PIPELINE INTEGRITY MANAGEMENT SYSTEM: A COLOMBIAN MODEL FOR DEVELOPING COUNTRIES

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Keywords:

- 'ALARP' (as low as reasonably practical): risk matrix zone where risk is considered tolerable and response mitigation could be developed, depending on the cost-benefit analysis results.

- Location Class: refers to an area's classification along the pipeline in accordance with criteria established in American Standard ASME 31.8S.

- 'HCA' (High Consequence Area): area established by one of the methods described in CFR Part 192 Title 49. It represents an area where failure of the pipeline may severely impact population.

- Identified Sites: area described by CFR Part 192 Title 49 and represents open spaces or closed spaces where a high population density exists under considerable time spans.

- 'PIMS' (Pipeline Integrity Management System): overall approach by the company to ensure the integrity of its pipeline system.

- 'PIR' (Potential Impact Radius): radius of a circle within which the potential failure of a pipeline could have significant impact on people or property.

- Risk assessment: systematic process in which potential hazards from facility operation are identified, and the likelihood and consequences of potential adverse events are estimated.

1. Background

Pipelines are Safe

Historical data indicates that pipelines are the safest means of transportation. Statistics show that pipelines are safer for fuel transport than roadway or railroad vehicles. This added to the fact that pipelines are more efficient provides enough reasons for its worldwide usage today and in the future. Nevertheless as it may happen in all works of engineering, pipelines may fail and such, failure situations bring dramatic and tragic consequences. Widespread historic data based on accidents related with natural gas transmission lines show it.

Pipeline Integrity Management System

It is simply not enough to claim that having routine maintenance activities as well as inspection, operational procedures and monitoring routines does the job. By all means this trade requires an integrated management of all these mentioned activities. The most important of such integrated management is that it should be exercised within a corporate or organizational culture that includes in its scope continuous risk evaluation and mitigation. In short, anyone wanting to do the job right requires a PIMS (Pipeline Integrity Management System).

Developing Countries

In addition to all difficulties that companies may have to overcome before achieving successful PIMS levels, gas transmission pipeline operators in Colombia have other difficulties and thus provide for this specific case study. Colombian companies are facing third world problems like urban expansion that has a life of its own, for which there is no previous possible planning. Such hasty urban expansion moves directly into the potential impact area of some pipeline system sectors and consequently provides grounds for all type of third party threats as a result of illegal connection to public utilities such as phone service, water service, and sewage. These threats present high risks and major problems with their assessment and mitigation.

A problem that is common to all operators is ageing: pipelines around the world are old and many are in poor condition. But in many countries in Latin America these old pipelines are within urban expansion and surrounded by many more people and buildings that were expected at the design stage. This is why operators must make additional efforts to rectify such situations: conventional maintenance activities are not enough to guarantee pipeline integrity and public safety.

PIMS Model by a Colombian Company

This paper presents how Promigas, a Colombian pipeline operator, has developed a PIMS based on semi-quantitative and quantitative risk assessment that has allowed focus on mitigation activities in most critical segments and has also allowed for design of customized action plans for each segment, to give more efficient risk control.

2. Aims

The sole and most important purpose of the PIMS is to provide a safe and trustworthy service of natural gas to the customers. Its main concern is to keep all possible negative effects on employees, community and environment to the lowest. In short the deliverable scope goes hand in hand with guaranteeing an operation without pipeline leaks or failures. In simple words, it’s to keep the gas inside the pipeline.

3. Methods

Pipeline System

This case study focuses its data and conclusions based on the experience of Promigas which is the registered name of the company that acts as operator of a pipeline system that provides natural gas for the northern region of Colombia, South America. The pipeline system in mention has a maximum transportation capacity of 15.3 million standard m3/d. It comprises 2,026 km of steel pipe and 309 km of polyethylene pipe, with diameters from 2 to 32 in (51 to 813 mm). It extends from the production sites at La Guajira, north-eastern Colombia, up to the last station, Jobo Terminal, which is located in the state of Sucre, north-western Colombia.

The main transmission line mentioned above receives the name of BCJ pipeline which in Spanish stands for Ballena-Cartagena-Jobo. Twenty two per cent (22%) of the total length of this main transmission line is classified as an HCA (High Consequence Area) due to its class location 3 coordinates, where multiple sites are identified such as (places with high population concentration such as schools, manufacturing companies), constructions used for human occupation and homes located on the right of way of the pipeline. The operational conditions of the pipeline in such tracings and the maintenance plan fulfil standard requirements for operation in location class 3, but the risk is higher every time due to continuous population expansion and execution of new construction for human occupation within the pipeline’s potential impact radius.

Aware of the great responsibility of the company against such situation, Promigas started out in 1999, an inspection, an integrity evaluation and rehabilitation program for the main transmission pipeline. Such included line inspection with MFL high resolution smart pigging among other direct and indirect inspections. Furthermore in 2004 it started out the PIMS based on established American standard ASME B31.8S.

PIMS Model Description

In agreement with American Standard ASME 31.8S the PIMS consists of 5 plans where the integrity management plan is the backbone of the system, as Figure 1 shows.

PIMS	**INTEGRITY MANAGEMENT PLAN**	It consists on identifying pipeline threats, gathering of data, risk assessment, integrity assessment and on responses to the previous with threat prevention, detection and mitigation, as well as inspection intervals.
	PERFORMANCE PLAN	The operator shall collect performance information and periodically evaluate the success of its integrity assessment techniques, pipeline repair activities, and the mitigative risk control activities. The operator shall also evaluate the effectiveness of its management systems and processes in supporting sound integrity management decisions.
	COMMUNICATIONS PLAN	The operator shall develop and implement a plan for effective communications with employees, the public, emergency responders, local officials, and jurisdictional authorities in order to keep the public informed about their integrity management efforts.
	MANAGEMENT OF CHANGE PLAN	Pipeline systems and the environment in which they operate are seldom static. A systematic process shall be used to ensure that, prior to implementation; changes to the pipeline system design, operation, or maintenance are evaluated for their potential risk impacts, and to ensure that changes to the environment in which the pipeline operates are evaluated.
	QUALITY CONTROL PLAN	Quality control is the documented proof that the operator meets all the requirements of their integrity management program.

Figure 1: PIMS Plans

The key elements of the PIMS plans defined by this company show a comprehensive, continuous work breakdown structure planning, as Figure 2 shows.

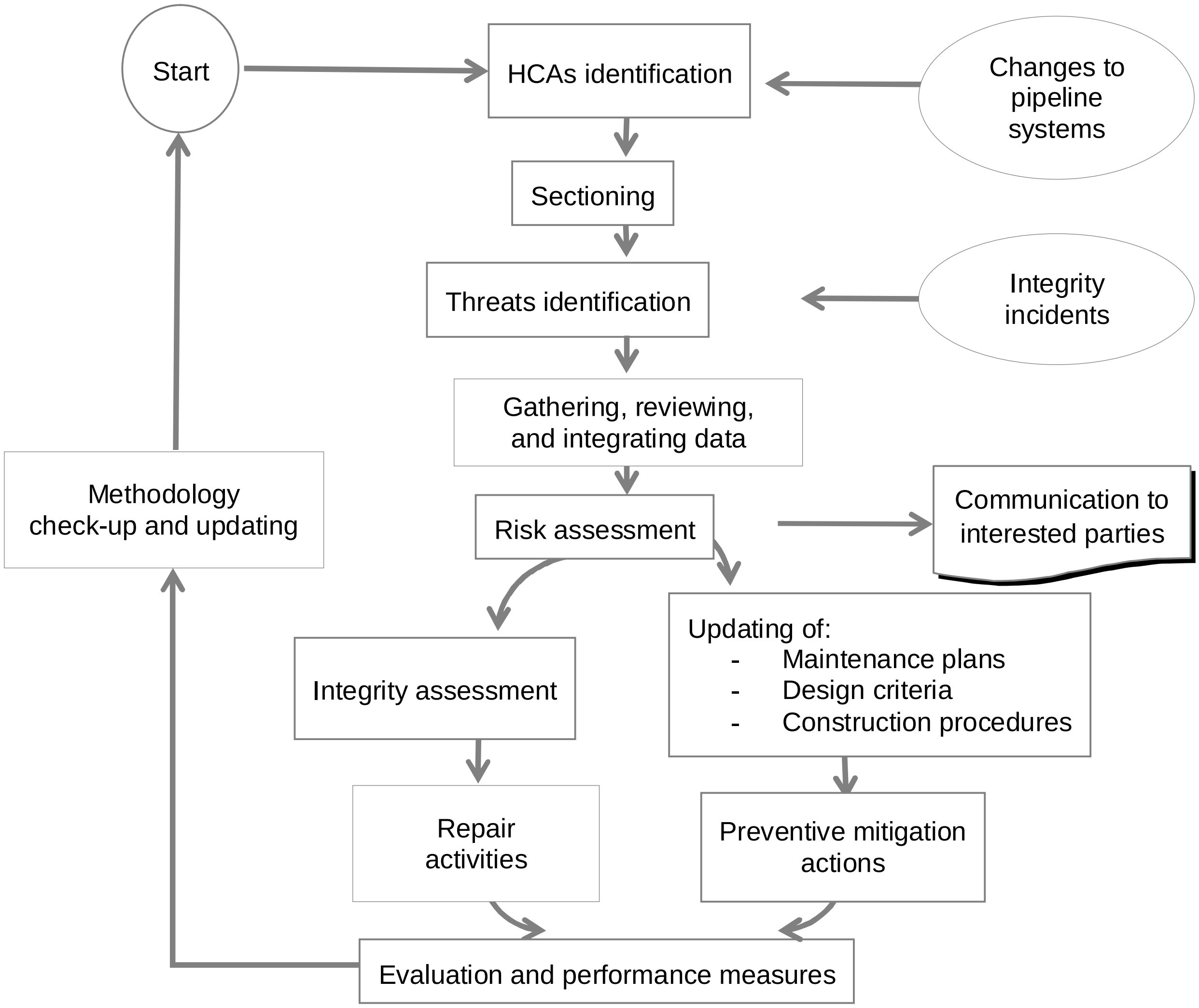

Figure 2: PIMS WBS

This continuous looping makes the system better each time. Provides ground in which all new inputs make the system work better.

The following is a brief description of these key elements of the PIMS:

- High Consequence Areas (HCA) identification: Identifying these areas is a must because in a possible scenario of pipeline failure, such places could have catastrophic impact on the community. These areas are the system's priority.

- Sectioning: Pipeline sectioning or segmenting eases data analysis and allows for risk calculation on particular zones. It is better to classify HCAs under independent segments that provide the possibility of analysis of specific data that applies for each of these segments.

- Threat identification: Identifying these threats is a must. For risk assessment to minimize potential failure it is very important to identify each and every threat. In the HCAs third party mechanical damage threat must always be considered as a main threat that could affect the pipeline integrity.

- Gathering, reviewing, and integrating data: For each of the identified threats the risk inducting variables must be defined. For each of the infrastructure segments all data related to the each variable must be gathered checked and integrated. In the HCAs the most significant consequence is the impact over the population, and to have a detailed risk assessment it is very important to count with complete data about type and location of construction as well as population characteristics.

- Risk assessment: At this point an analysis is done to identify most significant risks and consequently a prevention and mitigation plan of such risk is developed.

- Communication to interested parties: Risk assessment results give birth to effective communication plans for the communities in risk, these must know how to react in case of an emergency and it is at this point when they become an important prevention asset for the system. Lack of knowledge is not wanted by any means.

- Updating of maintenance plans, design criteria and construction procedures: Taking into account the risk assessment results, some changes in the maintenance plans, design criteria and construction procedures could be required. This alone changes maintenance planning because it not only follows the pre-scripted recipe stated on the standards for its daily activities but incorporates a most effective tool: risk assessment results.

- Preventive mitigation actions: These are defined from the risk assessment results and are generally included in the maintenance plan as: HCAs inspection with special frequencies.

- Integrity assessment: It is the complement of the risk assessment. It confirms mechanical integrity of the pipeline as well as the repairs to be performed. From the results of the integrity assessment the operator may define a rehabilitation plan for the pipeline (fitness for service) where HCAs must have priority.

- Repair activities: These are defined from the integrity assessment results.

- Evaluation and performance measures: Periodical evaluation of the systems are performed to test its effectiveness, these are indicators of the continuous improvement of the circular work structures in the PIMS.

- Methodology check-up and updating: Data results from the indexing allows for system adjustments and fine tuning.

- Changes to pipeline systems: Due to the dynamic nature of these lines, operational, maintenance and or design changes can arise; these should be evaluated to keep them from affecting the risk profile of the system.

- Integrity incidents: In case of failures, threats involved must be analysed and risk assessment is to be performed.

The PIMS is also audited by the quality management system of the company to ensure compliance to all requirements of such.

Risk Assessment Model

The PIMS of this company is based on semi-quantitative and quantitative risk assessment. Risks are evaluated from 2 different perspectives: the first is an absolute risk figure that corresponds to the number of fatalities per year; and the second is a relative risk figure where the risk is calculated in economic terms and presented as an amount of dollars per kilometre per year.

Risk in turn is the product of the probability of failure taking place and the consequence of such failure.

Probability of failure is calculated for 9 threat categories:

- Time dependent: Stress Corrosion Cracking (SCC), Internal Corrosion, and External Corrosion.

- Stable in Time: Manufacturing Related Defects, Defects in Pipeline Construction, and Equipment Failure.

- Independent of Time: Mechanical Damage, Operational Error, and Weather and Outside Force or External Natural Action.

Consequence of failure is calculated in 4 categories depending on the effect on:

- People: potential fatalities and potential injuries figures are estimated for a pipeline failure.

- Property: potential damage over third party property and public infrastructure is taken into account in case of pipeline failure.

- Business: pipeline repair costs are calculated as well as interrupted profits, indemnities to customers and the cost of the relieved gas.

- Environment: methane emission to the atmosphere and effects on forest and water bodies are estimated. Given the case that a pipeline crosses a sensitive environmental zone, detailed analysis of possible damages and management of such is done.

The following is a brief and broad explanation of the risk assessment model algorithm for calculation of probability and consequence.

The algorithm to calculate probability of failure has its root in a general tabulated failure frequency, which is nothing more than the historical records of this industry in particular. Two modification factors are part of the calculation. These can increase or decrease that general failure frequency. The first factor is directly related to the pipeline segment in study, depends on variables such as pipeline intrinsic conditions, operational conditions and on the environmental conditions surrounding such segment. The second factor refers to variables related to the system management and also to the proper or improper management of such system. This algorithm carries enormous amounts of information, therefore becomes extremely complex. The particular case of the BCJ (Ballena-Cartagena-Jobo) pipeline system carries around 150 variables, so the aid of software to handle such bulky loads of data and finally to calculate probability of failure of all pipeline systems is very important.

The algorithm to calculate consequence of failure is based on standards Risk Based Inspection methodology from API 580 and ASME B31.8S. To put it briefly, the consequence model sums up 7 phases.

1. Receptors definition: these are people, business, property and environment involved.
2. Event definition: the worst possible case was taken into account, for such case guillotine-type failure summed up with jet fire phenomenon.
3. Variables such as vulnerability, occupation levels and radiation levels were taken into account to estimate the potential damage to people or property.
4. Then it's necessary to calculate the Potential Impact Radius (PIR) with the specific operational conditions of the pipeline.
5. Estimation of the ignition probability after failure.
6. Calculating of specific consequence on each receptor type.
7. Finally the total failure consequence is calculated.

For executing a pipeline risk assessment calculations the pipeline must be divided in similar characteristics segments. For segmenting the BCJ (Ballena-Cartagena-Jobo) pipeline system the company uses the following 7 criteria:

- Line division of the Promigas pipeline system
- Maximum allowable operational pressure change
- High consequences areas
- Pipeline in an important waterway
- Dwelling on the right of way of the pipeline
- Casings, and finally
- Aerial spans

With such criteria 624 segments were obtained. Twenty nine per cent of such segments correspond to HCAs.

Once all the information is gathered and calculated the risk is to be calculated for each and every one of the segments. Next a classifying work is to be done until a matrix with all risk level data is achieved.

4. Results

It is important to clearly state that the risk evaluation model that has been started for pipeline integrity management reflects each segments critical points and allows for establishing and identifying the major risk segment group for pipeline integrity. The results value obtained do not represent exactly the real rate of failure as well as the magnitude of the consequences of such. These results represent the best risk approximation based on the available information. In successive re-evaluation of risk for the pipeline system of the gas transmission line such results will be updated and confirmed as better and more information is possible to obtain for analysis.

In Figures 3 and 4 risk evaluation result matrixes are shown for the gas transmission line BCJ.

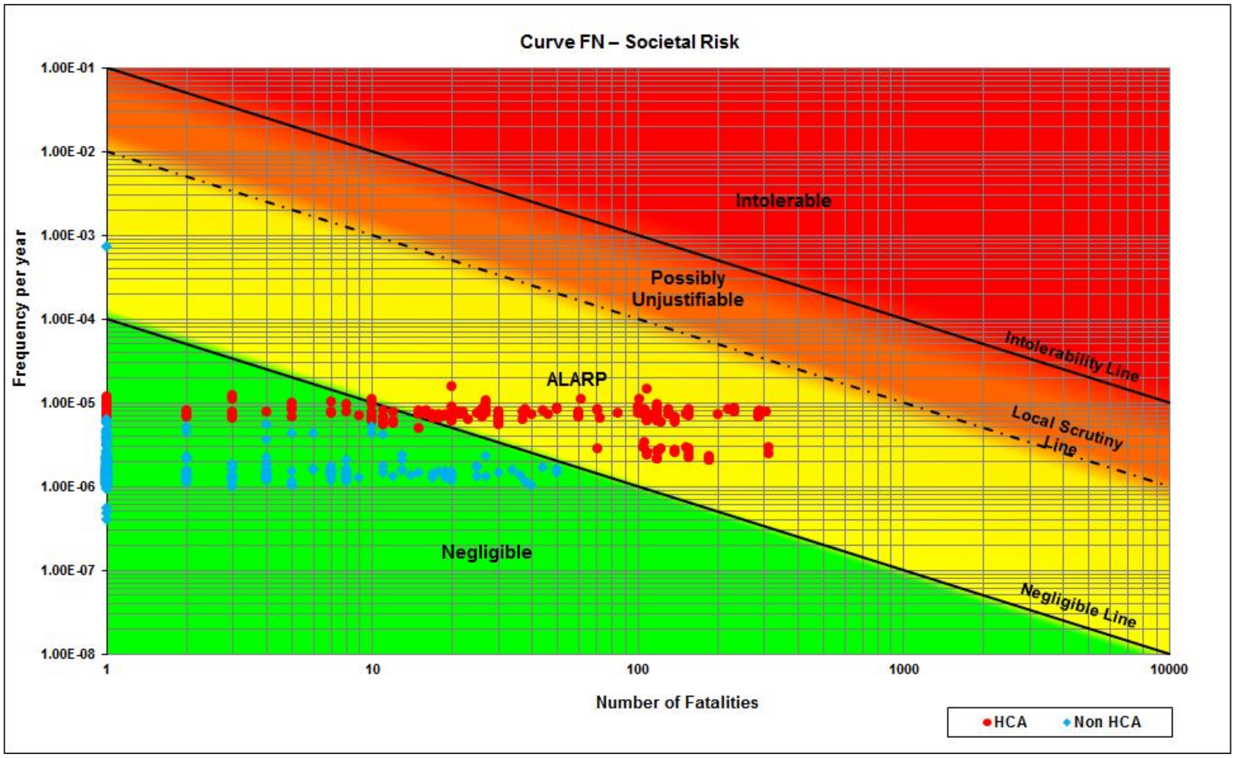

Figure 3: Societal Risk Results

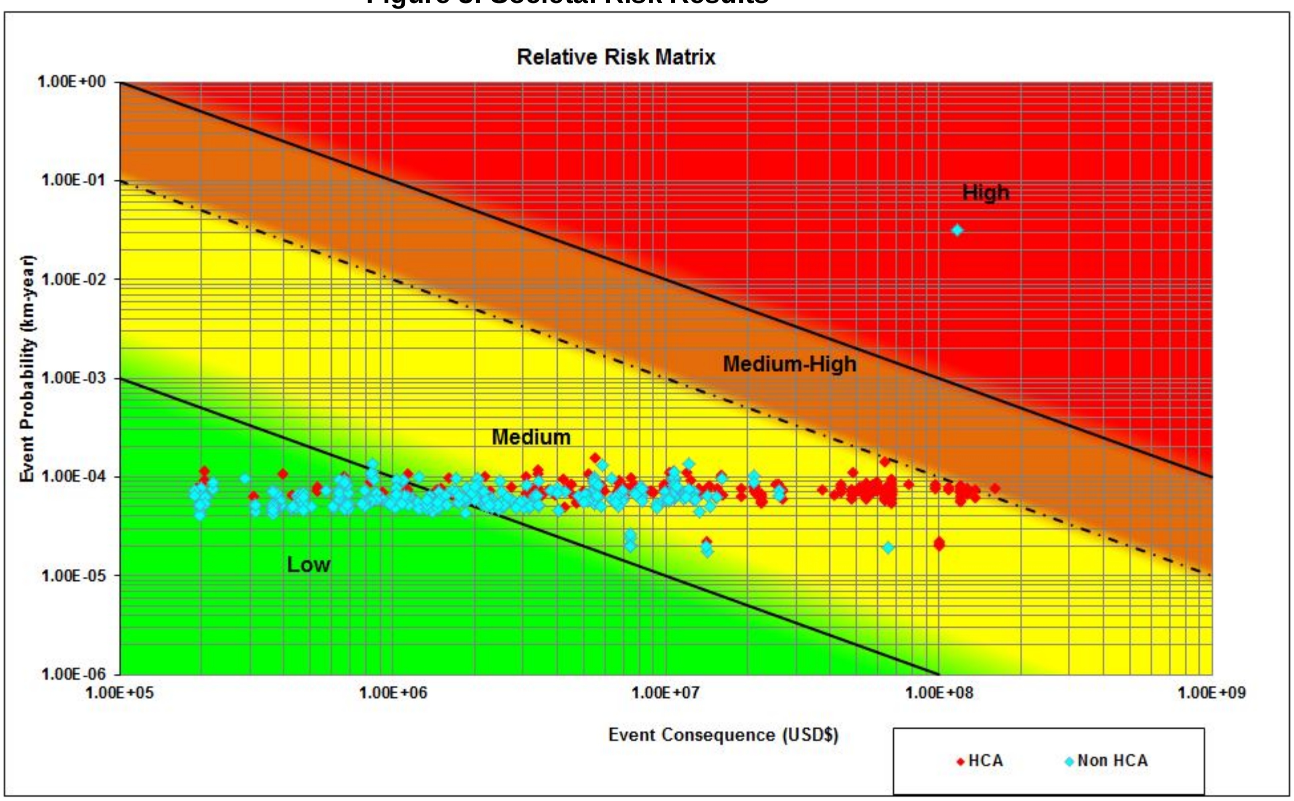

Figure 4: Relative Risk Results

The main risk evaluation results of the BCJ pipeline are:

- The results obtained from the societal risk show that 16.2% of the total length of the gas transmission line are found in the ALARP societal risk zone, which corresponds to 185 segments of pipeline located in 16 zones with identified people concentration or HCA. The remaining percentage (83.8%) is found on the negligible societal risk zone.

- In agreement with the results of the relative risk evaluation one segment was identified under high risk. It is a non HCA segment that corresponds to Magdalena River crossing. This segment shows high risk due to the fact that both the magnitude of the failure probability and the consequences are great. This segment has a high failure probability because the river in the last year has increased significantly its flow figures and changes in the river bed have taken place, impacting pipeline stability at the river crossing approaches. The consequences are great because of the impact on the business, but non are consequences in terms of fatalities or injuries.

- With the exception of the segment that corresponds to Magdalena River crossing, major impact zones by relative risk classification corresponded to segments in HCAs and were also found under the ALARP region of the societal risk.

- Once risk results were analysed for each of the consequences categories it was found that the effect on people represents 81% of the total relative risk value of the BCJ pipeline, as Figure 5 shows.

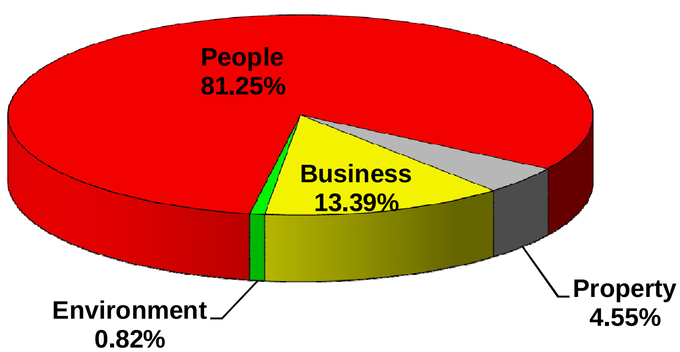

Figure 5. Relative Risk by Consequence Type

- The most significant thread of the main transmission line is the non-authorized third party intervention of the gas transmission line right of way. The thread is present in 22% of the gas transmission line were HCAs are located.

- All the identified HCAs in this analysis present a tolerable risk value as long as special risk mitigation actions are continued and developed such as: daily patrolling of right of way, mechanical protection of the pipeline in high intervention areas, installation of signals specially design for urban zones in expansion and community education.

- Although technical standards establish that pipeline patrols shall be performed at least once every 6 months in Location Class 3, and at least once every 3 months in Location Class 4; the company executes this activity on a daily basis. Such action reduces failure probability of the pipeline to 10% of the estimated failure frequencies of such type of areas.

- As a result of the year 2011 daily pipeline patrol in the HCAs, 588 incidents were detected that could have potentially been pipeline failure causes. As shown in Figure 6 33% of such incidents (196) were avoided on time. In other words such were detected before damages to the pipeline, the coating or the right of way took place. The remaining 67% of the incidents were detected when minor mechanical damage to the pipeline or the coating was already done or a new construction invading the right of way had begun.

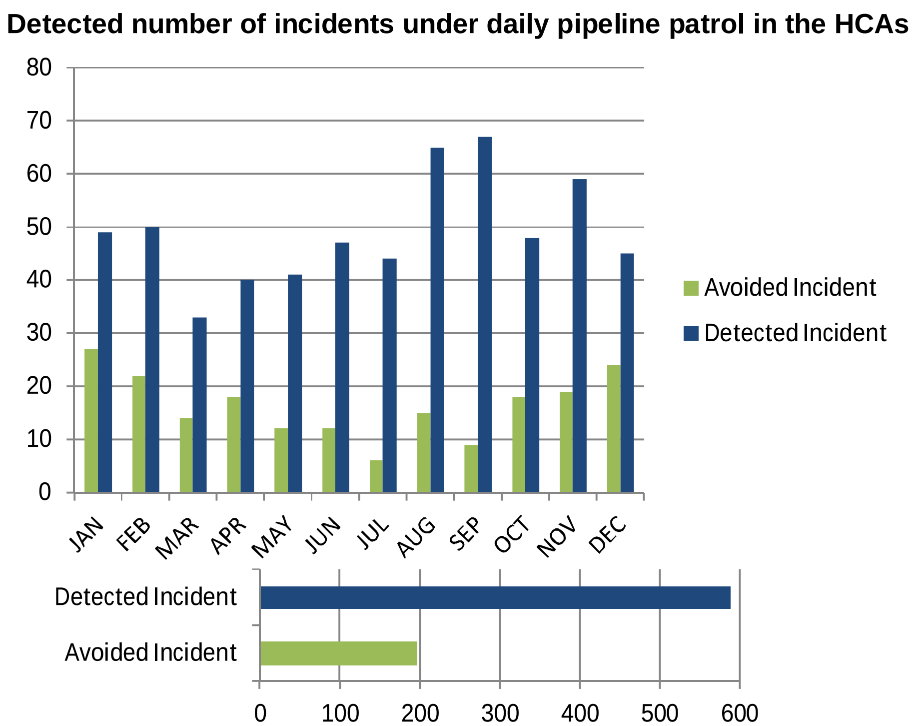

Figure 6. Incidents statistics in HCAs – Year 2011

- Although HCAs risk is tolerable because preventive actions maintain low failure probabilities, the consequences in such segments are not tolerable. The company is working to make the regulating entity aware of such situation so it recognizes within the gas transportation tariff any necessary investments for constructions of alternate transmission lines or replacement of such existing pipelines in the HCAs.

- While the relocation or the replacement of pipelines takes place in the HCAs zones the company has undertaken specific emergency attention plans for each zone that include: material and equipment for pipeline repair strategically located, medical centre attention locations, specialized entity contacts for emergency situations, etc., as well as communication management plans for crisis situations.

5. Summary/Conclusions

The start-up of PIMS based on risk evaluation allowed for confirmation of the following:

- The PIMS achieves valuable data for analysis and decision making through risk assessment.

- PIMS proves to be a most effective tool for placing resources in prevention, mitigation and detection activities at proper timing. PIMS achieves higher safety standards and reduces numbers of incidents all along the transmission line.

- Detailed models of risk evaluation allow for specific information of the key variables that control system risk, in such way that a gas transmission line operator is capable of designing action plans for each segment of the pipeline and identifying mitigation measures in addition to those established as prescriptions in the technical standards.

- For countries under development, where urban planning is not well defined, the PIMS is a key function to guarantee safety to nearby populations on the transmission line and so such activities don’t impact the gas transmission infrastructure integrity.