Issue 5/ 2020

ptj

eJournal

Pipeline Technology Journal

COMPREHENSIVE TOPICS

www.pipeline-journal.net

ISSN 2196-4300

Proximity despite the distance

Max Wedekind
Managing Director
DENSO Group Germany

Dear readers,

You'll certainly be familiar with this: you're talking to friends, chatting about everything from your private life to your work life, and everyone is talking about their experiences of their workplace from their own perspective: What characterises it, what has changed and what has not?

I usually try to answer the question with an image from pipeline construction. Imagine that you're a welder or a coating expert working on a construction site in crews of six to eight people for ten to twelve hours a day, not seeing your family for weeks on end, even in the times of coronavirus. Every day poses a new challenge which requires a quick and appropriate reaction – whether you are working in icy cold conditions or in the hot desert sun.

What counts in such a situation? Confidence in your colleagues and of course good products, the conviction that you are part of something big, reliability, sticking together as well as a love of hard work by hand. Because that's what has barely changed in the past 40 years – unlike in the offshore sector. Whereas the security and environmental protection requirements have become significantly greater and international standards are becoming more and more stringent, the following is still at the heart of the work of coating experts and welders in pipeline construction: manual work and precision on large building sites. Here, no day is like any other. And once evening comes, everyone is happy to have again found a solution to a new problem.

Particularly in times of crisis such as these, we face challenges that require new solutions. Confidence in good products and a good team are more important than ever before. Earlier this year we were still focusing on questions such as: What is going to happen? Will there be a slump in demand? Do we have to close our business during lockdown? We now know that the following is true: infrastructure projects are continuing, construction will not stop.

And if you asked me today what this difficult year has taught me, it would be one thing in particular: every change holds opportunities. One positive is the closer connection between employees, despite physical distance. Another positive is the more intensive personal contact within the team, characterised by understanding and uncomplicated assistance. We are convinced that we can overcome difficult situations only together with a flexible approach.

And we will find solutions to new problems – just like the welders and coating experts in their day-to-day work.

May it inspire you with confidence – and please enjoy reading this Pipeline Technology Journal!

Yours,

Max Wedekind, Managing Director, DENSO Group Germany

THIS ISSUE'S COMPLETE CONTENT

NOVEMBER 2020

Pipeline Technology Journal - ptj

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Pipeline.Technology.Conference

ptj Editorial Board

Pipeline Technology Journal

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Fax: +49 (0)511 90992-69
URL: www.eitep.de

Terms of publication: Four times a year

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Register Court: Amtsgericht Hannover
Company Registration Number: HRB 56648
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THE DEVELOPMENT OF GREEN AMMONIA AND THE FUTURE OF ENERGY TRANSPORT

"So why the roundabout way to ammonia," muses Angela Kruth, press secretary for Project Campfire at the Leibniz Institute for Plasma Research and Technology in Greifswald, Germany?

Kruth is referring to the process of electrolysis, a technique in chemistry and manufacturing that uses direct electric current in separating elements from naturally occurring sources. In this case a so-called cracker (just as in an oil refinery) is used to separate hydrogen and nitrogen molecules in ammonia. The hydrogen is then put into a gas motor or fuel cell in order to generate energy for ships.

Ammonia is much simpler, efficient and cheaper to store and transport than hydrogen. In order to move ammonia it has to be liquified, which happens at -33 degrees. Hydrogen on the other hand liquifies at -253 degrees. And thus the key point:

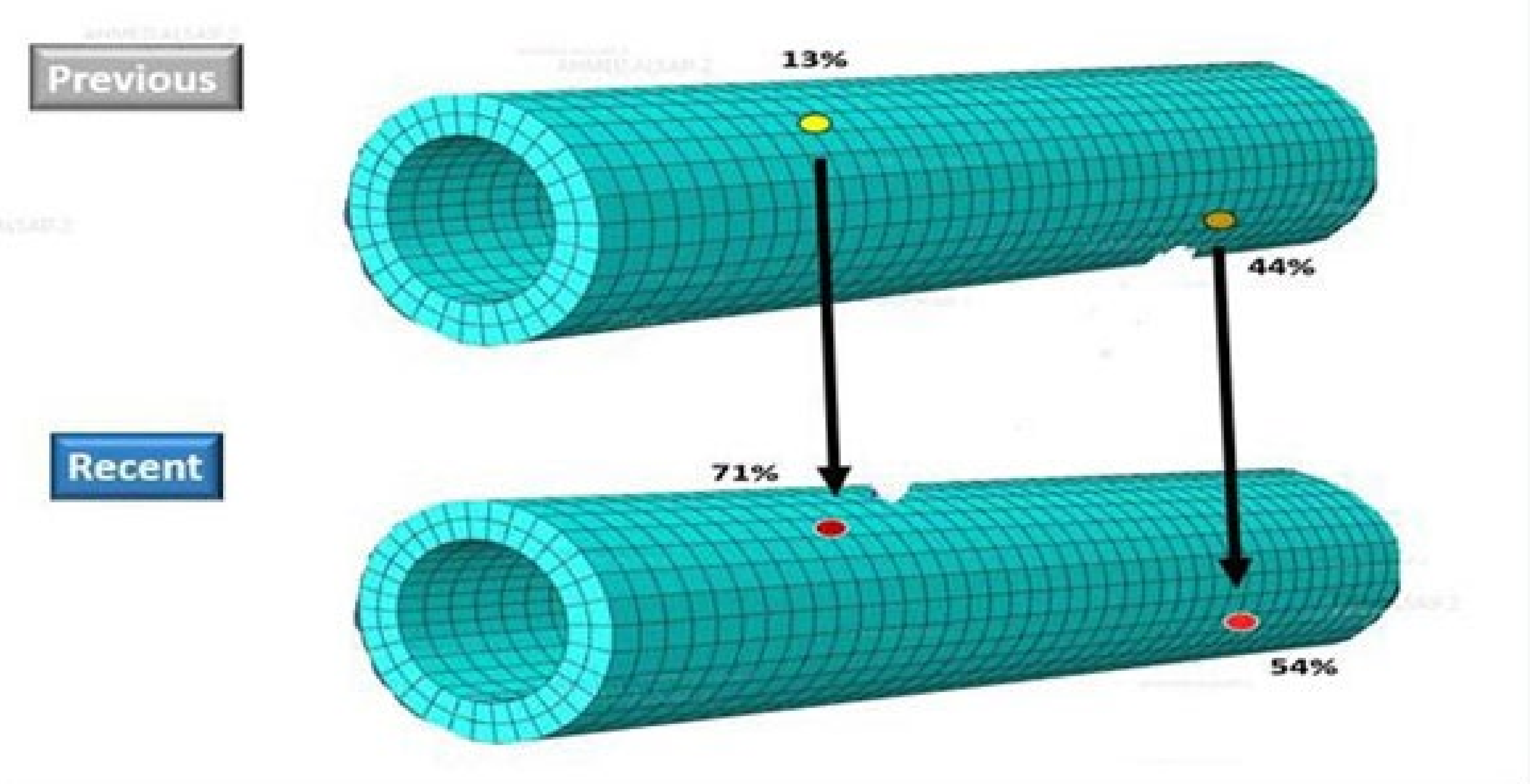
It takes a lot of effort (and money) to transport hydrogen. Scientists in Germany can solve this problem when hydrogen is "packed" in ammonia. And the longer the distance the greater the advantage of using ammonia.

Germany and the rest of the EU aim to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions. Ammonia will play a critical role in helping Germany to reach its climate goals, produced with green wind and solar energy delivered from countries that can deliver this in abundance: those in North Africa.

There is still much more research and pilot projects to be carried out. But assuming Africa can be linked to the power grids of Europe then a way will have been found to generate green energy with many applications at a reasonable price.

Read more at:
https://www.pipeline-journal.net/news/development-green-ammonia-and-future-energy-transport

Advanced Corrosion Growth Modeling In Pipelines For Repair Optimization



Nauman Tehsin, Mohammed Al-Rabeeah, Nader A. Al-Otaibi, Nasser Al-Qahtani > Saudi Arabian Oil Company

Abstract

Saudi Aramco operates a massive network to enable its position as world leading hydrocarbon producer, approximately 371 downstream cross-country pipelines with 446-sections, totaling 23,878 kilometers as at January 2020. Typical pipelines range in diameter from 4-inches to 56-inches, the average length of the pipelines ranges from less than one kilometer to above 1,000 kilometers.

Some of the pipelines have been in operation since 1960s, while new ones are continuously being installed. A good number of the pipelines are still in relatively good condition, while some have deteriorated in integrity as a result of various factors that include the environment, fluid property, flow conditions, etc. The pipelines transport different grades of hydrocarbons that includes stabilized and un-stabilized crude oil, associated and non-associated gas as well as sales gas, and various grades of refined products. Statistically, 64 percent of existing pipelines are now more than 20 years with-more-than 49% above 30 years in operation.

Some of the pipelines are operating under adverse conditions (low-flow, sabkha, etc.) that demands close corrosion monitoring. It was imperative to capitalize on Saudi Aramco integrity management processes to maintain safer reliable pipeline network. The ability to accurately determine the rate of corrosion growth along a pipeline is an essential input into a number of key integrity management decisions.

The main enabler process for Saudi Aramco pipeline integrity management is pipelines integrity plans. A key enabler of integrity plans is corrosion growth modeling. For that Saudi Aramco has utilized a huge amount of resources to manage the pipeline network integrity.

1. BACKGROUND

1.1 - PROCESS OVERVIEW

The core purpose of pipeline integrity management process is to responsibly contribute to the safety of people and the protection of the environment around pipeline transmission systems ensuring a reliable supply of hydrocarbons to internal and external customers. Pipeline integrity is driven by a continuous improvement to achieve and sustain excellence. Saudi Aramco Operational Excellence (OE) and Asset Integrity Management Systems (AIMS) framework, among the generic guiding documents that provide technical procedures for pipeline integrity management in conjunction with the best industry standards and Pipeline Research Council International (PRCI) methodologies. P&TSD OE # 5.1.3 Integrity Management Process, which is focused on scrapable transmission pipelines, sets the expectations for establishing pipeline integrity plans. The main benefits for Saudi Aramco are the prioritization of integrity activities (e.g. identification, assessment, mitigation, monitoring and preventative measures) via the P&TSD Pipeline Integrity Plans (PIPs) addressed to the pipeline areas. In addition, on-demand and scenario-specific evaluations also provide pipeline integrity condition forecasts for assessing potential rehabilitation, flow throughput, and operational and maintenance changes.

1.2- ENTERPRISE RISK MANAGEMENT

The pipeline integrity risk evaluation of the Saudi Aramco network of scrapable pipelines is periodically conducted in line with the Saudi Aramco Asset Integrity Management System (AIMS), the Enterprise Risk Management (ERM) guidelines and best industry-recognized practices (e.g. PRCI, API, and ASME). The evaluation provides the pipeline integrity likelihood of failure as values and categories (i.e. LoF: 1 to 5) using quantitative analyses (i.e. Probability of Failure –PoF-), which associated with qualitative Consequence of Failure categories (CoF: 1 to 8) provide the ERM matrix risk severities (i.e. A to F) for engineering and management decision making.

The Probability of Failure (PoF) is calculated using the worst condition scenario predicted at the time of the risk evaluation. Both the worst leak and the worst rupture-dependent remaining anomalies in the pipeline are analyzed using the latest ILI results and corrosion growth factoring pipeline characteristics and operation, date of anomaly discovery, repairs, release history, interacting threats (e.g. cracking susceptibility) and Subject Matter Expertise (SME) including the performance of the executed mitigative measures. Furthermore, the PoF for the worst leak and rupture scenarios are calculated factoring the ILI detection, identification and sizing uncertainty (e.g. tolerance and confidence; bias and scatter) that are aggravated by the other above-mentioned factors:

- External and Internal Corrosion SME knowledge to capture risk imposed by pipeline operating parameters and lack of mitigation measures.
- SCC and Fatigue Cracking susceptibility.
- Effect of the Increase of New Anomalies in the pipeline.
- Leak/Release Regency and frequency.

The PoF is assessed for both potential leaks and ruptures following the SAEP-306 "Assessment of Pipeline Defect" analysis and Pipelines Research Council International "PRCI PR-351-05308" methodology based on available ILI results including their associated detection, sizing and identification confidence. Hence, the pipeline condition and degradation mechanisms can be more analyzed by considering influencing factors such as pipeline cleanliness, repairs history and interacting threats. In summary, Probability of Failure in conjunction with the corrosion growth assessment enables prioritizing pipeline integrity activities in pipelines (e.g. identification, assessment, mitigation, monitoring and preventative measures) to ensure pipeline network safe operation.

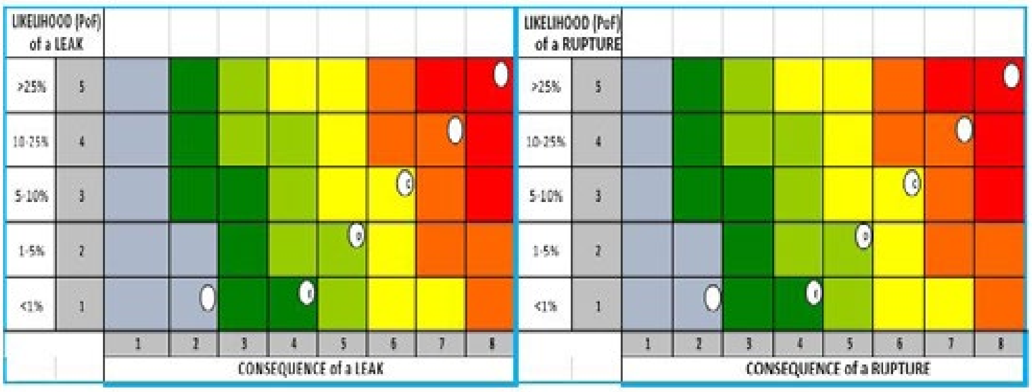


Figure 1: ERM Pipeline Integrity Risk Matrix Templates for Leak and Rupture

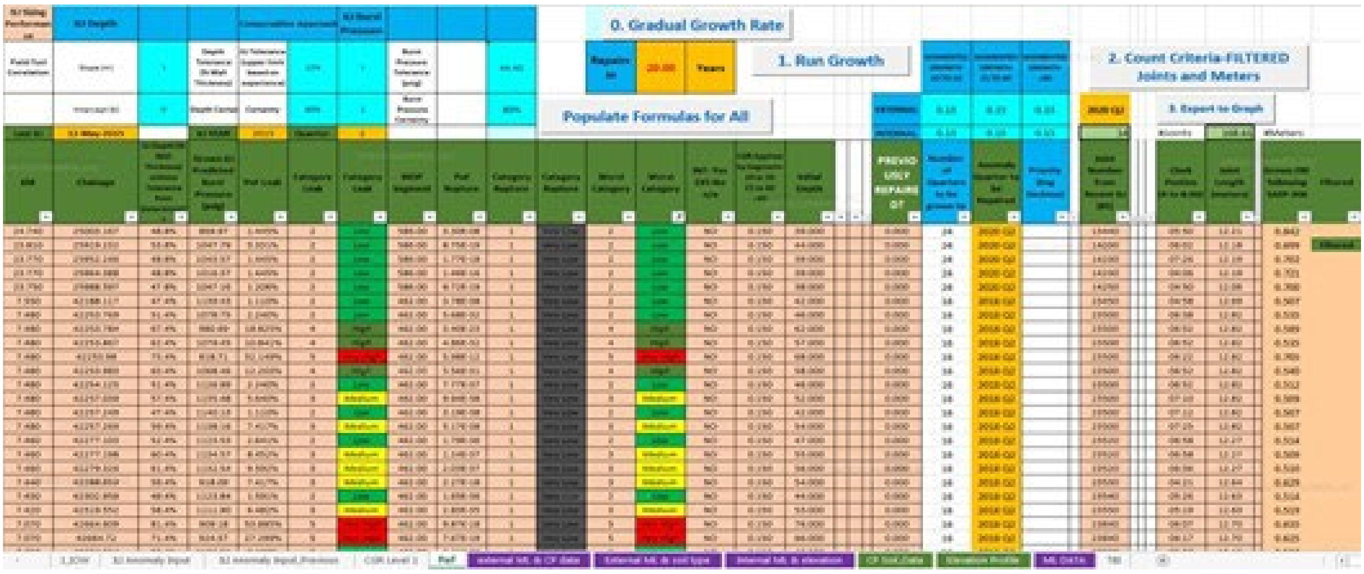


Figure 2: Probability of Failure (POF) calculation

1.2.2- CONSEQUENCE OF FAILURE

The Consequence of Failure (COF) value is determined based on ERM guidelines and description for different categories i.e. Business Interruption, Health, Safety & Security and Environment. For each of the categories, the pipeline is assigned with two COF values, one for leak and one for rupture, since the consequence of each scenario is considerably different. Hence, a single pipeline could have an anomaly with high COF and another with low COF depending on the mechanism of its failure and the driving category.

- Business Interruption: both the interdependence of the pipeline and the availability of a backup is the main consideration in the evaluation and selection of the COF category.
- Health & Safety: the factors influence the COF are the identified length of High Consequence Areas (HCAs) along the pipeline corridor, in addition to, the service of the pipeline without factoring the anomaly location.
- Environment: COF is determined based on an estimation of the failure spill volume compared to ERM limits and influenced by the service of the pipeline.

1.3- PIPELINE INTEGRITY PLANS (PIP)

The development procedure of pipeline Integrity Plan consists of six (6) sections as described in the following chart.

Each section will be explained briefly in order to describe the aspects that will be covered in each section.

- First section starts with the development of Integrity Operating Window (IOW). IOW sets up the operational limits of the processes and pipeline operating parameters.
- Second section covers threat identification using ILI summary. This involves analysis of ILI data including corroded joints and features for the last two ILI inspections. It shows the anomaly distribution, orientation and location along the whole pipeline.
- Third section of PIP integrate External Corrosion, Cathodic Potential and criteria and Soil type for analysis and evaluation. Also, this section integrates internal corrosion along with pipeline elevation profile to identify low areas and possibility of liquid hold up. This section highlights area that is affected due to low cathodic potential, soil corrosivity, water cut etc.
- Fourth section describes Criticality of threats (anomalies), Growth Rate associated with each type of anomaly (External Corrosion, Internal Corrosion and SCC), and the Time-to-Failure (for the worst anomaly on the pipeline). This section also provides the risk levels associated with the pipeline before and after the repair of critical anomalies. The risk levels are assigned as per the ERM guidelines for estimating PoF and COF.
- Fifth section includes the mitigation, prevention and monitoring measures required to maintain safe and reliable operations from the pipeline. This section addresses detailed actions that need to be taken such as pressure reduction, pipeline repair, external corrosion mitigation measures (CP enhancement, recoating, additional anode beds etc.), Internal corrosion mitigation measures (On-Stream scrapping frequency, corrosion inhibitor injection etc), and Re-Inspection interval of pipeline.
- The sixth and last section lists all the recommended, corrective and preventive actions to maintain safe and reliable operations from the pipeline.

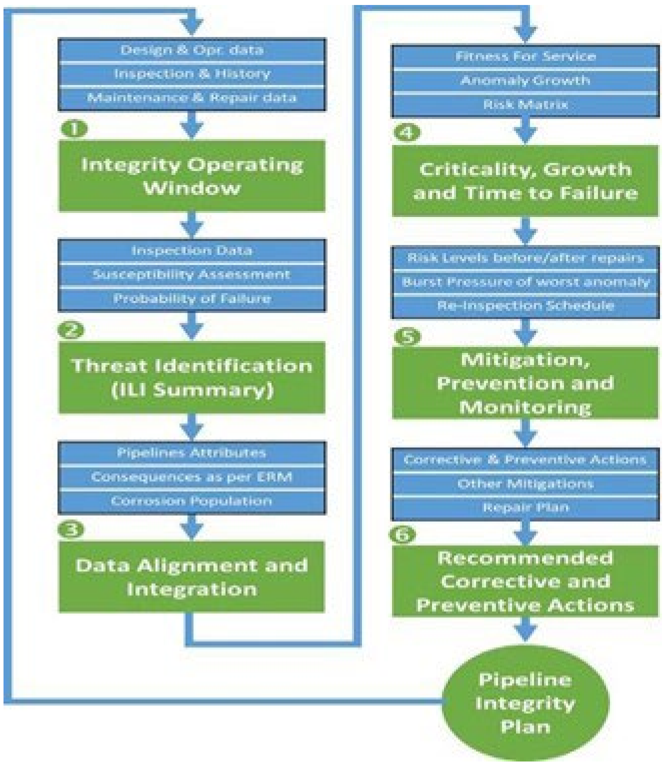


Figure 3: Pipeline Integrity Plan Development Procedure

2. CORROSION GROWTH MODELING

The ability to accurately determine the rate of corrosion growth along a pipeline is an essential input into a number of key integrity management decisions. For example, corrosion rates are needed to predict pipeline reliability (probability of failure and/or probability of exceedance) as a function of time, to identify the need for and timing of field investigations and/or repairs and to determine optimum re-inspection intervals to name just a few applications. As more and more pipelines are now being inspected using intelligent in-line inspection (ILI) tools for a second or even third or fourth time, pipeline operators require reliable guidelines for comparing repeat ILI data sets to obtain valid corrosion growth rates. There is presently no industry guidance on how to perform such data comparisons, which can demand significant effort and expertise to ensure accurate and meaningful correlations between often very large data sets. There are three main corrosion growth rate calculation methods typically used in the industry are; local growth rate estimation (Joint Maximum to Maximum), Combined Local and Segment Growth (Box to Box matching), and ILI Signal-to-Signal Matching (Combined Local and Segment Growth).

2.1- PREVIOUS CORROSION GROWTH MODELING

Saudi Aramco used to utilize an outdated corrosion growth modeling which is based on comparison of the two successive In-Line-Inspection (ILI) readings where the difference of the maximum corrosion depths measured in the successive ILI runs was divided over the inspection time period to obtain the corrosion growth rate.

- Step 1 - The maximum metal loss of a defect is considered as the metal loss of the joint on a previous run.
- Step 2- The maximum metal loss of a defect is considered as the metal loss of the joint on the recent run.
- Step 3 - Corrosion growth rate is calculated based on increase in metal loss in the joint with respect to time.
- Step 4 - As illustrated in figure 4 we assumed the two defects are the same.

This result in producing a conservative corrosion growth estimation and resulted in significant repair length, increased workload and reconditioning cost for the pipelines.

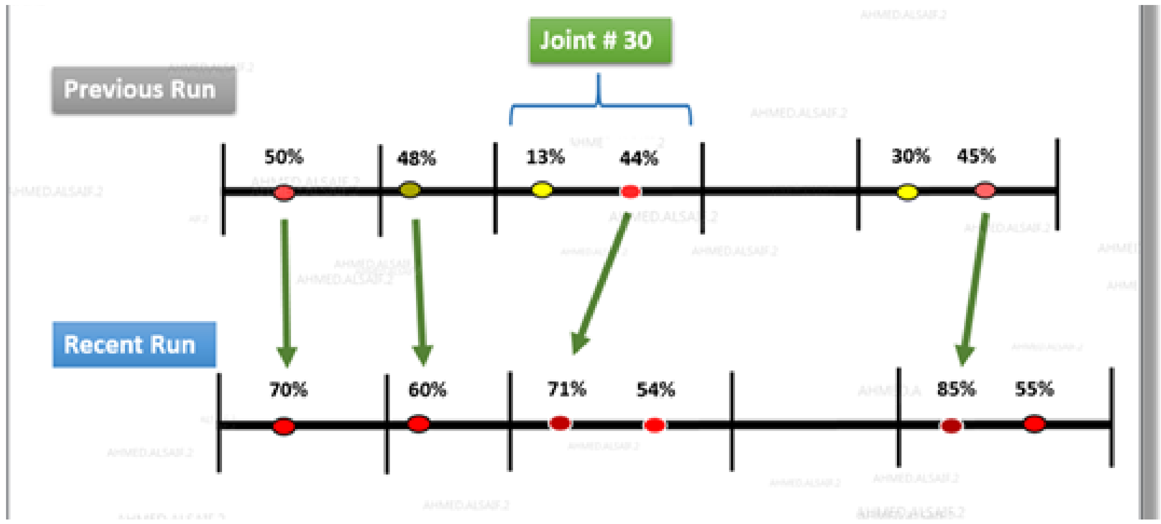


Figure 4: Joint to Joint Maximum Depth

2.2- SEGMENTAL CORROSION GROWTH MODELING

There is a more rational growth rate estimation method introduced by Pipeline Research Council International (PRCI) using statistical analysis. PRCI approach considers the segmental growth rate using statistical distribution and accounting for ILI tool tolerance and confidence interval. This results in a less conservative and more accurate growth rate prediction for the pipeline segments. As a result, it has been estimated that by using the new methodology for corrosion growth rate and defect assessment the overall reconditioning and repair workload has been reduced. Criticality assessments including enhanced level of fitness for service analysis involving corrosion clusters and deep pinholes can further be investigated using advanced corrosion growth models as described by PRCI.

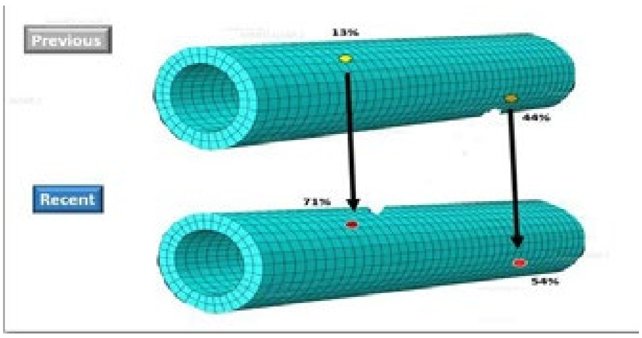


Figure 5: Segmental Corrosion Growth Rate Methodology

Segment growth rate estimation: The growth rate of a measure of the corrosion depth (typically taken as the change in the average depth in a segment) is estimated for a group of defects within a given pipeline segment. Note individual defects are not matched in this method. The six-step process for determining corrosion growth rates from repeat ILI data using these two approaches in an easy to follow (and implement) step-by-step format is given below.

- Step 1 - Obtaining the ILI data in the Right Format.
- Step 2 - Selection of the Comparison Methodology.
- Step 3 - Weld Alignment and Defect Consistency Check.
- Step 4 - Evaluation of Data LJ uncertainties.
- Step 5 - Determination of Corrosion Growth Rates
- Step 6 - Corrosion Growth Rate Checkpoints

2.2.1- FORMULATION INPUT

- PRCI Segment Growth

Standard deviation of the total growth (σi) using both ILI run distributions.

$$\sigma_t = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$$

- PRCI Localized Growth

Alpha (α) Factor for correcting the ILI growth error using the measurement from both ILIs (i.e. xm1, xm2) and the standard deviation of the measurement errors (σ)

$$\alpha = (x_{m2} - x_{m1}) / \sigma$$

Corrosion growth average (μ) and variance (υ) for anomalies with an alpha between 0.25 and 3.0

$$\mu_r = \left(\frac{x_{m2} - x_{m1}}{t}\right) \times \left[0.449 + 0.0846\alpha + 0.83/\alpha\right]$$

$$v_r = 0.861 + 0.0516\alpha - 0.227\alpha^2 + 0.0691\alpha^3 - 0.0062\alpha^4$$

For, $0.25 < \alpha < 3.0$

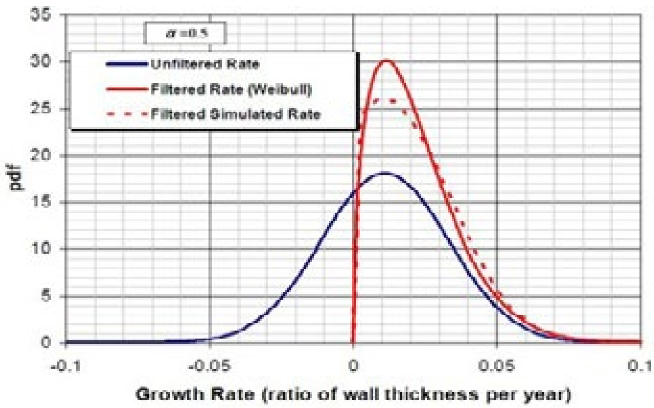


Figure 6: Growth Rate (ratio of wall thickness per year)

3. ADVANTAGES OF IMPLEMENTING ADVANCED CORROSION GROWTH MODELING

3.1- COST EFFECTIVE CAPITAL PROJECT

The intent of capital projects is to proactively identify, evaluate and pre-select pipelines far ahead of their potential for rehabilitation by applying advanced forecast analytics associated with the integrity condition. Corrosion growth and repair responses considering the associated ERM risk evolution. The methodology will consider, but not limited to, the following criteria:

- Joints with deteriorated condition.
- Accelerated deterioration (active corrosion and High growth rate).
- High cost to remediated damage and reinstate integrity (required rehabilitation Vs NDE) by identifying life cycle cost.

PTSD rehabilitation process is driven by two major enablers. Gathering and distribution of required information amongst all relevant organizations. Conducting thorough evaluations at an early stage, prior to business case development. The concept is based on introducing a thorough initial screening process, which will establish the justification and scope for any pipeline nominated for rehabilitation. The objective of the screening process is to develop optimum and reliable rehabilitation plans, which in effect maximizes the value of the rehabilitation efforts. The process deliverables will be used as basis for the project business case development as part of CMS stages, and as a corporate reference for the pipeline under evaluation. The above new process was deployed for the capital project program for scope evaluation as part of the rehabilitation master plan. PTSD has conducted the assessment of 12 selected pipelines to determine whether their inclusion in the Capital project program is more cost effective than multi-year repairs. The assessment evaluated the current integrity condition and its forecast identifying their integrity risk drivers, probabilistic growth and expected repairs over time. As a result, all 12 pipelines in capital project program will be deferred from it and re-evaluated for inclusion in the next capital project program. These pipelines vary in the size range from 12 inch to 42 inch and in length range from 7.2 to 105.2 Km with different services such as; Crude, Sweet gas, NGL and sour AXL. Furthermore, the average service life is almost 50 years.

P&TSD plans to incorporate the rehabilitation scope verification (if a business case can be supported or not) as part of the integrity plan process. The tools PTSD utilize to verify rehabilitation project scope are among the tools used for pipelines integrity plans, including the long term need of rehabilitation projects assessment as part of integrity plans will provide more consistent and systematic approach to defining the rehabilitation programs candidate pipelines.

PTSD has modified the probabilistic corrosion growth tool to include rehabilitation scope assessment. The tool will be tested using a number of candidate pipelines that has potential need for rehab projects. The initial criteria for selecting these pipelines include:

- Significant projected amount of repair
- High corrosion growth
- Operational challenges to maintain pipelines integrity (low flow, velocity, high water cut with no corrosion control measures… etc.)

3.2- REDUCTION OF WORKLOAD

PTSD used the enhance integrity assessment method (SÅEP-306 and PRCI corrosion growth rate estimation) to validate the results of this method on three (3) selective pipelines. The failure pressures and Estimated Repair Factors (ERF) were calculated by using both the Old method (Original ASME B31G and Max to Max comparison of the growth rate for each joint) and the new enhance method (using SAEP-306 Level

2 corrosion assessment with LPC equation and PRC' corrosion growth rate estimation). Further to this, Probability of failure (POF) were estimated for each corrosion defect using the ILI tool tolerance and certainty along with the confidence interval. Based on the probabilistic calculations, more advanced corrosion criticality assessments were performed using leak and rupture-dependent probabilistic modeling factoring the in-line inspection accuracy performance (i.e. tolerance as well as certainty). Hence, workload is now associated with likelihood levels defined by the Enterprise Risk Management (ERM) risk matrix for effectively managing risk. In order to mitigate the risk, the joints categorized as "Very High.", "High", and "Medium" risk ranking were selected for reconditioning.

Department	Pipeline	Reconditioning Workload based on Old Methodology-ASME B31G	Reconditioning Workload based on Improved Methodology- PRCI Level 1B with SAEP-306
SAPD	QA-8	114 meters	50 meters
EWPD	AY-1 (V)	197 meters	75 meters
HAPD	BB-1 (I)	175 meters	90 meters
Total		486 meters	215 meters

Table 1: Comparison of workload using original ASME B31G and enhance Integrity Assessment Method

The implementation of PRCI advanced corrosion growth rate assessments in combination with the new SAEP-306 had provided better and realistic estimation of

failure pressures to determine workload without impacting and compromising the integrity of the pipelines. Following this methodology has resulted in cost reduction of $4.04 MM.

4. CONCLUSION

In general, the implementation of PRCI advanced corrosion growth modeling allow the corporate to have more clear view and a better understanding of the pipeline network conditions. Based on this clear view, the repair load was reduced and less resources were required to maintain the integrity of the pipeline at the same level while the good understanding of the network help to initiate better mitigation actions and recommendations which improve the integrity plan and resulted in more efficient integrity process.

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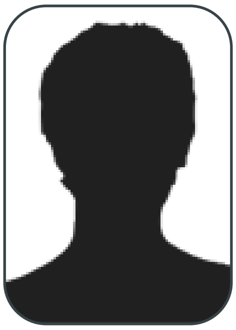

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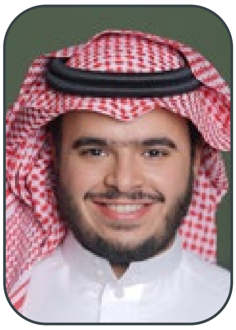

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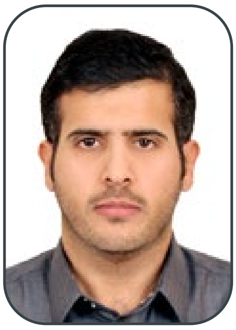
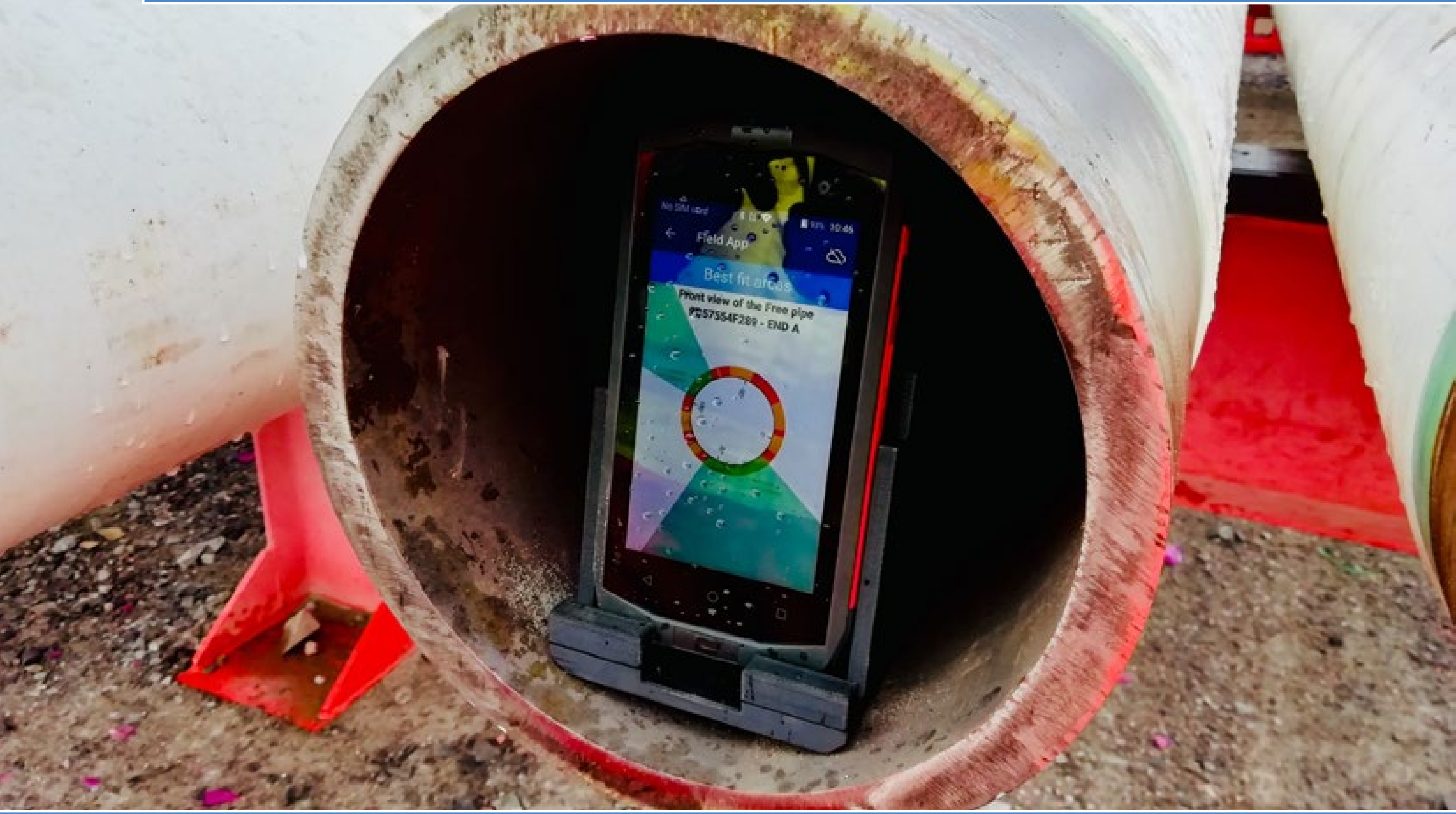


Translating Data Analytics Into Operational Instructions, An Innovative Smartphone App To Support Pipe Fit-Up Efficiency



Nicolas Gotusso, Thibault Masse > Vallourec

Abstract

Digital tools are everywhere in today's world. The Oil & Gas sector is known to be slow to adapt, however has already been embracing the digital change since several years. A wide range of initiatives and solutions have been developed, from big data and related analytics to augmented reality and internet of things.

Digital tools aim to cover the whole value chain, from engineering stage to construction and then life of field. Among the objectives are material and operations traceability, production monitoring but first and foremost ensuring operational efficiency. All those leads to data focused solutions.

Use of data focused solutions implies to develop the right analytics to maximize the use of recorded information. It also requires developing the right translation of those analytics to actual operational instructions to yield its full benefits.

This paper introduces an example of defining operational instructions based on data analytics, dedicated to line pipe welding operations. Based on pipe end measurement data and their analysis, the developed smartphone app provides pipe alignment instructions to the welders so that optimum positioning is instantly reached. It contributes to securing the production flow, anticipating risks prior to start of production and reducing production time. Last, being a digital solution also enables usage of the app by existing staff and remote implementation, removing mobilization constraints of physical services.

1. INTRODUCTION

Pipeline construction involves complex operations, from material manufacturing to pipe laying. This translate in constant research of efficiency improvement. During welding, high productivity is key to contain laying costs, while compliance to welding specifications is a must.

Fatigue and other engineering aspects lead to minimizing the acceptable misalignment (Hi-Lo) between pipes for a better assembly as well as reducing related welding defects. Variability of the pipe geometry therefore requires trial and errors at fit-up station which slow down operations and impact project planning.

Using unique pipe-end identification technology, the newly developed solution enables calculating achievable Hi-Lo value based on pipe-end measurement data. Operational efficiency is reached using a smartphone app providing pipe alignment instructions to existing personnel. App is built to be used in full autonomy by existing staff, thus enabling remote implementation. The solution is designed to result in optimized welding operations: reduced Hi-Lo, faster fit-up and reduced repair rate.

Additionally, pipe-end identification enables the app to support traceability of the welding operations by linking manufacturing data and enabling as welded sequence record to directly issue a digital twin.

This paper will give an overview of the analytics performed but will focus on their translation to operational introductions - smartphone app usage in the field - and its benefits.

2. SOLUTION OVERVIEW: FROM DATA ANALYTICS TO SMARTPHONE APP USAGE

The solution is fully independent from pipe production, and operates in the following sequence:

- Unique pipe-end identification
- Pipe-end Measurement data integration or on-site collection
- Compatibility analysis & associated recommendations
- Smartphone app usage at site

The solution fits within project workflow by design: pipe ends are identified and measured either during manufacturing or subsequent pipe transformation operations such as cladding or coating. Compatibility analysis report is then issued – during operations planning stage – to enable proper evaluation and define necessary on-site fit-up support. Last, whenever app usage is considered, smartphones will be delivered to existing teams with physical or remote training.

A. UNIQUE PIPE-END IDENTIFICATION

Unique pipe-end identification is key to ensure traceability of the data and easy identification of the pipe on-site. Pipe identification can today be achieved through various means and generally depend on material producers or customers' requirements.

In our case, a unique identification number will be allocated to the pipe-end. Each end will then be identified using data matrix tags – see Figure 1 – which will be applied on the outside surface of the pipe or the coating every 120° at three different locations from the pipe-end. These stickers ease and speed up the pipe-end identification, and redundancy is ensured by linking the unique identification number to the pipe tally number.

Figure 1: Data Matrix tags ensuring unique pipe end identification

Tags enable quick reading on site and remove risks of manual inputs error when identifying pipes. Specific ones were chosen to answer operational requirements such as tagging under the snow in Northern Europe, or withstanding high storage temperature in the Middle East – not to mention handling constraints.

B. PIPE-END MEASUREMENT DATA: INTEGRATION OR ON-SITE COLLECTION

Pipe measurement data can be either collected during pipe manufacturing and then integrated in the solution database or collected on-site using portable equipment.

With a productivity of 100 pipes per shift and per equipment, the portable measurement tool – see Figure 2 - can accommodate pipe sizes from 6'' to 60''. It is a carry on one thus enabling operations anywhere, in any configuration (e.g. pipes laying at coating premises, stored in racks). The tool allows live view of the measurement using a tablet, and upon measurement completion a report is issued including Inside Diameter (ID), Wall Thickness (WT), Outside Diameter (OD) and local or global out-of-roundness. Such report is of great benefit for quality control.

Last a reference line is drawn on pipe OD, ID and bevel face to represent the 0° position of the measurement. In

Figure 2: Portable Pipe End Measurement Tool

the case of welded pipes, the seam area can serve as the measurement reference position.

C. DATA ANALYTICS: THE PIPE-END COMPATIBILITY ANALYSIS

Once data has been collected, data analysis can start. Process aim to evaluate compatibility of the pipe-ends to ultimately anticipate the Hi-Lo that can be achieved during welding - and can be performed either considering inside Hi-Lo only but also both inside and outside ones.

Each possible pipe-end combination will be simulated by the developed algorithm, transforming geometrical data into an operational one. For one defined position of pipe ends, ID and OD Hi-Los are recorded all the way along the circumference. The maximum value will be kept as the decisive value. Next, the pipe is rotated by 1° and all the Hi-Los are recorded and maximum value kept. The process is repeated to cover the full circumference. In other words, for one pipe end combination, a total of 130 000 Hi-Los will be calculated.

These values will be used to generate a graph which show the evolution of the maximum Hi-Lo depending on the pipe rotation – see Figure 3 – and which introduce the concept of optimum pipe positioning.

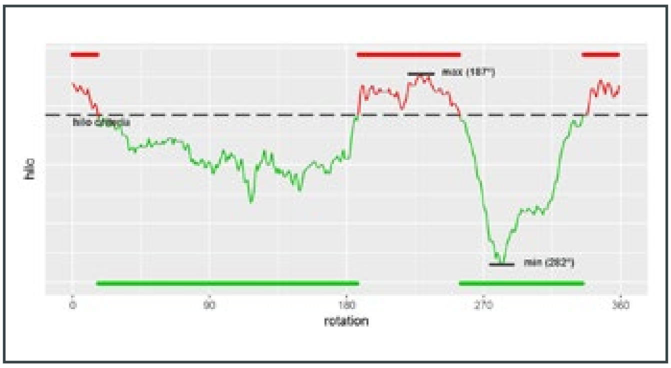


Figure 3: Hi-Lo evolution depending on pipe position

The minimum and maximum of the previously mentioned Hi-Lo curve of each combination will then be plotted in a chart providing the global compatibility of the batch vs the specified Hi-Lo requirement – see Figrue 4. A variety of colors highlight the different results:

- Green dots are pipe-ends combinations complying with the specified Hi-Lo regardless of their positioning and are therefore fully compatible.
- Yellow ones are pipe-ends combinations requiring one of the pipes to be rotated in order to comply with the specified Hi-Lo.
- Red ones are incompatibilities, pipe-ends combination not meeting the specified Hi-Lo.

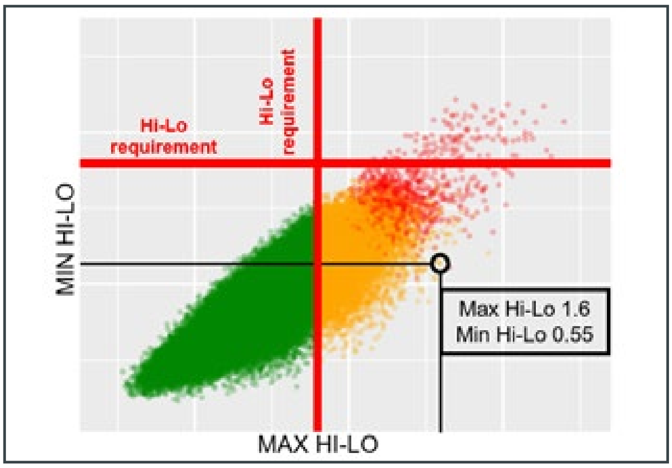


Figure 4: Compatibility Analysis Chart

This chart therefore provides a comprehensive overview of the capability to meet the Hi-Lo criteria using the defined batch of pipes and without sequencing, as well as the identification of potential necessary measures to ensure production efficiency.

D. OPERATIONAL RECOMMENDATIONS BASED ON DATA ANALYTICS

Operational recommendations are defined upon pipe-end compatibility analysis issuance and can serve different project objectives. Figure 5 describes the possible analysis results as well as the recommended approaches.

In the case of good compatibility, project teams may proceed as is or choose to reduce the defined Hi-Lo level for greater quality or installation benefits: fatigue performance, line lifetime or wider offshore laying window. Reducing the acceptance criteria might result in more pipe-ends combinations requiring a rotation and a greater number of incompatibilities.

In the case of medium compatibility, when the percentage of combinations requiring a rotation reach a certain thresh-

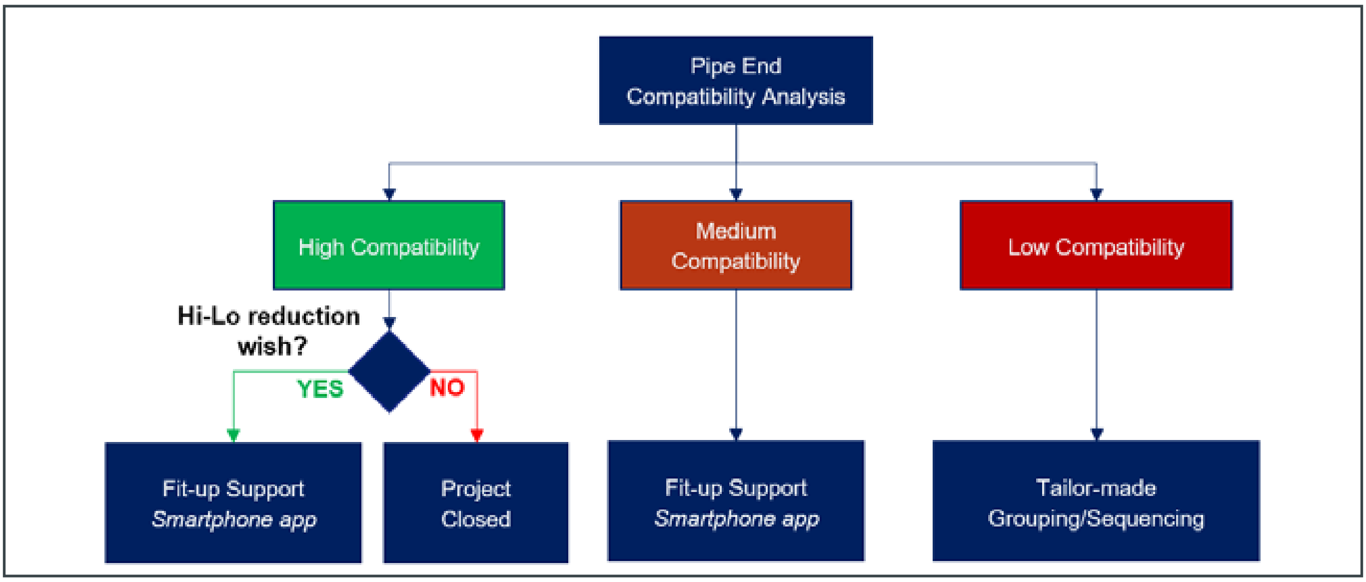


Figure 5: Decision tree upon analysis results

old (defined on project basis), on-site fit-up assistance is to be considered in order to maintain production efficiency. Idea being to provide instant match of those pipes to removes usual trial and error method creating delays.

Last, in the unlikely event of very low compatibility, specific approaches such as pipe grouping combined with the smartphone app and / or sequencing would then be used. Those are tailor-made solutions discussed with the project team.

In all cases, production efficiency is secured by providing instant match between pipes and identifying incompatible combinations as early in the process as possible. This is where operational instructions are necessary hence when smartphone app comes into play.

3. OPERATIONAL INSTRUCTIONS: SMARTPHONE APP USAGE IN THE FIELD

Easy to use, reliable and adapted to process conditions: these are minimum yet key requirements for field support solutions. In our line pipe case, conditions might be challenging ones with operations taking place in the middle of nowhere hence far from a network connection, teams might be rotating so need to be trained in a fast manner, and last the tool need to perfectly fit within the production process to ensure its adoption.

The smartphone app was developed to answer those criteria and to bring full autonomy to existing teams. Fully remote deployment is therefore possible – critical in the current times – compared to existing solutions implying support personnel being sent to site.

In the field, app is to be used right before fit-up. This enables identification of incompatibilities as well as definition of compatibility areas for pipe-ends combinations requiring rotation which removes time loss related to pipe rejection due to impossible fit-up, or empirical approaches to achieve optimum positioning.

All Hi-Lo calculations are done in-app - whether running in online or offline mode - which allow live adjustment of settings hence constant adaptation to field condition.

A. SUPPORTING ASSEMBLY OPERATIONS

During welding operations, no sequencing is required. Tags of the two pipe-ends to be welded together are to be scanned using the app. One of the two pipes is usually called of the fixed pipe as already welded to the mainline, the other one being called the free pipe. Once both identified, Hi-Lo curve will be automatically provided as well as the compatibility result.

There are three types of compatibility result – see Figure 6:

- Full compatibility, pipes can simply proceed as is to the fit-up station as Hi-Lo compliance will be achieved in any position.
- Incompatibility, in which case pipe is to be set aside in temporary quarantine
- Compatibility to be reached by rotating one of the pipes, compatible areas are then to be identified on pipes.

Recommendation is for pipes to be scanned during the tally-in or stringing operations, which usually the precedes fit-up and root pass. Identifying incompatibilities at this stage

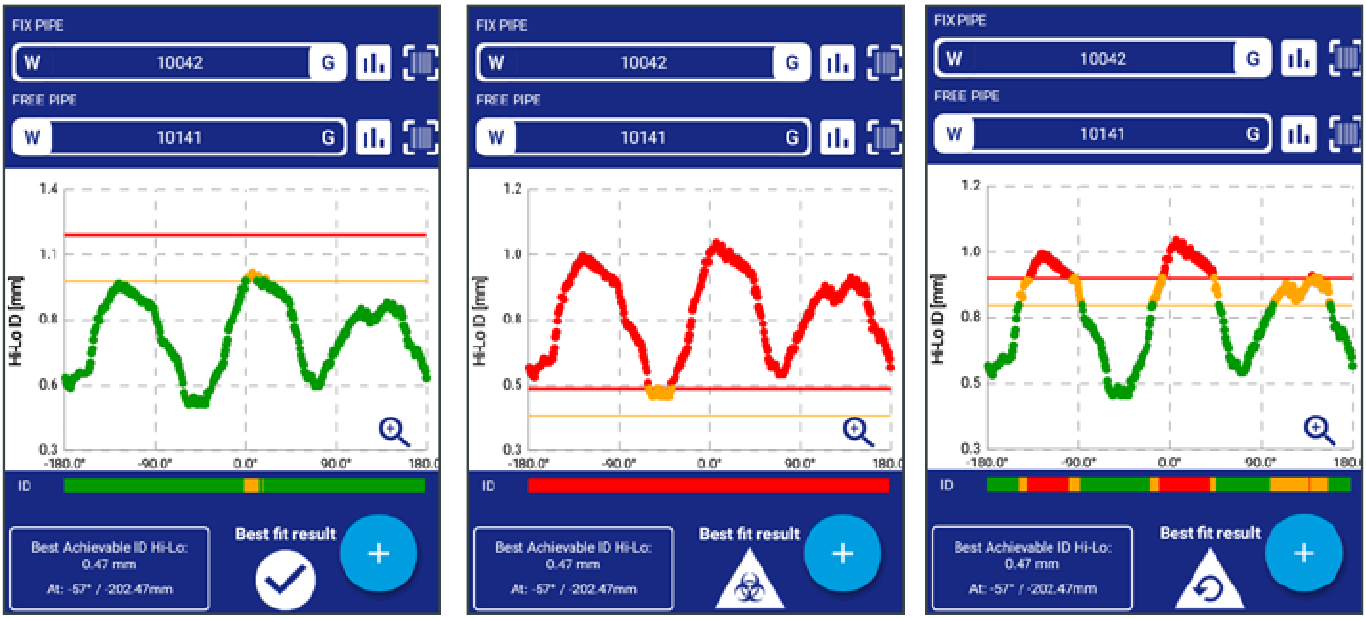


Figure 6: Compatibility results type

enables to avoid the impossible fit-up, i.e. the "no-match", and related time loss. When such case appears, the free pipe needs to be removed from the fit-up station and other one brought up, which can typically take up to 20 minutes.

Using the app, the free pipe creating incompatibility can directly be sent to the temporary quarantine. The same will be recorded by the app, which will automatically test compatibility of the quarantined pipe with all subsequent pipes scanned. As soon as compatibility is found, the app will propose to insert it again and provide compatibility with the preceding pipe and the following one – see Figure 7.

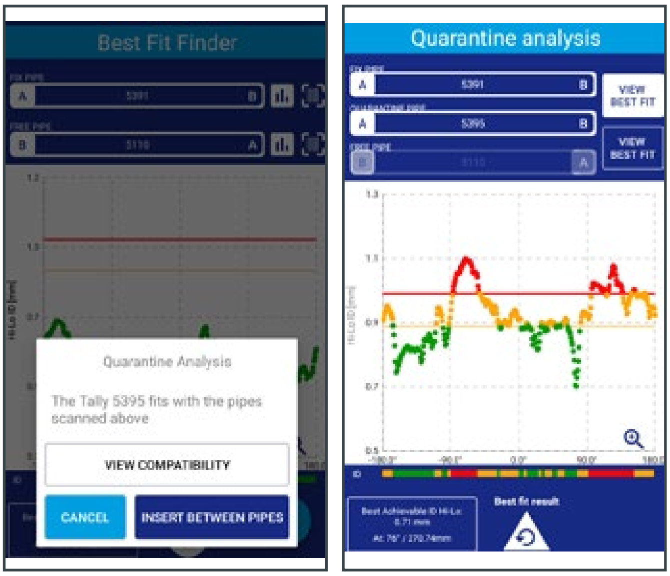


Figure 7: Quarantine call-back

Whenever compatibility is to be reached by rotating one of the pipes, compatibility areas marking is to be performed. Those will be displayed by the application along pipe circumference – see Figure 8. Smartphone then just needs to be placed in the free pipes, 0° reference line of the app adjusted with the one of the pipes, and compatible areas to be marked on pipe outside.

Green compatibility areas are Hi-Lo compliant ones, yellow ones are warning zones close to Hi-Lo limit and red are incompatibles ones. Yellow ones are considered to allow specific positioning that might be required by external factors such as line overall straightness.

Once free pipe marking is complete, it can simply proceed to the fit-up station. Welders only need to match the reference line of the fixed pipe with the compatibility areas marked on the free one - see Figure 9. Use of compatibility areas provide several options to the welder, whereas the line to line match used by existing solutions only offer one and thus imply a systematic rotation.

Figure 8: Compatibility areas marking on pipe

Perfect fit-up is then instantly reached as suitable positioning is already known when pipe reach the station. Considering that time for fit-up without rotation would be around 1 min where a rotation can take up to 5 minutes, the smartphone app strongly benefits to cycle time reduction.

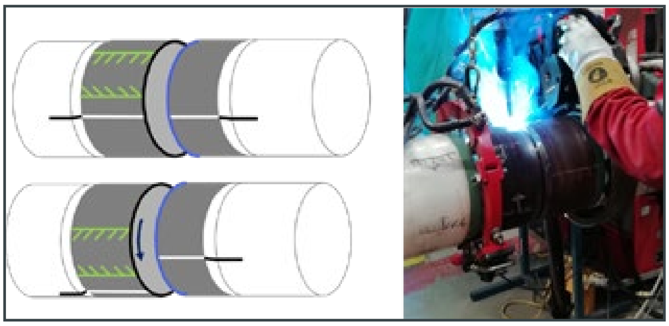


Figure 9: Use of compatibility areas at fit-up

B. APP SETTINGS: OPERATIONAL REALITY

As introduced, calculation is done in-app which enable live adjustment of the settings – Figure 10 - depending on the context. Facing a critical section, Hi-Lo can be reduced. Quarantine rate is slightly higher than expected, then continuity percentage can be reduced to lower the incompatibility rate accordingly.

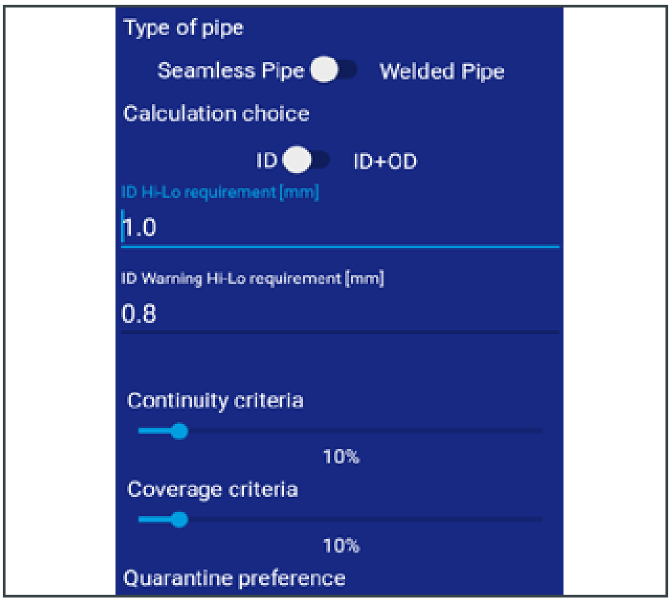


Figure 10: App Settings Screen

Hi-Lo set-up:
Two Hi-Lo values shall be defined in the app. The "Hi-Lo requirement" in mm which represents the upper Hi-Lo limit specified by the project specification and will define the red areas. The "Warning Hi-Lo" requirement considers a safety margin related to the bevel quality and other parameters that could slightly impact the measured Hi-Lo. "Warning Hi-Lo" defines the yellow areas introduced earlier.

Continuity and coverage criteria:
Expressed in % of the pipe circumference, the continuity criterion is the minimum length on the circumference respecting the Hi-Lo requirement. In other words, in case of compatibility on a short section it defines whether the app will recommend temporary quarantine or propose a rotation. The objective of this parameter is to bring operational reality in a theoretical calculation of the Hi-Lo. A compatibility area of few millimeters is often non reachable on the fit-up line due to the accuracy of the rotation applied or the marking itself. The coverage criterion represents the sum of all area respecting the minimum continuity area.

Longitudinal seam separation for welded pipes:
When welding longitudinally welded pipes, it is usually requested to avoid longitudinal seam to longitudinal seam butt-welding, to avoid aligning weaker areas – and hence stop as much as possible crack propagation shall one appear. In that sense a "seam separation" criterion is usually part of the project specification.

This criterion is fully managed by the app - can be entered as part of the settings and is highlighted in grey in the Hi-Lo curve but also when marking the compatibility area.

ID or ID&OD compatibility:
Hi-Lo and compatibility result can also be computed – whenever necessary - considering both OD and ID criteria instead of ID only. This is reflected by two different Hi-Lo curves; and displayed compatibility are combined ones.

4. TRACEABILITY & OPERATIONS RECORDS: ISSUING THE DIGITAL TWIN

The use of unique pipe end identification as well as a mobile device also enable the solution to enhance traceability, be it for pipes or operations. The developed app provides live and easy access to pipe manufacturing information, support further processing such as onshore multiple joint assembly and last enable recording of the as-welded pipe sequence. Those features aim to facilitate field operations. By removing the need for manual identification, it strongly reduces the risk of recording anomalies by directly issuing a digital twin.

A. LIVE PIPE DATA ACCESS

Pipe order information and actual production records can easily be linked to the unique identification number. Data from pipe manufacturing and/or operations can then be directly visualized in-app when scanning tags and or entering the identification number.

Figure 11 present examples of data that can be accessed

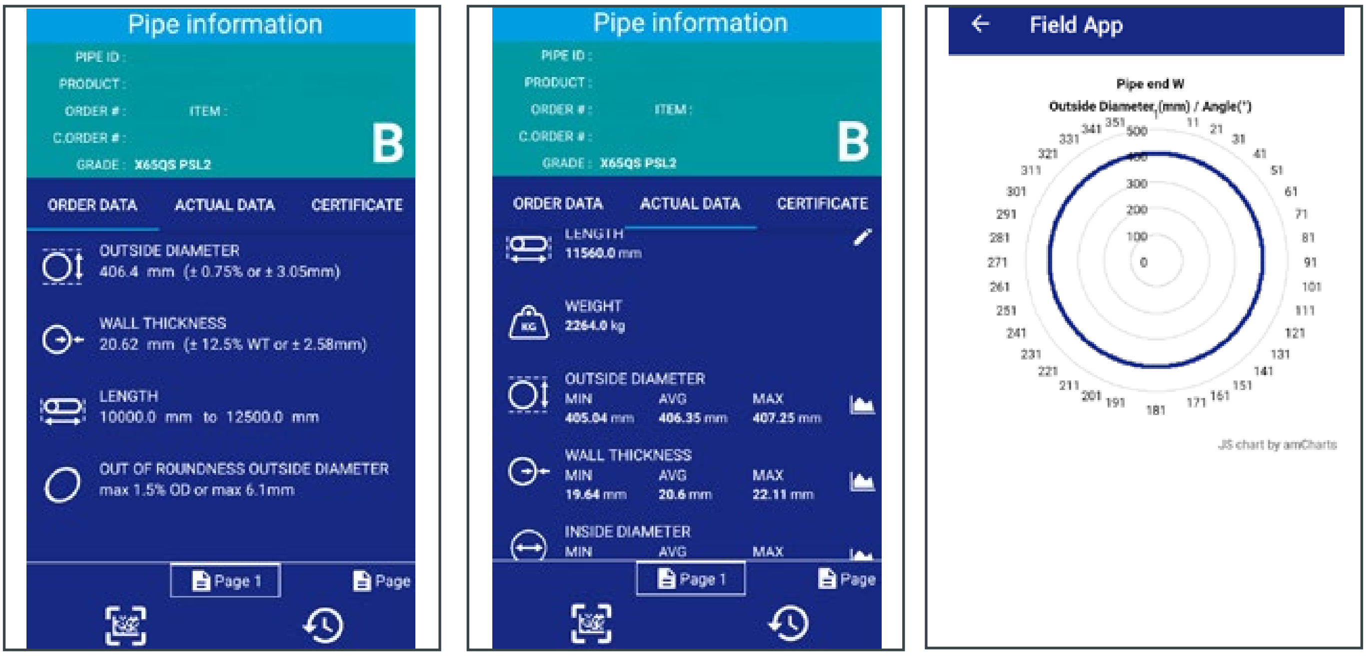


Figure 11: Live Data Access

using the app. Detailed visualization of pipe-end profile as well as wall thickness profiles along pipe length are available – all depend on data available. Inspection certificate – also known as MTC – can be accessed and extracted from the app.

Information is therefore very easy to be accessed and extracted directly in the field – even in offline mode – which translate into time savings. Additionally, risk of manual input error is removed as pipes are identified by scanning tags.

Figure 12: In-app multiple joint assembly creation process

B. MULTIPLE JOINT ASSEMBLY MANAGEMENT

Construction and installation of pipelines show very high daily operational expenditure. In order to reduce on-site or offshore operations, onshore multiple jointing is often performed – allowing to divide by at least two the number of welds during laying.

The app can also be used in such cases. The compatibility analysis can be performed on single joints in order to anticipate double jointing operations – an option could be to select the less compatible pipe-ends and weld them during multiple jointing – and app used for optimum positioning during welding operations. Once pipes are welded together and hence multiple joint created, the same can be recorded directly in the app using the multiple joint assembly management feature - see Figure 12.
A tally record is then created and can easily be extracted in MS Excel format. Once created, compatibility analysis can be re-run considering double joints only. In the same spirit, whenever used post multiple joint creation the app will also only consider multiple joints when identifying any of the pipes-ends in the field.

The same yield several benefits. First, traceability of multiple jointing operations is improved, and its tally extract can directly be embedded into the production tracking system. Second, the whole solution enables to perform time consuming operations – such as welding the less compatible pipe-ends - earlier in process to maximize mainline welding efficiency thus benefiting to the overall production flow.

C. AS-WELDED PIPE SEQUENCE RECORD

The developed app also allows to record the as-built incoming tally construction (i.e. as-welded, as-laid sequence) issuing immediately a Digital Twin to eliminate risk of manual input errors – see Figure 13. This as-built digital tally is automatically generated as pipes are scanned - and can easily be extracted.

Pipe position as well as its orientation are recorded, and information on the pipe or on the weld can be added live. The same support quality records and could also be easily integrated to production tracking system once extracted.

Last, when used for spoolbase welding the app also includes in this feature alert functionalities such as preventive alert for pipe assembly cumulative length check to prevent from manual pull and multi-jointing length dispersion.

5. CONCLUSIONS

Increased use of digital tools will benefit the line pipe industry, to support operational efficiency but also by enabling autonomy and remote deployment – critical in current times. Data centric solutions are now widely used, existing analytics enable lessons learned of past situations. When reactive enough, those can also be used for live field support as introduced in this paper.
Challenge then lies in transferring potentially complex analytics into a suitable operational assistance tool. Easiness to use, clear instructions and live adjustment are key parameters to ensure field adoption of a digital solution.

In the presented solution, pipe identification is as easy as scanning a tag with a smartphone - a gesture that is now becoming part of everybody's daily life. The compatibility analysis is transferred to the app in an easy-to-understand instruction: compatible as-is, rotation required, temporary quarantine. A clear cut and instant answer provided, which is usually the need of operational teams. Still, more detailed information – such as the Hi-Lo curve – remains available to be consulted whenever needed.
Last, reactivity is achieved by enabling live adjustment of the settings: shall there be a change of the operational context, the same can directly be reflected in-app.

Figure 13: In-app as-welded sequence Record

The app has now been used on 10,000 welds, which resulted in clear savings. No incompatible pipe reached the fit-up station thus removing downtime linked to pipe removal. Fit-up and root-pass station time has decreased up to 10% - resulting in some cases of a debottlenecking of the station. The same combined with a reduced weld repair rate – coming from reduced Hi-Lo variability thanks to analytics - can be translated in savings from 20k$/km to 75 k$/km depending on project daily operational expenditure. Additionally, thanks to tags identification and its embedded production recording features the app enhance traceability at site and diminishes the risk of manual input errors – which support existing digital twin approaches.

It is the opinion of the authors alone that – as any digital tool – the app is called for constant evolution to further support to field operations and increased benefits.

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Leak & Theft Detection Strategies: Integrating Established And Innovative Technologies

Harry Smith > Atmos International

Abstract

Pipeline leak and theft detection can be done through various technologies. There is no single best method as each pipeline is different and ideally, it is best to integrate several different methods within any detection system. Two of the most popular and established methods are flow balance and negative pressure wave, however, both have their challenges. Atmos International (Atmos) invests heavily in research and development and has developed new technologies such as fast scanning, nano wave and non-intrusive hardware to overcome these challenges.

Within systems that use flow balance, fast scanning allows for dramatic improvements to leak location with new filters decreasing detection time. For negative pressure wave systems, the development of inexpensive non-intrusive hardware means improving the performance of the new and existing systems (sensitivity, response time, leak location and reliability) and makes retrofitting leak detection technology even more accessible. Atmos received the prestigious Queens Award for Enterprise: Innovation 2020 for its Atmos Wave product and one of the recent innovations is the nano wave module. The nano wave module improves sensitivity during dynamic or steady-state conditions in pipelines to help detect smaller and slower leaks.

Pipeline leak and theft detection systems are facing many new challenges from pipelines that lack reliable communication infrastructure, limited or no power and instrumentation (aged pipelines) as well as a lack of adequate housing for the equipment. With stricter environmental policies being introduced around the world - API 1175 states there needs to be a clear strategy in place from leak detection vendors (such as Atmos International) to continuously evaluate their technology, leak detection performance is more important than ever and improvements need to be made to provide better sensitivity, response time, leak location accuracy and reliability (false positives).
This paper explores the improvements that Atmos has introduced to its leak detection systems.

1. FLOW BALANCE TECHNOLOGY

Utilizing flow readings on a pipeline is the most common method of pipeline leak detection being used for flow/mass balance (Atmos Wave Flow), statistical leak detection (Atmos Pipe) and RTTM systems. These systems have several advantages from being able to detect leak sizes of 0.5-1% of the nominal flow, detecting both spontaneous and creeping leaks while maintaining a low false alarm rate. However, one of its biggest disadvantages has been poor leak location when detecting a leak. As most systems utilize the flow signal data from the SCADA systems, they are limited by the refresh rate of the data, subject to the best-case refresh of one second but it can be as low as 2-10 seconds and in some cases even one minute.

This means that the best possible leak location accuracy of flow balance systems would have been +/-1km (based on a 1000m/s speed of sound). Atmos saw this as an area of the technology that needed improvement and developed an upgrade for its flow balance systems (Atmos Pipe and Atmos Wave Flow). The upgrade is known as "Fast Scanning". This upgrade utilizes modern hardware such as an AWAS unit (small compact RTU) that allows flow and pressure data to be acquired at 60Hz (60 samples a second). This data is then stored in a database. When a leak is detected by the system, that section of data is replayed at the higher acquisition rate, and an improved leak location is provided in real-time. The "Fast Scanning" upgrade has allowed Atmos to improve leak location accuracy from +/-1km to +/-150m.

As well as utilizing Atmos hardware, Atmos can use OPC UA protocol to improve the acquisition of the data from the SCADA RTUs as well (this only currently works with certain models of RTUs). The SCADA needs to support historical reads from OPC UA. (reference OPC foundation – OPC Unified Architecture Specification part 11: Historical Access, release 1.04).

A pipeline system in Costa Rica utilizes Atmos Pipe with the "Fast Scanning" module to improve leak location accuracy. A theft event triggered a leak alarm on the system and the "Fast Scanning" module activated to improve the leak location. This pipeline section is 56km long and transports multiproduct hence why it is often targeted by thieves.

A location of 9.280km was provided by the system and the theft event was located at 9.210km. This is a leak location error of +70m. If fast scanning wasn't being used, the standard SCADA rate of this pipeline of 5 seconds would have provided a leak location of 11.3km which is an error of 2km.

2. NEGATIVE PRESSURE WAVE

Negative pressure wave has several advantages for leak detection including fast response time, accurate leak location and good sensitivity specifically for theft detection. However, it has previously provided some challenges such as higher false alarm rates compared to flow balance systems and in some cases, can miss creeping or sponta-

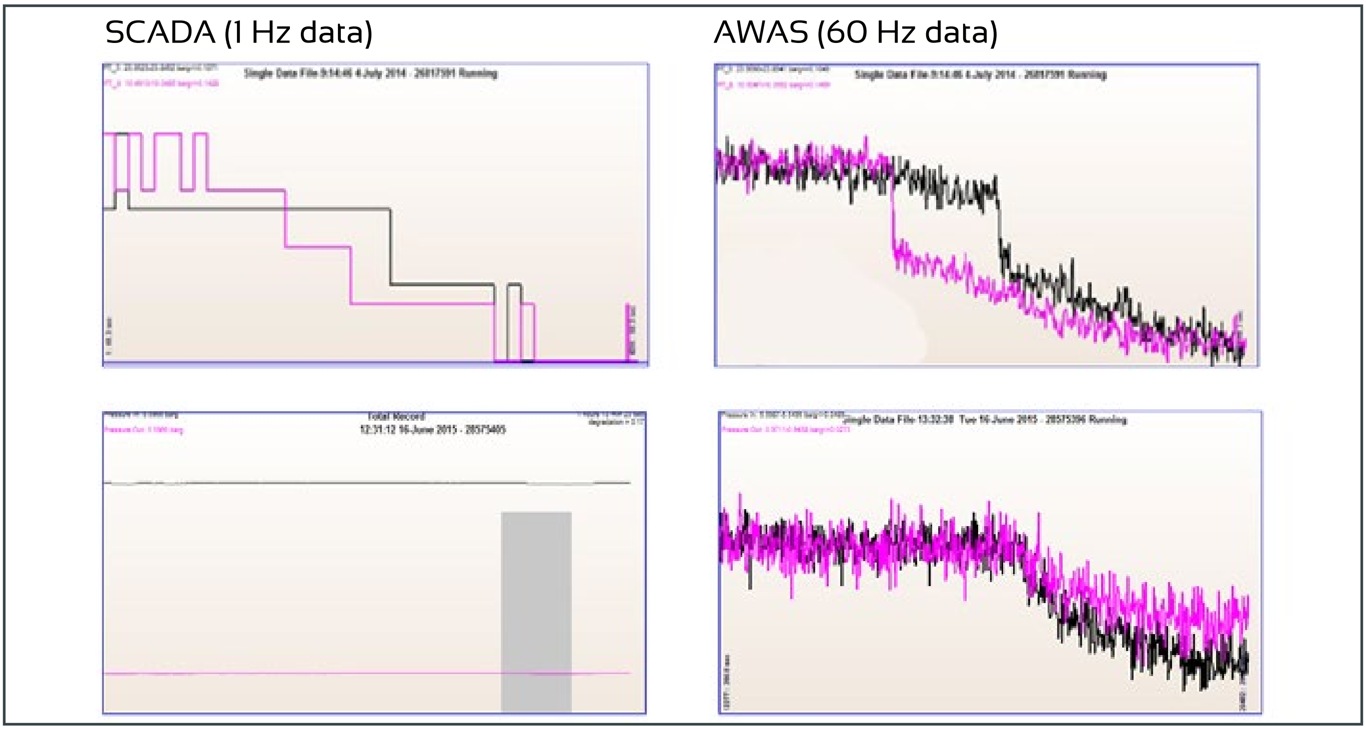

Figure 1: The advantage of higher acquisition data (60 Hz) compared to SCADA data (1 Hz)

neous leaks if the pressure drop isn't large enough, slack is present, or the pressure wave must travel a significant distance to be seen by a pressure sensor.

The solution to improving a negative pressure wave system has therefore been to focus on the ability to install additional pressure sensors along the pipeline, reducing the distance the negative pressure wave is required to travel. This has not always been possible due to the lack of available existing tapping locations and pipeline operators not wanting to modify the pipeline with additional tapping points.

To counter this, Atmos has developed a non-intrusive technology called "Atmos Eclipse". Atmos Eclipse is a self-contained, non-intrusive instrument unit that acquires pressure, flow and temperature data. All communication and data collection are completed within the unit meaning no cabinet space is required. The device can work with TCP/IP, 3/4G VPNs and line of sight radio link.

The device is ATEX Zone 1 certified and can detect pressure changes down to 10- 15mBar. The device works on diameters from 4" to 24". The device can also be buried to a depth of 2 meters (IP68 rated) to prevent tampering from thieves. Atmos Eclipse can be powered by solar/wind power to allow equipment to be installed in remote locations. Atmos Eclipse allows instrumentation to be installed in locations that might have not been possible before which means pipeline distances between sensors can be reduced resulting in improved reliability, sensitivity, leak location and response time that a negative pressure wave system can provide.

Figure 2: Atmos Eclipse units installed on pipelines

Atmos Eclipse has been purchased more than 90 times in the last two years and is installed on pipelines in the UK, USA, Singapore and Belgium. Figure 2 provides images of the Eclipse unit and how it is installed on the pipeline. Figure 3 and 4 provides a screenshot of the data collected by the Eclipse unit. Figure 3 provides flow and pressure data and shows the pipeline going from steady state to shut-in and the Eclipse can be been seen detecting the changes in flow and pressure caused by this operational change. Figure 4 highlights the Atmos Eclipse units detecting a pressure drop caused by a leak on the pipeline.

As well as new hardware available to the negative pressure wave method, additional software modules have been developed to improve sensitivity during dynamic or steady-state conditions in the pipeline to help detect smaller leaks, slow opening theft events and leaks in challenging multiphase pipelines.

This module is known as "Nanowave". The software module requires sensors to be distributed evenly along the pipeline; for example, for a 100km section they would be spaced every 20-30km, but the software module can be used on shorter sections of pipelines if there are four distributed sensors placed such as along a pipeline crossing rivers which is less than 2km long. The module and configuration can also be used to provide leak detection for multiphase pipelines. The Nanowave module has been designed to detect leaks that are less than 0.3% of the nominal flow.
The advantage of the module is the cross-checking of sensors with longer filters to look for small changes of

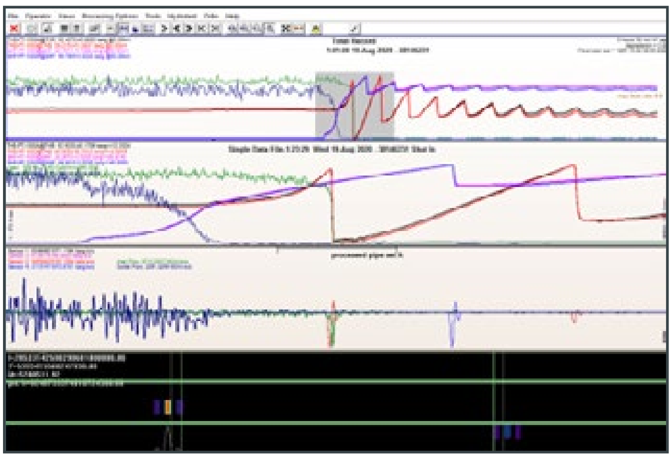

Figure 3: Atmos Eclipse unit data from a pipeline section

Figure 4: a leak detected by two Atmos Eclipse units.

pressure associated with the presence of a leak or theft. This module is designed to detect smaller leaks only to maintain reliability.

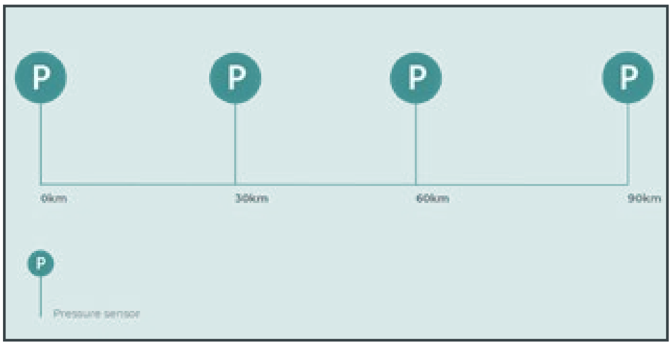

Figure 5: an example of the Nanowave configuration

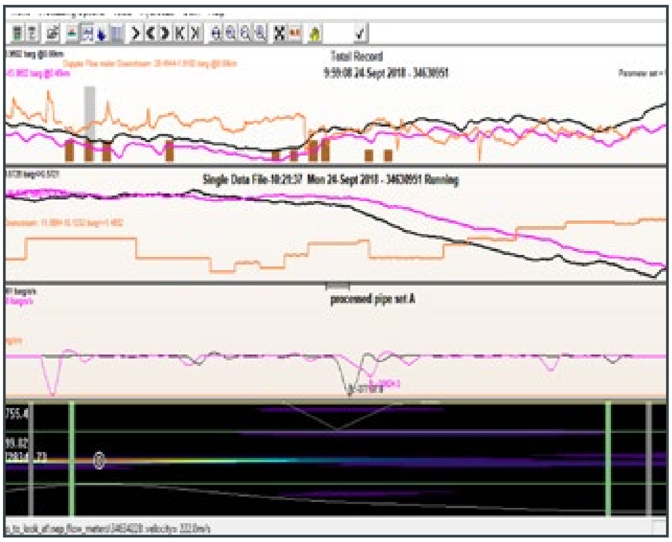

Figure 6: shows a leak detected by the Nanowave configuration

With these improvements to the negative pressure wave method (Atmos Wave) Atmos has been awarded the Queen's Award for Enterprise: Innovation 2020. The awards celebrate the success of exciting and innovative businesses that are leading the way with pioneering products or services.

3. THEFT DETECTION

Pipeline theft has seen a dramatic increase all around the world since 2013 and leak detection systems have been improved to meet this new challenge. Atmos has combined online leak detection systems such as Atmos Pipe and Atmos Wave Flow with offline analysis called "Theft Net". Experienced engineers trained in the latest theft detection techniques analyze the data in greater detail to locate the theft site within meters. The human element adds superior accuracy while maintaining highly sensitive theft detection without the distraction of false alarms. The advantage of this combined with an online leak detection system is smaller theft events less than 0.5% of the nominal flow can be detected and located.

Atmos has had lots of success over the world with theft detection, countries such as the UK and Costa Rica have benefited from utilizing Atmos Technology. The technology has acted as a deterrent in the UK as the systems will detect and locate the tapping very quickly making any theft operation uneconomical. Figure 7 provides a breakdown of the success Atmos has had around the world.

4. GRAPHICAL USER INTERFACES

As well as improving performance and reliability, it is important to improve how pipeline operators interact with the leak detection system. New improvements allow leak

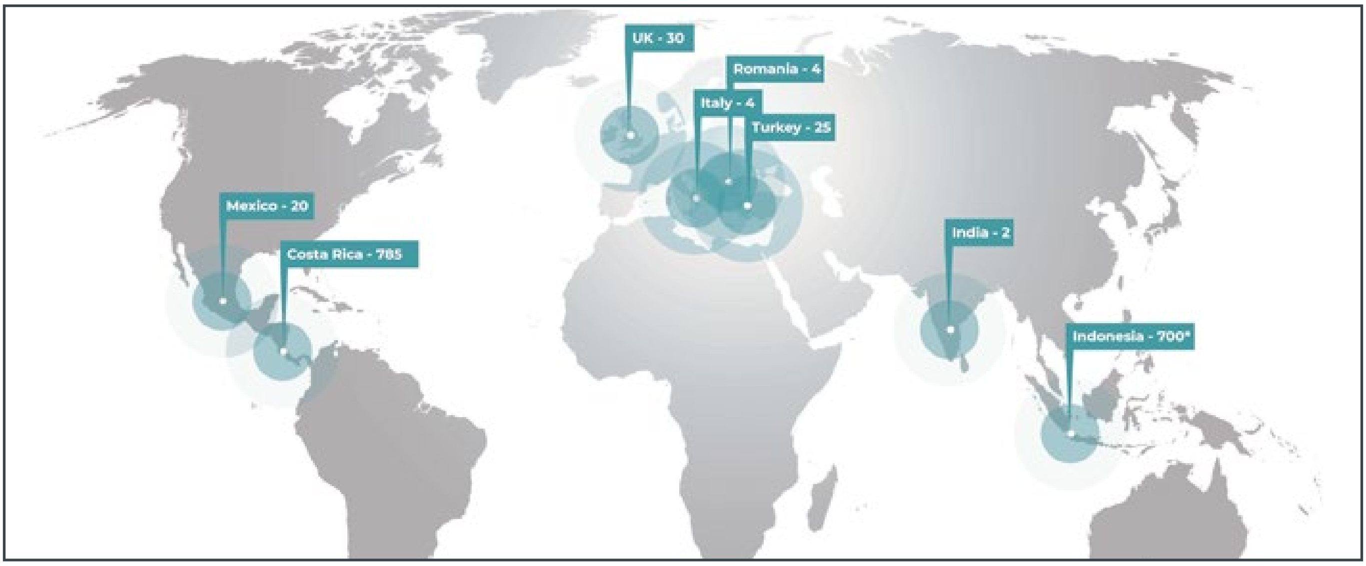

Figure 7: Detected and located thefts around the world
Helped a company in Indonesia dramatically reduce their theft problem from over 700 tapping points in 2013 to less than 10 tapping points in 2018 through a combination of technologies.

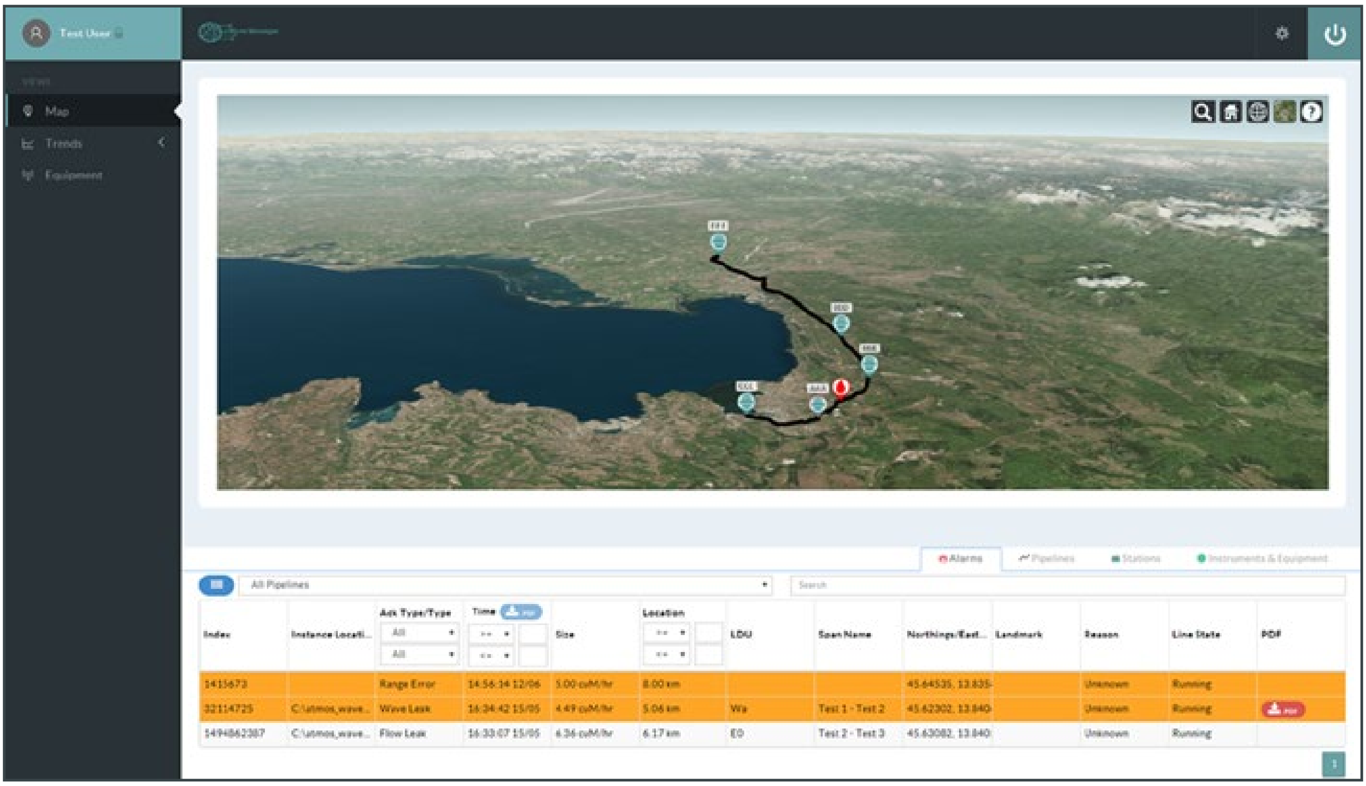

Figure 8: shows the Atmos Web GUI interface

detection systems to be presented through the internet and provide multiple users with secure logins using VPN connections to increase cybersecurity standards and reduce the risk of cyber-attacks.

The use of web graphical user interfaces (GUIs) means that you can provide access to the leak detection system to more people than just the control room operators of the pipeline resulting in a lower chance of leak alarms being missed or ignored in some cases. Other improvements include email and SMS leak alarms.

5. CONCLUSIONS

This paper shows that Atmos has identified several key areas that required improvement and has provided clear solutions to these areas. Leak detection systems will continuously need to be improved to provide better sensitivity, leak location accuracy, response time, reliability, usability and simplifying the installation process.

The ultimate goal of the pipeline industry is zero release of the product, with the ability to continually identify gaps in the technology, process and procedure. This is an aim we can all work towards.

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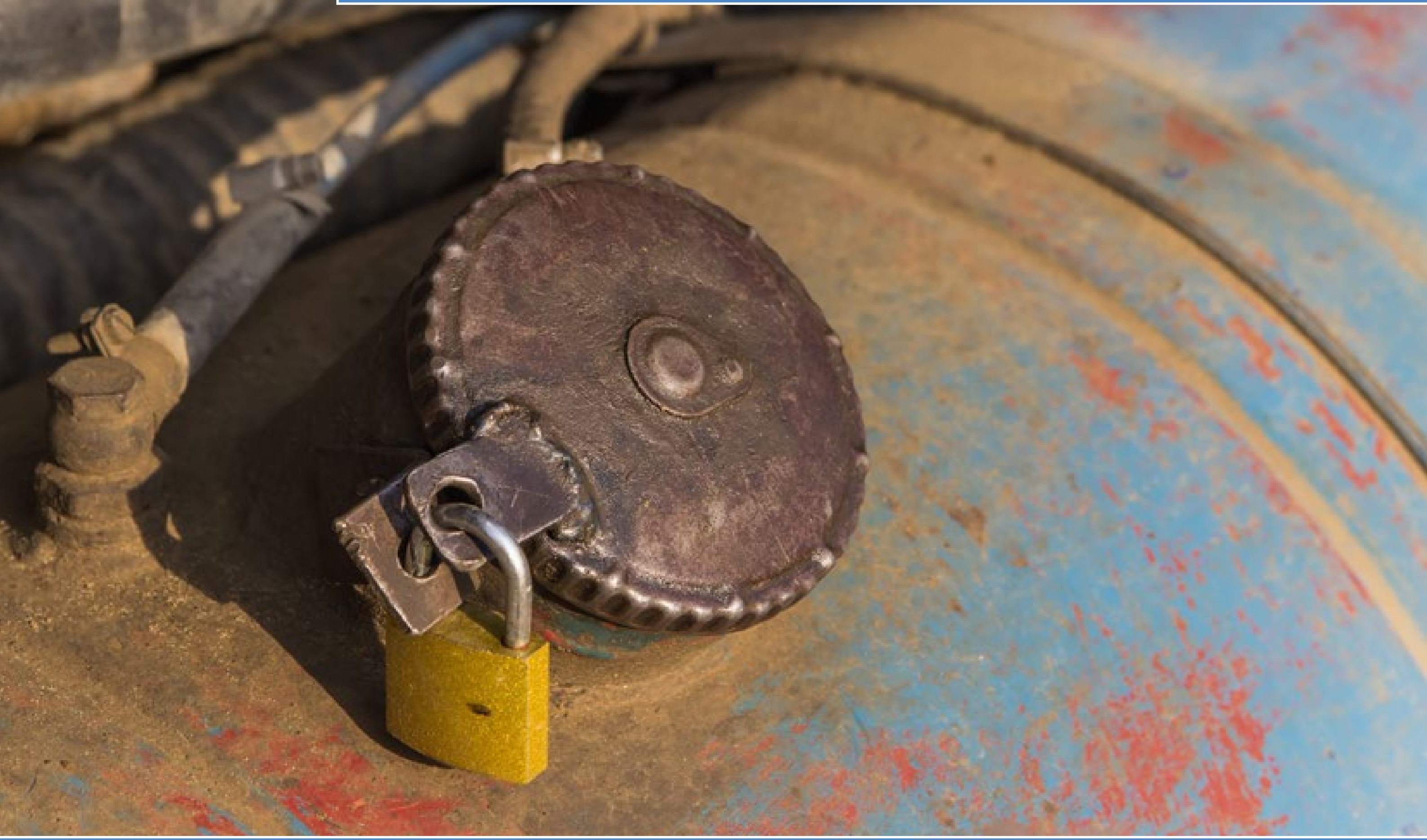
Detecting Illegal Tappings – A Research Case Study



Rene Landstorfer > Gottsberg Leak Detection

Abstract

Illegal hot tapping and product theft is a problem for pipeline operators all over the world.

As criminals use a wide range of different installations and are in many cases able to adopt their ways of siphoning and stealing to the pipeline conditions a research project had been started by GLD, together with another service company and two pipeline operators.

The aim was to simulate different siphoning possibilities along a line. Some of which had been copied from real ones detected at real theft locations and some had been set up by the operators in a way to avoid being detected.

They all had different set ups and the leak detection personal was not aware of locations and what kind of leaks had been prepared.

As in most cases hoses are attached to the hot tapping spot, some of the prepared leaks had them connected as well. Different length and diameters of the hoses had been used and also different valves at the outlets. The amount of siphoned medium was changing from location to location.

The article will cover the test set ups as well as the results of the leak detection run. It will show different leak signatures in the data related to the several test settings and gives an outlook on the abilities of the system.

All over the world, pipeline operators and oil companies are facing the problem of illegal tapings in their lines where product is stolen.

In some regions it is an increasing challenge, not only but also due to the current Corona crisis which costs a lot of jobs and pushed people into illegality. Additionally other crimes like robbery or burglary go down by numbers because people stay at home and do not go out on the streets as often as they used to. That brings some of the criminals to look for other ways to generate money.

On the other hand, in Europe the cases of product theft are going down due to the awareness of operators faced with this serious new threat. They reacted promptly, enhancing surveillance, improving leak detection system capabilities and increasing awareness of the problem with own staff, contractors and law enforcement authorities. Therefore since a peak in 2015 the numbers are going down significantly although the problem is far away from being solved. (Figure 1)

There are a lot of different technical options to address the issue. One of them is using leak detection pigs that are running inside of the line and are able to detect even the smallest product losses by means of acoustic data evaluation. Drawback of this option is that the tool needs to pass the point of illegal tapping while product is siphoned from the line. But as the criminals are quickly reacting to the efforts the pipeline operators are taking to catch them, this technology can find even the smallest amounts of product loss you could not find with other technologies.

The tools are running through the line, propelled by the flow during absolut normal operation and record all noises in the line. After processing the data the analysis starts and leaks can clearly be identified and distinguished from all other noises. Also a precise location with an accuracy of 1-5 m can be done within the first run and without any external tools needed.

Besides some other series of tests performed for that problem with customers and with different test setups we wanted to do some experimental runs in real pipelines. Together with the service company Integ from Slovakia who is also our representative for that region we could gain the pipeline operator Slovnaft to provide a line and test setups for our trial.

A 100 km Diesel line was chosen where 3 reproductions of different illegal tapping installations had been fitted to the line. In close cooperation all three partners had been working together for planning and execution. We had not been informed about the number of installations, the precise setup or location and the aim was to test the abilities of the leak detection tools.

The leakages / tapping spots had been installed in different ways that had been found in illegal theft points along the lines in the past. In all three cases valves hat been attached to the line and a hole had been drilled into the pipe wall. Then different fittings had been used which consisted of different smaller pipes and valves mounted behind the valve on the line. Two of the test setups also had a hose mounted which is a pretty common way to get the stolen product away from the line to a place where it can be stored or loaded for transportation. This helps them to hide far away from the line and helps to use the siphoning option for as long as possible.

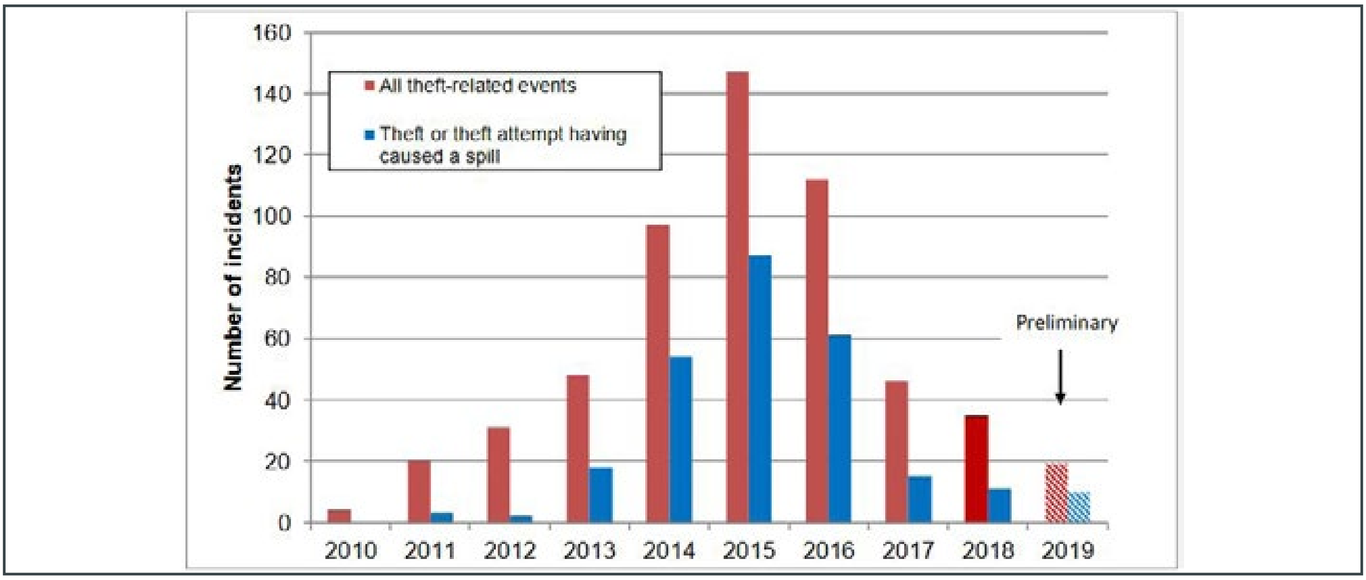


Figure 1 (Source: Concawe report)

In the past, GOTTSBERG Leak Detection has detected illegal tapings with hoses installed that had been up to 600 m long leading to a place in the wood far away from the actual line.

For the trial a GLD 202 leak detector with standard configuration had been used. (Figure 2) The tool is working on an acoustic basis, recording all noises during the pipeline run. The sound data is processed and a frequency analysis is performed to make statements about the origin of a signal.

In leak cases it would be expected to find clear high frequency signals between 5 and 50 kHz that are generated by cavitation occurring at the leak by pressurized liquid expanding to the outside of the line. These signals do not contain big amounts of frequencies in the areas below 2 kHz and also have a very unique signal geometry that helps with verification. Frequencies can slightly change due to various factors like Leak geometry, Pressure, medium or also the setup of installation behind the actual outlet at the line.

During the run the tool had been tracked to operate the artificial leakages at the time the tool passed them. The chassis for the electronics had been slightly modified to suit for that special pipeline and guarantee a safe and quiet locomotion for best run results.

Figure 2: GLD 202 leak detector

Figure 3: Leakage 1 setup

The different setups had been the following:

Sample through fully opened sampling branch DN80 and ball valve DN80. Leak simulated via 2m long pipe DN50 mounted to the DN80 valve with a DN15 valve mounted on the other end where the leak flow was controlled, leak flow: 1,38 m3/hr, 16,7 l/min It has clearly been identified within the run. Very distinct leak signal that could easily be detected even in the preliminary report.

With accumulated frequencies around 10, 30 and 40 kHz and also a very distinct signal geometry of the noise signal as well as the frequencies, the leak could be verified. Also the overall loudness and the clear signal to noise ration lead to the leak alarm.The location accuracy (picture x) was around +/- 5 m. The installation was placed in the small valve station right next to the located position of the tool.

Leak simulated via newly welded branch DN25, with ball valve DN25 and drilled with a 6 mm drill to the main pipeline. Intention was to simulate a crack in the pipeline, drilling stopped as soon as high frequency sound occured. Leak flow reduction done via ball valve DN25 partly opened, leak flow: 0,57 m3/hr, 9,5 l/min

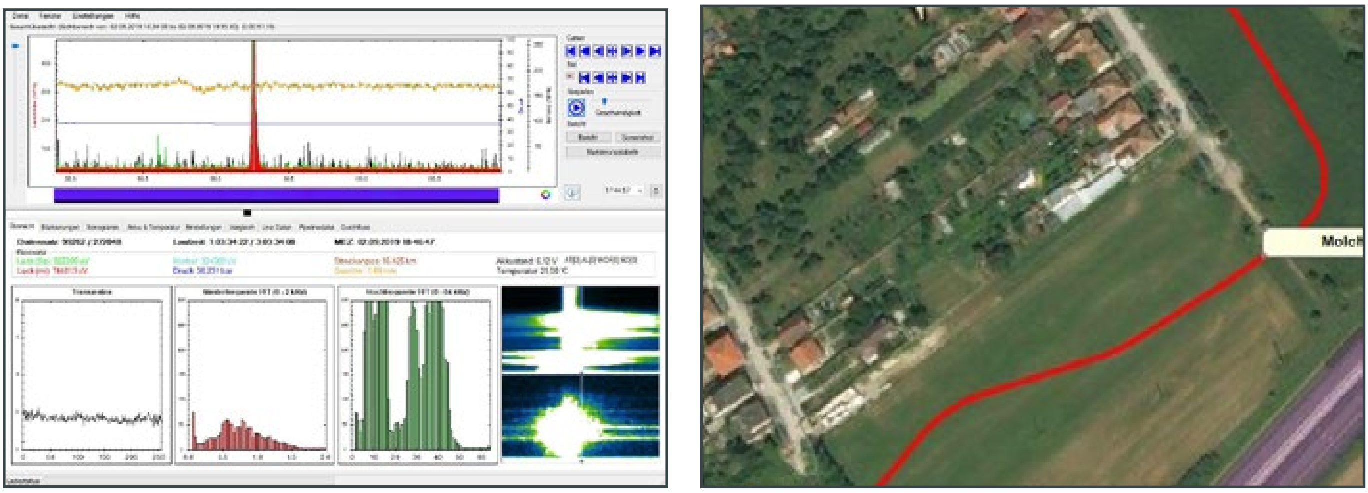


Figure 4: Leakage 1 run results

Figure 5: Leakage 2 setup

Clear leak signal that could be detected and located right after the run within the first on site data evaluation.

Again the leak could be verified by sound frequencies that compared to leak one have shifted a little bit to lower frequencies around 10 to 20 kHz and with lower amounts at the higher ranges. Additional verification could be done through signal geometry. Location accuracy was a few meters with the construction pit dug just in front of the station displayed in the GIS. Leak simulated via newly welded branch DN25, with ball valve DN25 and drilled with 6 mm drill to the main pipeline. Additional pressure hose DN25 ca 20m long with sampling set up consisting of DN50 pipe 2m long with DN15 valve at its end used to regulate the leak flow. leak flow: 1,38 m3/hr, 23,0 l/min.

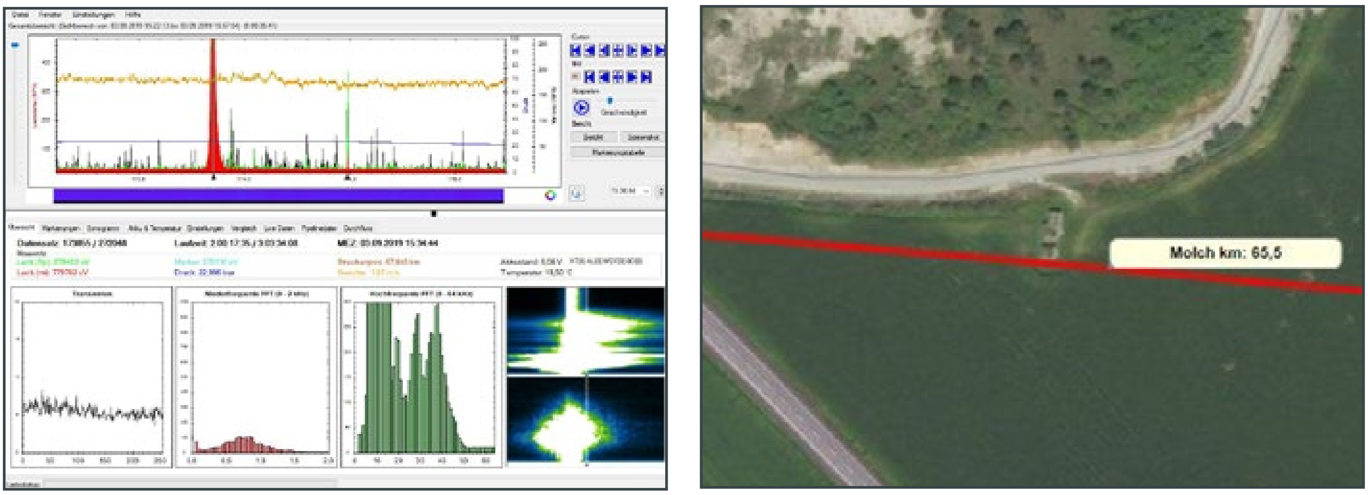


Figure 6: Leakage 2 run results

Figure 7: Leakage 3 setup

Compared to the two other leaks this one was not as distinct. It could not be detected through the first data evaluation on site and needed a deeper data analysis performed for the final report. The overall loudness of the signal is way more quiet which comes from the much lower pressure of only 9 bar compared to 23 and 36 bar at the other installations. Nevertheless it was possible to identify the noise as a leak that was also located at the right place with a high accuracy. Again there was a shift in frequencies to lower levels around 10 kHz with only one major peak besides at 25 kHz. Still the absence of bigger amounts of noise in other frequency ranges and the clear signal geometry of the sound gave the ability to flawlessly state a leak here.

All of the three leakages could clearly be detected with the leak detection tools and we had a location accuracy of around +/- 5 m within the first run. With some filter algorithm and frequency analysis it is possible to make precise statements about the origin of a noise recorded during the run. That not only helps to reliably avoid false alarms but also to know what is happening in the line during every minute of the run. In the current cases all tapings had clearly been identified as product leaking out of the line. Only difference from one setup to the others was that depending on the installation and the kind of turbulent flow at the extraction point, different frequencies had been produced. Also signal geometry changed with the different fittings. Nevertheless they all had been clear leak signals and could easily be distinguished to other noises in the line.

In the past Gottsberg Leak Detection has found many locations where criminals had been stealing product. In many cases hoses had been used and even been buried to avoid causing any attention. Also the treatment of the pipe wall differs a lot from big holes of 2 cm to plenty of small holes of less than 5 mm to avoid being detected with intelligent pigging by staying below the threshold of these tools. In some cases also different holes had been hot tapped and with the siphoning spots had then been connected to one hose for loading the stolen product. (Figures 9 and 10)

Figure 9: small holes of less than 5 mm

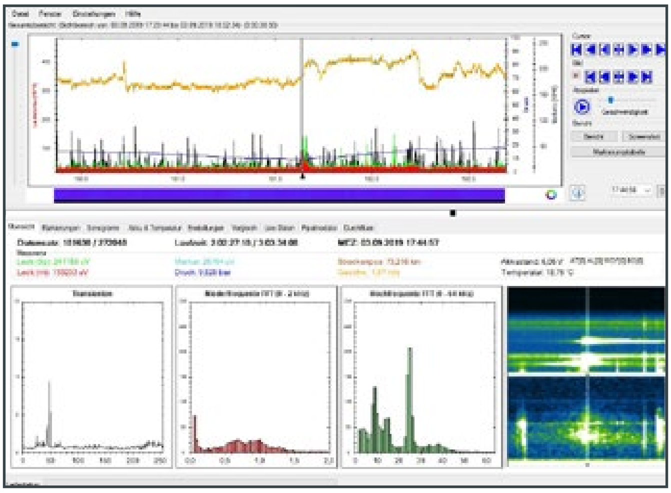


Figure 8: Leakage 3 run results

Figure 10: big hole of 2 cm

Concluding it should be mentioned that there still isn't the one for all technology to detect illegal tapings and product theft. Especially because the criminals are in many cases very sophisticated and can relatively quickly react on the counteractive measures of the operators by adapting their installations. Another big issue still is that they are very well informed about the pipeline operation. In many cases they already know when and how the operator reacts to their attacks and can then respond accordingly. It is already known that the criminals have connections to the inside of the operating company in many cases. For example they know exactly when the batch operation of the line provides diesel and at which time it does not make sense to steal because for example crude oil is transported. That all doesn't make it easy to find the right solution to address the problem and in the end it probably leads to a solution of combining different technologies and approaches and of course to sensitize the own personnel as well as the public to be attentive towards these offenses.

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GOTTSBERG LEAK DETECTION

Novel Classification Of Leak Detection And Third-Party Intrusion Enabling Best-In-Class False Alarm Rate

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Abstract

We demonstrate PrismaFlowTM's best in class events detection and classification capabilities accompanied by negligible False Alarm Rate (FAR). A 35 km long pre-deployed optical cable inside a conduit was used as the sensor. Originally deployed for communication purposes, the optical cable, running along the infrastructure, was placed along highly noisy environment such as highways, rural roads, railway, and through farm fields.

1. INTRODUCTION

In recent years there has been a growing interest in distributed fiber-optic sensing for monitoring oil and gas pipelines. This innovative technology, based on the translation of the back-scattered signal of a light pulse that propagates along the optical fiber to acoustic signals [1], is a cost-effective solution for pipeline monitoring, especially when installed on infrastructure with pre-deployed optical fiber communication network. It has a relatively short ramp-up time and can cover long pipelines, in a distributed manner, with a small number of optical interrogator units. Pipeline leakage typically generates both pipeline mechanical vibrations and acoustic signals, originate from the interaction between the leaking substance and the soil surrounding the pipeline. Both effects, the mechanical vibrations and the leak induced acoustic signals, can be sensed by an adjacent optical fiber cable. Digging activity, that might threaten the pipeline integrity, creates strong seismic signals in the ground, that are readily detected by sensitive optical interrogators.

However, in a real-life scenario, there are many other sources of these types of signals along the pipeline, such as traffic, farming, and construction as a few examples. The signals from these sources, that are also detected by the optical interrogator, must be filtered out by the system, and not lead to alerts.

In fact, the high False Alarm Rate (FAR) or Nuisance Alarm Rate (NAR) of fiber-optic sensing systems is the limiting factor of the existing technology and is mainly originating from low data quality that leads to insufficient classification capabilities.

Prisma Photonics pipeline monitoring system, Prisma-Flow™, uses its novel Hyper-Scan Fiber-Sensing™ technology [2,3], an ultra-sensitive sensing capability to generate data with a very high signal to noise ratio (SNR), even when using pre-deployed fiber-optic cables (fiber optic cables in conduit experience a 20dB of sensing signal attenuation [4]). Advanced machine learning capabilities harnessed together with the high data SNR enables extraction of a large set of features that assist, for example, in differentiating background noises from digging activities that endanger the pipeline. These features enable the construction of novel real-time algorithms for classification of different activities, leading to a dramatic decrease in the false and nuisance alarm rate.

2. METHODS

In Figure 1 we compare the seismic signal originating from four human steps located at a distance of 30 meters from a buried optical fiber. We compare signals obtained by our system as would be seen by current fiber scan technology. Using typical Distributed Acoustic Sensing (DAS) is shown in Figure 1a, the steps are masked by the Rayleigh fading from a location 100 meters down the fiber. In comparison, in our Hyper-Scan™ data shown in Figure 1b, the steps are easily resolved. Moreover, there are important signal features such as linearity, and frequency content, that cannot be extracted from standard DAS data, and are of high importance for advanced classification algorithms implementation. Special attention should be given to the high background noise in km 10.37, detected by standard DAS (Figure 1a), and leading to a false alarm. In Figure 1b,

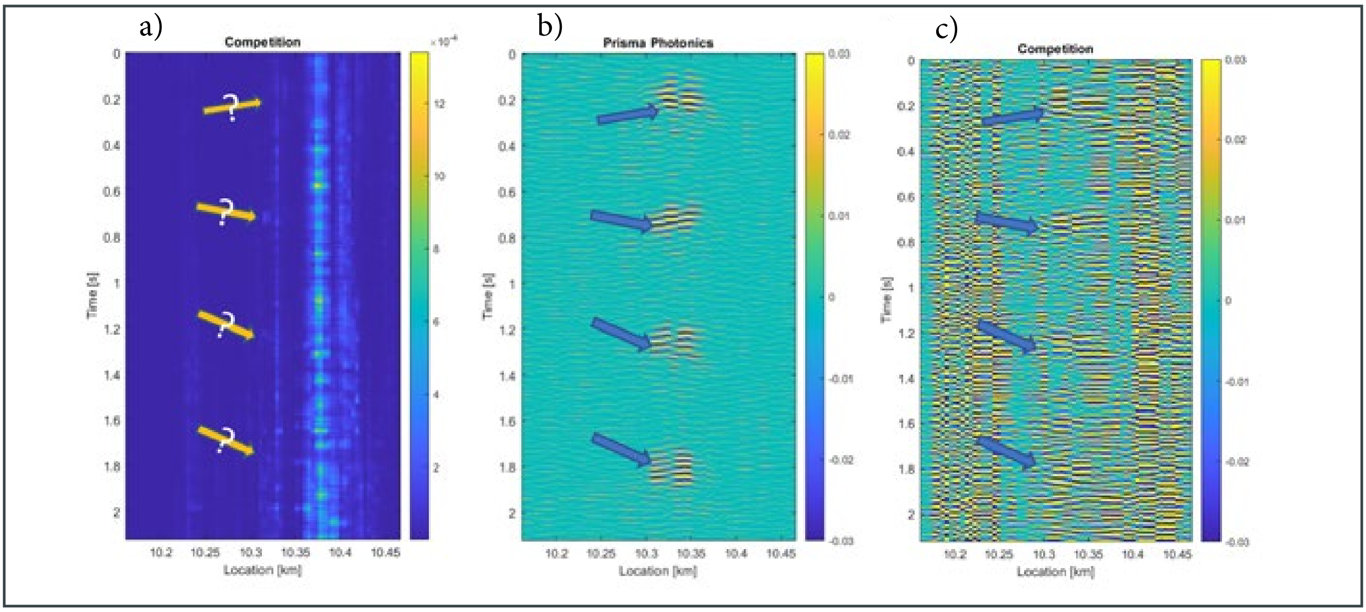

Figure 1: The data obtained by typical DAS technologies and Prisma's Hyper-Scan technology (Center). The same data was taken with our system and then modified to simulate the alternative measurement schemes: (a) Typical DAS, (b) Hyper-Scan™, and (c) A linear phase change method. All graphs are of the same 4 steps taken at a distance of ~30 meters from a buried fiber, approximately 10km down the fiber. Arrows mark the location, and time of each of the steps.

this background noise is completely filtered out by our Hyper-Scan™ technology. There are other methods for extracting the mentioned above advanced signal features , however, in the presence of noise, or weak signals these methods suffer from significant noise and signal quality reduction as presented in Figure 1c. Needless to say, the quality of those data samples can lead to a very high system FAR.

In pipeline third party intrusion (TPI) detection, the interest is in signals originating from locations closer to the monitored asset. The challenge that is faced in these situations is less one of threat detection, but rather of being able to differentiate the threats from many background signals, originating from permitted activities in the vicinity of the pipeline, such as trains, vehicles, or agriculture.

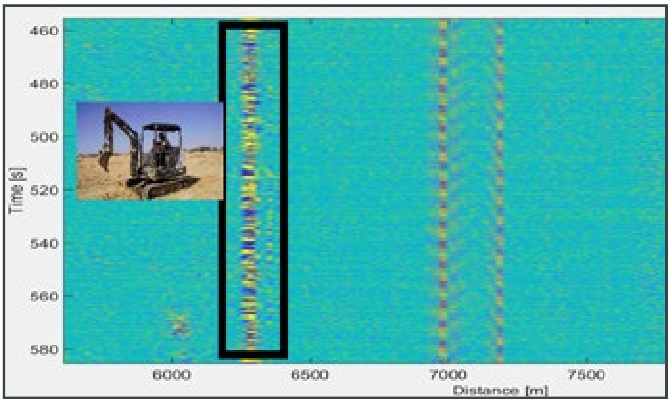

Figure 2: A signal of a mechanical digger, digging 10 meters from pipeline (@6.3km). The water irrigation pump station (@7km), is clearly distinguished, by the regular periodic signal.

We harness the high SNR and the richness of the data obtained by our Hyper-Scan™ technology to extract differentiating features, that would otherwise be masked by noise. These features are then used to distinguish the threatening activities from the permitted ones. As an example, we show in Figure 2 the signal obtained by a mechanical digger digging 10 meters away from the pipeline. An example of human digging using a hoe, is presented in Figure 3.

In Figure 4 we demonstrate the advantage of Hyper-Scan™ technology in feature extraction. In the figure, we see the signal of a digger 20 meters from the pipeline. While the digger can be seen by both standard and Hyper-Scan™ technologies, using the Hyper-Scan™ technology, it is possible to discern the individual scrapes of the digger, the signal of the digger motor, and thus other features such as dropping the dirt from the bucket. Data obtained from numerous recordings of such activities was used to extract features that differentiate diggers from other vehicles and background signals (i.e. defining a digger signature) and build an automatic classifier that detects only diggers.

3. RESULTS

In order to demonstrate the classification capabilities of our system, and the ability to distinguish between permitted background activities and TPI threats, we tested our algorithms on a 35 km long segment of a pre-deployed optical telecom cable. The cable is buried in a conduit along a gas pipeline running along various landscapes, including both urban areas and agricultural fields. The pipeline runs along railways, highways, construction sites, and cities.

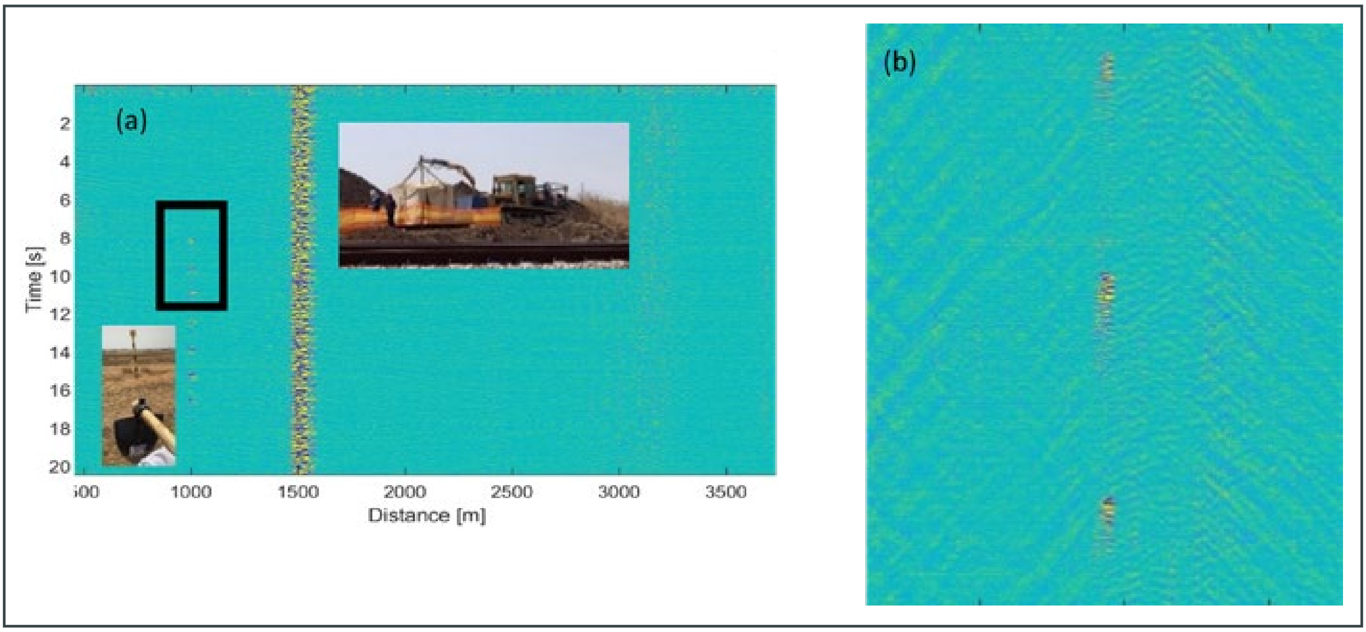

Figure 3: A signal of human hoe digging at 10 meters from the pipeline. In (a) the hoe digging is performed 500 m from a construction site (observable at 1.5km). (b) is a closeup of a few of the hoe hits (Black square in a).

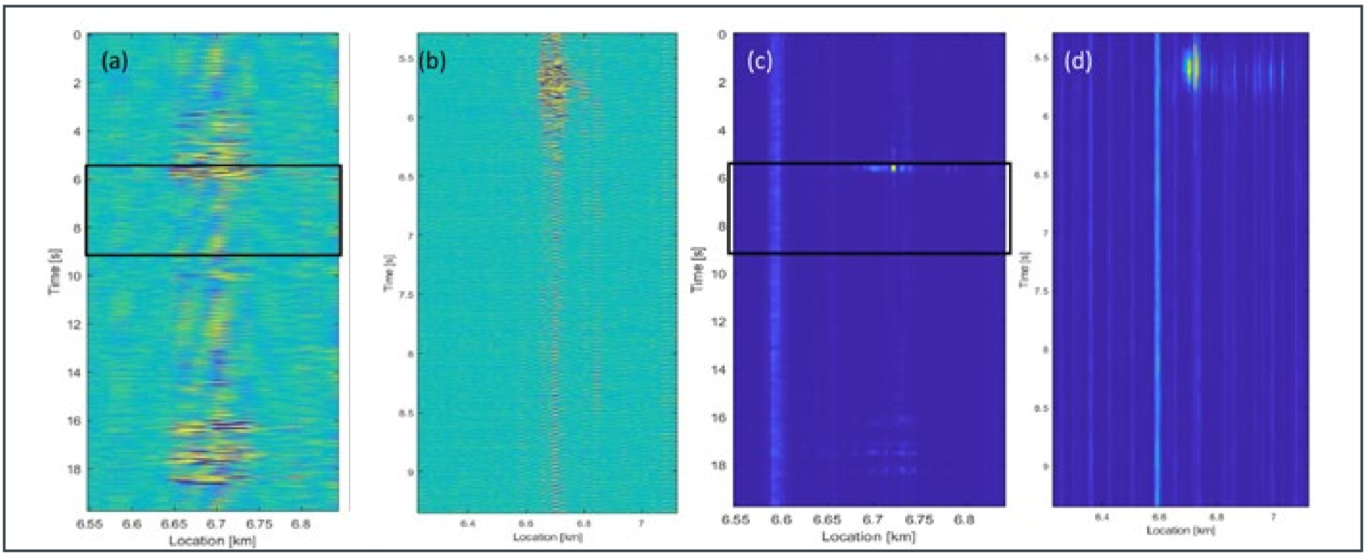

Figure 4: A closeup of ~20 seconds of digging. Using Hyper-Scan™ (a) and typical DAS (c). (b) and (d) are 4 second closeups of the black boxes in (a) and (c), respectively. At second 4-5, the digger scraped the ground. A second scrape started at second 16. Using typical DAS the scraping is somewhat visible, but system noises are also present, which in fact are more significant than the digging. In the Hyper-Scan™ image (a), both the scraping and the motor signal in between are clearly visible. Aliasing and sampling issues in (a) are removed in the closeup, which displays both the scraping itself and the motor periodic signal.

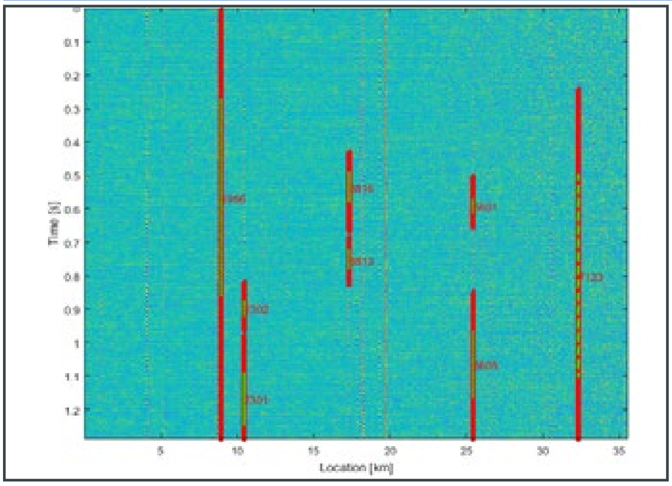

Figure 5: A 1-second data strip of a 35km long monitored pipeline. The monitoring fiber is a single fiber out of the many exist in the pre-deployed fiber cable, laid in a duct buried along the pipeline. At any given moment there are several activities detected and classified by the system.

In Figure 6 we present a 24hr summary of the output of our algorithm. During 24 hours of a typical day there were 92,514 activities measured and classified not to be a digging threat.

In addition to detecting threats to the pipeline, the high sensitivity of the system can be used as well to detect and classify very small leaks from the pipe itself. In Figure 7 we present spectrogram figures of the signal obtained from a fiber buried 0.5 meters from a pipeline gas leak simulation setup. PrismaFlowTM is capable of detecting leaks as low as 200 standard liters per minute (SLPM) through a 4mm orifice diameter. While the detected acoustic signal depends on the rate of the leak and not on the percentage of the gas flow, this corresponds to a 0.002% leak for a typical flow of 500 MMcf/d, an unmatched system sensitivity leading to industry world record.

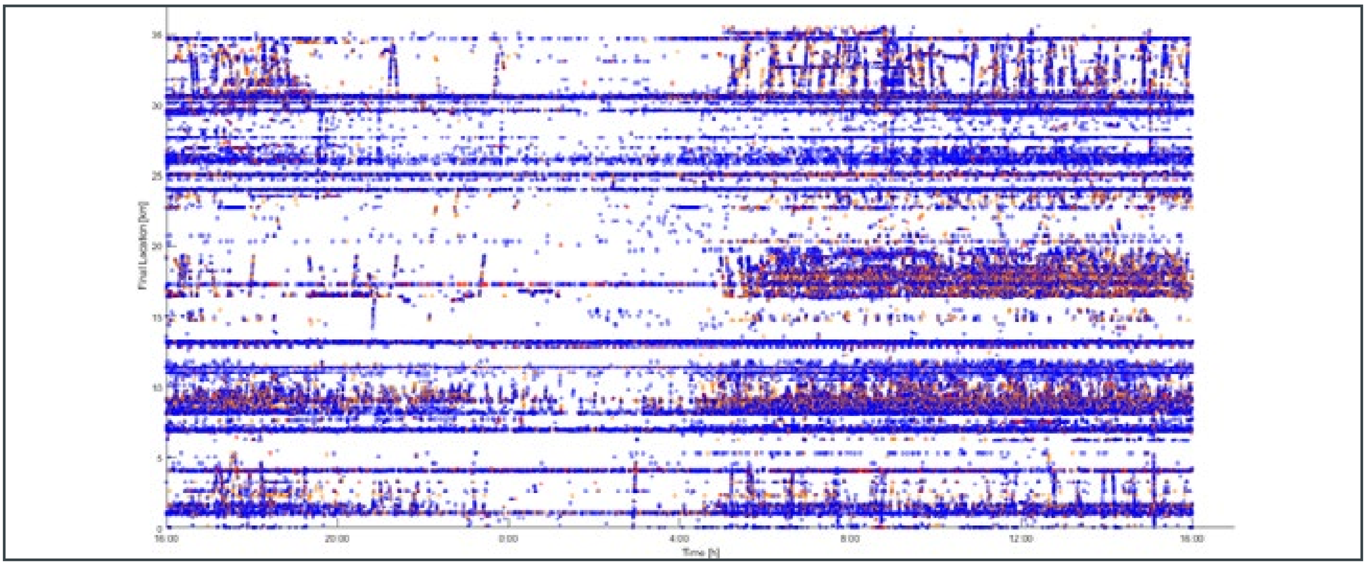

Figure 6: The output of the algorithm for a typical period of 24 hours. 92,514 events were recorded and classified. The false alarm rate was 0, i.e. no activities were classified as digging activity. During daytime there is more activity than during the night. Segments near highways, and train tracks are also visible, along with fields, where there was agricultural activity.

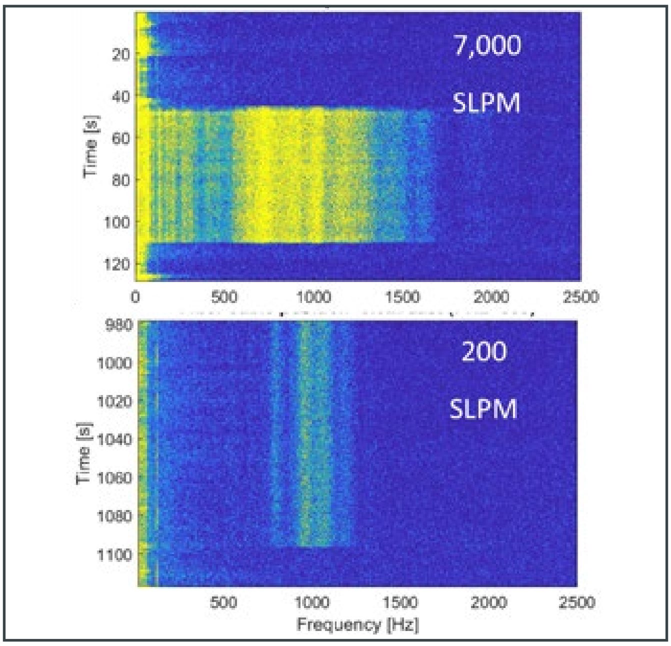

Figure 7: A spectrogram of the signal recorded by a standard telecom cable buried in a conduit 0.5 m from an initiated Gas leak. Two Gas leaks are shown: Top: A 7000 SLPM leak from an orifice with a 12 mm diameter, corresponding to 0.1% flow. Bottom: 200 SLPM leak from an orifice with a 4 mm diameter, corresponding to 0.002% of a 500MMcf/d flow.

In Figure 8 we present a spectrogram figures of the signal from a pipeline liquid leak simulation setup. The detected leak is as low as 20 liters per minute (LPM) this corresponds to a 0.02% leak for a typical liquid flow of 1,000,000 B/D.

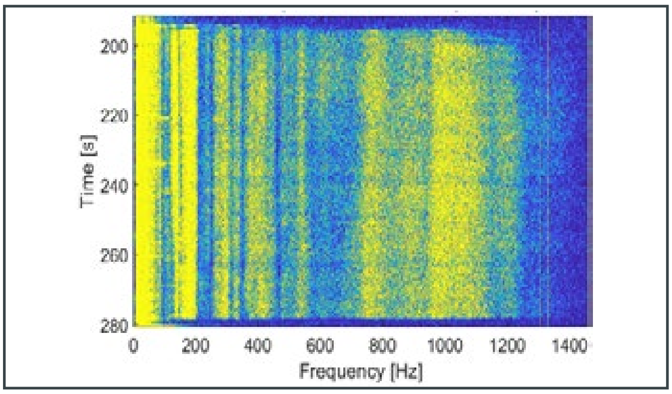

Figure 8: A spectrogram of the signal recorded by a standard telecom cable buried in a conduit 0.5 m from an initiated liquid leak. A 20 LPM leak, corresponding to 0.02% flow of typical liquid flow of 1,000,000 B/D.

4. CONCLUSION

We have demonstrated PrismaFlowTM's high signal-to-noise ratio, which enables superior detection rates and sensitivity. This enables use of pre-deployed non-optimal optical fibers for ultra-sensitive fiber optic sensing. In addition, it gives flexibility in the distance of cable burial location from the pipe itself. Moreover, it enables measurement with high detail content. This content is used for feature extraction, which leads to excellent classification capabilities. We demonstrated a negligible false alarm rate in a 35 km long pre-deployed optical cable inside a conduit, running along infrastructure placed along highly noisy environments such as highways, rural roads, railway, and under agricultural fields. In addition, we demonstrated unprecedented gas leak detection capabilities of as low as 200 SLPM.

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SOLARES

Stress Corrosion Cracking (SCC) Susceptibility Screening Enhancement

Mohammed Al-Rabeeah, Nader A. Al-Otaibi, Nauman Tehsin > Saudi Arabian Oil Company

Abstract

Stress Corrosion Cracking (SCC) is a well- known threat to the integrity of oil and gas pipelines. SCC is a damage mechanism that typically results in axial cracks on pipelines due to simultaneous action of tensile stress, potent environment (soil, coating, electrolyte etc.), and the pipeline material (poor microstructure). Small cracks are initially formed around the corroded area (Initiation) which tend to coalesce under the combined impact of applied stresses (pipeline hoop stress), cyclic stresses (pressure cycling) and residual stresses (bends, change in direction, and point of inflection). SCC remains a significant issue largely because the industry's understanding of this phenomenon is still evolving and practical methods of addressing SCC are not as mature as methods for addressing other failure causes.

ASME B31.8S provides a basic framework for determining the SCC susceptible segments of buried pipelines. This framework is based on pipeline operating parameters, environment, age and condition. The variables considered in ASME

B31.8S were subjective in nature and do provide a detailed methodology of how to prioritize pipeline segments for their susceptibility to SCC and optimize the cost of Crack Detection In-Line- Inspection (CD ILI). Besides other variables, cyclic pressures variations are very critical to analyze the initiation of cracking on pipelines. The differential stresses produced in the pipeline as a result of pressure cycles are capable to initiate cracking in vintage pipelines even at relatively low amplitude.

Saudi Aramco studied the behavior of these cyclic stresses on their liquid pipelines and found that consistent cyclic pressure fluctuations of medium to low magnitude coupled with potent cracking environment and vintage pipe material may generate conditions that make the pipelines susceptible to SCC. This paper describes the enhanced SCC susceptibility criteria that was used by Saudi Aramco to optimize CD ILI inspection cost and effectively address the SCC threat on their pipelines.

1. INTRODUCTION

Pipeline stress-corrosion cracking (SCC) is an ongoing integrity concern and significant issue for oil and gas pipelines operation. SCC on buried pipelines results from simultaneous presence of tensile stress, a corrosive environment, and a material that is susceptible to SCC. ASME B31.8S provides a basic framework for determining the SCC susceptible segments of buried pipelines.

Saudi Aramco operates a combined pipeline network of more than 23,000 kilometers in length. A significant number of Saudi Aramco pipelines were built prior to 1980 with tape coating, thereby increasing the susceptibility to SCC. In Saudi Aramco pipeline network, SCC was found around 2005-2006. In period of 2008-2016 Saudi Aramco applied the ASME B31.8S for determine the SCC susceptibility criteria to manage and prioritize all SA pipelines. ASME B31.8S provides a basic framework for determining the SCC susceptible segments of buried pipelines. This framework is based on pipeline operating parameters, environment, age and condition. Based on that criteria, 109 Crack Detection (CD) In line Inspection (ILI) runs were conducted using Electromagnetic Acoustic Transducer (EMAT) and Ultrasonic Crack Detection (UTCD). As a result, 26 pipelines showed presence of SCC. These cracks were later verified through direct examination. Based on the number of confirmed pipelines with cracks verses the inspected pipelines, Saudi Aramco identified a high need to enhance the SCC susceptible criteria to be more practical and applicable to SA pipeline network. Therefore, a comprehensive study carried out at to enhance the SCC susceptibility criteria. The study consisted of three phases. Phase 1 involved developing a process to integrate existing literature and datasets, such as in-line inspection (ILI), field verification and geospatial data to assess the extent of the SCC threat. Phase 1 also involved the initial implementation of the developed process to a set of study pipelines. Phase 2 concentrated on developing an understanding the effectiveness of in-line inspection and hydrostatic pressure testing as mitigation against existing SCC and Phase 3 culminated in developing a framework for the continual improvement of SCC Management Plans based on the results of Phases 1 and 2. The three phases consisted of eight tasks, as shown below:

Phase 1. Establish a Baseline
- Collect and Align Data
- Evaluate In-line Inspection Accuracies
- Estimate True Defect Population

Phase 2. Estimate Mitigation Effectiveness
- Assess Effectiveness of In-Line Inspection Programs
- Assess Effectiveness of Hydrotest Programs

Phase 3. Develop Integrity Management Plans
- Develop SCC Management Plan for Study Pipelines
- Develop Generic SCC Management Plan

The study pipelines include hazardous liquid, natural gas, condensate, and NGLs. Diameters range from 12 to 48 inches. Most are coated with tape. All are over 30 years old. 26 pipelines with SCC and 17 pipelines without SCC, as shown in Table 1.

	NO CRACKING FOUND		CRACKING FOUND	
PREDOMINANT OD, IN	*COUNT*	*LENGTH, KM*	*COUNT*	*LENGTH, KM*
12			2	122.9
14			1	63.5
16			1	7.3
20	1	44.6	1	106.0
24	3	49.7	6	75.3
26	1	14.7		
28			1	56.0
30	4	77.6	5	222.6
32	1	46.3		
34	1	76.2		
36	2	121.4	1	44.0
38			2	132.0
40	1	96.0	3	232.8
42			1	62.0
46	3	224.3	1	49.8
48			1	86.0
TOTAL	17	750.8	26	1260.2

Table 1: 26 Study Pipelines with Cracking and 17 Study Pipelines without Cracking

2. SCC BACKGROUND

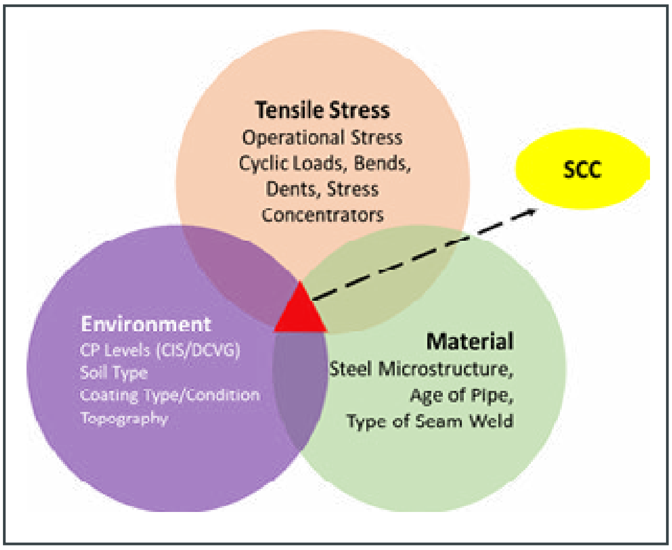

Figure 1: SCC Background

Stress Corrosion Cracking (SCC) is a well- known threat to the integrity of oil and gas pipelines. SCC is a damage mechanism that typically results in axial cracks on pipelines due to simultaneous action of tensile stress, potent environment (soil, coating, electrolyte etc.), and the pipeline material (poor microstructure). Small cracks are initially formed around the corroded area (Initiation) which tend to coalesce under the combined impact of applied stresses (pipeline hoop stress), cyclic stresses (pressure cycling) and residual stresses (bends, change in direction, and point of inflection). The coalescence process results in formation of large cracks also known as (crack colonies). The cracks propagate axially and radially under the action of poor environment (damaged coating, corrosive soil with electrolyte and insufficient CP to protect the external surface) and tensile stress (Growth). SCC remains a significant issue largely because the industry's understanding of this phenomenon is still evolving and practical methods of addressing SCC are not as mature as methods for addressing other failure causes.

3. GENERAL SCC SUSCEPTIBILITY CRITERIA (ASME B31.8)

SCC was found in Saudi Aramco pipeline network around 2006. Following this discovery of SCC, Saudi Aramco built on ASME B31.8S criteria for identifying SCC susceptible segments to prioritize its network to manage the utilization of the EMAT technology. The criteria were based on pipeline operating parameters, environment, age and condition. An Extensive Field Verification program was put in action that illustrated the capabilities of the EMAT ILI tools. Based on the ASME B31.8S criteria, 109 were selected for Crack Detection (CD) In line Inspection (ILI) in the period of 2009-2016. As a result, 26 pipelines only showed presence of SCC.

Based on the number of confirmed pipelines with cracks verses the inspected pipelines, Saudi Aramco identified a high need to enhance the SCC susceptible criteria to be more practical and applicable to SA pipeline network. This paper discusses in more detail how the Saudi Aramco enhanced the ASME B31.8S prioritization criteria. A statistical evaluation of the data compiled in the 1st phase of the comprehensive study was conducted along with the literature review. The Saudi Aramco used logistic regressions [1,2] to identify factors that increase or decrease the likelihood that cracking is present. The trends that were identified relate to coating type, pipe grade, pipeline age, diameter, thickness, metal loss, cathodic protection (CP) level, slope, and pipe type. The Saudi Aramco used the findings to profile crack susceptibility in the pipelines found with SCC and for the Saudi Aramco pipeline network as a whole to identify pipelines susceptible to cracking to include in the future ILI runs.

PHASE 1 ESTABLISH A BASELINE

The Saudi Aramco aligned a variety of data sets provided by Aramco against the centerline from the most recent in-line inspection (ILI) runs. The Saudi Aramco aligned multiple sets of ILI data by identifying girth welds within the datasets that match and then adjusting the locations of the features (rubber banding the data) based on their respective distances to those matched welds. Two alignment spreadsheets were prepared for each study pipeline. The overlay spreadsheets were designed to quickly identify changes, such as an increasing or decreasing number of ILI calls over time, and correlations, such as the presence of metal loss near creeks and river crossings. The data aligned for the first spreadsheet (ILI overlay spreadsheet) included:

- Elevation profile, locations of girth welds, casings, valves, sleeves, bends, and supports
- Cathodic protection readings
- ILI results from up to four of the most recent MFL, UT-wall, EMAT, UT-crack inspections (actual depths or depth classes for internal and external corrosion, mill related features, girth weld features, and crack-like features)

The second spreadsheet (the general overlay spreadsheet) prepared for each of the study pipelines includes only the most recent crack and metal loss inspections (up to two total), the other information summarized above, plus the following information:

- Pipe diameter, wall thickness, grade, and coating type
- MAOP, cyclic pressure severity
- Dig locations and dig summary information
- Field Verification Results (summaries of dig information)
- Topography information (locations of depressions, slopes, undulating areas, calculated from elevation profile)
- Available Field/Operational data (e.g., soil type, when available)

Figure 2 is an example of the first type of overlay spreadsheet (Figure 3 provides a legend), while Figure is an example of the second type. In the ILI overlay, the four in-line inspections included in the plot are results from a 2013 ultrasonic crack detection (UTCD) inspection in the top row, a 2014 MFL inspection in the second row, a 2011 ultrasonic wall thickness (UWD) inspection in the third row, and a 2008 corrosion detection pig (CDP) in the fourth row. The fifth row includes the elevation and cathodic protection data. The Saudi Aramco also created a dig summary spreadsheet that tabulates findings from the field and nondestructive testing (NDT) reports. Here, each entry in the spreadsheet lists the results from one set of NDT examinations in the field. The purpose of the dig summary spreadsheet was to provide data for statistical analyses. For this study, there were over 800 sets of NDT data relating ILI calls to field findings. The dig summary spreadsheet includes crack dimensions and locations as determined in the field and an assessment of whether the indications are likely SCC, possibly SCC, or not SCC. Where available, photographic evidence was used in this assessment; otherwise, the descriptions in the field reports were used.

In addition to the assessment of whether cracking was present, the types of information included in the dig summary spreadsheet from the field reports include:

- Line segment
- Weld identification number
- Item number (when multiple indications were found at the same location)
- Defect type, size, depth, length, and width, if given
- Measured wall thickness
- Coating type and condition
- Pipe type
- Repair method
- Field observations and remarks
- Excavation date
- Inspection type (e.g., MPI, UT, Phased Array)
- Source of information (document name)

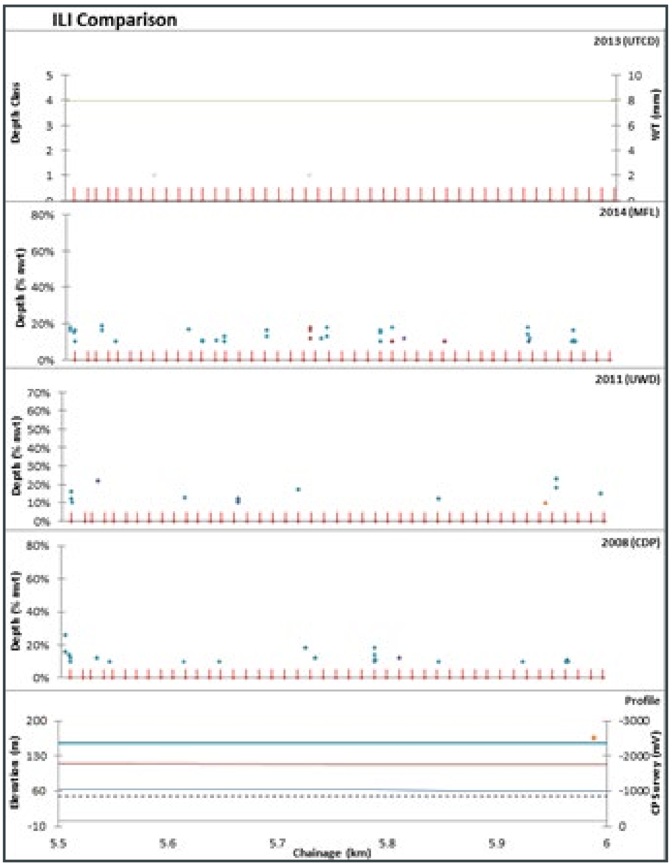

Figure 2: Example ILI Overlay Chart

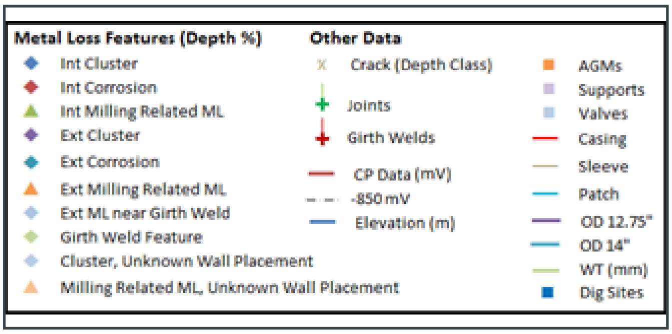

Figure 3: Overlay Chart Legend

The Saudi Aramco added information from the overlay spreadsheets into the dig summary spreadsheet. Additional information included:

- ILI results from each inspection for the pipe joint that was excavated, including but not limited to the number, types, and severities of reported ILI anomalies.
- Cathodic protection reading information.
- Elevation and topography information (e.g., depressions, slopes, undulating area).
- Nominal pipe and coating properties (diameter, wall thickness, grade, seam weld type, if known).
- Data from several hundred excavations are included in the dig summary spreadsheet.

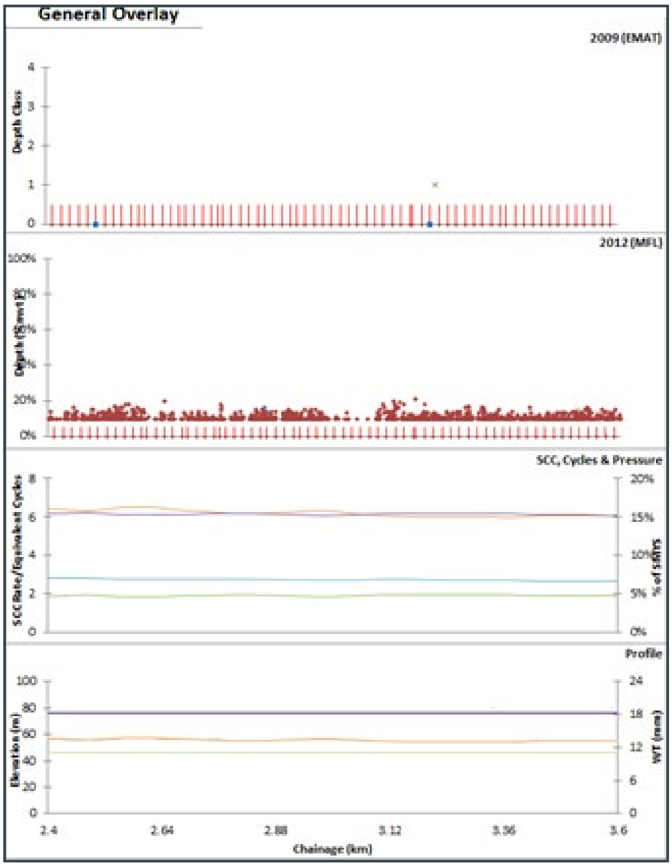

Figure 4: Example General Overlay Chart

3. STATISTICAL ANALYSIS OF THE DATA

Next, the Saudi Aramco statistically evaluated the data compiled and described previously, along with the literature review. The goals of the statistical analysis were to:

- Determine characteristics of locations where cracking has and has not been found,
- Compare the characteristics of crack locations with the results of the literature review,
- Identify trends in the data that can provide predictive statistical relationships between the crack locations and the site characteristics.

The analyses focused on identifying trends related to isolated parameters (for example, the ability of coating type by itself to predict cracking) using logistic regressions. Further statistical analyses were used to determine the potential to develop a multi-variable analysis or a hybrid model (i.e., one that combines subject matter expert input and the statistical analysis).

The Saudi Aramco used logistic regressions to identify factors that increase or decrease the likelihood that cracking is present. In statistics, logistic regressions are regression models where the dependent variable is categorical (descriptive), rather than numeric (as with ordinary linear regressions). Logistic regressions are used in many fields, such as, medical and social sciences. The technique can also be used in engineering applications, for example, to predict the probability of failure (or of finding cracking). Logistic regressions can be binary (two possible outcomes, such as, cracking is or is not present) while others consider multiple outcomes (three or more possible outcomes). The analyses discussed below were all binary with respect to outcomes.

The logistic regressions were used to calculate the odds of a given outcome (cracking is or is not present) for different values of an input variable, where the input variable could be categorical (descriptive, for example, coating type) or continuous (for example, age). The regressions were used to calculate the ratio of the odds of finding cracking to determine how much more (or less) likely a given outcome was as a function of the independent variables. The factors studied in the regressions were largely based on results from the literature review:

- Coating type
- Pipe grade
- Pipe type (seam weld type)
- Age of pipeline (years)
- Number and severity of metal loss calls in the area
- Diameter and thickness
- Topography (slope)
- Average and maximum pressure
- Number of equivalent cycles
- Estimated SCC growth rate

The last three factors are related.

Coating Type
The logistic regression provided the following results for comparisons between coating types. For each logistic regression, the Saudi Aramco calculated an Odds ratio , which represents the relative likelihood that cracking will be found based on a comparison of the independent parameters (e.g., coating type). The following table shows the results comparing different coating types by category.

Level A	Level B	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Coating 1	Coating 2	3.2530	1.73	6.11
Coating 3	Coating 2	4.0907	1.86	9.00

Table 2: Logistic Regression Results for Coating Type

Here, the regression shows cracking is over three times more likely under Coating 1 (Level A) than Coating 2 (Level B), as shown in the odds ratio, while the likelihood of finding cracking on Coating 3 is about four times more likely than Coating 2. Coating 1 and Coating 3 are tape coatings, while Coating 2 is FBE. Thus, cracking is far more likely under tape coatings than FBE coatings, as expected based on prior data and experience.

The numbers in parentheses at the end of the row represent the 95% confidence interval on the odds ratio. For example, for the Coating 1 to Coating 2 comparison, the 95% confidence interval around the odds ratio is 1.73 to 6.11. For the Coating 3 to Coating 2 comparison, the interval is 1.86 to 9.00. The larger the confidence interval, the less certainty there is in the odds ratio. An odds ratio of 1.0 indicates the two parameters being compared are the same. If the 95% confidence interval does not contain 1.0, the

results are considered statistically significant at the 95% level. If the confidence interval contains one, the results are not statistically significant at the 95% confidence level. For the two coating examples shown above, the results are statistically significant at the 95% confidence level.

Pipe Grade
Logistic regressions were performed for other combinations of independent parameters. Analyzing grade as a continuous variable showed no relationship between pipe grade and cracking likelihood. Analyzing grade as a discrete (categorical) variation, gave the following results by category:

Level A	Level B	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
42000	35000	0.50	0.19	1.33
52000	35000	0.25	0.11	0.58
60000	35000	0.36	0.18	0.74
70000	35000	0.24	0.12	0.48

Table 3: Logistic Regression Results for Pipe Grade

Here, the last three rows (comparing 52 ksi steel to 35 ksi steel, 60 ksi steel to 35 ksi steel, and 70 ksi steel to 35 ksi steel) are statistically significant because the 95% confidence interval does not include 1.0. The first row (comparing 42 ksi steel to 35 ksi steel) is not because the confidence interval includes 1.0. So, cracking is less likely in grade X52, X60, and X70 pipe compared to grade B pipe (an odds ratio that is less than one indicates the first factor is less likely than the second factor in predicting cracking). Even though grade is generally not associated with the likelihood of finding SCC based on the literature study and experience, the results indicate Grade B has a higher likelihood. There is little difference in relative likelihood due to pipe grade for X52 and above.There is another possibility regarding the results discussed above: the steel grade could be correlated with another parameter that also affects cracking susceptibility. For example, if 35 ksi steel is more common in older pipelines, and age affects cracking susceptibility, the results could be explained by the interdependence between age and cracking susceptibility. This type of correlation is still under evaluation.

Pipe Type

Pipe manufacturing type was treated as a categorical variable. The results showed seamless pipe to be about six times more likely to experience cracking than submerged arc (SAW) or spiral weld pipe (SPIR). SAW and SPIR pipe had a likelihood of 0.27 compared to that of electric flash welded (EFW) or electric resistance welded (ERW) pipe:

Level A	Level B	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
SAW/SPIR	EFW/ERW	0.27	0.14	0.51
SMLS	SAW/SPIR	6.03	3.11	11.71

Table 4: Logistic Regression Results for Pipe Type

This finding was also not expected based on the literature and experience. Again, the result could be the consequence of cross correlations with other parameters that affect cracking susceptibility. For example, seamless pipe is known to contain mill defects, such as surface breaking laminations and slivers, which can be confused with SCC and other forms of cracking.

Pipeline Age

The Saudi Aramco expected the likelihood of cracking to increase with age. When age was treated as a continuous variable, the results indicated the likelihood of finding cracking increased about 2.6% per year:

Parameter	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Age, Years	1.026	1.01	1.05

Table 5: Logistic Regression Results for Pipeline Age

The above results show a 95% confidence interval that is close to including 1.0. So, the results are somewhat speculative.

Diameter and Thickness

Continuous logistic regressions were performed on diameter and wall thickness, even though these parameters are generally not associated with the likelihood of finding SCC. The analyses showed a negative relationship between cracking and pipe diameter: for each two-inch increase in diameter, the likelihood of finding cracking decreased by about 7%. This trend was most apparent at diameters below 20 inches. As before, mill defects in seamless pipe, which is made in smaller diameters, could be skewing the results.

Parameter	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Diameter (in)	0.9651	0.95	0.98

Table6: Logistic Regression Results for Diameter

The analyses showed a negative relationship between cracking and wall thickness: for each increase in wall thickness, the likelihood of finding cracking decreased.

Parameter	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Nominal WT (in)	0.1345	0.022	0.83

Table 7: Logistic Regression Results for Wall Thickness

Correlations between diameter, wall thickness, and other parameters are still under investigation.

Presence of Metal Loss on Joint

Logistic regressions were performed in several ways with regard to the presence of metal loss on the joints: the presence of any metal loss (binary: yes/no), the maximum metal loss depth, and the number of metal loss calls (as an indicator of the amount of coating damage on a pipe joint). There was a statistically significant relationship between the presence of metal loss and the cracking likelihood. On average, having metal loss on a pipe joint increases the likelihood of finding cracking by about two thirds:

Level A	Level B	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
ML	No ML	1.68	1.03	2.74

Table 8: Logistic Regression Results for Presence of Metal Loss

The likelihood as a function of depth of metal loss was somewhat unexpected. The results were not statistically significant at the 95% confidence level. This is contrary to a commonly held notion that cracking is more likely in regions of shallow metal loss.

Parameter	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Max ML Depth	5.7688	0.66	50.16

Table 9: Logistic Regression Results for Maximum Metal Loss Depth

Finally, there was no statistical significance between the number of metal loss features and the likelihood of finding cracking:

Parameter	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
ML sum (#)	1.00	0.99	1.01

Table 10: Logistic Regression Results for Number of Metal Loss Calls

Slope

Slope was treated as a continuous variable. The results indicate an increase in likelihood as Binary Fitted Line Plot P(1) = exp(-1 .450 + 0.0643 Equiv 36% Cycles [cycles/yr])/ (1 + exp(-1 .450 + 0.0643 Equiv 36% Cycles [cycles/yr])) the slope increases. This finding is unexpected. Tape coated lines are generally considered more susceptible in low lying areas that alternate between periods of wetness and dryness.

Parameter	Odds Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Slope (m/m)	5637	9.5	3.33E06

Table 11: Logistic Regression Results for Terrain Slope

The odds ratio for slope is significantly larger than the odds ratios for the other parameters studied. This is due, in large part, to the smallness of the slope values. Additional analyses of other parameters, such as the average stress in the pipe, are underway.

Pressure (Stress) Related Factors

The last parameters discussed here are related to the pressure (stress) in the pipeline. Various logistic regressions were performed against average and maximum stress, the number of equivalent 36% SMYS stress cycles, and the estimated SCC growth rate. The strongest correlations were found between the maximum number of equivalent 36% SMYS cycles per year on the pipeline segments and the likelihood of cracking. Figure 5 is a binary fitted line plot showing how the likelihood of cracking increases with the number of equivalent cycles.

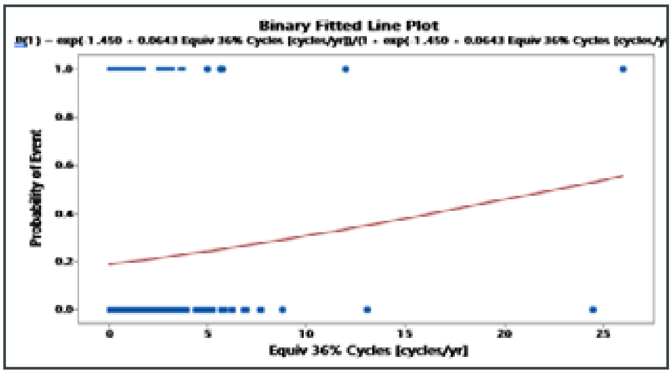

Figure 5: Binary Fitted Line Plot for Equivalent Cycles

4. SUMMARY OF STATISTICAL ANALYSIS

This paper discusses how Saudi Aramco enhanced prioritization criteria for identifying pipe segments with a higher likelihood of finding cracking. A statistical evaluation of the data was conducted along with the literature review. Saudi Aramco used logistic regressions to identify factors that increase or decrease the likelihood that cracking is present. The trends that were identified relate to coating type, pipe grade, pipeline age, diameter, thickness, metal loss, CP level, slope, and pipe type. Table 12 summarizes the findings.

Factor	Trend
Coating Type	Cracking much more likely under tape coating than FBE (as expected
Pipe Grade	Cracking more likely in Grade B pipe than in X52 to X70 pipe
CP Level	Cracking likelihood decreases slightly with increasingly negative close-interval survey potentials
Pipeline Age	Cracking likelihood increases with age
Diameter	Cracking more likely for diameters less than 20 inch
Thickness	Cracking less likely in thicker wall pipe
Metal Loss	Cracking more likely on joints with metal loss and as metal loss depth increases
Elevation Slope	Cracking likelihood increases with increasing slope

Table 12: Trends in Cracking Likelihood

Finally, Saudi Aramco established Stress Corrosion Cracking (SCC) Management Program based on the enhanced criteria that listed in Table 13 to optimize the number of Crack Detection In- Line-Inspection runs.

ASME B31.8S Criteria	Enhanced Criteria
Stress Level > 60% SMYS	Maximum Stress Level > 60% SMYS Average Stress Level > 40% SMYS
Non-FBE Coating	Non-FBE Coating Number of Coating Disbondment Features and length (High Density)
N/A	Number of Equivalent Pressure Cycles ≥ 36% SMYS
N/A	Number of Metal Loss Features & Severity (High Density)
N/A	Pipe Grade (X35, X42, X52)
Age> 10 Years	Age> 10 Years
Distance from PS or Comp. Station ≤ 32 km (20 miles)	Distance from PS or Comp. Station ≤ 32 km (20 miles)
Temperature > 100 F	Temperature > 100 F

Table 13: SCC Enhance Criteria

NOMENCLATURE

CDP - Crack Detection Pig
EFW - Electric Flash Welded (Pipe)
EMAT - Electromagnetic Acoustic Transducer ERW - Electric Resistance Welded (Pipe)
ILI - In-line Inspection
MAOP - Maximum Allowable Operating Pressure SAW - Submerged Arc Welded (Pipe)
SCC - Stress Corrosion Cracking SPIR - Spiral Welded (Pipe)
UT - Ultrasonic Testing
UTCD - Ultrasonic Crack Detection (Pig) UWD - Ultrasonic Wall Detection (Pig)

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of the Saudi Arabian Oil Company.

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3. IPC2016-64348 (Susceptibility of Stress Corrosion Cracking in Liquid and Gas Pipelines)

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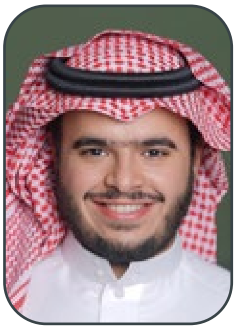

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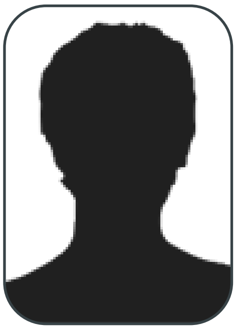

Association

IAOT - International Association of Oil Transporters
Czech Republic
www.iaot.eu/

DVGW - German Technical and Scientific Association for Gas and Water
Germany
www.dvgw.de

Automation

Siemens
Germany
www.siemens.com

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