A Case Study for Bow-tie Methodology Utilization for Pipelines

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1. INTRODUCTION

The vast range of major accidents which occurred in industrial activities in a not too distant past, showed the importance of seeking to prevent accidents and minimize environmental damage, damage to persons, damage to the assets and damage the company's image. Often, risk assessments are made roughly and thus ultimately lead to serious consequences such as financial losses, environmental impacts and impacts at the company's reputation and harm to the safety of people.

The large amount of accidents caused by risk management fail and the growth of pipelines utilization for natural gas transportation were the main motivations to study a good methodology to evaluate the pipeline safety management [1].

2. OBJECTIVES OF THE WORK

This study aims to provide a tool for improving risk management: the Bow-tie diagram. This diagram is intended to analyze the effectiveness of existing controls in the process to be studied and facilitate the understanding of risk management, by presenting a graphical interface, both by people who know the process, as by that are not directly linked to it. Furthermore, the diagram establishes the relation between the barriers that prevent the occurrence of threats, and Recovery Preparedness Measures to minimize the consequences.

Another key point of the Bow-tie methodology is the identification of the project Shortfalls, allowing them to be proposed Recommended Action to remedy these Shortfalls.

In this paper, was used as a case study a natural gas pipeline to the presentation, analysis and interpretation of Bow-tie methodology in pipelines.

3. BOW-TIE DIAGRAM

The Bow-tie technique is used to present the major hazards of an enterprise in order to facilitate the understanding of people from all levels of an organization of risk management and its importance. The better understanding of the risk management by operators through Bow-tie technique has facilitated decision making in case something goes wrong, especially for facilities that are highly complex [2 – 4].

The Bow-tie methodology provides a comprehensive view of the relation between the top event, the threat of it, the barriers, the mitigating measures, Escalation Factors and their controls and consequences. Its use is generally made to demonstrate the control of hazards related to Health, Safety and Environment [5, 6].

The Bow-tie diagram is based on HEMP (Hazards and Effects Management Process) methodology [7]. The HEMP methodology and the use of Bow-tie diagram explore in more detail the protection systems of an installation. Even if the installation has barriers and Recovery Preparedness

Measures, these may fail. There are many opportunities for decay and wear of the protection system, from design flaws to inadequate maintenance, lack of procedures, conflicting objectives, lack of communication, inadequate training, etc. The Bow-tie diagrams analysis verify the efficiency of these barriers, and proposes solutions in case of failure of it [4, 8].

Throughout the elaboration of Bow-tie diagrams, pending issues or Shortfalls are identified in the venture, Recommended Actions are proposed to address them, and a responsible for the implementation of the proposed actions can be assigned also. The presentation of Bow-tie diagrams and Recommended Action list, connected to their own responsible, allows the workforce to see clearly the distribution of responsibilities and the possible consequences of a task being performed incorrectly, and also become them the "risk owners". In this manner, the commitment of employees to prevent their occurrence is increased [8].

4. CASE STUDY: NATURAL GAS PIPELINE

The pipeline proposed for the analysis comes from a refinery (Section I) and follows leading natural gas to a Gas Distribution Company (Section II). Outside the boundaries of the enterprises, the pipeline is grounded with a minimum coverage of 2 meters and covers an essentially industrial region, passing by a few residential areas. It has a length of approximately 3,600 meters, a nominal diameter of 16 ", with an operating pressure of 26 kgf /cm2, and the maximum allowable working pressure (design pressure) of 40 kgf /cm2, an operating temperature of 22 °C, with nominal capacity of 90,000 Nm3/h. The pipe material is carbon steel and is in accordance with the API standard RLX60. The construction and installation of the pipeline were performed according to NBR 15280-2.

The natural gas being carried has the following composition: 94% methane, 4% ethane, 1.5% propane and 0.5% nitrogen. The main dangers inherent in the natural gas flowing in the pipeline are associated with the high flammability of the product and may cause accidents involving fires and explosions.

The simplified flowsheet of the natural gas pipeline is shown in Figure 1 below.

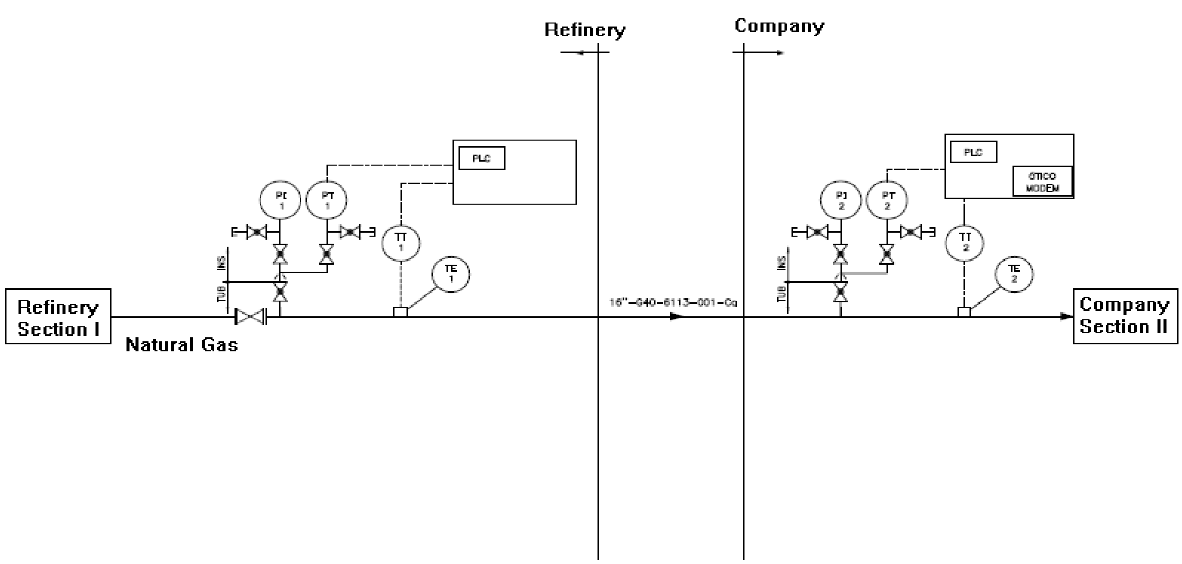

Figure 1 – Simplified flowsheet of the proposed natural gas pipeline

To carry out the case study, some assumptions were adopted with regard to the protection, control, inspection and the emergency plan.

To avoid corrosion by the soil on the outer surface of the pipes at deployment phase an anticorrosive coating using the triple-layer polypropylene was added. In order to protect the pipeline against electrochemical corrosion due to possible leakage currents present in the region, the pipeline has a cathodic protection system for all its buried sections [9, 10].

The Control and Supervision Central of the pipeline is located in the refinery and allows the monitoring of the natural gas flow to the Gas Distribution Company. The control system has local indicator and pressure transmitter, sensor and temperature transmitter, metering flow unit of mass and safety valves (lock), which are located in Sections I and II.

The system is responsible for obtaining the information emitted by the pressure and temperature transmitters, flow meters and by the transmission of signals to the actuators of the block valves (safety valves) that have the principle On - Off [10]. Instruments and cables are connected to a programmable logic controller (PLC), which information is sent to a digital distributed control system (DCS) [10].

The refinery has a control room where the operator performs operations for the transfer of natural gas via DCS. Some operators are responsible for visually inspecting the condition of the valves, i.e., check whether they are open or closed, using specific checklists and confirming the data aligned with control room. However, there is no direct communication between them. The system makes the control of flow, pressure, and temperature with the operator located in the control room monitoring through DCS [10].

If an abnormal condition of transfer is identified (as leaks in the pipeline or other problems in the flow) which generates a difference of at least 3% in the flow values measured in instruments located between the points I and II, the gas transfer operation should be automatically interrupted by the actuation of the block valve (safety valve) located at these points. If an abnormal condition such as this, occurs, an audible alarm will sound at the control room, alerting operators so that they could take appropriate actions. In case of non-performance of the automatic lock, operators will be required to close the valve manually [10].

To perform the operational stages of natural gas transfer, operators should follow the operating procedures.

In order to protect the facilities, preventing actions of others or vehicle traffic, the pipeline route is signaled by boards and standardized landmarks. These signals are only suitable for daytime.

There are periodic preventive maintenances to ensure reliability of: equipment of the cathodic protection system, block valves and its drive system, indicators of pressure and temperature, flow meters, equipment of the firefighting system and signaling of the pipeline [9, 10]. However, the preventive maintenance plan is outdated.

The refinery has personnel for daily patrols of the stretch crossed by pipeline to the Gas Distribution Company. There is no direct communication between the patrol workforce and the local police [9, 10].

One alternative of the inspection is visual observation along the pipeline route, seeking anomalies that could cause risk to it. It is made a periodical inspection using A-frame method in order to evaluate the state of coating and external corrosion of the pipeline.

There is no direct communication between staff of the inspection and the control room.

Regarding the Emergency Response Plan, the refinery and the Gas Distribution Company have the same resources for emergency action. The refinery is responsible for the pipeline integrity and emergence response of the parts that are inside the refinery and along the gas pipeline route, except for the segment that is part of the Gas Distribution Company. In the pipeline stretch that is within the limits of the Gas Distribution Company, the integrity of the pipeline and the control system and the emergence response involving this section are under the Company's responsibility that should use its Emergency Response Plan. The Emergency Response Plan has specific procedures for each accidental event. These emergency control procedures establish a set of actions that involve emergency communication with the Environmental Agency, Civil Defense and Government Agencies competent, driving additional features of the Environmental Defense Center and the Mutual Assistance Plan and the specific combat actions for natural gas.

For the main activities involving the natural gas pipeline procedures that describe each step of the activity to be performed by the operator are developed and updated.

5. METHODOLOGY

In order to prepare this paper, the authors constructed the Bow-tie Diagrams for the natural gas pipeline described previously. The authors identified the hazards to be used in Bow-tie Diagrams using the methodology Hazard Identification (HAZID) [3].

The HAZID was performed and the main hazards related to the natural gas pipeline were identified. The paper did not consider occupational hazards as slips and falls. The authors identified the main causes that could lead to the hazards release. The identification of causes involving natural gas pipelines was based on the report of European Gas Pipeline Incident Data Group [11]. The paper did not consider intentional human actions as terrorism or vandalism. The main causes of the accidents are exposed below in the Figure 2.

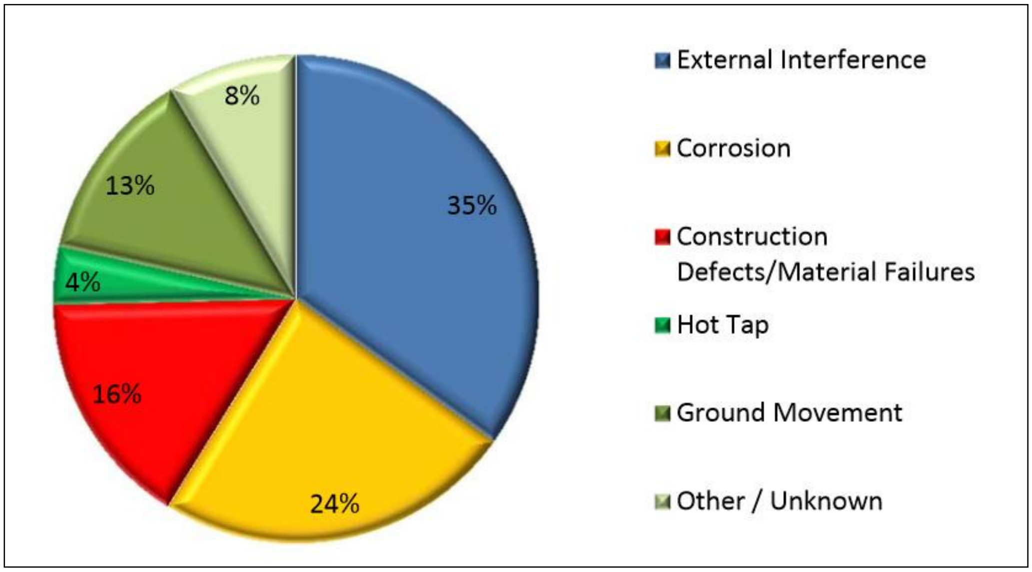

Figure 2. Accidents Distribution (2004-2013) [11]

The authors also identified the consequences of the hazards release. It was considered only the consequences with potential to generate damage to people, assets or environment.

Furthermore, the authors listed the safeguards that protect the pipeline, avoiding the occurrence or mitigating the impacts of an accident. Therefore, the safeguards should be identified previously to the risk classification of the accidental scenarios. The frequency and the severity of the accidental scenarios were classified according to Petrobras Standard N-2782 Rev.C. This Standard was chosen due to its recognition before other Brazilian organizations. The need to propose recommendations related to the risks was also based in this Standard.

Through the HAZID worksheets results, the authors started the construction process of the Bow-tie diagram. This construction was based on the HEMP Methodology and was done using the version 6.1 of THESIS Software. This software was developed and supplied by ABS Consulting that permitted the usage of the software to construct the Bow-ties. The THESIS supplied a platform to construct the Bow-tie diagram and connect the HSE critical control measures with the activities and tasks related [7]. The main aspect of

THESIS is that connecting a HSE critical task required, it was warrant the maintenance of controls integrity [7].

The construction process of the Bow-tie Diagrams was based in the follow steps [2, 3]:

- Hazard identification through HAZID methodology to select the hazards that will be constructed as Bow-tie diagrams;
- Evaluation of the top events caused by the hazard release;
- Identification of the threats that could lead the hazard release, generating the top event;
- Identification of consequences/ impacts of top event and the application of the risk classification performed in the HAZID into the consequences inserted in the THESIS Software;
- Identification of barriers that avoid or decrease the top event frequency and Identification of Recovery Preparedness Measures that limit the consequences effects [12]. The barriers and Recovery Preparedness; Measures were classified in specific categories created to the Study and presented in Table 1 below;
- Identification of Escalation Factors capable to increase the failure likelihood of barriers or Recovery Preparedness Measures;
- Identification and Classification of existing controls that blockage the Escalation Factors, decreasing the failure likelihood of a barrier or a Recovery Preparedness Measure;
- Evaluation of the efficiency of each barrier and Recovery Preparedness Measure, classified according to the Table 2, presented below;
- Identification of Shortfalls in the pipeline. These Shortfalls could be related with the threats, consequences, barriers, Recovery Preparedness Measures, Escalation Factors and Escalation Factors controls;
- In order to blockage these Shortfalls, the authors proposed Recommended Actions that could ensure the maintenance integrity of controls.

Table 1 – Classification categories of barriers and Recovery Preparedness Measures with related colors assumed

Administrative	
Project	
Out of Operation	
Inspection	
Maintenance	
Not implemented	
Operation	
Control System	
Signaling	
Safety system	

Table 2 – Efficiency levels of barriers and Recovery Preparedness Measures

Efficiency Categories	Efficiency Level Description
HIGH (HIGH)	Barriers or Recovery Preparedness Measures that are adequate and have a good integrity level.
MEDIUM (MED)	Barriers or Recovery Preparedness Measures that are adequate but do not have a good integrity level or that have a good integrity level but are not so adequate
LOW (LOW)	Barriers or Recovery Preparedness Measures are not adequate and do not have a good integrity level.

6. RESULTS

In order to construct the Bow-tie diagram, the top event: Large leak of Natural Gas was selected in the HAZID and occurred by the release of the hazard: Natural Gas in Pipeline. The Bow-tie diagram is presented in the figure 3 below.

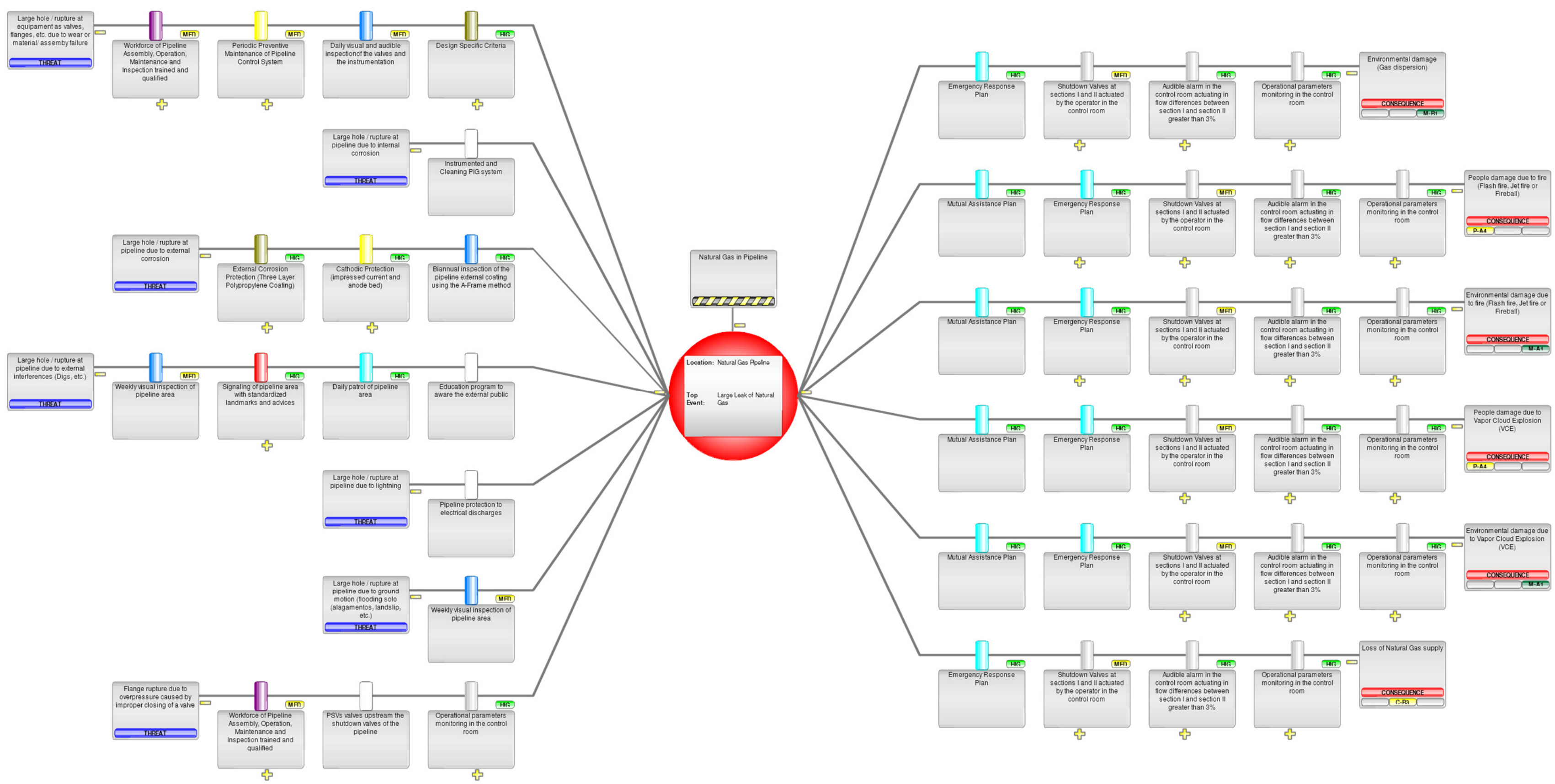

Figure 3 - Bow-tie Diagram to Case Study of Natural Gas Pipeline

The Escalation Factors of barriers and Recovery Preparedness Measures and their controls categorized are presented in the Tables 3 and 4 below.

Table 3 – Barriers Escalation Factors and their related controls categorized

Barrier	Escalation Factor	Escalation Factor Controls
Workforce of Pipeline Assembly, Operation, Maintenance and Inspection trained and qualified	Procedure not followed	-
	High workforce turnover	-
	Work overload	Reduced work hours
Periodic Preventive Maintenance of Pipeline Control System	Maintenance workforce with poor quality	HR restructuration
Design Specific Criteria	Changes in natural gas characteristics	-
External Corrosion Protection (Three Layer Polypropylene Coating)	External coating damage	-
Cathodic Protection (impressed current and anode bed)	Rectifier malfunction	Periodic Preventive Maintenance of Rectifier
Signaling of pipeline area with standardized landmarks and advices	Pipeline signaling damage	Periodic Maintenance of Pipeline Area Signaling
Operational parameters monitoring in the control room	Instrumentation failure	Instrumentation maintenance

Table 4 - Escalation Factors of Recovery Preparedness Measures and their related controls categorized

Recovery Preparedness Measure	Escalation Factor	Escalation Factor Controls
Operational parameters monitoring in the control room	Instrumentation failure	Instrumentation maintenance
Audible alarm in the control room actuating in flow differences between section I and section II greater than 3%	Alarm system damage	Alarm system maintenance
Shutdown Valves at sections I and II actuated by the operator in the control room	Valve failure	Shutdown valves maintenance
	Operator failure	Operator trained and qualified
Emergency Response Plan	Firefighting equipment failure	Firefighting equipment maintenance

During the construction process of Bow-tie diagrams, pipelines Shortfalls were identified and these Shortfalls could be related to threats, consequences, barriers, Recovery Preparedness Measures, Escalation Factors and Escalation Factors controls. For each Shortfall identified, the authors proposed Remedial measures that create an Action Plan to be implemented.

Shortfalls and Recovery Preparedness Measures were identified to threats, barriers, Escalation Factors and Escalation Factors control. The tables 5, 6, 7 and 8 present the relation between Shortfalls and their respective Recommended Actions for each applicable element from Bow-tie diagram.

Table 5 – List of Shortfalls and Recommended Actions to Threats

Shortfall	Recommended Action	Threat
Lack of inspection to verify internal corrosion	Evaluate the implementation of a instrumented and cleaning PIG system to the pipeline	Large hole / rupture at pipeline due to internal corrosion
Lack of education programs to aware the external public	Implement an education program to aware the external public	Large hole / rupture at pipeline due to external interferences (Digs, etc.)
Lack of pipeline protection to electrical discharges	Implement a pipeline protection to electrical discharges	Large hole / rupture at pipeline due to lightning
Lack of relief valves to release the pressure	Install PSVs valves upstream the shutdown valves of the pipeline	Flange rupture due to overpressure caused by improper closing of a valve

Table 6 – List of Shortfalls and Recommended Actions to Barriers

Shortfall	Recommended Action	Barrier
Lack of communication between inspection workforce and control room	Provide communication between inspection workforce and control room	Daily visual and audible inspection of the valves and the instrumentation
		Biannual inspection of the pipeline external coating using the A-Frame method
		Weekly visual inspection of pipeline area
Maintenance Plan Outdated	Update Maintenance Plan	Periodic Preventive Maintenance of Pipeline Control System
Inefficient signaling in the nightly period	Implement adequate signaling of pipeline area to nightly period	Signaling of pipeline area with standardized landmarks and advices
Lack of communication between Patrol workforce and local police	Provide a fast way of communication between the patrol control and the local police	Daily patrol of pipeline area

Table 7 – List of Shortfalls and Recommended Actions to Escalation Factor

Shortfall	Recommended Action	Escalation Factor
Lack of incentive to Workforce	Improve Human Resources Management	High workforce turnover

Table 8 – List of Shortfalls and Recommended Actions to Escalation Factor Control

Shortfall	Recommended Action	Escalation Factor Control
Maintenance Plan Outdated	Update Maintenance Plan	Periodic Preventive Maintenance of Rectifier Periodic Maintenance of Pipeline Area Signaling Instrumentation maintenance Alarm system maintenance Shutdown valves maintenance Firefighting equipment maintenance

7. CONCLUSIONS

The Bow-tie diagram utilization for natural gas pipeline allows a clear visualization of the risk management process and facilitates, through its graphic interface, the understanding of stakeholders who are not directly involved with the operation of the pipeline.

The construction of Bow-tie diagrams allowed the identification of Shortfalls at pipeline operation that are not identified by others risk analysis. Through the identification of these Shortfalls, it was possible to propose Recommended Actions to remedy them.

It were proposed 9 Recommended Actions, including updating the Maintenance Plan, the implementation of a communication between inspection and control room workforce, the evaluation of an instrumented PIG system and pipeline cleaning implementation, and implementation of a system to protect pipeline against electrical discharges.

The threat large hole/rupture in the pipeline due to internal corrosion, did not presented barriers to prevent or reduce the frequency of occurrence of it, so despite the fluid does not present corrosive characteristics, it was proposed an evaluation of an instrumented PIG system and pipeline cleaning implementation, since the presence of contaminants can not be totally eliminated.

Also for this threat large hole/rupture in pipeline due to lightning, it was proposed the implementation of a system to protect pipeline against electrical discharges, because this threat do not have barriers that can control the lightning action.

It is also essential to update the Maintenance Plan and the implementation of a communication between inspection and control room workforce as Shortfalls related to these actions appears frequently in analysis.

For Recommended Action proposed, it is necessary to make an Action Plan. Responsibles and deadlines for these actions should be defined. It is important that one employee does not assume or a huge part of actions, so that actions are carried out more quickly and effectively.

The Bow-tie diagrams should be revised and updated always when Recommended Actions, barriers or Recovery Preparedness Measures are implemented, i.e.; new threats, consequences, Escalation Factors are identified, or some other change in pipeline operation be done. Therefore, the utilization of THESIS 6.1 software facilitates the management and updating of this information, avoiding those others Bow-tie diagrams have to be built from the beginning to meet these changes.

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