

RISK-BASED INSPECTION METHODOLOGY AND THE USE OF REAL-TIME IMMERSIVE TECHNOLOGY IN NATURAL GAS AND/OR NATURAL GAS LIQUIDS PIPELINE TRANSPORTATION SYSTEMS FROM AN INSPECTOR'S PERSPECTIVE

First Author

Edilberto Gutierrez Ortiz
Lima, Perú

Second Author

Roger Lopez Tuesta
Lima, Perú

Third Author

Alfredo Pilares Pfuño
Lima, Perú

Fourth Author

José Unzueta Graus
Lima, Perú

SUMMARY

Peru has more than 1,500 kilometers of natural gas and natural gas liquid transportation pipelines, including gathering systems, which are exposed to different geotechnical risk conditions along their routes.

For this reason, it is necessary to identify the risks and then define a prioritization criterion to execute the corresponding inspection actions. In this sense, a risk-based inspection methodology was developed, considering an acceptability criterion based on the Analytic Hierarchy Process (AHP) method by Saaty.

Finally, some risk sections located in hard-to-reach areas, require the use of immersive technology in real time that allows achieving the objectives of the inspection actions.

NOMENCLATURE

| | |
|------|---|
| AHP | Analytic Hierarchy Process |
| ROW | Right of way |
| FPV | First Person View |
| GIS | Geographic Information System |
| NG | Natural Gas |
| NGL | Natural Gas Liquids |
| RBIM | Risk-Based Inspection Methodology |
| RPA | Remotely Piloted Aircraft ¹ |
| RPAS | Remotely Piloted Aircraft System ² |

1. INTRODUCTION

In Peru, regarding NG and NGL transportation pipelines, by the year 2023, there is an approximate length of 1677 kilometers of ROW that cross the jungle, highlands and coastal areas, in which there are “geohazard” (geotechnical and hydrotechnical issues) with the potential to affect the integrity of the pipelines and affect the continuity of the NG and NGL transportation service.

On the other hand, the Inspector has the responsibility, among other things, of verifying the regulatory compliance of

the NG and/or NGL pipeline transportation companies (Inspected Company) in order to ensure the supply of natural gas as part of national energy security. In this context, considering the extensive length of the pipelines, the geographical complexity, and the limited availability of resources, the Inspector's question is: Where to carry out the inspection actions? In response to this query, the RBIM was designed, which takes as input geohazards information provided by the Inspected Entities and other available public sources, processes it, and produces a matrix that efficiently guides field inspection actions, translated into an Annual Inspection Program.

The RBIM involves creating a risk matrix in which the geotechnical risk factors are identified, as well as their corresponding risk level. Regarding the risk factors, the weighting of their level of importance or relevance must be carried out, and for validation, the Saaty's Analytic Hierarchy Process (AHP) method is used, which provides an acceptability criterion.

After that, the identified risk areas are grouped into risk sections. Following this, using expert judgment with the Delphi method, each risk section is evaluated based on the risk matrix, obtaining a score for the corresponding prioritization section. Subsequently, the inspection action orientation matrix is obtained for each Inspected Company.

Finally, some prioritized sections have difficult to access to development the inspection in normally condition, for these reason is required to use a real-time immersive technology is planned through the utilization of Special RPAS (Remotely Piloted Aircraft Systems) Flights with FPV technology, in order to optimize field supervision times. This technology allows the Inspector to visually experience, in real-time and immersive, the image from the first-person view of the RPA or drone, direct the aerial inspection operation, and perform zoomed-in optical approaches of up to 30X to identify potential geotechnical issues on the ROW and/or verify mitigation actions implemented by the Inspected Entities.

¹ Term that appears in the Complementary Technical Standard 001-2015 of the General Directorate of Civil Aviation of Peru

² Idem to the previous

2. RISK-BASED INSPECTION METHODOLOGY

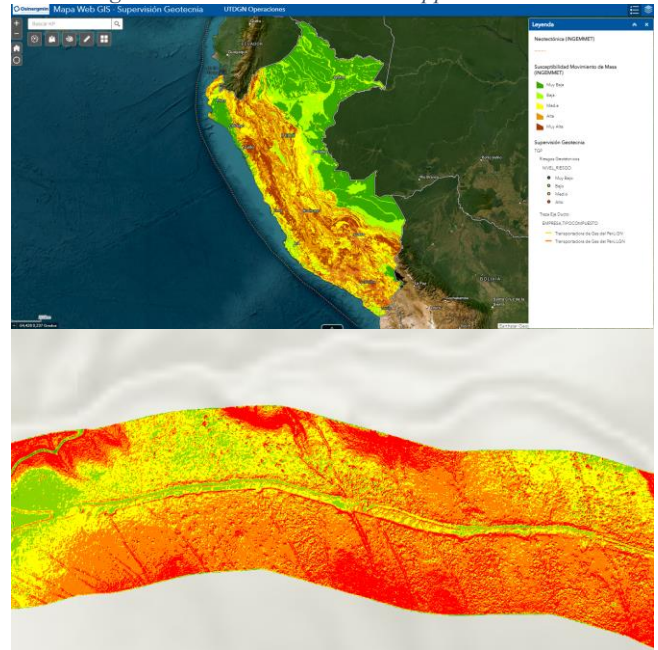
In order to obtain the main input of the RBIM, the Inspector, in order to focus his inspection actions on the ROW whose length is 1677 kilometers, requests the Inspected Entities, with an annual frequency, the information related to geotechnical risks. Additionally, we collected information from publicly available sources of Peruvian State Entities about the geotechnical issue, and this is supplemented with existing information that we collected during that inspection action. All this information is stored in our Geospatial Database (Geodatabase).

In line with the above, by the year 2023, it was possible to identify 755 risk areas, of which 495 correspond to the jungle, 216 to the highlands, and 44 to the coast. This information, along with what was mentioned in the preceding paragraph, was stored in the institution's Geodatabase and processed using GIS in order to generate web applications (see Figure 1) that enable the visualization and grouping of risk areas.

It is important to note that the GIS contains technical information that allows the corresponding geotechnical analysis to be carried out, including:

- ✓ Public Company Information:
 - Geological Map of Peru (INGEMMET).
 - Map of susceptibility to mass movements in Peru (INGEMMET).
 - Map of Neotectonic Faults (INGEMMET).
 - Map of Peru's climatic classification (SENAMHI).
 - Topographic Map of Peru (IGN).
 - Peru Seismic Map 2022 (IGP).
- ✓ Own Information:
 - Areas with a history of geotechnical and hydrotechnical issues.
 - Aerial images and orthophotos obtained by drone overflight.
 - Digital Terrain Models obtained by drone overflight.
 - Satellite images.

Figure 1: Geotechnical GIS Web Application



Source: Self-created based on Web GIS - Osinergmin

Subsequent to what has been indicated, deskwork is carried out to group the risks, then we identify a 168 risk sections, each of which requires a specific inspection action to verify compliance with relevant regulations.

Finally, the RBIM is applied to the risk sections to prioritize inspection actions, following these steps:

2.1 Identifying Risk Factors

This involves defining risk factors that are related to the occurrence of a geotechnical risk, which, if realized, would impact buried NG and NGL pipelines and could affect the supply of natural gas, generating some measure of restriction in its service. In this context, it is necessary to identify risk factors applicable across all Inspected Entities in Peru engaged in NG and NGL pipeline transportation activities (see TABLE 1).

2.2 Determining Risk Levels

This step entails defining the risk levels to be considered, as well as assigning a valuation to each risk level. Each organization can adopt this criterion as per its risk management policy. For this case, five risk levels have been defined, each with corresponding values ranging from 0.1 to 1.0 (see TABLE 1).

Table 1: Detail of Risk Factors and Risk Levels

| Risk Factors | RISK LEVEL | | | | |
|-----------------|---------------|----------|-------------|-----------|----------------|
| | Very Low Risk | Low risk | Medium risk | High risk | Very High Risk |
| | 0.1 | 0.25 | 0.5 | 0.75 | 1 |
| Rainfall | | | | | |
| External Forces | | | | | |
| Slope | | | | | |
| Studies | | | | | |
| Monitoring | | | | | |

Source: Self-created

The Pairwise Comparison Matrix (PCM) is a square matrix containing paired comparisons (pairwise comparison) of risk factors.

$$A = \begin{pmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{pmatrix}$$

According to the following table, pairwise comparisons are conducted, specifying the preference scale for each risk factor in the comparison column against the risk factors in each row.

2.3 Determining Valuation Criteria

For each risk factor and level, a clear and precise geotechnical criterion must be defined, so that it is used at the time of its assessment by a group of geotechnical professionals (see ANNEX 1).

Table 2: Valuation Criteria

| Rainfall | Existing External Forces (Mass Movements) | ROW Based on Slope | Geological / Geotechnical Studies | Geotechnical Monitoring Frequency |
|----------|---|--------------------|-----------------------------------|-----------------------------------|
| | | | | |

Source: Self-created

Table 4: Pairwise comparison

| Risk Factors | Rainfall | External Forces | Slope | Studies | Monitoring |
|-----------------|----------|-----------------|-------|---------|------------|
| Rainfall | 1 | 1 | 2 | 3 | 3 |
| External Forces | 1 | 1 | 1 | 3 | 3 |
| Slope | 1/2 | 1 | 1 | 2 | 1 |
| Studies | 1/3 | 1/3 | 1/2 | 1 | 1 |
| Monitoring | 1/3 | 1/3 | 1 | 1 | 1 |

Source: Self-created

2.4 Determining the level of importance or relevance of risk factors

In this stage, the aim is to prioritize the risk factors. This is achieved by adopting Thomas Saaty's Analytic Hierarchy Process (AHP) method, which validates this hierarchy through an acceptability criterion, according to the following detail:

2.4.1 Pairwise Comparison among Risk Factors

A Pairwise Comparison Matrix (PCM) is created, establishing the order of relative importance among risk factors based on Expert Judgment. This comparison is carried out using the Analytic Hierarchy Process (AHP) contained in Thomas Saaty's method [1]. This method employs a scale with values from 1 to 9 to assess the relative preferences of both elements (See TABLE 3).

Table 3: Scale extracted from the method proposed by Thomas Saaty

| Preference Comparison | Numerical Rating |
|--|------------------|
| Extremely Preferred | 9 |
| Between very strong and extremely preferred | 8 |
| Very Strongly Preferred | 7 |
| Between strongly and very strongly preferred | 6 |
| Strongly Preferred | 5 |
| Between moderately and strongly preferred | 4 |
| Moderately Preferred | 3 |
| Between equally and moderately preferred | 2 |
| Equally Preferred | 1 |

Source: The Analytic Hierarchy Process, Thomas L. Saaty, 1980

2.5 Determining Hierarchy Coefficients

In this stage, the development of the Pairwise Comparison Matrix involves the following steps:

- Sum the values in each column of the PCM.
- Divide each element of the matrix by the total of its column. The resulting matrix is referred to as PCM-Normalized (PCM-N).
- Calculate the average of the elements in each row, corresponding to the risk factors being compared.
- As a result, the resulting vector is obtained, in which the hierarchy coefficients (importance) of each risk factor are found.

Table 1: Determining Hierarchy Coefficients

| Risk Factors | Rainfall | External Forces | Slope | Studies | Monitoring |
|-----------------|----------|-----------------|-------|---------|------------|
| Rainfall | 1 | 1 | 2 | 3 | 3 |
| External Forces | 1 | 1 | 1 | 3 | 3 |
| Slope | 1/2 | 1 | 1 | 2 | 1 |
| Studies | 1/3 | 1/3 | 1/2 | 1 | 1 |
| Monitoring | 1/3 | 1/3 | 1 | 1 | 1 |
| | 3.17 | 3.67 | 5.50 | 10.00 | 9.00 |

Source: Self-created

Table 2: Calculation of Resultant Vector

| Risk Factors | Rainfall | External Forces | Slope | Studies | Monitoring | Resultant Vector |
|-----------------|----------|-----------------|-------|---------|------------|------------------|
| Rainfall | 0.32 | 0.27 | 0.36 | 0.30 | 0.33 | 0.32 |
| External Forces | 0.32 | 0.27 | 0.18 | 0.30 | 0.33 | 0.28 |
| Slope | 0.16 | 0.27 | 0.18 | 0.20 | 0.11 | 0.18 |
| Studies | 0.11 | 0.09 | 0.09 | 0.10 | 0.11 | 0.10 |
| Monitoring | 0.11 | 0.09 | 0.18 | 0.10 | 0.11 | 0.12 |
| | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Source: Self-created

2.6 Verifying the Consistency of Risk Factors Hierarchy

- a) As part of the AHP process, the Consistency Ratio (CR) is determined, which is calculated using the following formula:

$$CR = \frac{CI}{RI} \quad (1)$$

Where:

CI: Consistency Index

RI: Random Consistency Index

- b) Regarding the consistency index, it is determined according to the following expression:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

Where:

n : Number of compared risk factors.

λ_{max} : It is the sum of the components of the result of the matrix multiplication

- c) Regarding λ_{max} , it is calculated as follows:
 d) It is the sum of elements in the matrix resulting from the product of the Pair Comparison Matrix (PCM) with the "Resultant Vector" Matrix.

Table 7: Matrix Product

| Risk Factors | Rainfall | External Forces | Slope | Studies | Monitoring | Resultant Vector |
|-----------------|----------|-----------------|-------|---------|------------|------------------|
| Rainfall | 1 | 1 | 2 | 3 | 3 | 0.32 |
| External Forces | 1 | 1 | 1 | 3 | 3 | 0.28 |
| Slope | 1/2 | 1 | 1 | 2 | 1 | 0.18 |
| Studies | 1/3 | 1/3 | 1/2 | 1 | 1 | 0.10 |
| Monitoring | 1/3 | 1/3 | 1 | 1 | 1 | 0.12 |

Source: Self-created

This results in the following matrix:

Table 8: Result of Matrix Multiplication

| λ_{max} |
|-----------------|
| 1.6196 |
| 1.4349 |
| 0.9411 |
| 0.5091 |
| 0.6014 |

Source: Self-created

From which the result is obtained, that $\lambda_{max} = 5.11$

- e) Regarding the Consistency Index (CI), it is determined directly, selecting the value of "n" in the following table.

Table 9: Calculation of Consistency Index (CI)

| n | Random Consistency Index (RI) |
|----|-------------------------------|
| 3 | 0.525 |
| 4 | 0.882 |
| 5 | 1.115 |
| 6 | 1.252 |
| 7 | 1.341 |
| 8 | 1.404 |
| 9 | 1.452 |
| 10 | 1.484 |

Source: Aguarón and Moreno-Jiménez, 2003

- f) Based on the size of the matrix, the values of the Consistency Ratio (CR) are considered acceptable when they are lower than the Acceptable Consistency Ratio (AR), as detailed in the following table. If CR exceeds AR, the hierarchy must be reviewed.

Table 10: Acceptable consistency ratio (AR) Indicator

| Matrix Size | Acceptable Consistency Ratio |
|--------------------|------------------------------|
| 3 | 5% |
| 4 | 9% |
| $5 \leq n \leq 10$ | 10% |

Source: Aguarón and Moreno-Jiménez, 2003 – Modified

TABLE 10: ACCEPTABLE CONSISTENCY RATIO (AR) INDICATOR

- g) From what was detailed above, there is a table for the acceptability criteria to verify the consistency of the hierarchization carried out in the Pairwise Comparison Matrix (PCM).

Table 11: Pairwise Comparison Matrix (PCM)

| λ_{max} | Consistency Index (CI) | | Adaptability Criterion | | | |
|-----------------|------------------------|--------|-------------------------------|------------------------|-----------------------------------|----------------|
| | n | CI | Random Consistency Index (RI) | Consistency Ratio (CR) | Acceptable Consistency Ratio (AR) | Meets Criteria |
| 1,6196 | 5 | 0,0265 | 1,115 | 2,376% | 10% | Meets Criteria |
| 1,4349 | | | | | | |
| 0,9411 | | | | | | |
| 0,5091 | | | | | | |
| 0,6014 | | | | | | |
| 5,11 | | | | | | |

Source: Self-created

In this regard, it can be stated that the hierarchy criteria established in the Pairwise Comparison Matrix is acceptable. Therefore, the level of importance for each risk factor should align with the resultant vector. In other words, the weight of each risk factor such as rainfall, external forces, slope, studies, and monitoring is 32%, 28%, 18%, 10% and 12% respectively.

2.7 Determining the Priority Level of Risk Sections

Once the risk factors and their level of importance or relevance have been identified, and with the input from the list of geotechnical risk sections prepared, we proceed, for each section, to associate the risk factors and define through an Expert Judgment the risk level (very low, low, medium, high and very high) represented by each section, for this you must consider the criteria detailed in numeral 2.2. After that, a priority index is obtained by summing up the obtained values.

Table 12: Section Prioritization

| Risk Section | Risk Factors | | | | | | Index | Priorit y |
|--------------|--------------|-----------------|--------|---------|------------|--------------|-------|-----------|
| | Rainfall | External Forces | Slope | Studies | Monitoring | $\Sigma(FR)$ | | |
| | 31,71% | 28,07% | 18,47% | 9,96% | 11,78% | | | |
| Section 1 | Low | High | Low | Low | Low | 0,390 | 2 ● | |
| Section 2 | Very high | Low | Medium | Low | Low | 0,534 | 2 ● | |
| Section 3 | Very high | High | Medium | Low | Low | 0,674 | 1 ● | |
| ... | ... | ... | ... | ... | ... | ... | ... | |
| Section 66 | Low | Low | Low | Medium | Medium | 0,304 | 3 ● | |
| Section 67 | Medium | Low | Low | Low | Low | 0,329 | 3 ● | |
| Section 68 | Low | Low | Low | Low | Medio | 0,279 | 3 ● | |
| Section 73 | Low | Low | Low | Low | Very low | 0,232 | 3 ● | |

Source: Self-created

In this case, the Inspector has defined the following actions for each priority index:

Table 13: Frequency of Inspection Actions

| Ranking | Frequency of Supervision Actions per Year (minimum) | |
|------------|---|------------------------------|
| Priority 1 | 0.61 a 1.00 | 03 Inspection ³ . |
| Priority 2 | 0.36 a 0.60 | 02 inspection. |
| Priority 3 | 0 a 0.35 | 01 Inspection. |

Source: Self-created

Finally, it should be noted that the RBIM allows the inspector to efficiently guide field inspection actions in order to be able to warn the operator of the NG and NGL pipeline transportation system, the existence of any geotechnical issues that requires maintenance actions. And/or additional mitigation measures in order to safeguard the integrity of the pipelines.

3. USE OF IMMERSIVE REAL-TIME TECHNOLOGY

Once the risk sections have been defined and prioritized, an inspection schedule is established. Subsequently, the risk sections are reviewed to identify the difficulty of access and/or are of long length and/or there is some type of restriction to access the ROW, based on this the use of real-time immersive technology is planned through the use of RPAS Special Flights, in order to optimize the supervision times of the sections in the field. In the last year, Inspection has brought innovation by introducing immersive technology through RPAS.

This disruptive technology involves the use of First Person View (FPV) goggles worn by the Inspector. These goggles allow the Inspector to view the images captured by the RPAS camera in an immersive and real-time manner, experiencing the perspective of the RPAS in the first person, as it moves along the inspected section. RPAS transmit real-time images captured by their digital cameras directly to the FPV goggles, with a high resolution of 3840 x 1080 (single screen: 1920 x 1080)1080).

Furthermore, the Inspector can control the aerial operation, including movements, turns, speed, angles of view, and even optical zoom (without image distortion) of up to 30X (30 times more without distortion) in order to warn and record possible geotechnical issues in the ROW through aerial photographs and/or videos and/or verify the mitigation actions implemented by the Inspected Agents as part of regulatory compliance. Likewise, if considered, you can carry out on-site supervision of certain progressive stations to collect more details, thereby reducing daily supervision times.

³ An inspection should be considered by field, remote or desk inspection.



FIGURE 2: IMMERSIVE REAL-TIME TECHNOLOGY



FIGURE 3: GREATER SPATIAL REACH AND AERIAL



FIGURE 4: RPAS INSPECTION



FIGURE 5: RPAS INSPECTION



FIGURE 6: RPAS INSPECTION

4. RESULTS OF THE USE OF IMMERSIVE TECHNOLOGY

In order to assess the benefits of Traditional Inspection and compare it with the outcomes of RPAS Inspection, which has two aspects (Regular Technology and Immersive Technology), five comparison factors have been defined (See Table 14):

- **Human Mobility: Traditional Inspection** requires significant movement by the Inspector throughout the inspected area. In contrast, the **RPAS Inspection** requires less movement of the same, because it is only enough to define launch points of the RPA for aerial flights.
- **Inspection Experience: Traditional Inspection** offers a real-time superficial inspection with visualization of the inspected area, through the use of human vision. **RPAS Inspection**, on the other hand, provides two types of experiences based on the visualization device used:

- **RPAS Inspection with Regular Technology** provides a real-time superficial inspection with visualization of the inspected area using a tablet or smartphone.
- **RPAS Inspection with Immersive Technology** provides a real-time comprehensive inspection with visualization of the inspected area using of FPV goggles.
- **Inspection Perspective: Traditional Inspection** provides a ground-level perspective, limited to human visual range. **RPAS Inspection**, on the other hand, offers an aerial flight perspective, which provides the following benefits:
 - **Greater Spatial Reach:** Allows Inspectors to supervise a greater spatial reach in less time compared to Traditional Ground Inspection (16 greater spatial reach).
 - **Creative Aerial View:** By inspecting segments from an aerial perspective, the inspector is able to capture unique and creative images and videos (panoramic macro views and detailed micro views) that would not be possible through Traditional Ground Inspection (limited to ground-level views).
- **Optical Magnification Capability: Traditional Inspection** does not have the capability to carry out optical magnifications, because it is subject to human vision. On the other hand, RPAS Inspection allows the use of digital cameras with high optical magnification capabilities. In the case of the Inspector, there is a camera capable of up to 30X optical zoom, which allows the Inspector to zoom in on specific elements without compromising image quality. The 30x optical zoom means that the optical system can increase the apparent size of an object by up to 30 times compared to its actual size in normal view. This allows the Inspector to capture finer details of distant elements without physically approaching them.
- **Control of External Factors:** The **Traditional Inspection** is susceptible to distractions due to the existence of external factors that surrounds the Inspector. In contrast, **RPAS Inspection** offers two

types of External Factors Control based on the visualization device used:

- **RPAS Inspection with Regular Technology** does not provide control over External Factors, through the use of Tablets or smartphones, as it does not allow isolating the physical and visual environment that surrounds the Inspector. It does not block external visual distractions and therefore does not allow complete focus on terrain inspection.
- **RPAS Inspection with Immersive Technology** does provide a high level of control over External Factors, through the use of FPV goggles. It allows:
 - **Isolation from the Environment and Task Focus:** FPV goggles isolate the physical and visual environment that surrounds the Inspector, blocking external visual distractions and allowing complete focus on terrain inspection.
 - **Enhanced Perception:** FPV goggles improve visual perception by providing a clear, focused, and high-definition view of what is happening in the inspected terrain, without unnecessary visual distractions.

Table 34: Inspection Comparison

| | Traditional Inspection | RPAS Inspection | |
|----------------------------------|--|--|-------------------------------------|
| | | Regular Technology | Immersive Technology |
| Human Mobility | ↑↑↑↑ | ↓↓↓↓ | ↓↓↓↓ |
| Inspection Experience | Superficial in real time with direct observation | Superficial in real time through the use of a Tablet or smartphone | Deep in real time by using FPV lens |
| Inspection Perspective | Ground-based | Aerial | Aerial |
| Optical Magnification Capability | None | High | High |
| Control of External Factors | ↓↓↓↓ | ↓↓ | ↑↑↑↑ |

Source: Self-created

5. CONCLUSION

The RBIM allowed the inspector to identify and prioritize his inspection actions in sections where there are geotechnical risks that could affect the integrity of the buried pipelines. As a result, sections of the ROW were identified that had not received timely attention from the operator in terms of repair and/or mitigation measures.

Furthermore, it should be noted that use of RPAS with Immersive Technology offers greater benefits compared to RPAS with Regular (traditional) Technology, because it allows the user to improve his attention and concentration during the flight and avoid external distracting factors, which has allowed the identification of geotechnical issues that affected the buried pipelines.

REFERENCES

- [1] Saaty, Thomas. *The Analytic Hierarchy Process*, 1980.
- [2] Aguarón, J. and Moreno-Jiménez, J. M. The Geometric consistency index: Approximated thresholds. *European Journal of Operational Research*, 2003.

6TH INTERNATIONAL PIPELINE GEOTECHNICAL CONFERENCE IPG 2023

ANNEX I Valuation Criteria

| Risk Factors | Risk level | | | | |
|--|---|---|--|--|---|
| | Very Low Risk | Low risk | Medium risk | High risk | Very High Risk |
| | 0.10 | 0.25 | 0.50 | 0.75 | 1.00 |
| Rainfall | COAST Chala -> 0 - 500 masl Maritime Yunga -> 500 - 2300 masl | HIGHLANDS Puna -> 4001 - 4800 masl Janca -> 4801 - 6768 masl | HIGHLANDS Quechua -> 2300 - 3500 masl Suni -> 3501 - 4000 masl | HIGH JUNGLE Fluvial Yunga -> 1001 - 2300 masl Rupa Rupa -> 401 -> 1000 masl | LOW JUNGLE Omagua 80 - 400 masl |
| External Forces (Mass Movements) | N.A. | * DOES exist or existed a Mass Movement (M.M), NOT ACTIVE, DID NOT cause any damage to the Pipeline, Mitigation Work COMPLETED. | * DOES exist or existed a Mass Movement (M.M), currently NOT ACTIVE, DID NOT cause any damage to the Pipeline, and Mitigation Work NOT COMPLETED. * DOES exist or existed a Mass Movement (M.M), currently NOT ACTIVE, DID cause or could cause damage to the Pipeline, Mitigation Work COMPLETED. * DOES exist or existed a Mass Movement (M.M), currently ACTIVE, DID NOT cause or could cause damage to the Pipeline. * DOES exist or existed a Mass Movement (M.M), currently ACTIVE, DID cause or could cause damage to the Pipeline, Mitigation Work currently COMPLETED. | * DOES exist or existed a Mass Movement (M.M), currently NOT ACTIVE, DID cause damage to the Pipeline, and Mitigation Work NOT COMPLETED. | * The ROW crosses a geological fault * The ROW does NOT cross a geological fault, A Mass Movement (M.M) existed or exists, currently ACTIVE, DOES cause or could cause damage to the Pipeline, and Mitigation Work NOT COMPLETED. |
| | * There is NO existence or past occurrence of a Mass Movement (M.M), NO Erosion issues due to Furrows or Gullies. | * There is NO existence or past occurrence of a Mass Movement (M.M), but there are Erosion issues due to Furrows and Gullies. There is NO damage/exposure to the buried pipeline. | N.A. | * There is NO existence or past occurrence of a Mass Movement (M.M), but there are Erosion issues due to Furrows and Gullies. There IS damage/exposure to the buried pipeline. | N.A. |
| Slope | * Area with flat to slightly sloped (undulating) topography 0° - 5° | * Moderately inclined slope. 6° - 15° | * Very inclined slope 15° - 22° | * Steep slope or Escarpment 22° - 32° | * Very steep slope or Very escarpment > 32° |
| Geological / Geotechnical Studies | * DOES have Geologic-Geotechnical Study involving the risk area. Geotechnical/Geophysical tests and/or monitoring are NOT necessary. Detailed plans for each risk area are available | * DOES Have Geologic-Geotechnical Study involving the risk area. Geotechnical/Geophysical tests and/or monitoring are necessary. Tests have been conducted. Detailed plans for each risk area are available | * DOES Have Geologic-Geotechnical Study involving the risk area. Geotechnical/Geophysical tests and/or monitoring are NOT necessary. Detailed plans for each risk area are NOT available * DOES Have Geologic-Geotechnical Study involving the risk area. Geotechnical/Geophysical tests and/or monitoring are necessary. Tests have been conducted. Detailed plans for each risk area are NOT available | * DOES Have Geologic-Geotechnical Study involving the risk area. Geotechnical/Geophysical tests and/or monitoring are necessary. Tests have NOT been conducted. * Does NOT have Geologic-Geotechnical Study involving the risk area. Detailed plans for each risk area are available. | * Does NOT have Geologic-Geotechnical Study involving the risk area. Detailed plans for each risk area are NOT available |
| Geotechnical Monitoring Frequency | DOES Require Geotechnical Instrumentation, Geotechnical Instrumentation data logging (**) during the rainy season: a) In real time | DOES Require Geotechnical Instrumentation, Geotechnical Instrumentation data logging (**) during the rainy season: a) Between 1 to 15 days | DOES Require Geotechnical Instrumentation, Geotechnical Instrumentation data logging (**) during the rainy season: a) Between 16 to 30 days | DOES Require Geotechnical Instrumentation, Geotechnical Instrumentation data logging (**) during the rainy season: a) Between 31 to 45 days | DOES Require Geotechnical Instrumentation, Geotechnical Instrumentation data logging (**) during the rainy season: a) At least once b) No data recorded, due to lack of Instrumentation implementation and/or being out of service. |
| | Does NOT require Geotechnical Instrumentation, Patrol Frequency during the rainy season: a) In Jungle, every 1 to 15 days b) In Sierra, every 1 to 30 days c) In Coast, at least 2 times | Does NOT require Geotechnical Instrumentation, Patrol Frequency during the rainy season: a) In Jungle, every 15 to 30 days b) In Sierra, every 31 to 45 days c) In Coast, at least 1 time | Does NOT require Geotechnical Instrumentation, Patrol Frequency during the rainy season: a) In Jungle, every 31 to 45 days b) In Sierra, every 46 to 60 days c) In Coast, at least 1 patrol outside the rainy period | Does NOT require Geotechnical Instrumentation, Patrol Frequency during the rainy season: a) In Jungle, every 45 to 60 days b) In Sierra, over 60 days c) In Coast, no patrols | Does NOT require Geotechnical Instrumentation, Patrol Frequency during the rainy season: a) In Jungle, over 60 days b) In Sierra, no patrols |

(*) Different possibilities

(**) Implementation of the Geotechnical Instrumentation is based on actions established in corresponding studies, including the Strain Gauge.