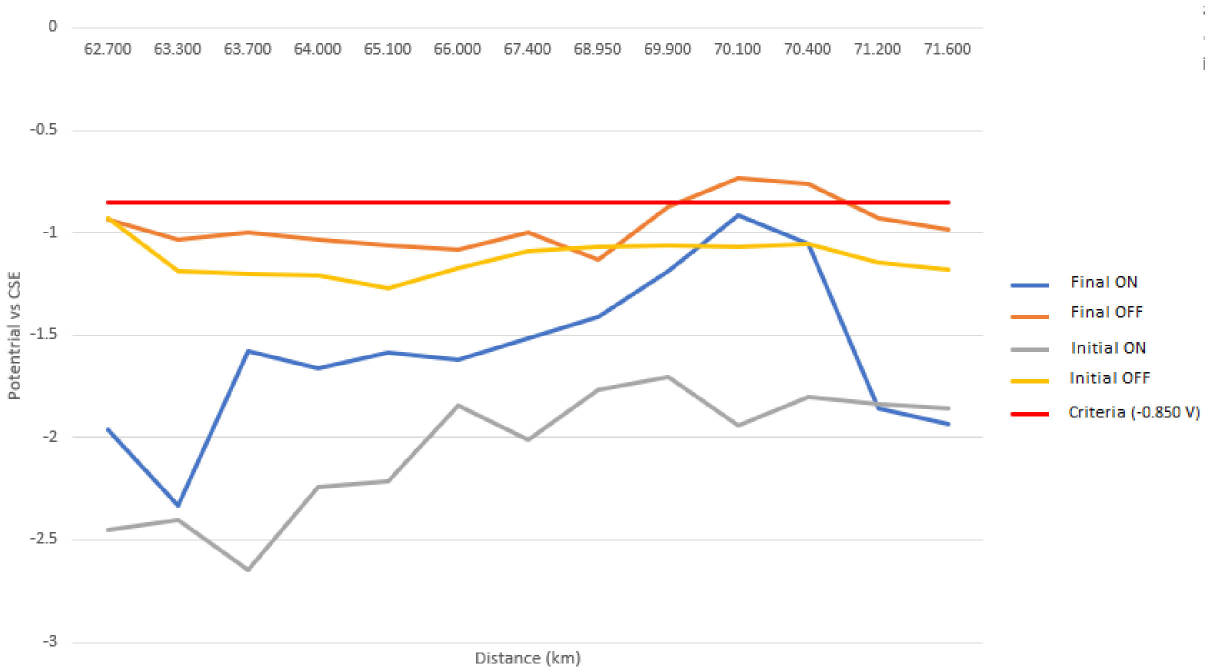

Figure 4. Potential measures obtained before and after disconnecting the bond

Further investigations were done in both pipelines to demonstrate if connecting both system or isolating them were the best solution for both parties. Different testing and surveys (current drainage, DCVG, CIPS and test pots survey) were carried out in order to confirm the cause of the lack of CP, confirm if increasing the existing CP system was enough to solve the lack of CP and finally to confirm if an upgrade on the existing CP system in the area was suitable. It was demonstrated that isolating both systems and installing a new TR in the area would solve the problems for both parties. This mitigation plan was adequate to minimize the stray currents between the pipelines and also raise the pipeline existing low potentials. The new TR was commissioned in November 2018 confirming that the pipeline is currently protected and is not affecting third parties.

3.2. **Results of the analysis**

The combination of different sources of data is paramount to create valuable integrity action plans. Treating the anomalies alone could mislead the general picture of the pipeline. Changes in a pipeline could be due to different factors and they should be analysed to get a better understanding of the condition of the asset.

The risk assessment model has been refined after these findings to include anomalies under the ILI action plan if they are over-protected close to third party lines:

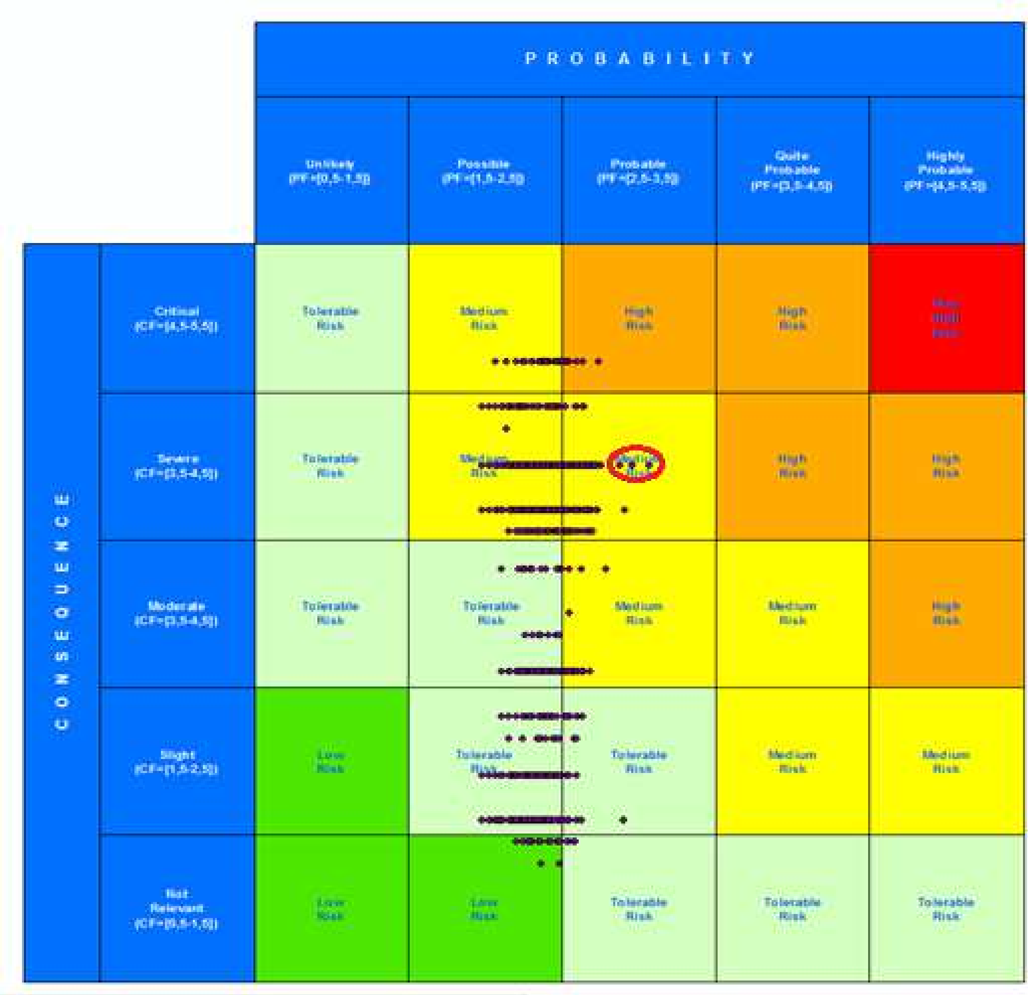

Figure 5. Definitive risk matrix of the pipeline

Using this new model was possible to detect another bond that was draining Cathodic Protection into other system.

4. Case Study 2

After the completion of the first case study successfully, a new approach was followed to review potential impact on the pipelines of third parties and the consequences of a leakage using different sources and available data.

The purpose of the present study was to carry out a vulnerability analysis against damage caused by third parties (illegal tappings) on oil pipelines. These acts may cause direct product theft, damage to the pipeline integrity and an increase in the risk associated.

The vulnerability analysis carried out in different sections of the pipeline network was undertaken through multivalent analysis based on geographic information. As in previous case, the assessment of an isolated event could lead to wrong assumption so the following technical information was identified to prepare analysis scenarios:

- Cartographic network files.
- Mapping of the areas of the study.
- General characteristics of the areas.
- Main pipeline characteristics.
- Operation history in the lines.
- Historical illegal tappings archive on selected sections.
- Benchmarking across different companies.
- Public available data.
- Illegal tappings scenarios or modus operandi to consider.

Once all these data were populated from different sources, the geographic analysis was planned in two phases:

- General Vulnerability Analysis: A regional analysis across different networks was carried out to the relationship between illegal tappings and different parameters such as terrain surface roughness, terrain slope around pipeline, accessibility to main transport routes (highways, roads and paths), population close to pipelines, high tree cover density areas and distribution of organised crime groups across the network. The results per variable were classified in 5 levels being the 5 the highest likelihood in the model.
- Detailed Vulnerability Analysis: A detailed vulnerability analysis against 3 generic location types was carried out, identifying specific areas that may have high vulnerability.
    - Type I location: Areas close to pipelines and secondary roads or paths.
    - Type II location: Areas close to pipelines with high tree cover density around where pipeline is not visible from roads or population areas.
    - Type III location: Areas in which the extraction of product could take place inside a big building.

4.1. **Analysis of criminal infractions**

Pipeline illegal tappings are normally linked to theft of product from a pipeline, loss of primary containment of the pipeline, or unauthorised activity in the vicinity of the pipeline. Organized crime bands presence is usually related to different crimes types such as weapons possession, robberies, etc. For this reason, criminal rate per habitant was used as an important parameter in the general analysis of the pipelines network.

Using the public records of crime rates by area, the following histogram was calculated after performing an analysis of the variable across the pipeline network. The histogram represents the crime rate value on the x-axis, illegal tappings frequency on the y-axis and the surface of each bar is proportional to the values frequency represented.

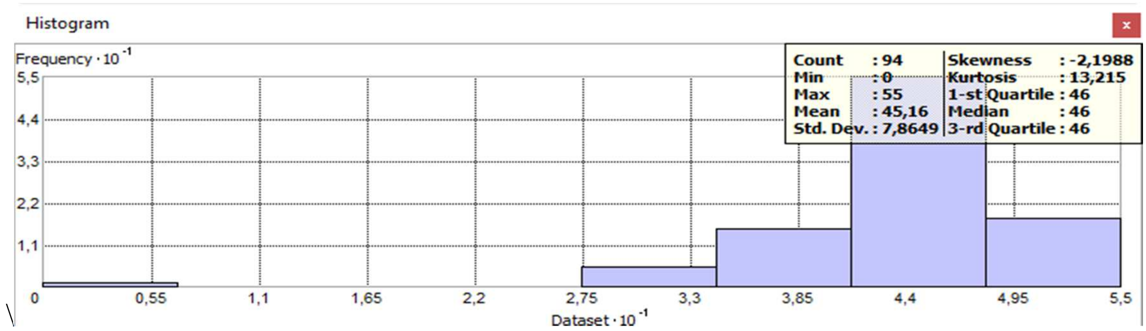

Figure 6. Crime rate frequency histogram in illegal tappings areas.

4.2. **Ground orographic analysis**

Ground orography limits the accessibility, visibility and alertness against possible vigilance patrols. Different parameters were evaluated being terrain slope the most important parameter in the general analysis of the pipelines network. The different parts of the network were classified into 5 vulnerability levels using Digital Elevation Model SRTM data from NASA. It was assigned 1 to the highest slope level and 5 to the lowest slope level.

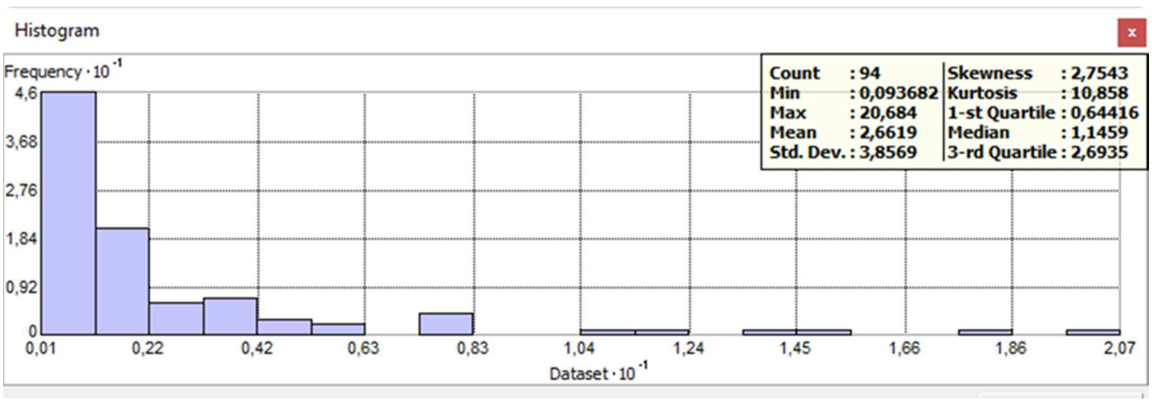

Figure 7. Slope frequency histogram in illegal tappings zones.

4.3. **Accessibility analysis**

Illegal tapping areas usually have an easy and fast access and a quick getaway. Thieves' vehicles must find a fast connection to main roads as part of a rapid evacuation strategy. For this reason, information associated to the main transport network with velocity categories was used as an important parameter in the general analysis of the pipelines network.

Based on the information provided in the road network data with speed categories, the time cost displacement for each meter was calculated with the least accumulative cost distance for each point to the nearest source over a cost surface. The accumulated cost distance was calculated in time for any point located 1,500 m from the pipeline. The purpose of this calculation was to find the nearest communication route with more than 70 km/h permitted speed.

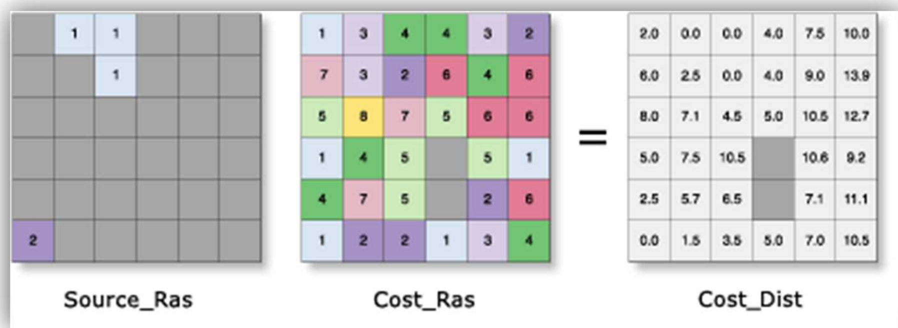

Figure 8. Calculation method for accumulated cost

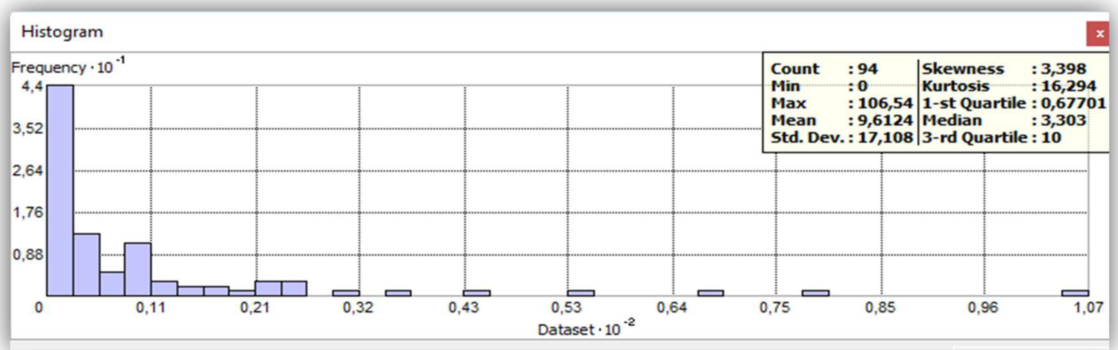

Figure 9. Accessibility frequency histogram (minutes) along illegal tappings

4.4. **Land uses analysis**

Areas with a low visibility allow organized gangs steal the product in a discreet and comfortable manner. For example, high tree cover density areas are the perfect places for thieves to hide when they make illegal tappings. A land use characterization was performed for each pipeline segment using the Corine Land cover from European Environment Agency.

4.5. **Population analysis**

Stolen product from the pipeline could end up in surrounding population hands as the main target is to sell it as soon as possible. Therefore, local population could be potential customers. The analysis of this variable was compared to the location of the pipelines and previous events. There is no other information in this variable that allows the model to be refined. The preliminary analyses were carried out using different distances (5, 10, 20, 30 and 50 km) and it was concluded that an illegal tapping could happen in a pipeline within an area of 20 km.

The following graph was calculated after performing an analysis of the variable across the pipeline network.

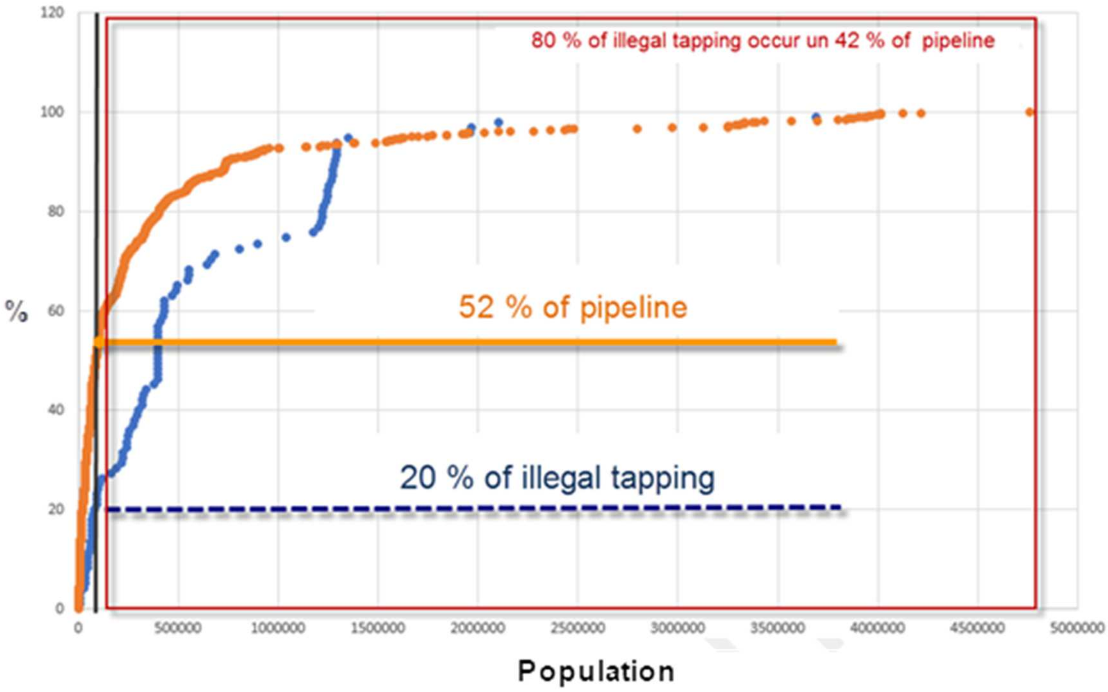

Figure 10. Number of illegal tapping compared to area population

4.6. **Results of the analysis**

After the vulnerability analysis with the factors described above, every section of the different pipelines was categorized in four different vulnerability types from low to very high depending on the likelihood of the event. As a result of this study, the risk of every single section of pipeline has been identified, knowing the most vulnerable locations

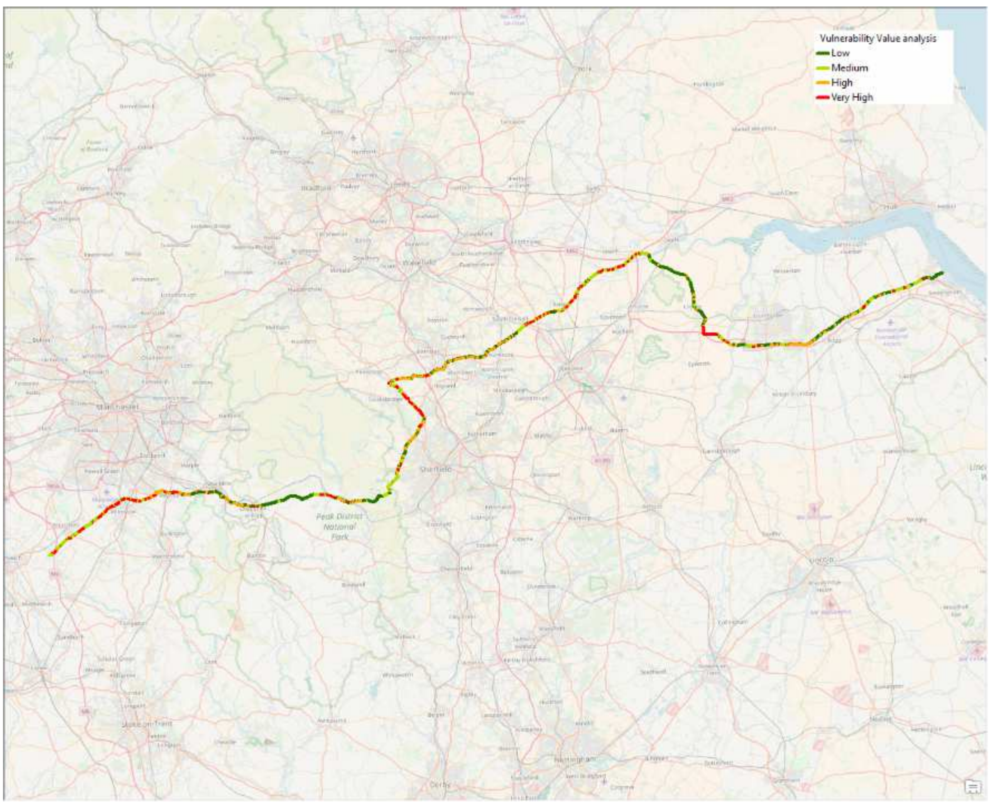

Figure 11. Vulnerability map of the pipeline

5. Conclusions

These two cases demonstrate how powerful and important is to use and analyse properly all data available to make right decisions for the integrity of the pipelines. Main conclusions of these studies are as follows:

1. A datum considered alone could drive to make wrong assumptions or decisions.
2. Modelling the system always turns the data into the information.
3. There is a great amount data and different resources available within the companies and in the market, which could be used to understand the pipeline integrity issues.
4. Not all the data available is useful and overloading a system will not make a model better.
5. Data that could be geo-referenced within a map should be analysed via a Geographic Information System.
6. Models must be continuously updated to improve themselves.
7. Sharing data between operators could help to solve quickly integrity problems on the cross-country pipelines.

6. Literature

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