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DENSO
For all those thinking big.

The African Pipeline Market

Amine Idriss Adoum
Director
NEPAD Agency

Dear readers,

The year 2020 has been unprecedent due to the Covid-19-Pandemic, which has sadly resulted in the millions of deaths and infections. It has also transformed our society both positively and negatively. The restrictions imposed on us restricted our movement but have produced innovations that enabled us to adopt new practices for life in all its facets to continue.

Despite the challenges, the African Union Development Agency (AUDA-NEPAD) together with our Partners, our mother organisation, the African Union Commission (AUC), the various Regional Economic Communities, Regional Power Pools, Continental as well as Regional Bodies and our development partners. We have managed to attain milestones in the major continental infrastructure programmes, mainly the development of the second phase of the Programme for Infrastructure Development in Africa, Priority Action Plan (PIDA PAP II), but also the Africa Single Electricity Market (AFSEM) and the Continental Power Systems Masterplan (CPSM).

PIDA PAP II, will set the continent's priority infrastructure projects in Transport, Energy, ICT and Water for the next decade (2021-2030). The AfSEM and CPSM will set the regulatory, policy & instructional framework, identify priority energy infrastructure projects and develop a roadmap for the creation of a single energy market on the African Continent. The combined effect of these two programmes will be to stimulate industrialisation and intra-Africa trade under the Africa Continental Free Trade Area, which will come into effect in 2021. In addition, the long-term goal of the CPSM is to enable Africa to trade electricity with Europe, the Middle East and Asia through existing and future interconnections.

I have singled out these initiatives because they have one thing in common with the Pipeline Journal, which is the promotion of oil and gas pipelines as well as emerging trends such as green hydrogen. Traditionally, PIDA PAP has included priority oil and gas pipelines in East Africa and pipelines linking West Africa to North Africa. AfSEM will develop a continental oil and gas pipeline masterplan and the CPSM will address the prospects and opportunities for green hydrogen for electricity storage. These programmes will draw lessons from on leak detection and third-party intrusion as well as illegal tapings from the existing pipeline infrastructure particularly in Nigeria and pipeline protection from sabotage, for e.g. in Mozambique.

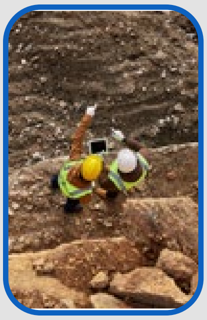
As we start the third decade of the 21st century, Africa is positioning itself to exploit these emerging trends. Africa will develop the infrastructure (including pipeline) for the production, distribution and upstream beneficiation and use of oil, gas and hydrogen to accelerate Africa's electrification and energy independence.

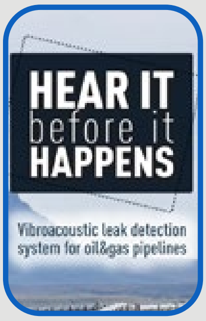
Yours,

Amine Idriss Adoum, Director, Programme Delivery and Coordination, NEPAD Agency

THIS ISSUE'S COMPLETE CONTENT

DECEMBER 2020





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PIPE LAYING WORK ON NORD STREAM 2 COMMENCES AGAIN IN THE BALTIC

Undeterred by the threat of punitive sanctions if work on Nord Stream 2 resumes, the construction of the last hundred plus meters of the gas pipeline on the seabed of the Baltic picked up again after a one year hiatus.

Swiss-Dutch company Allseas suspended the laying of pipes in December 2019 following the clamor of various Washington senators for sanctions, leaving Russia to utilize its own resources to construct the 1,230 kilometre (km) pipeline, which is designed to double the 55 billion cubic meter annual gas capacity of the existing Nord Stream pipeline.

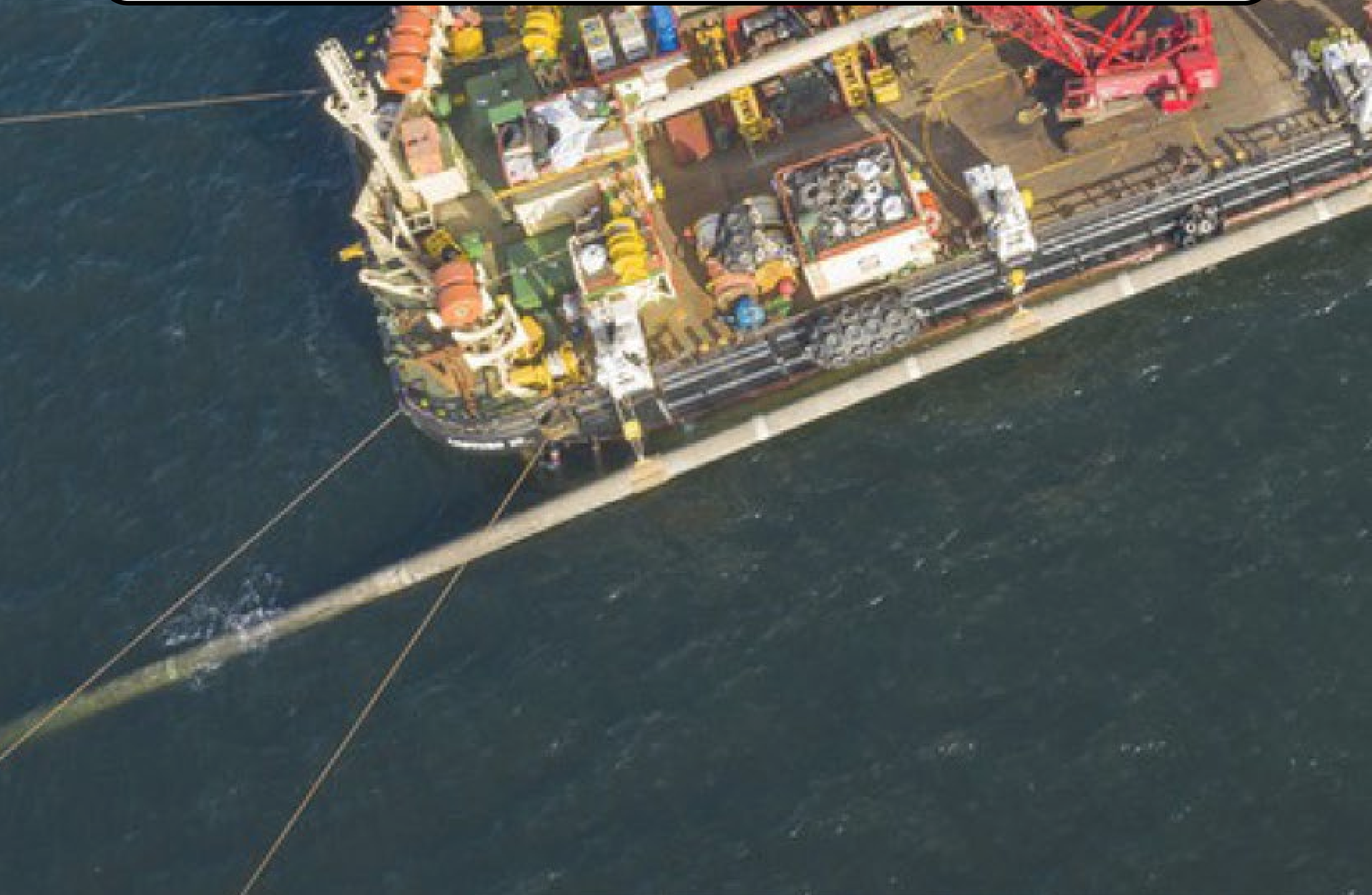
Nord Stream AG said in a press release that “the pipe laying vessel Fortuna [sailing under the Russian flag] will lay a 2.6 km section of the pipeline in the German Exclusive Economic Zone in water depths of less than 30 m (100ft).”

The company added that all construction works would be implemented in full compliance with existing permits and it would provide information about further offshore construction activities in due course.

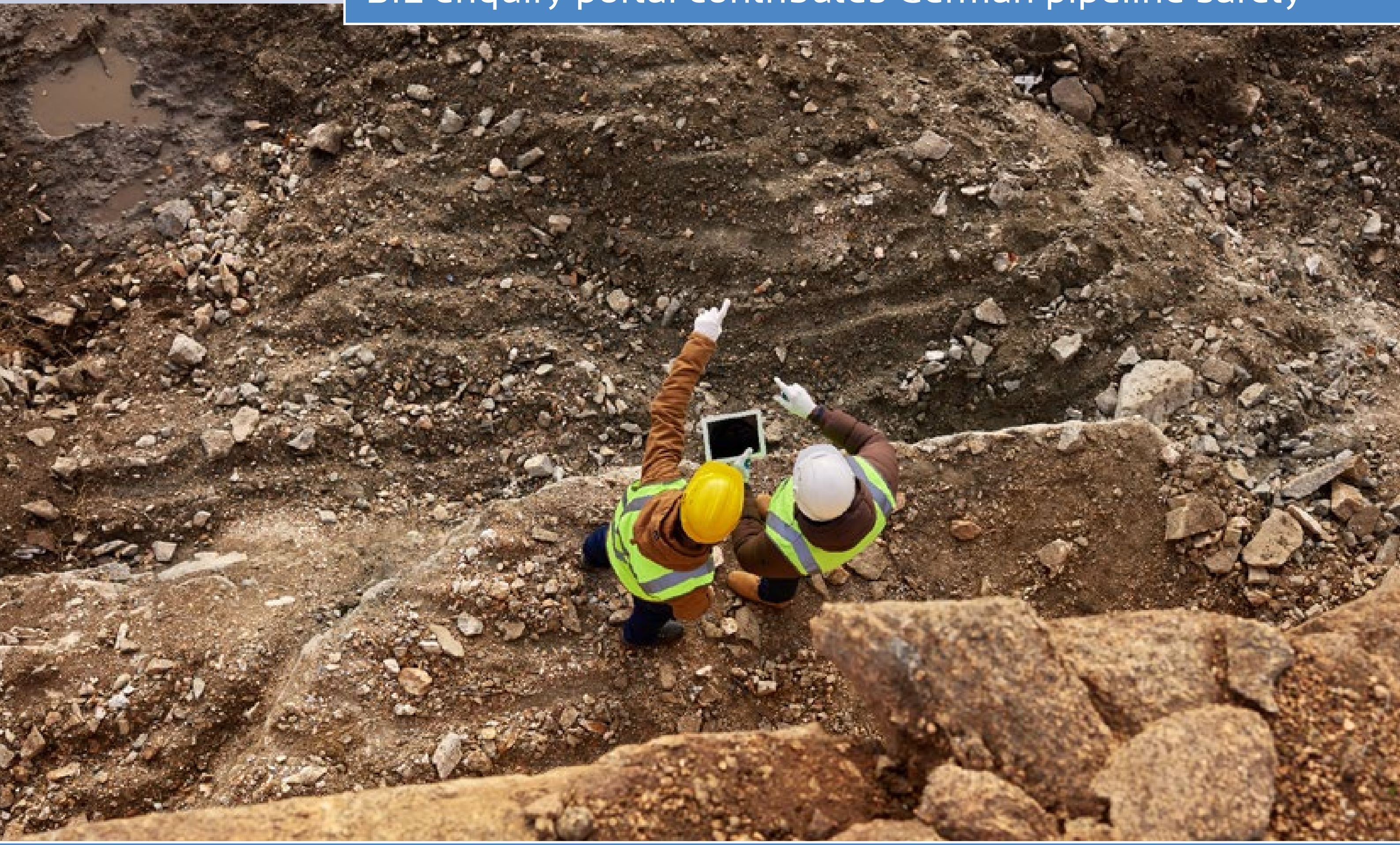
The consortium, led by Russian gas giant Gazprom, has still to lay more than 100-km of pipeline, although more than 90% of the project has been completed.

Washington’s official rationale for opposing the project is that it would threaten the EU’s security by increasing the bloc’s dependence on Russia.

Read more at:
https://www.pipeline-journal.net/news/pipe-laying-work-nord-stream-2-commences-again-baltic



BIL enquiry portal contributes German pipeline safety



Jens Focke, Ingo Reiniger; Markus Heinrich > BIL eG; Wolter Hoppenberg RA Partnerschaft mbB

Abstract

A highly developed society naturally believes that it has eliminated its risks. Insurances, traffic information, social systems, legislation, and finally all kinds of regulations weigh us down in a corset of security of our own actions, which can hardly lead to negative consequences. Infrastructure and pipeline security is a valuable asset, on whose functioning we depend day by day. The COVID 19 crisis in particular has made it clear to us that digitization has become an economic necessity.

The number of construction activities in Germany has increased rapidly in recent years and there is no sign of this trend slowing down. The limited space available is increasingly leading to parallel laying of underground infrastructure and bundling of routes. If the price of risk provisioning only becomes apparent at the moment of damage, this is not only too late, but negligent in the case of the requirements of the energy turnaround and a digital "Smart City".

LINE INFORMATION IS MORE THAN JUST INFORMATION

On closer inspection, the overall process of management information is far more complex than the literal sense of the word initially suggests. However, the circle of participants can be clearly divided into two subgroups: those searching and those to be found. What are their tasks? What are their challenges? This understanding helps to understand the process in its entirety and to identify possible improvement potentials through the use of digital solutions.

1ST GROUP OF PARTICIPANTS: THE NETWORK OPERATOR

The operator maintains an underground pipeline system, which is invisible in the ground and functions without interruption as long as there is no external intervention. The operator is obliged by law and regulations to provide information about the location of his pipelines if there is a legitimate interest. He therefore has the duty to make himself known when he is requested. If he is not requested, he is automatically not involved in the process of providing management information.

The event statistics of the German association of the gas and water industry e.V. (DVGW) has named corrosion and external mechanical influences as THE two main causes of damage to the infrastructure of its members since 1920. A damage share of more than 60 % is stated actually due to external mechanical influences, mostly from construction equipment.

These statistics can also be applied to other sectors. From the point of view of the pipeline operators, the construction enquiry process and the information process are thus a highly safety-relevant matter. On the one hand, it is essential for pipeline operators to be informed about all activities along their lines and routes. On the other hand, the operator's documentation department should be able to provide digital infrastructure data at short notice so that this data (together with data from other operators) can be homogenized and used on the construction site and construction equipment.

2ND GROUP OF PARTICIPANTS: THE PIPE-SEARCHING CIVIL ENGINEER

The damage balance sheets like to circulate the dredger driver as the last link in the chain of possible culprits. However, inadequate construction preparation, e.g. due to incomplete documentation on site regarding pipe locations, and monitoring of the construction project are often the reason for the damage event.

The planning of a construction project requires the early investigation of the surrounding area for pipe locations. The building contractor can often prove that he has actually made a request for pipe information. However, this has not reached the damaged pipeline operator. This is often due to ignorance on the part of the requesting party about the existence of the operator. In the past, the local public utility (with the same name) was considered the central contact person who also passed on his information to the neighbouring operators. The meanwhile increased number of operators, other media carriers and the multiple changes of concession and name in all branches of industry keep the established research services on their toes.

This challenge to the construction applicant to make the invisible - the underground infrastructure - visible is thus associated with an enormous research effort without any guarantee of having completely identified "everything underground". How nice it would be to have a centralized, nationwide and cross-divisional portal for construction enquiries in Germany, with which all network operators can be reliably identified and addressed

CHALLENGES FOR THOSE INVOLVED

In Germany, the federal structure of legislation and the large number of industry associations make it extremely difficult to create a legal standard for management information. An agreement process requires a high degree of willingness to compromise on the part of all parties involved, for example, when it comes to agreeing on uniform digital standards for data provision and exchange.

However, the agreement process only includes three essential aspects:

- It should be possible to carry out a standard enquiry process under the initial conditions described above, even if the system requirements of the operators in question differ or are not available.
- The implementing organization should be accepted across all industries and meet the legal requirements and applicable regulations (see next paragraph).
- Its attractiveness should motivate users and possibly urge them to comply with due diligence requirements.

DUTIES OF THE CIVIL ENGINEER

Damage to pipelines constitutes an infringement of property rights within the meaning of German legislation.

According to this jurisdiction, the civil engineer must always obtain a plan information before starting any civil

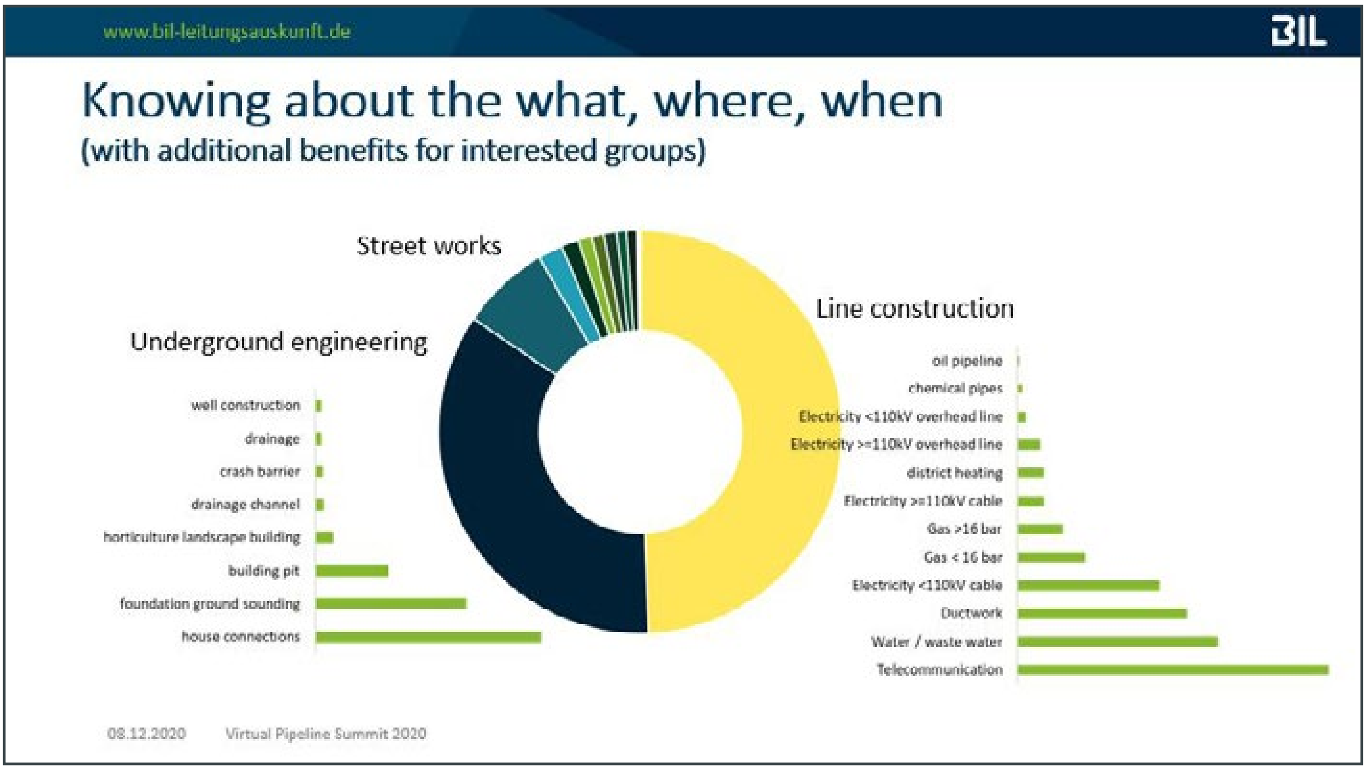


Figure 1: Knowing about the what, where, when

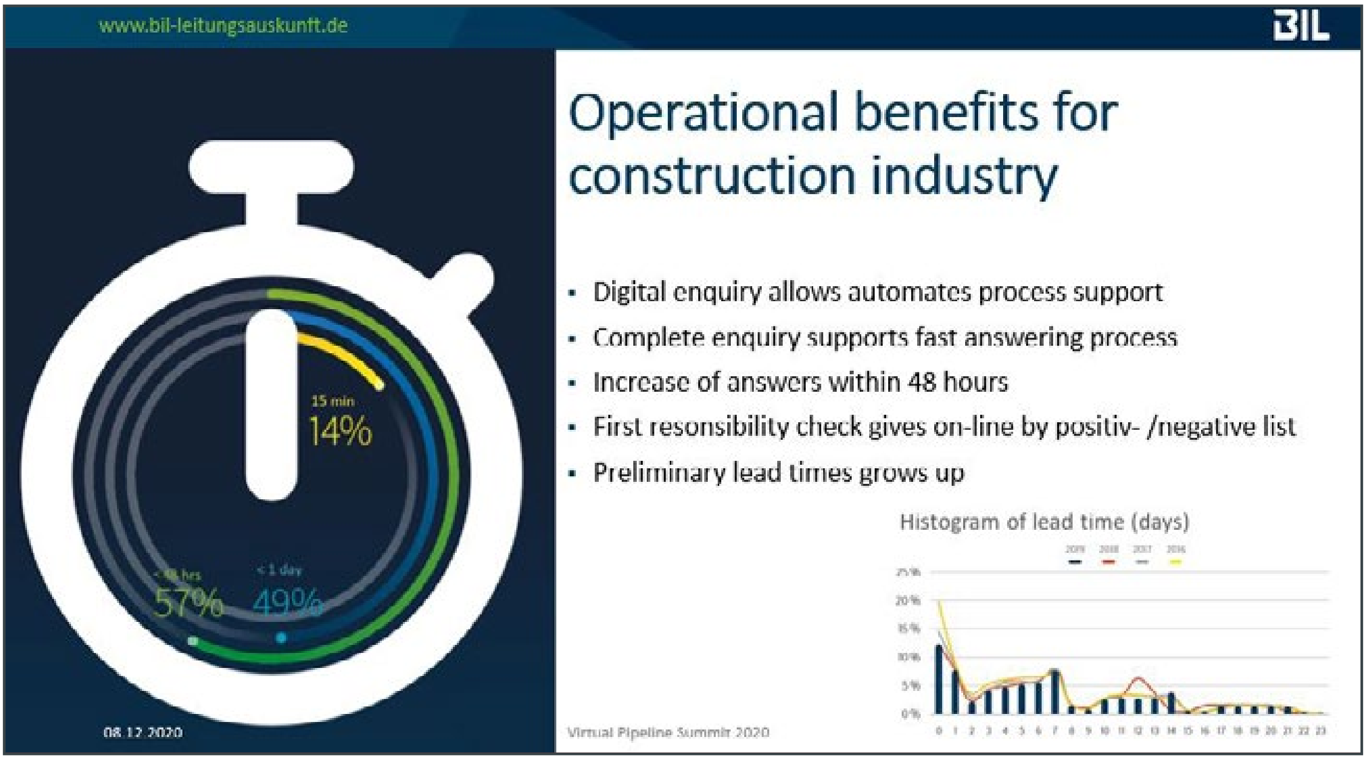


Figure 2: Operational benefits for construction industry

engineering work - this does not only include excavation work, but also any measure with a major impact on the condition of the soil, for example, driving with particularly heavy equipment or compaction . This information must be obtained where reliable documents are available, which is only the case with the network operator himself or with a service provider who has contractually committed himself to provide information to the network operator.

COST BURDEN FOR INFORMATION

In accordance with elementary legal principles, everything speaks in favour of an obligation on the part of the network operator to offer at least one method of providing information free of charge, whereby online planning information is the most practicable method in this respect. As already explained above, line and cable network operators are responsible, as operators of lines as sources of danger, for ensuring that these do not pose any danger to third parties (obligation to maintain safety on the roads). According to general legal principles, the cost burden for prevention measures in connection with traffic safety obligations is always borne by the duty bearers.

BIL AS BEST PRACTICE AS BASIS FOR REGULATIONS AND LAWS?

A good four years after the BIL portal went live, the original 17 over 100 line and network operators of all divisions have become those who process their line information via the BIL portal and have abandoned their own approaches in favour of the joint solution. A full participation of the operators from the sectors high pressure gas and mineral oil can be noted. The registered cooperative was chosen as the legal form, because as an cooperative BIL does not pursue any profit-making intentions and the operating costs of the portal are allocated to the participating companies depending on the length of the pipeline or the size of the supply area.
The portal used generates a reduction of the actual construction requests to be processed by the participating operators due to the automated upstream responsibility check.

10 % up to 80 % and can also achieve considerable increases in effectiveness. In 2019, almost 50% of the inquiries in which responsible network operators were identified could be answered within 24 hours. The standardized and complete recording of inquiries in BIL and the possibility of software-supported processing even allows for largely immediate information in many cases: 14 % of all inquiries were answered within 15 minutes. In addition, it was found that the majority of the inquirers (50 %) obtain information relatively shortly before the planned start of execution (one week before), which shows the expectations of the line seeker (2nd and 3rd group of participants) regarding the desired processing time. However, in the case of more complex and long-running construction measures (e.g. building construction, approval procedures, power generation), a trend towards longer inquiries (average lead time: between 80 and 160 days) is visible.

Digitization and its potential for simplifying and accelerating business processes with high communication requirements is not an isolated task here, but an opportunity and an obligation for cooperation and can only be solved jointly.

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Application of Distributed Fiber Optic Sensing for Pipeline Integrity and Security

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Abstract

Even the smallest leak can have devastating consequences. The protection and monitoring of pipeline infrastructure is critical to the continued performance of the pipeline. Loss of integrity, through accidents or malicious activity, can have a significant impact on the environment, on reputations and on finances. Distributed Fiber Optic Sensing is a technology that can be employed to provide real-time Leak Detection, Third Party Intrusion and Scraper Tracking all from a single networked platform.

DISTRIBUTED FIBER OPTIC SENSING

Distributed Fiber Optic Sensing describes several technologies that can be utilized to convert a fiber optic cable into an array of distributed sensors by connecting it to an optical Interrogator Unit (IU). Fundamentally, the technology relies on launching laser light along the fiber optic cable and detecting light that is scattered back along the fiber. As light propagates through the fiber it interacts with microscopic inhomogeneities in the glass. These interactions result in a small fraction of the light being scattered. A smaller fraction of which is captured in the fiber optic cable and propagates back towards the detection stage of the IU.

The scattering of light is a continuous phenomenon and the optical fiber is stratified into channels that represent different locations along the fiber by using the time-of-flight between launch and detection. DFOS systems look to detect changes in the scattered light that result from the effect of physical events on the fiber. Vibrations, strain, and thermal changes are the primary sources of signal variation and by monitoring changes in the scattered light DFOS can be used to interpret events occurring along the length of the fiber in real-time.

Inhomogeneities in the fiber that lead to the scattering of light can be naturally occurring or artificially introduced. Naturally occurring mechanisms include Rayleigh, Brillouin, and Raman scattering while artificial mechanisms such as Fiber Bragg gratings can also be employed. The OptaSense DFOS technology relies on Rayleigh scattering, which occurs from the interaction of light with sub-wavelength particles in the glass fiber. The oscillating electric field of the light interacts with the electric polarizability of the particles, which are induced to oscillate at the same frequency as the light and become radiating dipoles (Figure 1). A fraction of this scattered light is captured by the fiber optic cable and propagates back towards the IU.

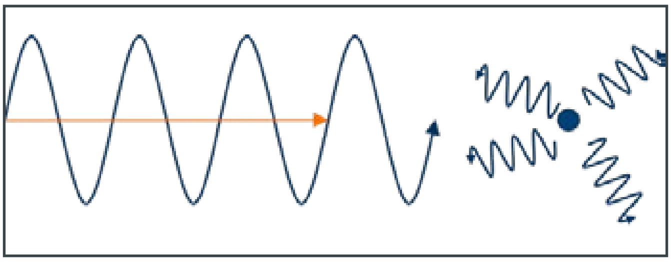

Figure 1: Illustration of Rayleigh scattering mechanism. Light interacts with a particle inducing it to oscillate at the same frequency and become an electric dipole radiating light at the same frequency

Rayleigh-based DFOS is typically considered to be a distributed acoustic sensor (DAS) – being sensitive to vibrations. However, technological developments are allowing Rayleigh-based sensors to be used as strain and temperature sensors as well, providing a full-suite of detection from a single technology. Brillouin-based technologies are generally employed for distributed temperature or strain sensing (DTS/DSS) while Raman-based fiber optic technologies are used solely for distributed temperature sensing (DTS).

QUANTITATIVE AND QUALITATIVE

The data produced by a Rayleigh DFOS system falls into two categories. Basic systems can produce qualitative (or intensity) based data while more advanced systems monitor phase changes and can output quantitative measurements of the relative change in optical path length between two points along the fiber – this is essentially a measure of the strain on the fiber though it isn't strictly the same.

Qualitative based systems are suitable for detecting that something is happening to the fiber while quantitative systems may be necessary when knowledge is required of what is happening to the fiber. Figure 2 illustrates the difference between the two categories of system in response to the passing of a train where the fiber is installed alongside the track. The shaded region to the right-hand side shows the behavior of each system prior to the arrival of the train while the left-hand side shows the response as the train passes. On the qualitative system there is a clear disturbance to the fiber during the train pass, however the quantitative system provides a much clearer and consistent response with the passing of each bogie. A further difference between qualitative and quantitative systems is the inter-channel response; on a qualitative system the response of each channel is wholly independent of each other while on a quantitative system the response of each channel will be coherent. The coherent response of quantitative systems allows more advanced processing techniques such as beamforming to be performed and can enhance the signal to noise ratio.

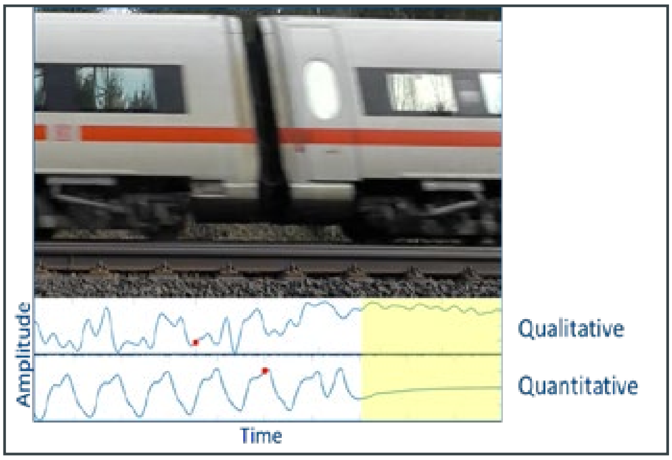

Figure 2: Data from qualitative and quantitative systems responding to the passing of a train

For many applications qualitative IUs are sufficient. These simpler systems benefit from their lower cost and wider range of operation and form the majority of global installations (though technological advancements may change that in the future). Impulses and vibrations are readily detectable and the combination of signal detection routines with logical processing creates heuristic algorithms that can classify a variety of events based on key characteristics. For instance, a person walking parallel to a monitored fiber will manifest as a periodic series of impulses that will move along the fiber at a walking pace. The fundamental principles of detection will remain the same when using a quantitative system though it may be possible to provide further information such as the offset of the walker from the fiber and their bearing.

Some scenarios do require quantitative IUs such as seismic event and fracture monitoring where the interaction and propagation of waves in the ground is to be monitored. Long-term strain monitoring (for dams and bridges for example) is an exciting new area of application that is being made possible by ongoing developments in quantitative DAS. The future of leak detection will also benefit from quantitative DAS systems as we will come back to later in the article.

HARDWARE

OptaSense has a range of interrogator units that allow us to provide the most appropriate technology for the installation requirements. The standard workhorse is the qualitative OLA2.1 unit, which provides 50 km of fiber optic sensing and has been employed all over the world for a wide range of applications. All other interrogator units in the range provide quantitative measurement capability. The ODH4 is an advanced, short-range, quantitative interrogators. The ODH-F unit can operate as either a short-range quantitative system or as a longer-range qualitative system. Finally, the QuantX and ODH5X IU's are long-range quantitative solutions providing similar measurement range to the OLA2.1; the ODH5X offers an optimized 10 km of sensing capability but supports a long-lead in fiber for applications such as sub-sea monitoring.

Detection ranges are largely dependent on the amount of light being scattered back and are specified on the basis of standard, single-mode fiber with a one-way optical loss not exceeding 0.25 dB/km. This range is typically specified as 10 km for short range solutions and 50 km for long range solutions, which OptaSense have defined based on where we consider the system performance to be acceptable.

PIPELINE INTEGRITY MONITORING SYSTEM

When it comes to pipeline monitoring, DFOS systems can provide three key areas of capability: Leak Detection, Third Party Intrusion, and Scraper tracking.

LEAK DETECTION

One of the core capabilities of a DAS pipeline monitoring system is the ability to detect leaks quickly and reliably. A leak can have a range of effects on the surrounding environment and the OptaSense leak detection system continuously monitors for four different phenomena. These are the Negative Pressure Pulse (NPP – sometimes referred to as a Negative Pressure Wave (NPW)), Orifice Noise (OFN), Strain, and Temperature (DTGS). Illustrations of each of these effects are shown in Figure 3. Depending on the nature of the leak and the pipeline installation some of these effects may not be observed. The 4-mode Leak detection system does not require all leak modes to be present for an alert to be raised.

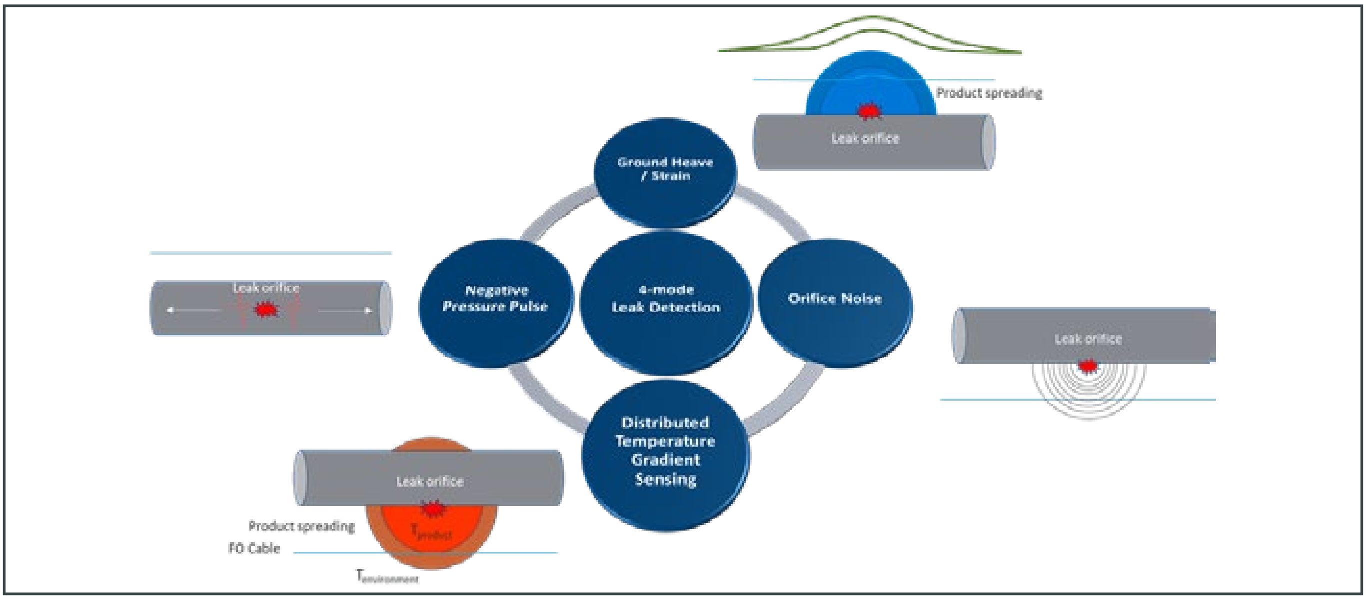

Figure 3: OptaSense 4-mode Leak Detection System with illustrations of each mode

At the instant that a pipeline loses integrity, a pressure drop occurs. This drop in pressure generates an NPP that propagates inside the pipeline away from the leak location at the speed of sound in the fluid. As the signal propagates out in both directions along the pipe it forms a characteristic V shape that points directly to the source as can be seen in Figure 4.

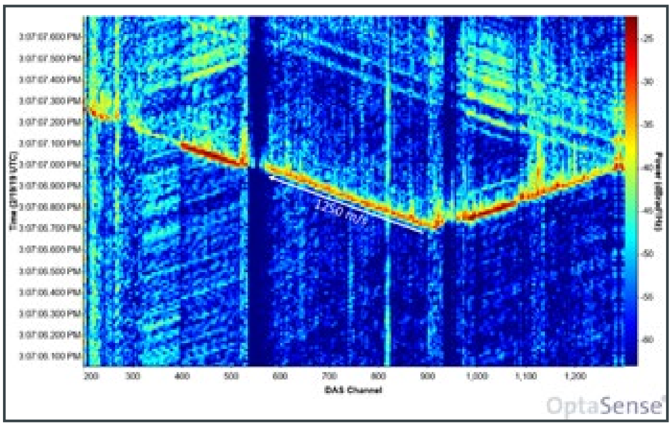

Figure 4: Waterfall plot showing the characteristic V-shape of an NPP

OFN

Orifice noise arises as fluid is ejected from the pipeline and causes vibrations in the pipeline and the surrounding environment. The effect of these vibrations appears as amplification of the spectral content in the vicinity of the leak. Figure 5 is a spectrogram showing the spectral content of a leak event. The first 30 seconds of the data are prior to the leak event and the spectrum is typical of the background environment. When the leak begins there is a significant amplification of the signal across the frequency range. The moment that the leak valve is closed the spectral content returns to that of the background environment.

STRAIN

The force of fluid being ejected from the pipeline can cause the pipeline to flex and the surrounding ground to shift (for a buried pipeline). Ground movement is particularly noticeable in highly compressed gas pipelines where the fluid can undergo significant expansion into the surrounding area. The effect of the fluid ejection imparts strain into the fiber optic cable, which can be detected. The effect is more clearly visualized on a quantitative system and Figure 6 illustrates the response of the system to a leak on two co-located optical channels. After the start of the leak, an increase and relaxation in the measured phase is observed on both channels – the segment marked as 'Strain'. A further increase in the measured phase is likely to also be the result of strain on the fiber resulting from further ground movement.

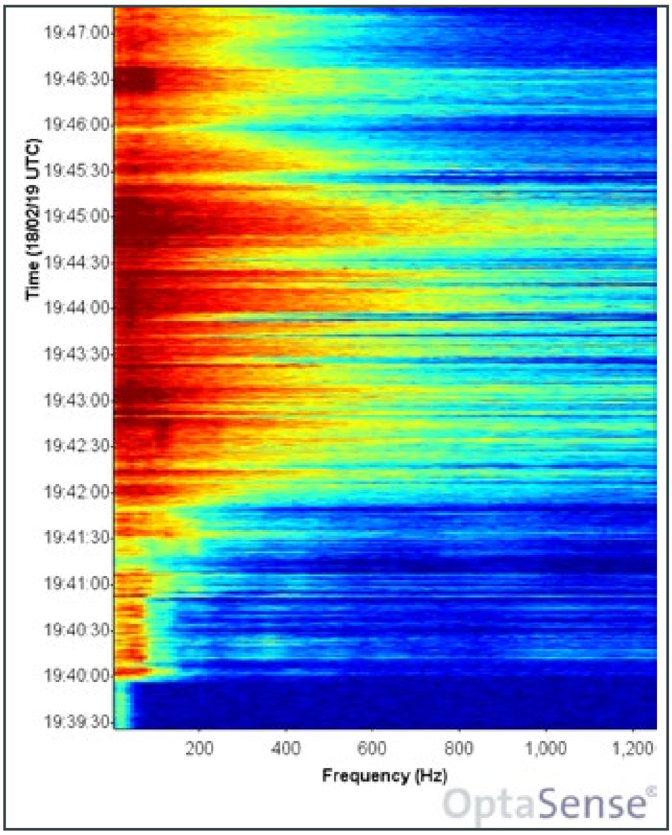

Figure 5: Spectral content of an optical channel in the vicinity of a liquid leak at a rate of approximately 125 L/min

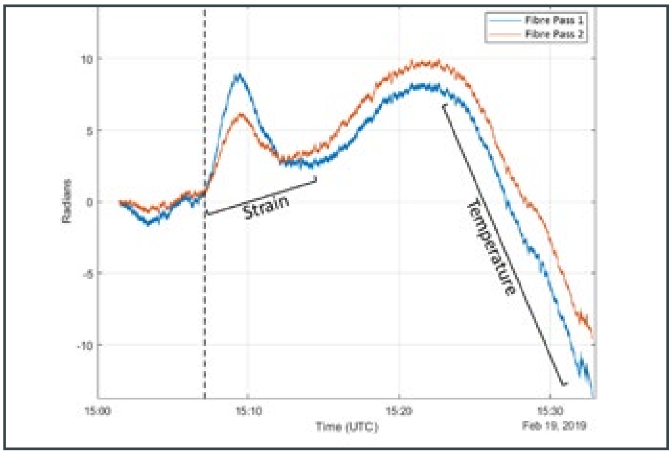

Figure 6: Plot of quantitative phase measurement where the effects of strain and temperature changes on the system can be observed. The dashed line indicates the start of the leak event

TEMPERATURE CHANGE

Where a pipeline product is at a different temperature to the fiber (or undergoes Joule-Thomson cooling) thermal changes will permeate towards the fiber during a leak event. While Rayleigh-DFOS systems do not directly measure the temperature of a system, they are sensitive to changes in the temperature.

As with the effects of strain on the fiber, it is easier to visualize the effects of temperature changes on a quantitative system. Referring again to Figure 6, the negative trend that is observed in the region marked 'Temperature' corresponds with the effect observed as the fiber temperature changes. This change occurs nearly 20 minutes after the start of the leak owing to the time required for thermal effects to reach the fiber. Based on typical sensitivities the change observed in the marked region corresponds to a temperature change of 20 mK, a change in temperature below the sensitivity of traditional DTS systems.

QUANTITATIVE RAYLEIGH-DFOS FOR LEAK DETECTION

The OptaSense Leak detection system is currently based upon qualitative systems. However, advances in quantitative systems have the potential to improve leak detection capability even further. With a strain and temperature capable IU and the ability to separate the two from each other, Rayleigh-DFOS can be used to give absolute temperate and strain outputs by directly tracking each components movement from a calibrated baseline. As well as opening a host of new applications, the potential benefits to leak detection performance are very exciting.

VALIDATION AND VERIFICATION

While the occurrence of these effects is not in doubt, it is vital that we can specify the limitations of the system for leak detection. Over the past decade OptaSense has undertaken and been party to many leak trials with a wide range in how representative they are of a genuine leak event. These trials have all provided valuable data but of particular note are the larger trials that we have undertaken at the full-scale flow-loop facilities of SINTEF in Norway and CTDUT in Brazil (Figure 7). These are the most representative and realistic leak trials undertaken to date and have informed the performance bounds that are placed on the OptaSense Leak Detection system.

SINTEF

In 2017, OptaSense undertook a series of leak tests on a large, full scale flow-loop run by SINTEF in Norway. The trial was conducted on an above-ground pipeline and tested a total of 540 different conditions. Liquid, gas and mixed-phase products were tested over a range of pipeline pressures and leak sizes. The trials at SINTEF were undertaken using a quantitative IU to provide the greatest possible understanding of the leak-induced behavior. Overall, this trial provided valuable data on the performance of the OptaSense system and a more expansive white paper on the trial can be obtained by contacting OptaSense.

CTDUT

In 2019, to further validate the system and gain understanding of how small a leak can be detected, OptaSense undertook a further series of trials at CTDUT in Brazil. This trial focused on a buried pipeline with the fiber installed 0.5 m away from the pipeline at the limits of the fiber installation specification. Like at SINTEF, a bespoke test spool was installed on a 2.5 km flow-loop that could host liquid, gas and mixed-phase testing. Leaks were initiated by rupture discs and automated valves to provide data on the effect of a sudden loss in pressure compared to a slower drop. The rate at which fluid leaked from the pipeline was controlled by varying the size of the leak orifice.

Figure 7: Photographs of leak test sites at SINTEF and CTDUT

The use of burst discs allowed recreation of a sudden loss of pipeline integrity. As a result, the observed NPPs were significantly clearer compared to those obtained from the slower pressure drop arising with a fast-acting valve (Figure 8). Further details of the CTDUT trials are contained in a white paper, which is also available by enquiry.

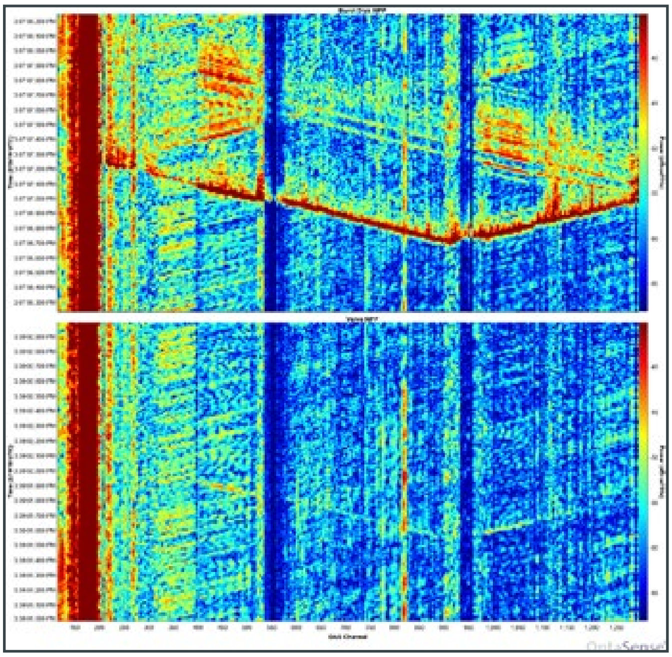

Figure 8: Comparison of NPP signals generated with (top) and without (bottom) the use of a burst disc. The NPP signatures both arise from a 3 mm diameter orifice, which created a leak at a rate of approximately 10 L/min.

PERFORMANCE

The extensive testing that OptaSense has undertaken provides assurance that the system will detect leak events as intended. Using the data from all of our trials, OptaSense have been able to produce a specification indicating the minimum detectable leak size and expected response times for the leak detection system (Table 1).

For the smallest leaks, the only indicator may be an NPP, at the instant pipeline integrity is lost. As such, this is considered to be the most valuable signal and can generate a Leak NPP alert by itself. While the detection is almost instantaneous, the stated 1-minute response time accounts for the amount of time required for a trained operator to acknowledge, investigate, and confirm the alert.

The other three modes of leak detection are less sensitive and for larger leaks the NPP detector is augmented with a fused leak approach. This builds confidence by combining detections from each of the leak modes. Recognizing that not all leaks are the same, it is not necessary for all leak modes to be present for the system to identify a leak.

FIELD DEPLOYABLE SYSTEMS

While it is of course valuable to verify performance in controlled trials it is recognized that clients often prefer reassurance from in-field validation on their own pipelines. To this end we have developed several methods for undertaking in-field validation while addressing the obvious issues that arise with starting an actual leak.

1. Burst disk testing at convenient access valves allows the generation of NPP signals within the pipeline (Figure 9). While this test does require confinement in the pipeline, the rapid reaction time of the test allows integrity to be restored swiftly and without significant loss of product. Where environmental contamination is a concern the product can be released into a suitable container for capture. Alternately, it may be a viable option to replace the product in the pipeline for the purposes of testing.

Early in 2019, a client undertook burst disk testing of their own to demonstrate the operation of the system while OptaSense engineers were available to provide remote support and guidance. After identifying and resolving an issue arising from a trapped pocket of air in the pipeline the testing was completing successfully.

Buried Pipeline Performance	Typical Sensitivity	Response Time		Location Accuracy
		Typical	Variances	
Liquid Leak NPP	15 LPM	1 min	/	±10m
Liquid Leak All Modes	150 LPM	5 min	1 to 15 min	
Gas Leak NPP	2000 SLPM	1 min	/	
Gas Leak All Modes	5000 SLPM	5 min	1 to 15 min	

Table 1: Sensitivity and Response times for OptaSense Leak Detection System

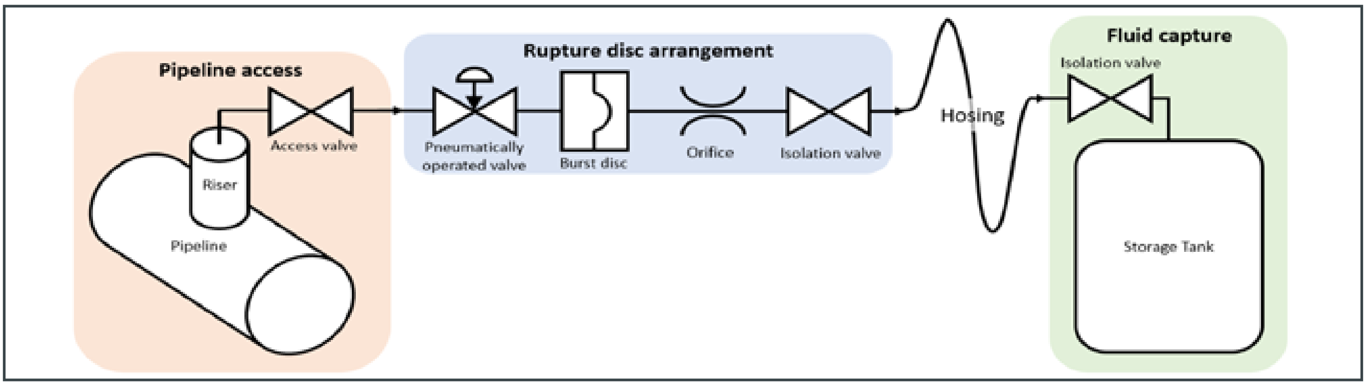

Figure 9: Schematic showing arrangement for in-field burst disc testing

2. Ground fluid injection at high velocity allows replication of the signals associated orifice noise, strain and temperature effects on the fiber (Figure 10). These leak signals require extended durations in order to validate performance, which can only be undertaken with environmentally safe materials. An injection probe is inserted into the ground on the opposite side of the fiber to the pipeline at an equivalent offset. This reduces the likelihood of pipeline damage from probe installation and during the test itself. OptaSense's system is capable of gas injection at flow rates and pressures which are selected to best simulate a given pipeline's likely leak mode.

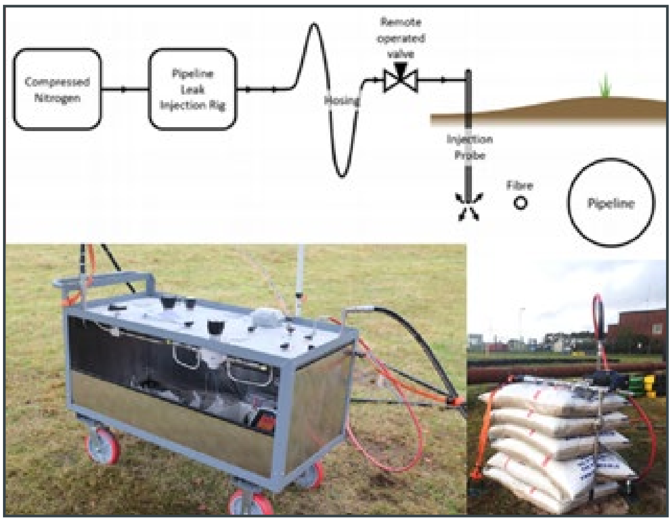

Figure 10: Schematic showing arrangement for ground fluid injection testing

3. The response of the leak detection system is the result of physical changes to the monitored optical fiber. Recognizing that it is difficult and undesirable to replicate a physical leak, the OptaSense Leak Simulation Unit (Figure 11) allows stimulation of a test fiber with representative signals that have been obtained from other leak tests. In a similar way to how a loudspeaker replicates electronic signals in a form that we can hear, the effects of a leak on a fiber are recorded using a quantitative DAS system, which can then be replicated via a fiber stretcher. This portable system can be connected into a system at suitable access points. The system is a point stimulator and, as such, the NPP signal cannot be replicated by this method.

Figure 11: Image of Leak Simulation Unit

In the future there is a desire to offer leak validation through the injection of synthetic data. While the synthesis of data is a relatively simple task, without empirical data obtained from real-world trials there is no guarantee that synthesized data is truly representative of a leak. In support of this goal, OptaSense have employed quantitative systems wherever possible during leak testing in order provide the basis for understanding and developing the representative models necessary for synthesizing leak data.

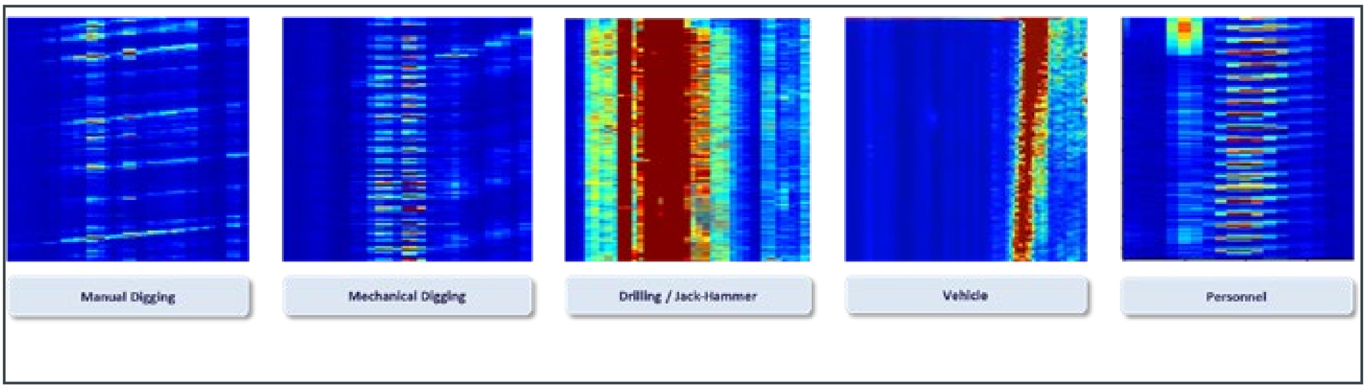

Figure 12: TPI activities can be classified by their unique fingerprints

THIRD-PARTY INTRUSION (LEAK PREVENTION)

Pipeline leaks may occur naturally while others may be the result of intentional sabotage. The second of the three core capabilities in a DFOS PIMS system is for the monitoring of TPI. A prelude to intentional sabotage will be likely to include a range of activities in the vicinity of a pipeline. Such activities involve personnel and manual or mechanical tools, which can be detected and categorized by the DFOS PIMS system. Of course, there can be other reasons to monitor for TPI beyond the prevention of pipeline leaks.

The presence of digging and drilling in the vicinity of a pipeline are likely to be of great concern while vehicle movements and the presence of personnel may simply require operator awareness. DAS systems can detect and classify these events based on the unique fingerprint of each activity (Figure 12).

For example, the basis of detecting activities such as personnel movements and digging is the detection of a series of impulses. However, there are distinctive features to each activity that allow separate classification. Personnel signals will generally consist of periodic impulses that move at a walking pace along the fiber while digging will be more intermittent and remain in one location. Mechanical digging can be separated from manual digging by virtue of larger amplitude signals and the presence of tones arising from the engine.

An issue of great concern to some clients is that of illegal hot tapping. In the build up to a hot tap event, there will be detectable activities observed in the vicinity of a pipeline prior to the event itself. Personnel and vehicle movements, digging and drilling are all likely to occur in a localized area and be detected by the DAS system. As alerts are raised on these events an operator can raise a suitable response prior to the pipeline integrity being compromised. Not long ago, a client observed unusual activity on their system – several vehicle alerts along with personnel and digging alerts over several minutes at a single location. In response to these alerts the operator informed the local security who were dispatched to the identified location. A search of the area revealed fresh ground disturbance and a cache of tools was discovered under nearby bushes. Thankfully, on this occasion the pipeline was not compromised.

SCRAPER TRACKING

The final area where DAS can be employed is in the tracking of scrapers through a pipeline. As the scraper interacts with the walls and features of the pipeline it generates considerable signal. The ability to identify and track the scraper is a valuable capability for several reasons. Figure 13 shows a scraper being tracked through a 33 km monitored section of pipeline.

Foremost, the signal generated by the scraper has the potential to be a source of nuisance alarms. Key to suppressing such alarms is knowledge of the location of the scraper. Further benefits arise from knowledge of how the scraper is moving through the pipeline. The speed at which the scraper is moving can allow estimation of the arrival time at destination, while variations in the speed can indicate restrictions on flow such as the build-up of material within the pipeline or even pipeline damage. It is possible that a scraper could become completely stuck and knowledge of the accurate location of the scraper will minimize the cost and time of recovery.

SYSTEM ARCHITECTURE

The distributed architecture of the OptaSense DFOS system is one of its greatest strengths. In principle, a single operator from a single location can monitor several thousand km of asset. Of course, in practice this is too much for a single operator and it is more realistic that multiple operators will have access from multiple locations.

A typical system architecture is shown in Figure 14. Enclosures along the length of the asset house two optical interrogation units to provide up to 100 km of fiber optic

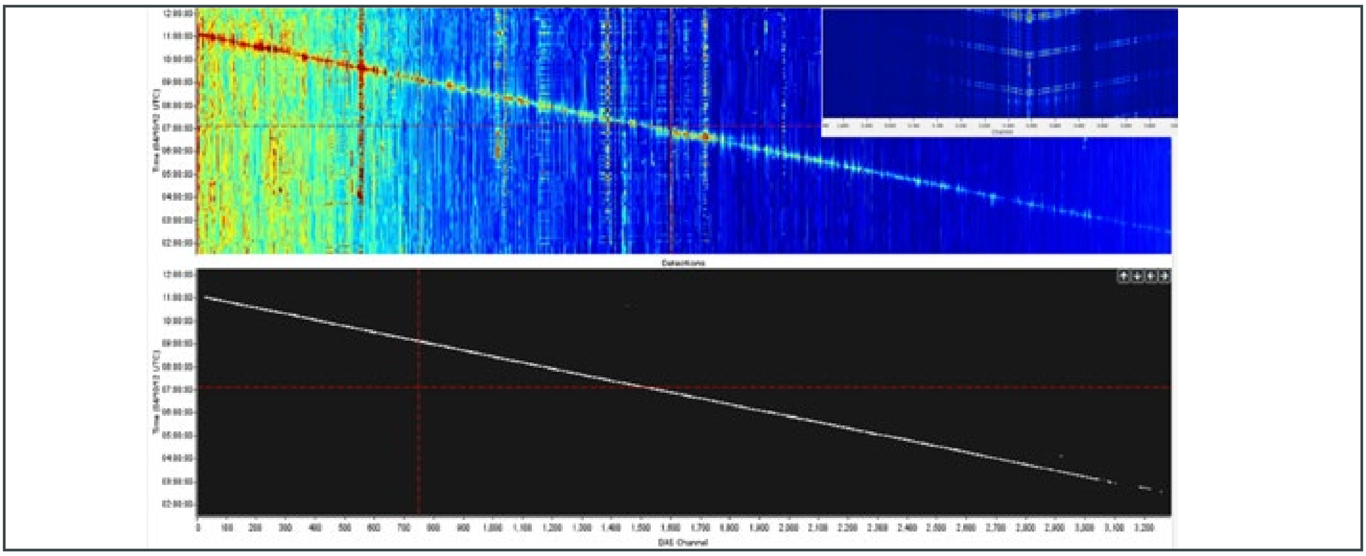

Figure 13: (Top) Waterfall showing scraper travelling 33 km over a 9 hour period; (Bottom) Scraper detections used to track path through the pipeline; (Inset) Magnification showing the pressure wave signal generated by a scraper

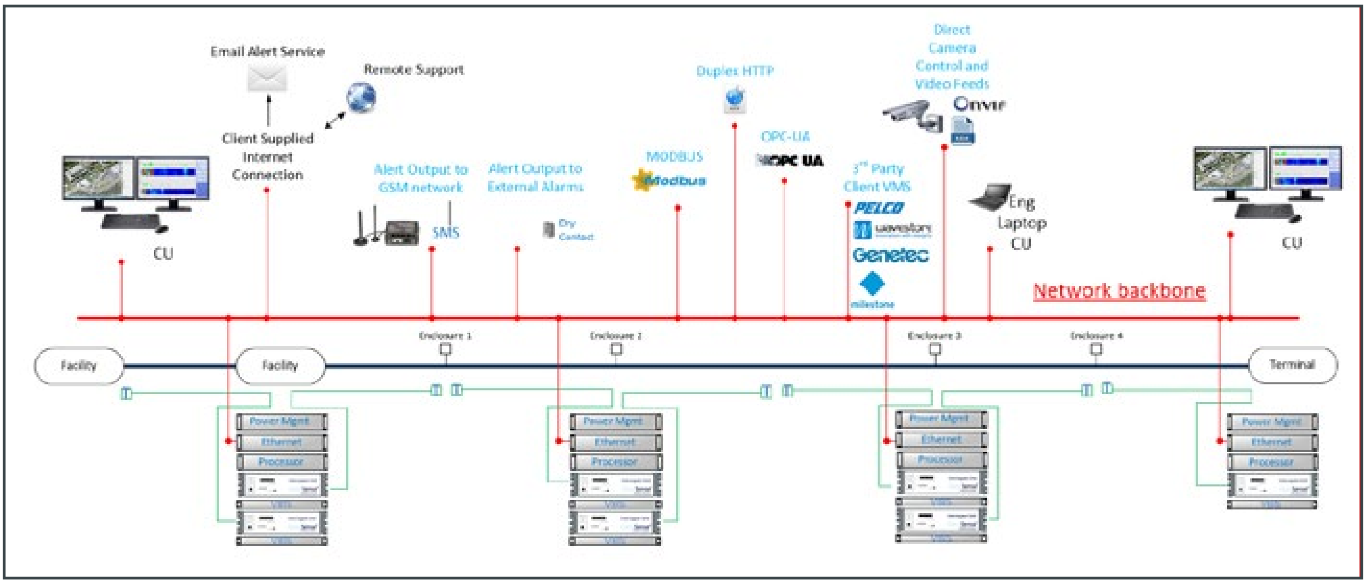

Figure 14: Schematic of typical system architecture

coverage from each site. Each enclosure is networked together (via another optical cable) to provide 'anywhere' access. The networking of all the systems supports the database redundancy of the OptaSense system that allows nodes to be lost/replaced without having to reconfigure the entire system.

At any location along the asset where network access exists, control units have access to all interrogation systems that are installed to allow remote monitoring, tuning and configuration. Furthermore, where external network access can be provided OptaSense have a 24/7 support team ready to provide remote assistance. The network backbone also provides connectivity for external services such as forwarding alert information, controlling networked cameras and directing UAVs (unmanned aerial vehicles) where to go.

While fully networked, the OptaSense control software allows configuration of each control unit to be limited to that necessary for the operator. For instance, in a pipeline control room one device could be configured for pipeline security (TPI) while another is configured for pipeline integrity (leak alerts) and another for pipeline operations (scraper tracking). Each operator is presented with what appears to them as a dedicated system. Ultimately however, they are all using the same underlying sensor.

FIBER INSTALLATION

In principle, DFOS systems can be implemented within existing telecommunication infrastructure on any spare, single-mode fiber optic cables. However, for leak detection capability the proximity of the cable to the pipeline is critical and OptaSense specify performance on the basis that the fiber is installed within half a meter of the pipeline. Outside of this range it is expected that performance will be diminished. For TPI classification the proximity to the surface is the important factor and ideally the fiber should be within 0.5 m of the surface.

SUMMARY

Distributed Fiber Optic Sensing provides a suite of pipeline monitoring capabilities from a single integrated platform.

- Thousands of km of pipeline can be monitored in real-time to provide the intelligence that supports pipeline security and integrity. The platform offers additional benefits such as scraper tracking and multiple other potential applications.
- Leak detection performance that exceeds conventional systems with the capability to detect extremely small leaks almost instantaneously. A range of validation approaches are available which can be used to highlight this performance on any field-deployed system.
- The underlying sensor can be existing fiber optic cables or custom-installed; and while interrogator units may improve and change over time, the underlying sensor - the fiber optic cable – will stand the test of time meaning that costly groundworks to repair/replace the sensor are an unlikely scenario.
- The future of Rayleigh DFOS promises even greater pipeline monitoring capability with quantitative systems enhancing the detection sensitivity and providing a means for absolute temperature and strain monitoring.

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Optimize your pipeline integrity program and get greater control and responsiveness

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Ready for use under operational conditions

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10x Cost Advantage
Regular inline inspection of pipelines has become a reality

The operating system for pipeline integrity

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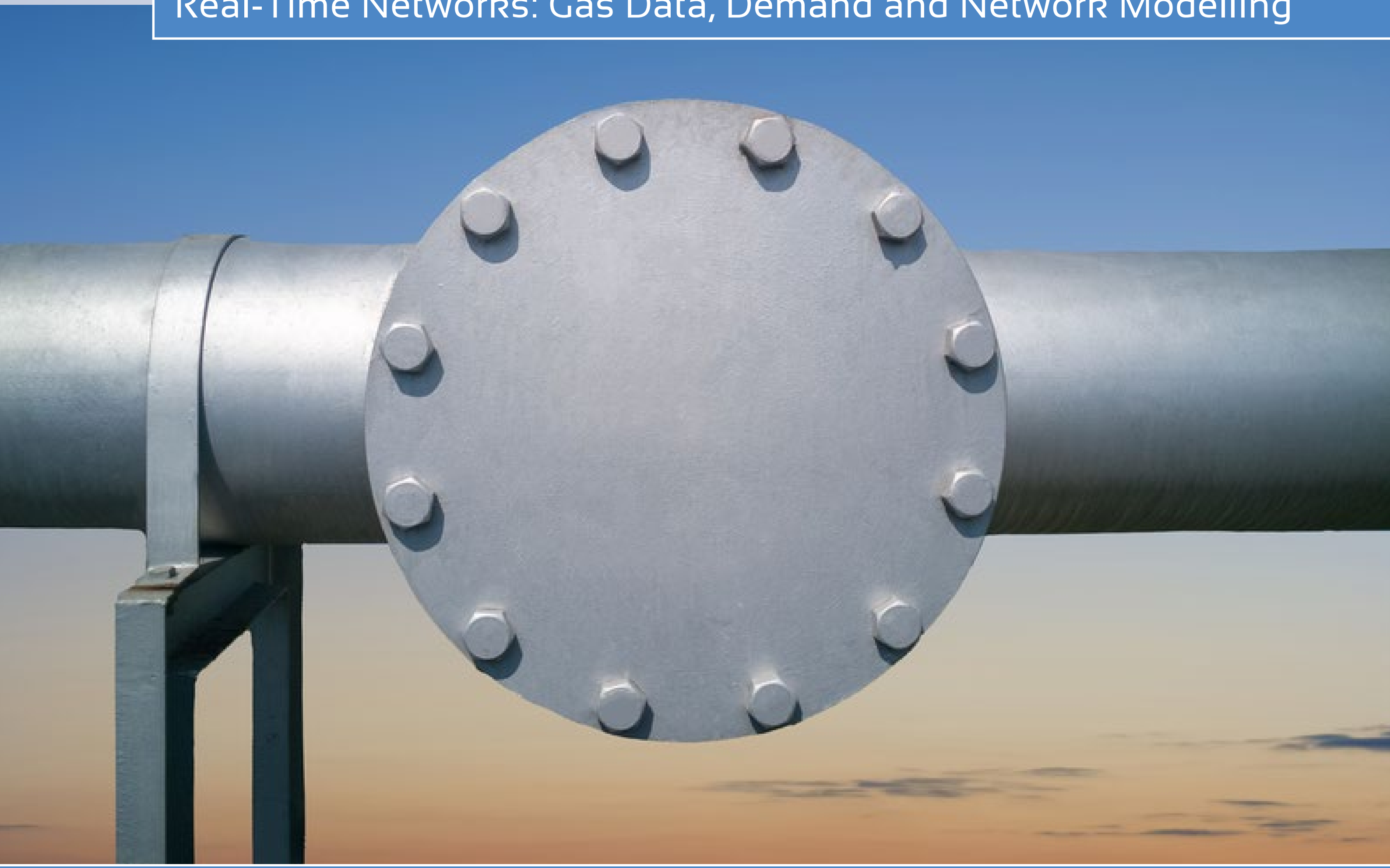
Real-Time Networks: Gas Data, Demand and Network Modelling



David Gower, Sarah Kimpton, Andrew Gordon > DNV GL

Abstract

The gas industry in Great Britain has experienced fundamental change over the last 20 years and is continuing to change rapidly. There has been a reduction in indigenous supply, with an acceleration in the connection of new unconventional sources through biomethane supplies and the potential for hydrogen blending in the future. These changes are targeting the transition of the gas system to meet the requirements net zero emissions by 2050.

Added to this there have been significant changes in consumer behaviour and use of gas, combined with the advent of downstream renewable technologies.

With over 80% of GB peak energy demand supplied by the gas network, the gas system has a very significant role to play in the journey to a lower carbon future. Key to this is a flexible distribution network that can be adapted to the evolving energy needs of the country.

The GB gas networks methods for network modelling and management are outdated, however. They are based on a transmission network spine, supplying downstream distribution networks fed by a consistent source of natural gas with a limited range of Calorific Values (CV). Current demand algorithms have been developed to ensure security of supply at a peak demand condition, and 'snapshot' steady state modelling at a worst-case scenario underpins all capital and investment within the distribution networks. Off-peak analysis of the system is achieved through basic scaling of these peak values.

These demand algorithms are based on research carried out in the early 1980s and are basic in their approach, lacking the flexibility needed for modelling the current and future requirements of the gas system. The emergence of unconventional sources of gas, such as biomethane, and the potential for changes in quality requirements, and thus range of CV, for gas allowed to enter the system, require far greater network modelling capability to ensure efficient network design and management.

This paper is formed from extracts from the soon-to-be-published Real-Time Networks Report to the Gas Industry.

PROJECT AIMS

The RTN project, awarded overall funding £7.4m through Ofgem's Network Innovation Competition, commenced on 01 April 2016 and was completed on 01 April 2020.

The aim of this project was to create a real-time modelling approach that will enable a gas network for the future that is flexible, secure, cost effective and safe. The objective was to provide the detailed understanding of bottom-up demand, and its application in network modelling of the below 7 bar systems, which will be the basis for optimal gas network design and operation.

The project sought to meet the complex needs of the modern energy market, with gas central to the overall mix and to decarbonisation. This included a requirement to develop an understanding of the challenges facing the gas industry by undertaking a pilot demonstration of a real-time network.

A planned and controlled trial on a typical gas distribution network was carried out, incorporating existing SGN infra-structure, as well as new sensors and loggers, to provide the data for testing the real-time network concept.

The current algorithms used for demand estimation are documented in the IGEM Guidance IGE/GL/1 "Planning of gas distribution systems of MOP not exceeding 16 bar". It is anticipated that if output from the project is adopted by the industry the update of that guidance will follow.

PARTICIPANTS

SGN – Distribution Network (DN) funding licensee - re-sponsible for:

- Project direction, management and support in critical areas

DNV GL – project partner - responsible for:

- turnkey installation of sensing equipment
- provision of cloud services
- development of demand modelling, network analysis approaches and prototype systems

Other participants, selected for their competence in key roles, were:

Orbital Gas Systems
Main contractor for installation of sensor equipment.
Kiwa UK
Laboratory testing of consumer renewable technologies.
Technolog Ltd
Provision of consumer flow logging and data collection

DEVELOPING THE DEMAND MODEL

The Real-Time Networks project involved the installation of flow logging at a large number of sites throughout SGN's South East Local Distribution Zone (LDZ) as well as sens-ing technologies in a test area centred in Medway, again within the SE LDZ. The outputs from these flow logging

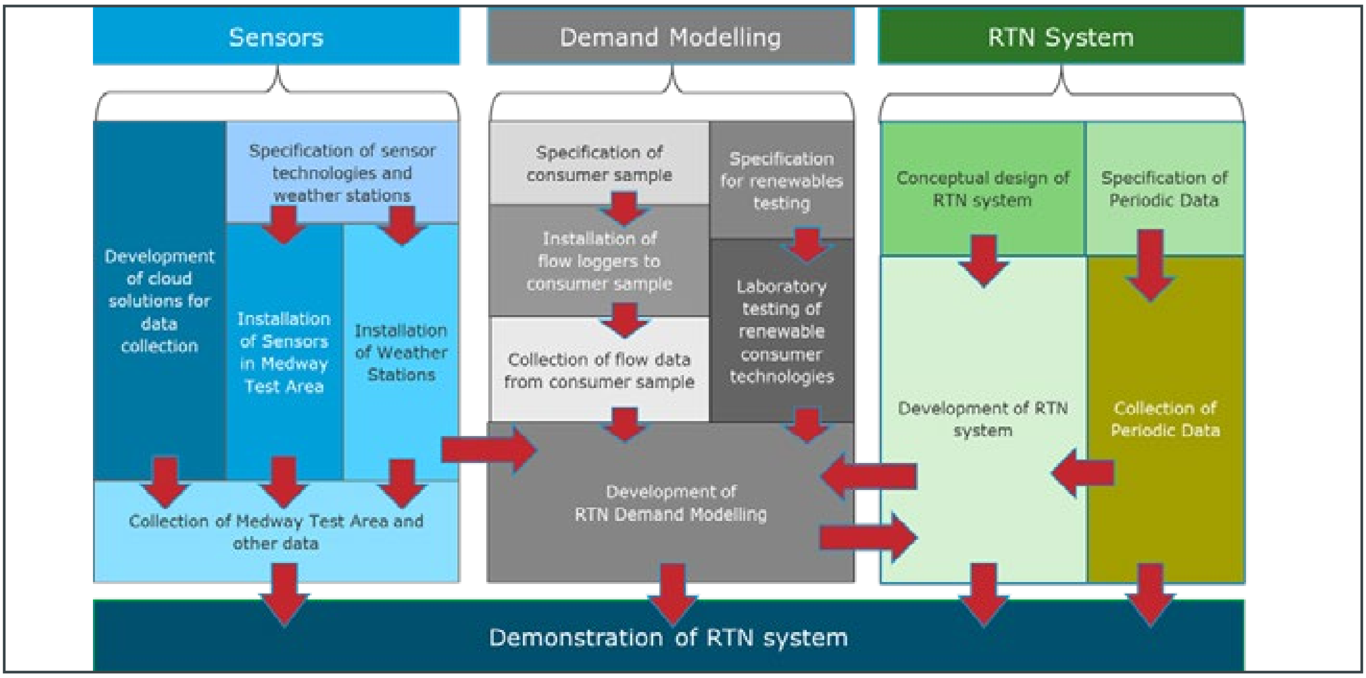


Figure 1: Elements of the RTN project

and sensing technologies supported the development of a Real-Time Network simulation and the revision of network modelling approaches and data management methods. A novel cloud-based system incorporating existing industry standard software was developed, along with a Demand Model that facilitates real-time modelling, analysis and advanced forecasting.

The project sought to create a stream of real-time data and associated 'big data' analytics that allow network operation to be understood and modelled in a more detailed and accurate manner than has previously been possible.

The overall objective was to optimise gas network design and operation assumptions, and the activities involved in achieving this objective were as follows:

- Identify, procure and install consumer meter loggers to measure demand for a statistically representative sample of consumers as part of the field trial;
- Develop a novel cloud communications system to pass data to and from the network model and demonstrate proof of concept for such technologies and interfaces with all components of the system;
- Undertake laboratory tests to develop an understanding of the impact of renewable technologies on gas demand and incorporate the findings within the demand model;
- Develop a Demand Model and a Real-Time Network Model (with network analysis elements carried out using "Synergi Gas" network simulation software) to demonstrate proof of concept of the same.

DEMAND MODELLING IN REAL-TIME NETWORKS

The demand estimation element of the Real-Time Networks project brought together the fundamental principles for accurately modelling both peak and off-peak consumer profiles for all types of consumer demand.

The Demand Model was developed to carry out the following functions:

- Operate at 6-minute, hourly or daily granularities, with the user able to select and switch between these levels as required.
- Define and work with consumer groupings that maximise model accuracy (rather than using the existing groupings from the current demand algorithms).
- Estimate 1:20 Peak 6 demand and off-peak demands for any individual consumer or group of consumers, from a single consumer site up to a full LDZ.
- Calculate 6-minute or hourly consumer profiles for a full day for any set of off-peak conditions supplied by the user (e.g. validation conditions).
- Include a direct continuous relationship between demand and the factors that drive changes in it (weather conditions, time of day, day of week, time of year).
- Calculate both peak and off-peak demands on a node-by-node basis for use in network analysis.
- Include a full treatment of diversity under peak conditions, so that the number and combination of consumers of different types is taken into account in all calculations, with no assumption of coincidence of peaks of the different consumer types.
- Carry out all analyses and return results within an elapsed time that does not inconvenience the user.

MODEL DEVELOPMENT

The statistical models, data manipulation algorithms and validation/verification processes used in the project were first developed during the IFI19 and subsequent Demand Allocation projects carried out for National Grid Distribution (now Cadent Gas Ltd) between 2008 and 2015. These models form the basis of the work carried out for the Real-Time Networks project. The following models were built and/or project areas addressed in the development of the Demand Model:

- The Demand Model
  - Off-Peak Demand Estimation
  - Scatter Estimation
  - Peak Calculation (statistical optimisation for the 1:20 peak demand)
  - Between and Within Group Diversity – recognising that not all consumers of the same type take gas at the same time and consumers of different types will have profiles of flow that are distinct from other consumer types.
  - Demand Scaling – recognising that individual consumers behaviour will vary in scale for one consumer to another of the same type.

- Consumer Categorisation
  - Cluster Analysis (for group definition – defining the distinctive grouping that any one consumer will fall)
  - Discriminant Analysis (for group assignment – ensuring that all consumers from across the LDZ may be clearly identified as falling into the groups identified from the cluster analysis)
  - Categorisation quality scoring

The SGN Demand Model has been trained using the full set of available logger data, which covers the time period from 01/12/2017 to 31/12/2019. The training range contains two full winters and two full summers and includes both extreme cold conditions (including the "Beast from the East") and hot summer conditions.

- The Peak and Off-Peak Accuracy Assessment Tool
  - o Designed to facilitate high volume runs of the Demand Model under a wide variety of conditions for training and testing
  - o Enables Demand Model optimisation and performance testing

For the Real-Time Networks Project, additional development work was carried out in all these areas. The models were then retrained on new data and applied to SGN networks, and detailed quality assurance work was undertaken to prove the fitness for purpose of all of the models and algorithms.

The Demand Model is the foundation upon which the whole RTN approach is built. Whilst there are a large number of innovations within the scope of the project, these are all based on the fundamental principle of improving the accuracy and flexibility of demand estimation. Accurate demand estimation means that modelled demands will be closer to reality, at every level from single consumers up to full networks, and for any set of peak or off-peak conditions of interest. This information can then feed into network modelling and provide the basis for all of the innovations associated with the RTN project. The Model was therefore developed to fulfil the requirements for modelling the gas system: to provide a direct link between specified conditions and demand, to allow accurate estimation at any level of the network, and to facilitate a full and accurate application of diversity. These are all areas where the broad-brush approach of the IGE/GL/1 equations introduces inaccuracy, and it is therefore these areas that were targeted in the design and implementation of the RTN Demand Model.

CONSUMER DATA FOR DEMAND MODELLING

Regardless of the statistical composition of the Demand Model, its output can only be as good as the data used to train it. Therefore, a great deal of care was taken to ensure that the logger samples were appropriate, in terms of the sample sizes, the geographical spread and the quality of data returned.

Loggers were installed at both domestic and non-domestic sites throughout SE LDZ during 2017, with the sample stratified into six sub-regions of the LDZ to ensure that it was representative not only by usage type but also geographically. Sample sizes were specified for each consumer type/sub-region stratum and the logger installation process managed to ensure that these targets were hit. The resultant distribution of sites across the LDZ for each consumer type is shown in Figure 2.

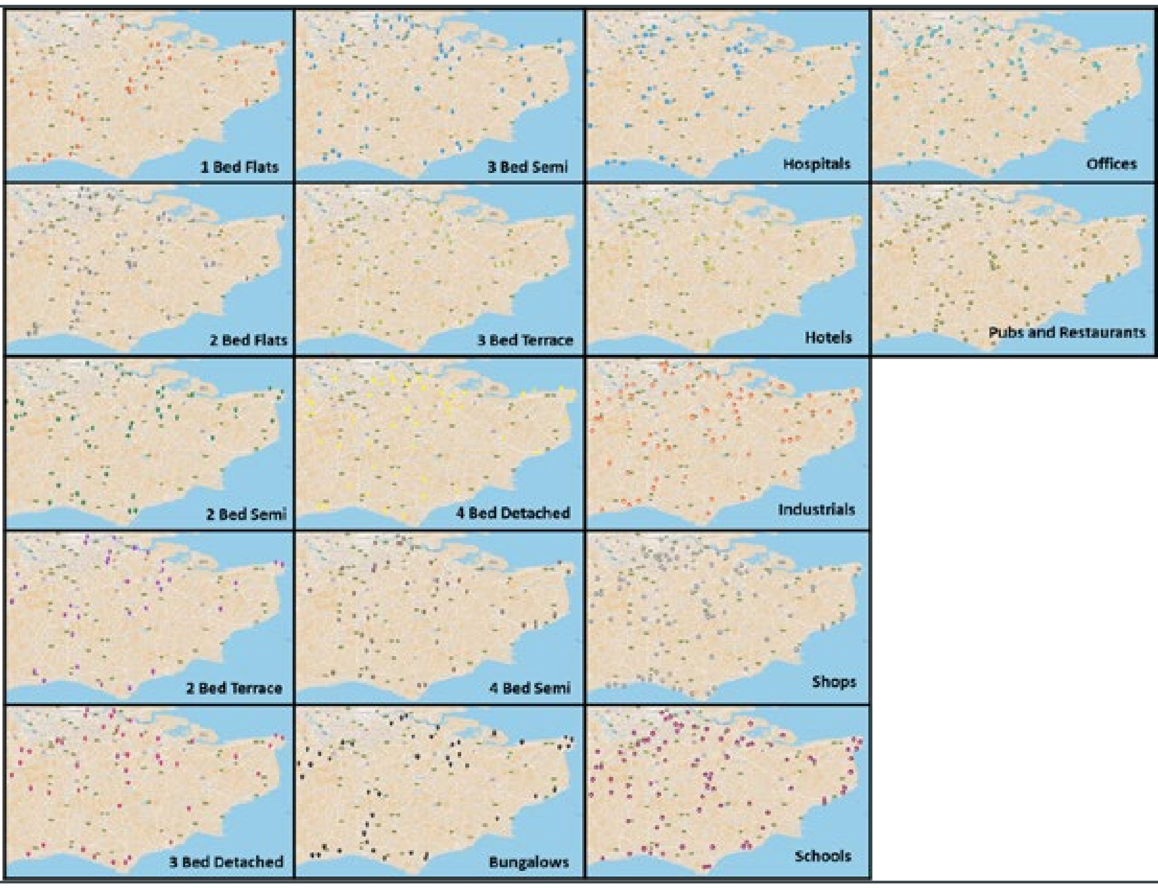


Figure 2: The distribution of the consumer sample by Post Code across the South East LDZ

In total, 1194 loggers were installed during the RTN project. Of these, 1004 returned sufficient good-quality data to be included in the final training process. When simulated data is included, all of these loggers contain full uninterrupted data for the full training period (761 days, making a total of 182,640 6-minute periods).

In addition to its core 6-minute functionality as described above, the Demand Model also works at hourly and daily granularity levels. The base calculations in the model are always carried out at the 6-minute level regardless of the output granularity, and so the majority of training is at this level. When running at hourly or daily levels, the base 6-minute time periods are aggregated to the output granularity as appropriate during the course of the run, and as such some of the training process needs to be carried out individually for each of the available options. In particular, diversity relationships are required that are specific to each granularity.

The definitive training set of consumers was defined for the final train of the model, and the process included the following steps:

1. Retrieve all available flow data for all loggers.
2. Run quality assurance process on all logger data – removing loggers with insufficient valid data or suspect consumer profiles.
3. Replace all gaps in data from retained loggers with simulated data.
4. Aggregate data to consumer type level. Train consumer model and variation model (at 6-minute granularity) for each consumer type.
5. Carry out quality assurance of fitted data from the new models.
6. Generate diversity curve sets for each consumer type at each granularity level.
7. Generate off-peak adjustment factors to optimise Demand Model performance across all background conditions (Composite Weather Variable (CWV) and Day of Week).
8. Carry out up to 10,000 test runs per consumer type using the Accuracy Assessment Tool. These cover all consumer group sizes from 1 (single consumer) to the maximum number of sites available for each consumer type. For each run, results from the Demand Model were compared against actual logger data to ensure maximum accuracy of the model under all conditions and for all consumer group sizes.

Example daily and 6-minute consumer profiles for randomly selected loggers at different types of site are shown in Figures 3 to 6 (anonymised). These typically show the expected annual consumer pattern, with a degree of temperature sensitivity at all types of site, along with the less predictable on/off within-day profiles of the 6-minute consumers.

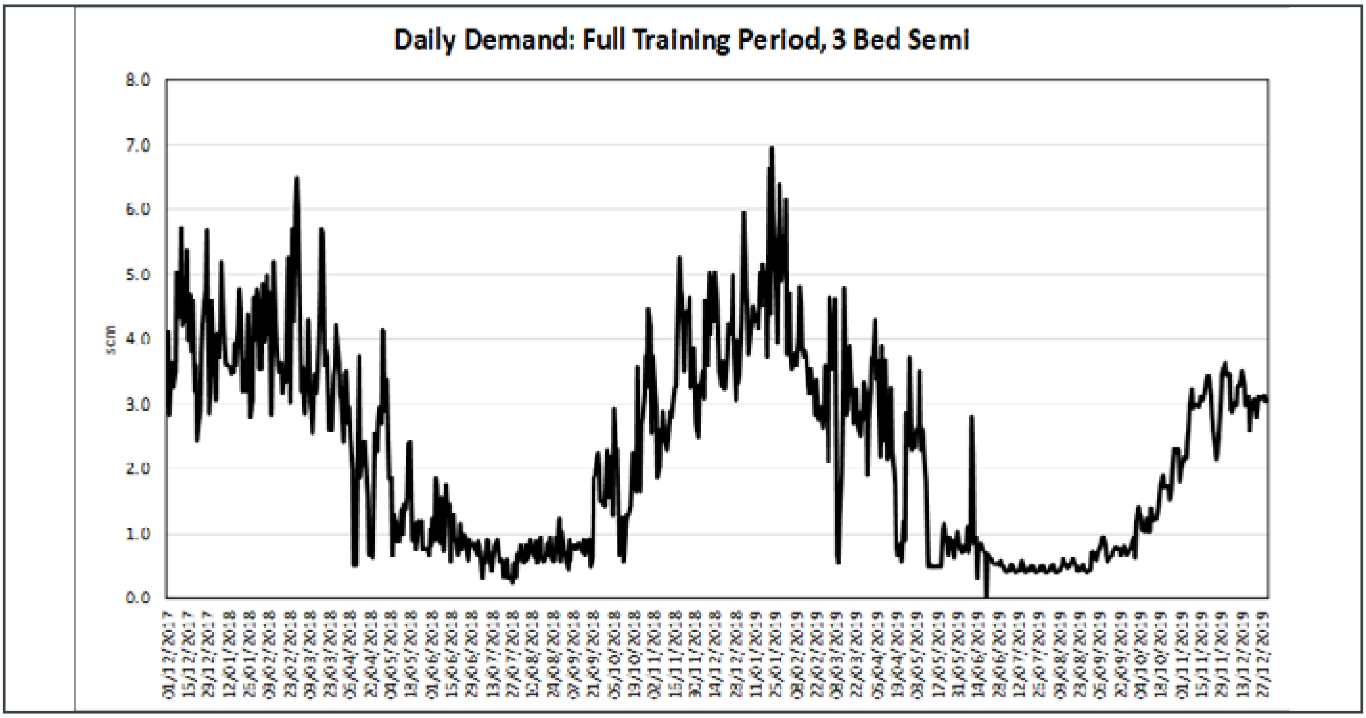


Figure 3: Daily Demand – Example 3-Bed Semi

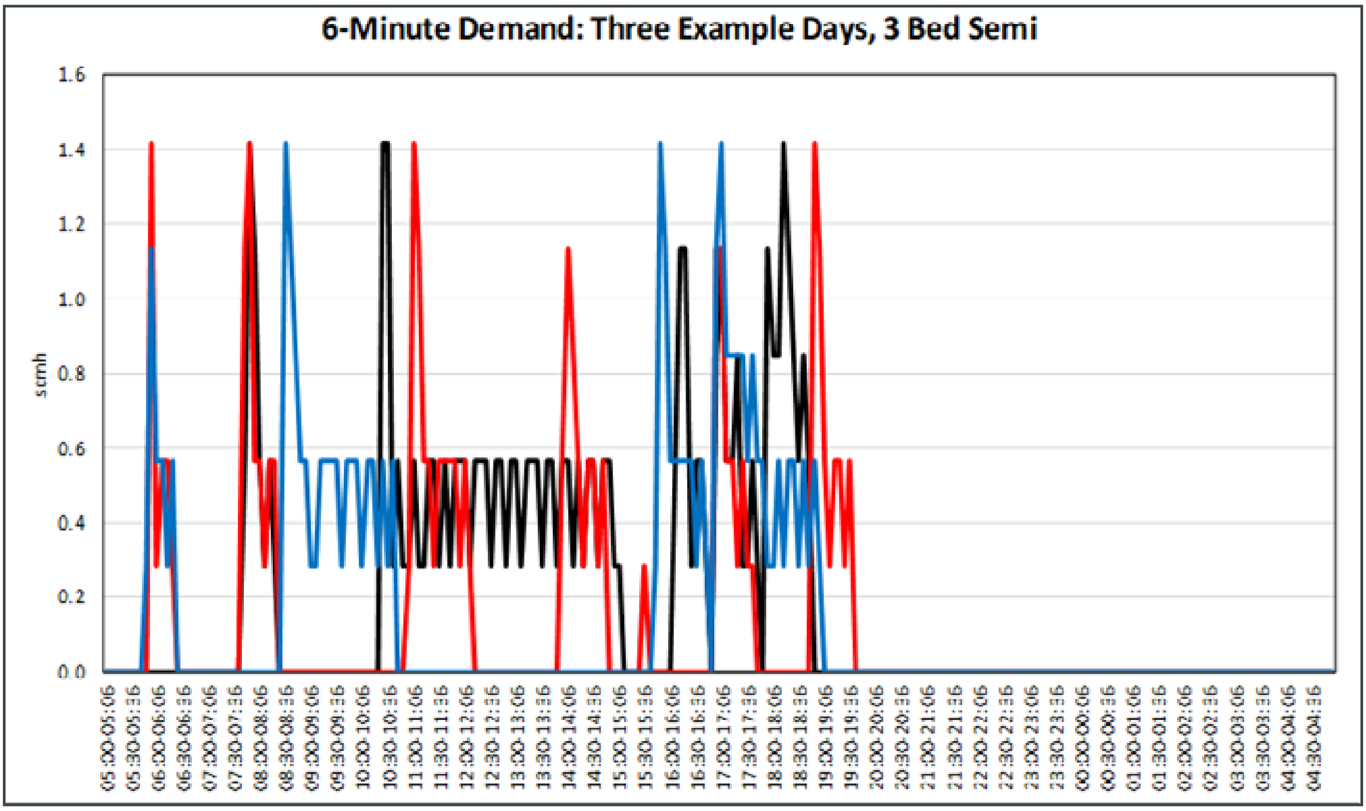


Figure 4: 6-Minute Demand – Example 3-Bed Semi

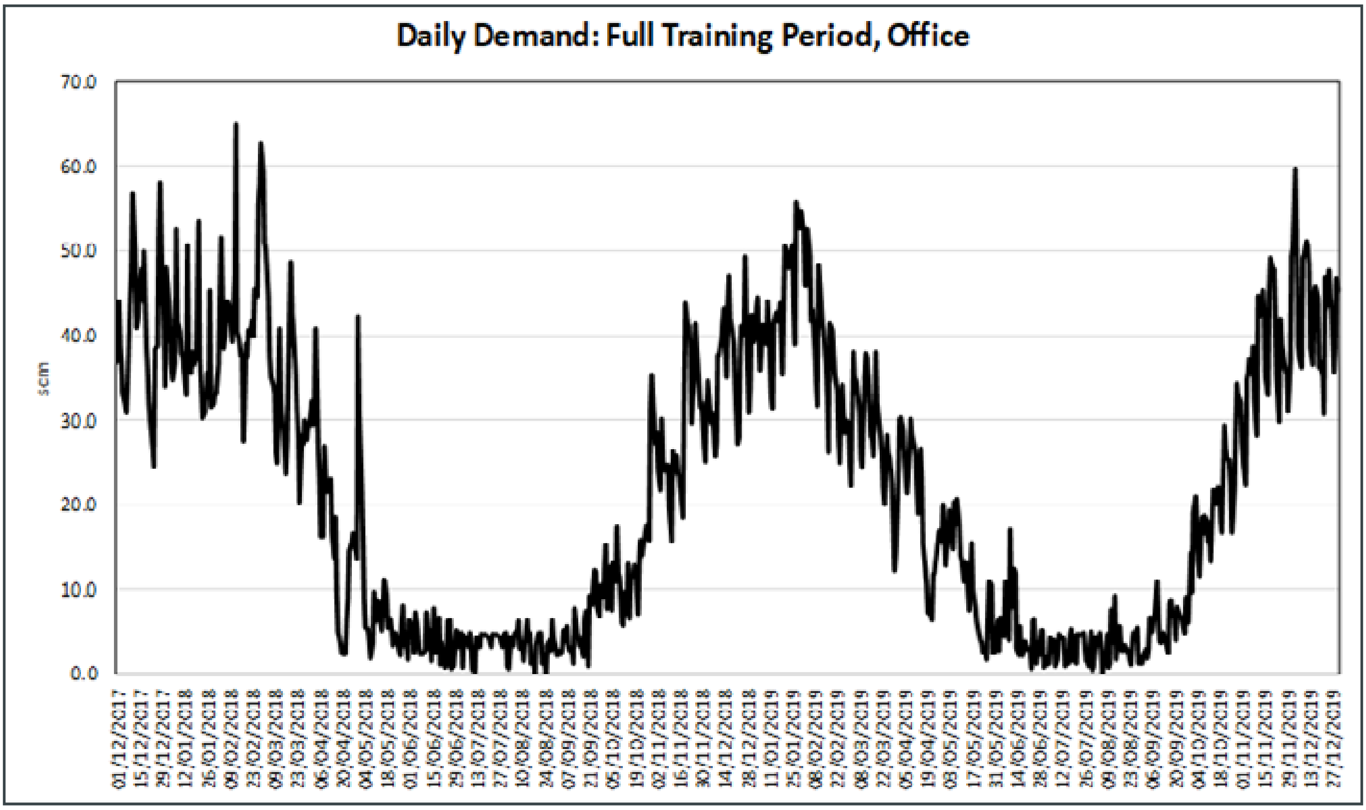


Figure 5 : Daily Demand – Example Office

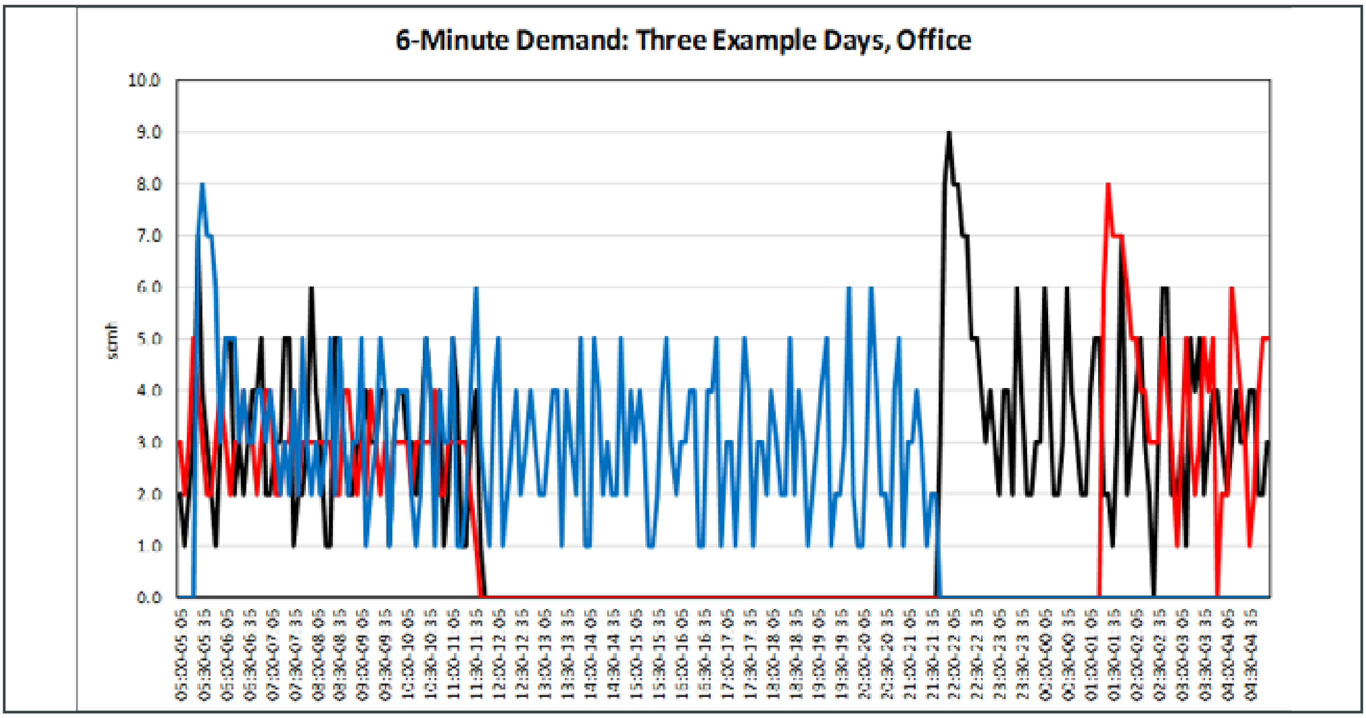


Figure 6: Daily Demand – Example Office

Domestic Types	Non-domestic Types
• 1 Bed Flat	• Offices
• 2 Bed Flat	• Shops
• 2 Bed Terrace	• Hospitals
• 3+ Bed Terrace	• Further Education
• 2 Bed Semi-detached	• Primary Schools
• 3 Bed Semi-detached	• Secondary Schools
• 4+ Bed Semi-detached	• Hotels and Multiple Occupancy Domestics
• 3 Bed Detached	• Pubs and Restaurants
• 4+ Bed Detached	• Industrials
• Bungalow	

Table 1 The RTN consumer classification categories

TESTING THE PEAK DEMAND MODEL – BACKGROUND

The Accuracy Assessment Tool approach ensures that the Demand Model is accurate over all of the consumer categories, run group sizes and background conditions that can be tested. Each run consists of the Demand Model estimate being calculated and compared to actual data from randomly-constructed groups of logger sites, which means that the Demand Model is always tested against actual data from the field, under all conditions.

An example of the Accuracy Assessment Tool output is given in Figure 7 for a 3 Bed Terrace house.

These results show that the 1:1 estimate from the Demand Model (the red line on the graph) remains very close to the actual observed 1:1 from the consumer logger data for all group sizes. This is evidenced by the ratio of these two values staying close to 100%. This shows that a high degree of confidence can be held in the model output as it has been shown to be accurate in calculating the 1:1 peak for all tested conditions. The 1:20 peak is calculated using exactly the same principles, and so the same degree of confidence can also be held in these estimates.

These results are consistent with the accuracy figures for the Demand Model quoted across all stages of the RTN

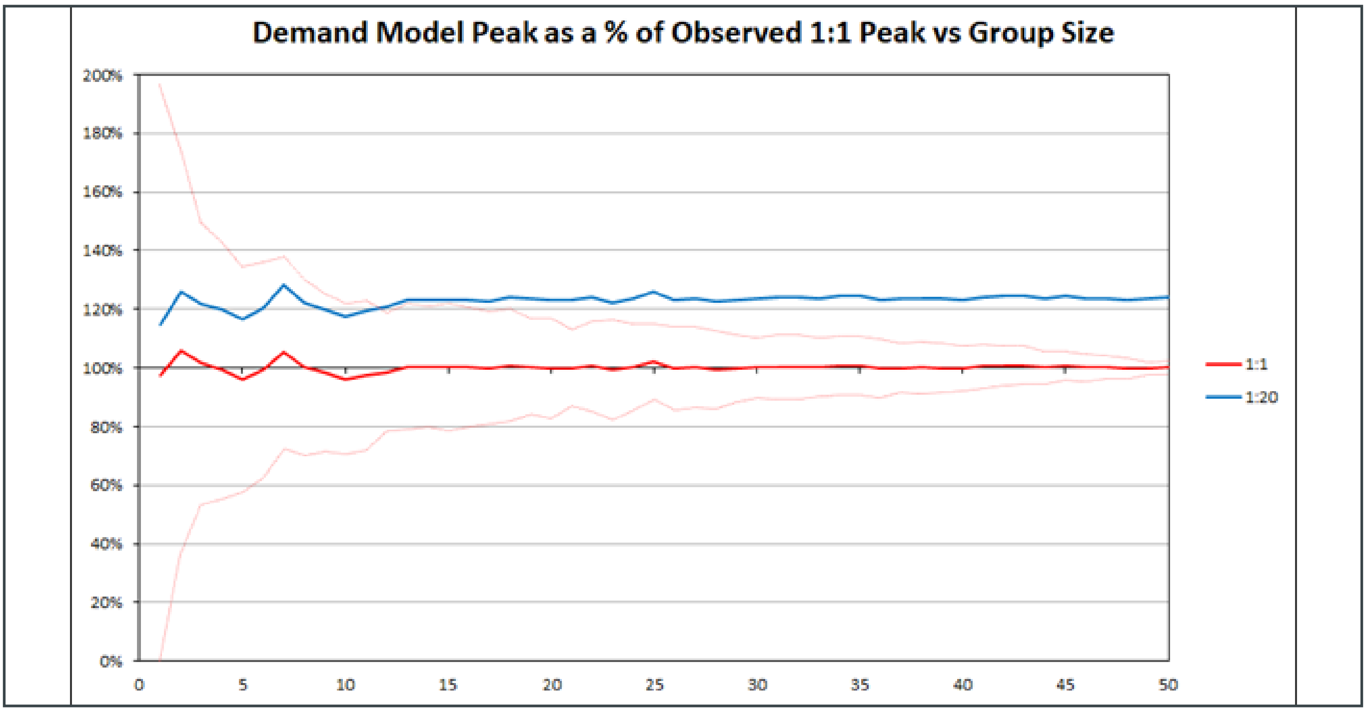


Figure 7 – Demand Model Results: 3BT

project. In the final train of the model not only is the full set of 2+ years training data available for use, but actual logger data for the same time period is available for this performance verification process. This means that a wide range of conditions is represented in the test dataset and that a high degree of confidence can be held in the actual peaks that the Demand Model is optimised to and tested against.

Critically, the testing of the Demand Modelling through the Accuracy Assessment Tool shows that the RTN Demand Model is significantly more accurate than the current IGE/GL/1 approaches used by the GB gas industry.

THE APPLICATION OF THE DEMAND MODEL TO NETWORK ANALYSIS

The Demand Model can be applied throughout the RTN System developed in the project to provide analyses for a number of different purposes as outlined in Table 2.

FOCUS ON 1:20 PEAK DEMAND – VARIABLE DIVERSITY

Variable Diversity is the name given to the modelling system, developed for the RTN project, for accurately handling diversity at

Condition / Purpose	Description
1:20 Peak	The theoretical demand level that will occur for one 6-minute instance in 20 years. It is an extreme reaction to cold weather, but is not directly related to a specific weather condition (CWV).
Off-Peak	The typical level of demand which the different categories of consumer are anticipated to experience, dependent on CWV, period of day, day of week, and month of year -output may be at a 6-minute, hourly or daily granularity.
Real-Time	The Real-Time model uses a history of measured demand to adjust the Off Peak demand estimate for a specific site - accurate estimate of demand for up to 48 hours ahead.
Automated Validation	An automated process to determine the range of acceptable pressures that may be seen at a pressure logger location within a network model, for comparison to measured pressure - determine if the model and measured data are sufficiently in agreement for model validity.
Renewable Technologies	A process that adjusts the demand models to reflect the presence of renewable technologies for consumers within the network models. Selected penetration levels applied to network model for analysis.
Long term planning	A planning module that provides the estimation of long-term peak and off-peak demand, incorporating Renewable Technologies.
CV	A network analysis process that provides an estimate of the level of CV at key points in the SE LDZ Medium / Intermediate Pressure (MPIP) network model, based on adjustment of the volumetric analysis of LP networks

Table 2: RTN Prototype System – application of the demand model to network analysis

all levels across complex looped networks. The principle of diversity can be stated very simply: different sites will not necessarily hit their peak demands at the same time. The application of this concept requires knowledge of the number and combination of loads downstream of any given point in a network, so that the correct level of adjustment for non-coincident peaks can be applied. The complexity arises from the fact that low pressure (LP) networks very rarely have a simple tree-style structure where the direction of flow is fixed, but instead have very high levels of complex looping. This creates different flow configurations for different demand conditions, and makes the exhaustive application of diversity extremely challenging. Variable Diversity is the complex iterative method used to solve this problem in RTN.

The approach to diversity embedded in the IGE/GL/1 equations is necessarily very simplistic and can be stated as follows: full diversity for domestics, no diversity for non-domestics. This basic broad-brush approach is necessary for the current equations because there is no "middle ground" with diversity – in order to move away from a system with very basic diversity assumptions, the full, exhaustive Variable Diversity approach is required.

Figure 8 illustrates the 1:20 peak demand and the impact of variable diversity. Key to this approach is that demand at any point in a network model is dependent on the number of consumers, the type of consumers, and the Annual Quantity (AQ) of gas used by these consumers downstream of that point. The accurate treatment of diversity in RTN creates a significant reduction in demand at network source compared to the current approach: if the whole of the Medway Test Area (nearly 29,000 sites) were downstream of a single point the peak flow in that pipe has been calculated as 20,713 scmh, which is some 34% lower than the peak demand calculated by the current demand algorithms. Toward the extremity of the network, in a position where there were only say 50 sites (representing a mix of consumer types) downstream of a point then the flow would be of the order of 44 scmh and would represent only a 12% reduction in demand.

It should be noted that the purpose of RTN is to improve the accuracy of peak modelling, not just to reduce the peak. The "full diversity for domestics" principle stated above for the existing system results in the current equations under-estimating peak demand at domestic extremities where there is little or no diversity between consumers. At these points the Demand Model will return increased demand compared to the current approach.

Despite this increase in demand at a number of extremities, there are significant reductions in pressure drop in

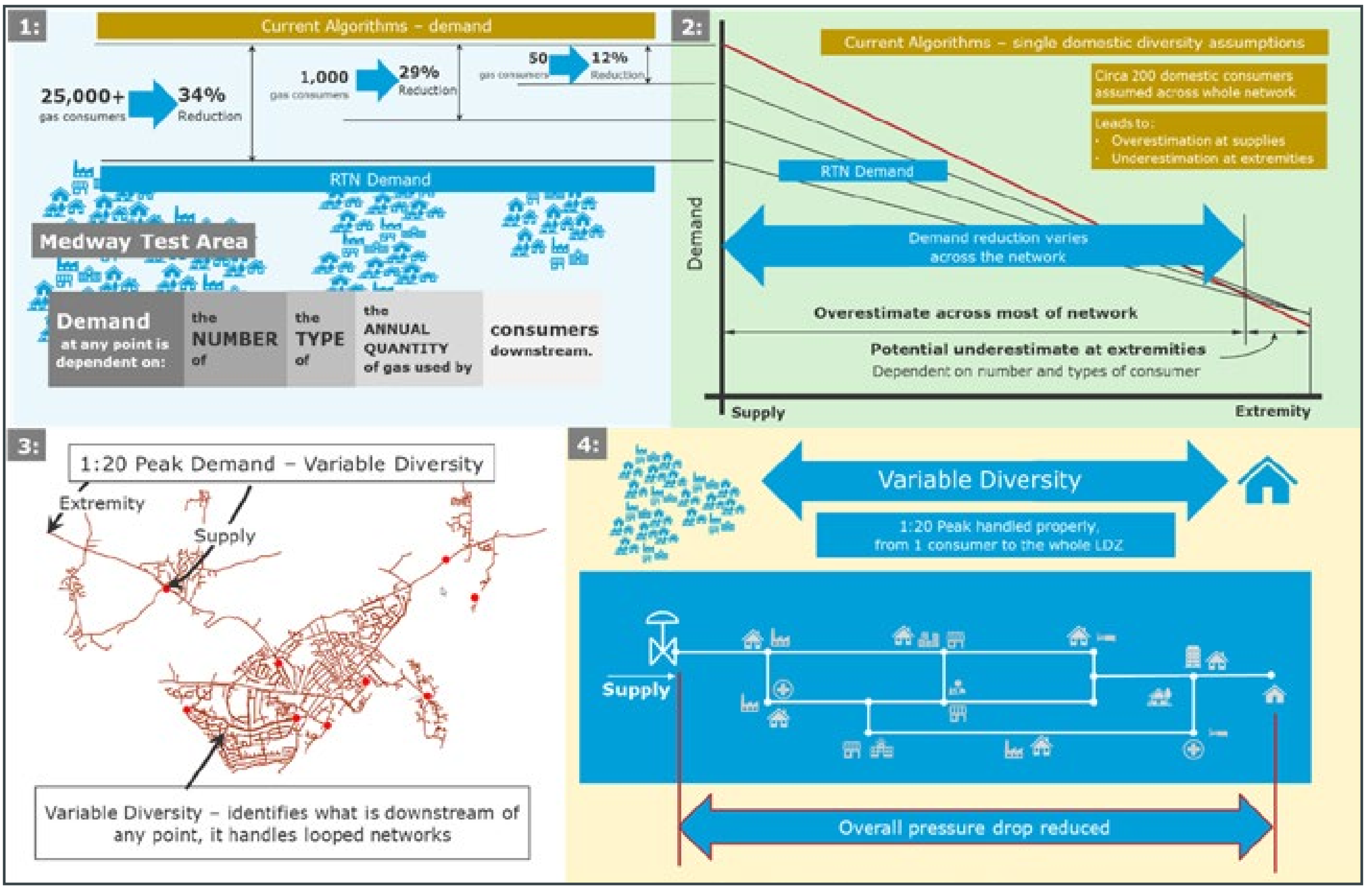


Figure 8: Infographic for Peak Demand Modelling and variable diversity

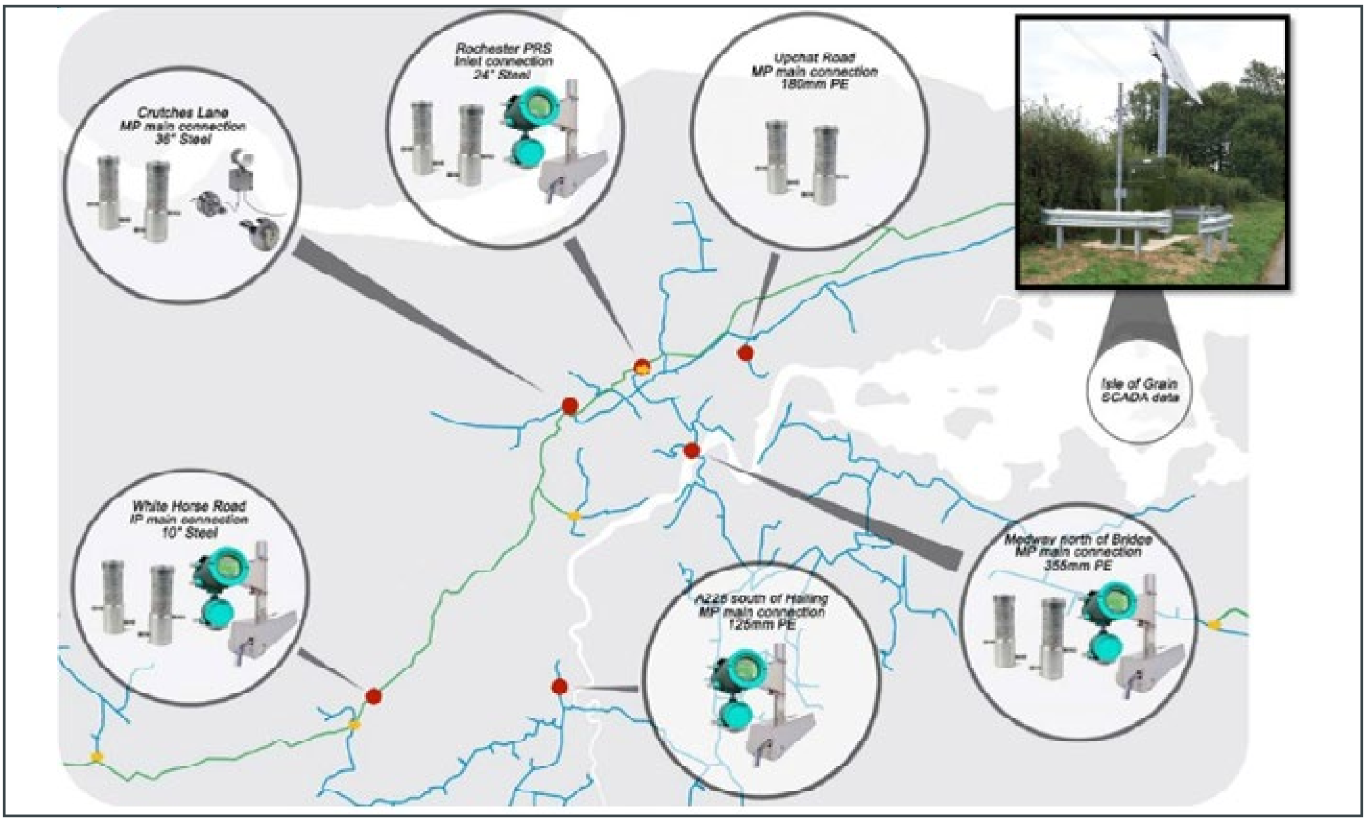


Figure 10: The Medway Test Area

the system due the reduced demand in the remainder of the network. Therefore, it remains the case that the overall pressure drop across the system is very likely to be reduced compared to current modelling approaches.

MEDWAY SENSORS AND THE REAL-TIME NETWORKS PROTOTYPE SYSTEM

Alongside improved demand and network modelling it is always necessary to measure data at points within the network to validate the modelling approach used and to confirm results at key locations where modelling alone cannot provide the assurance needed.

For the RTN project, sensors were installed to provide validation of the network and demand modelling approaches developed in the project and to act as an example of critical data that can be used to give assurance of the day-to-day performance of the modelling system.

The purposes of the different sensor types and calculations used for the Medway Test Area are illustrated in Figure 11.

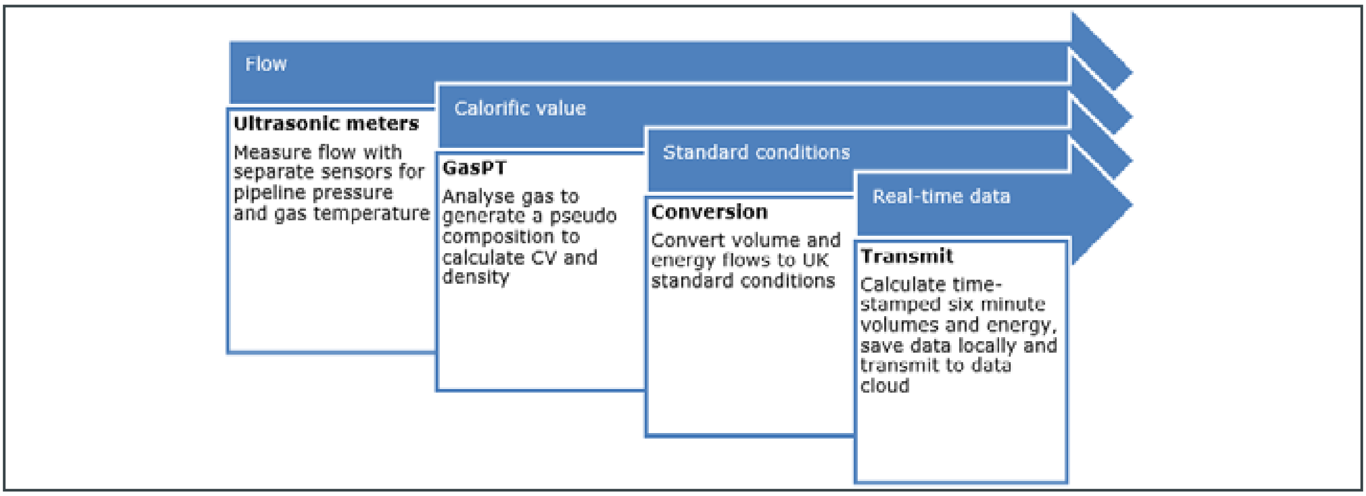


Figure 11: Purpose of the sensors

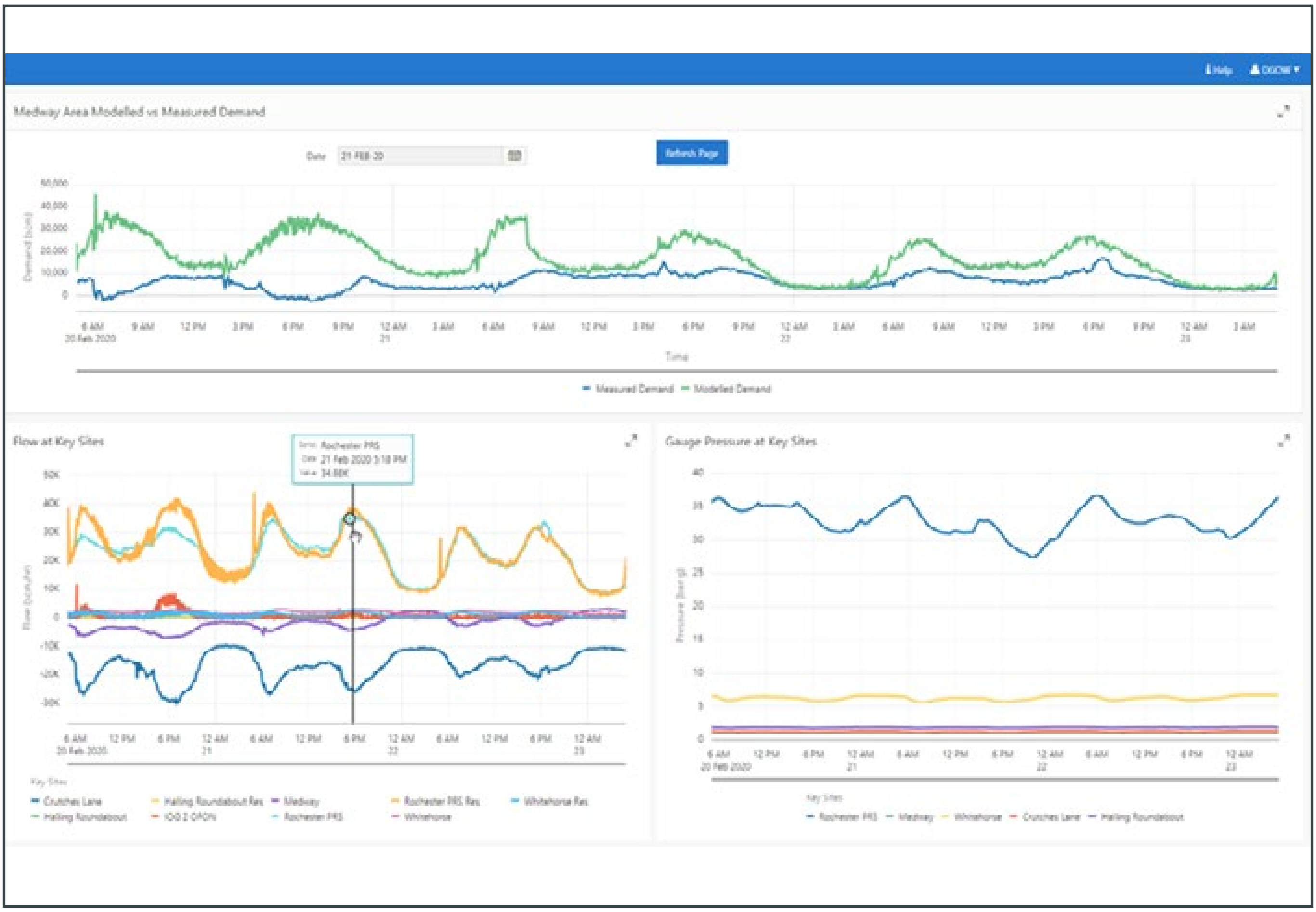


Figure 12: The Real-Time Networks system

Further sensors were installed across the SE LDZ, to collect weather data as the basis of calculating local CWVs, in order to develop approaches for more accurate application of off-peak demand modelling.

A cloud data solution was developed to capture and store all data transmitted from the sensors in a data historian. The data from the historian was passed to the prototype RTN modelling system which handles the RTN analyses required. This process was developed to provide a working example of the data capture, transfer and application within a Real-Time system.

The RTN System (Figure 12) has been developed to enable network analyses of below 7 bar systems to be run using each type of demand modelling approach developed through the RTN project. The System contains data for the Test Period (01-Dec-2019 to 29-Feb-2020) when all sensors were installed isolating the Medway Test area from the wider network.

Depending on the type of analysis requested, the System is able to use the appropriate sensor data (flows, pressures, CWV) together with the consumer and associated data to carry out analyses designed to reflect the on-line operation of the network (Real-Time and Off-peak runs). Other standard analyses (e.g. 1:20 Peak analysis) don't require sensor data input but use the base consumer data needed.

BENEFITS TO THE GAS INDUSTRY

A high-level summary of the key benefits is provided below:

IMPROVED ASSURANCE OF SECURITY OF SUPPLY

- An up to date and accurate demand modelling approach that reflects current gas usage by consumers taking gas from below 7 bar systems.
- Where the modelling is applied, this accuracy will provide assurance to the gas industry that the security of supply to consumers may be assessed and actions may be determined to ensure that minimum pressures at peak and off-peak conditions are maintained.
- An understanding of how consumers react at peak and all off-peak conditions.

REDUCED COST OF INVESTMENT

The improved understanding of 1:20 peak demand may be applied to network analysis through the variable diversity approach and applied to:

Replacement Design in LP systems and District Governor Sizing

The project has also identified that replacement design of the system to meet 1:20 demand can reduce Repex whilst maintaining minimum pressures. Analysis has shown reductions of flows required at district governors, which would impact the potential requirement for and design of District Governors for any proposed rebuild programme needed.

The links to Local Transmission System (LTS) and PRS design

A clear understanding of the peak flows required by the lower pressure tiers can support the assumptions for modelling of the LTS and design of PRS requirements with an accuracy that is not achievable with current approaches.

- Drivers include: Off-peak demand from hour to hour and day to day across all conditions supporting improvements in operational control of networks above and below 7 bar, including building network models and booking of capacity.

ACCOMMODATE GREEN GASES – GREEN TRANSITION

The improved understanding of off-peak demand across all conditions also supports improvement in the CV modelling of the MPIP system. CV Modelling involves the iterative analysis of the MPIP system to adjust volumetric demand at a standard CV for the LP systems to reflect the actual CV at critical points in the system.

The RTN processes would support the green transition by:

- Tracking gas quality through the MPIP system to assess the impact of CV variations on the requirements for design of the low-pressure systems.
- Refining the modelling of the MPIP system using Off-peak and Real-Time demand modelling to include the impact of variations in CV entering the MPIP system.
- These processes would support the increased access and tracking for:
- Biomethane, including the removal of propane,
- LNG with removal or reduction in nitrogen ballasting, and
- Hydrogen blend injection

OTHER BENEFITS:

- Modelling 100% Hydrogen Systems
- Modelling the impact of consumers making increased use of renewable technologies.
- Off-peak demand modelling supports improvement in the operational control of the networks above and below 7 bar.
- Improved management of leakage.

SOFTWARE AS A SERVICE – IMPLEMENTATION OF RTN

A key aspect of the project has been to consider how the outcomes from the RTN project may be implemented through SaaS offerings. To achieve this a pathway has been developed from core tools that offer the starting point for DNs in the replacement of their current systems.

The core solutions will be expanded to incorporate all aspects of the RTN modelling at least at a core level. Detailed planning is in hand for these stages. To make best use of RTN modelling and the SaaS offering it is possible to develop the RTN system to provide business-focussed services. Such services make use of the analyses available through the RTN system to provide specific outputs to meet business needs, and there is a wide range of options possible that will be based on identified business need.

Figure 13 illustrates the development of DNV GL's Integrated Demand System (IDS) as a platform for the implementation of RTN, with access to run and review results of those services through the User Interfaces and Dashboards. A range of potential business-focused services are included which may contribute to the energy transition of the gas system, along with other options such as more automated approaches to replacement design.

CONCLUSIONS

Digitalisation, big data and decarbonisation are major themes across all modern businesses, and the RTN data methodology can play a key role in those processes for the gas industry. The RTN project demonstrates the optimised collection of data for training and maintenance of an accurate and flexible gas demand model, fit for the challenges of completing the mains replacement programme and of energy transition currently being faced by the gas industry.

The outcomes of the project may be implemented as SaaS offerings that will facilitate the transition to a greener gas system.

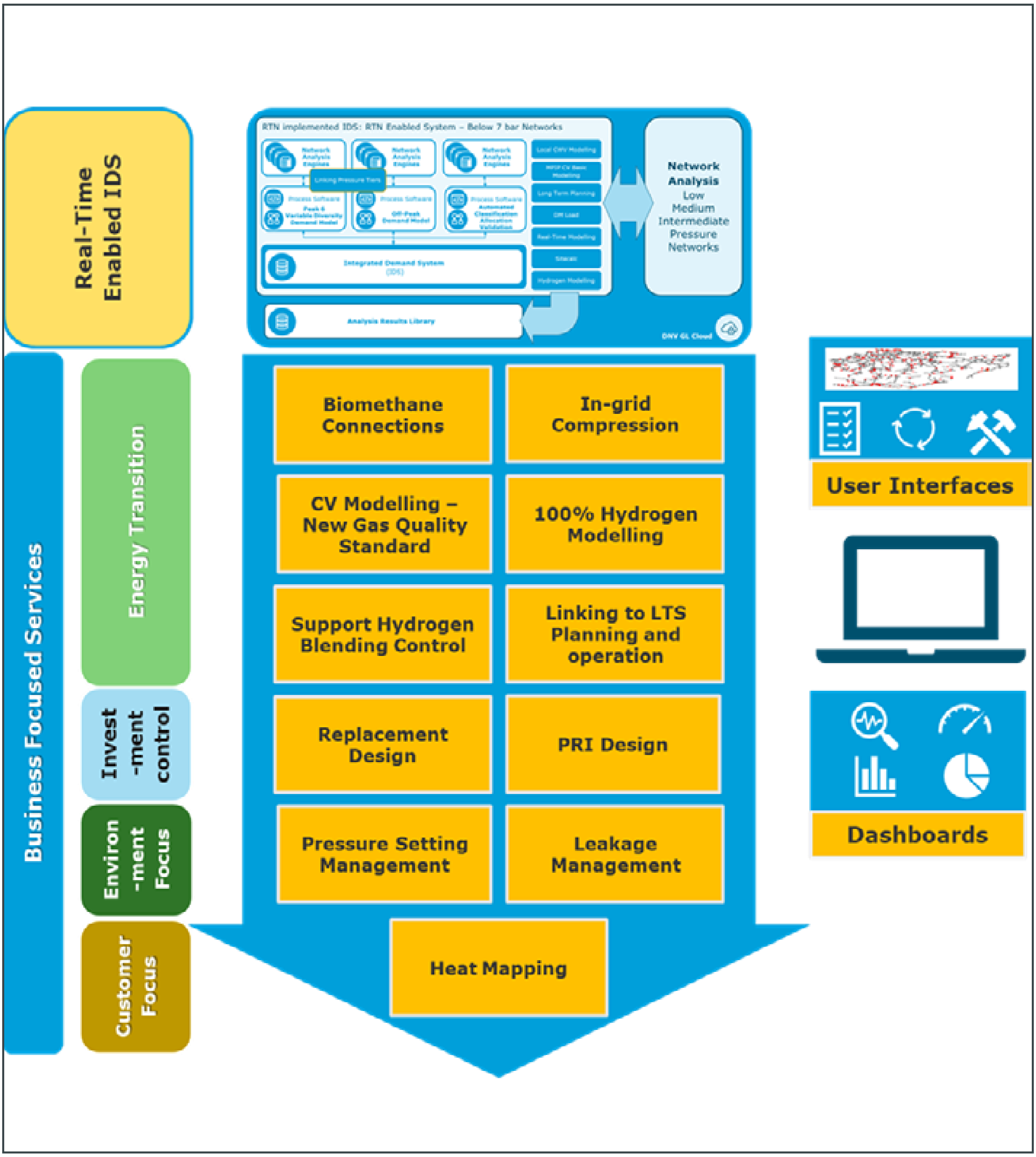


Figure 13: Overview of potential business focussed services

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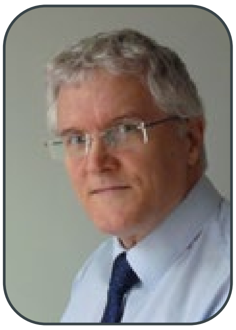

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Versatile technology for Leak Detection, Third Party Interference and Integrity Assessment applications: Vibroacoustics

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Abstract

Leak detection, TPI (Third Party Interference) and asset integrity are crucial topics in pipeline monitoring, although they often require costly procedures and systems. In order to support the pipeline integrity management, Eni S.p.A, in collaboration with Solares JV, developed the e-vpms® (Eni Vibro-acoustic Pipeline Monitoring System).

This technology, patented by Enis SpA, was specifically designed to detect impacts and spillages on Oil & Gas pipelines, illegal tapping and precursor events, but also to be capable of performing general-purpose integrity assessment tasks.

The evolution of the system, in terms of sensor sensitivity and algorithms, led to the development of a powerful software module for the TPI detection, classification and localization. This module is able to perform the recognition of the preparatory activities preceding the illegal tapping, such as digging operations.

To date, the e-vpms® is able to cope with many asset integrity issues, not related to illegal operations, ranging from the real-time PIG tracking, to the failure detection during hydraulic tests or the valve status assessment.

Scope of this work is to introduce not just the basic capabilities offered by the system, which are Leak and Impact Detection along Third Party Interference Detection – as manual digging activities – but also show the many other capabilities which the system can fulfil, among which PIG Tracking, Valve Status Quality Assessment, Failure Detection, Earthquake Detection and more.

INTRODUCTION

The current e-vpms® system installations span all over the world, with a very good focus in Europe, especially in Italy, but also in South America and in Nigeria, where to date many regions are protected. Today the e-vpms® technology protects more than 1400 km of pipelines all over the world and in Italy protects about the 100% of the finished product pipeline network.

Currently, the technology is used for real time monitoring of oil and gas pipelines in different scenarios; it is non-invasive, cost-effective, and ideal for retrofitting existing transport lines. In fact, the e-vpms® sensors are typically mounted on a pipeline using the existing derivations. The whole system can monitor hundreds of kilometers with very few sensors, against intrusions, spillages and impacts, beyond just detection.

The current definition of the e-vpms® is a suite of technologies for integrity monitoring for many applications as, over the years, many capabilities were added, exploiting in full the potential offered by the domain of vibroacoustics.

The e-vpms® is an integrated platform of applications and services, which can be divided in two main categories:

the LD system, to detect leaks and impacts, but also precursor events before they turn into leaks and the LD+TPI system, to monitor and localize digging activities on the pipeline, right on top or nearby.

Moreover, exploiting the data acquired by both the LD and LD+TPI, it is possible to provide many advanced services or specialized analysis for asset integrity purposes, such the real-time PIG tracking, valve status assessment, failure detection during hydraulic tests and earthquake recognition.

One of the winning features of the e-vpms® is its cost-effectiveness, since it requires very few sensors even to cover very long distances; it is also resilient to sabotage attempts, because the software AI is able to reconfigure itself on-the-fly if anything happens. Its success is also due to the very low FAR (False Alarm Rate), which is less than one false Alarm/Year per a 100km pipeline according to the statistics of real pipelines protected over the years.

The distance between stations depends on the required performance level and the specific issue of the pipeline; it can be up to 50km in selected cases. In ordinary conditions, the nominal accuracy is under 25m even though in some optimal cases the system reached also less than one meter of localization performance.

Scalability and an unmatched adaptability to any kind of operational condition make the system a real asset for all the pipeline operators. e-vpms® is able to work with pretty much any pipeline diameter, any typical pressure and any liquid or gas, it supports multi-product batches and the full integration with the existing equipment and SCADA/DCS platforms; both pumping and sealed conditions are monitored without limitation of the minimum leak quantity. Pipelines monitored by e-vpms® can be both onshore and offshore, for crude or refined products and even injection water pipelines.

THE PRINCIPLE

The e-vpms® is a multipoint network of vibro-acoustic sensors installed on the pipeline at a variable relative distance, usually tens of kilometers (see Figure 1). The vibro-acoustic wave-field is a combination of sound, pressure and vibrations, which if used together and at the same time can provide deep and wide information to detect a large variety of physical phenomena.

Whenever anything happens, acoustic and elastic waves are generated from the source location and travel at the speed of sound in both directions; the vibro-acoustic sensors record such waves and a central processing unit gives the alarm, together with the location and classification of the triggering event where feasible.

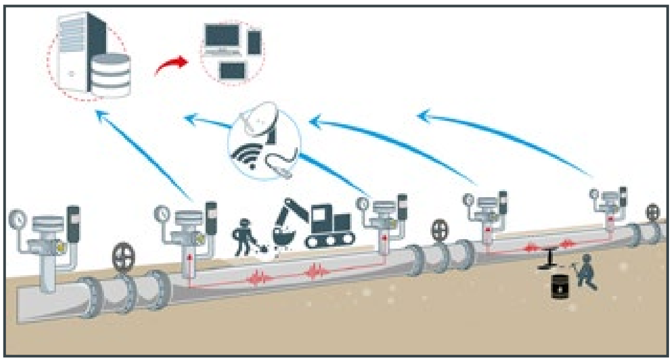

Figure 1: A schematic of the e-vpms® principle

The vibro-acoustic wave-field produced by any kind of mechanical interactions reaches the sensors, that send data to a central processing unit responsible for alarm notification. When vibrations produced by digging activities occurs on the pipeline a perturbation of the vibro-acoustic wave-field travels along the pipeline reaching the e-vpms® sensors. When a spillage occurs a perturbation of the vibro-acoustic wave-field run inside the pipeline reaching the e-vpms® sensors.

Mainly, the system processes pressure waves, which are already widely used in the industry to detect leakages in many conditions. Dynamic pressure data allows both detection and accurate localization, but the vibrational component is always present particularly on the pipeline shell. It travels at the speed of elastic waves for many kilometers, although is very hard to detect and its detection requires very sensitive equipment and advanced techniques of signal processing.

Pipes are efficient wave-guides for sound transmission; because of this, sounds and vibrations can be used to track many phenomena that are not detectable by a simple pressure-based system. So that the pipe acts as an ideal wave-guide, it must be filled of fluid at a minimum pressure of 1 barg. Regarding to typical sounds inside the pipe, the e-vpms® can also use the pump noise as an active acoustic source to perform particular tasks, or, by means its patented adaptive noise removal, it can ensure the best-in-class SNR (Signal-to-Noise Ratio) to strongly enhance the performance of leak or impact detection.

Currently e-vpms® is served in two main flavors. The first one is called LD, which stands for leak and impact detector. It can detect impacts, leaks and some precursor events or preparation activities, which happen typically before the illegal tapping. In this configuration, the typical distance between sensors is from 15km to 30km in liquid, and 5km to 10km in gas; in selected scenarios, like for offshore installation, the distance can be up to 50km.

The system can perform many other things, such as PIG tracking, asset integrity and failure detection.

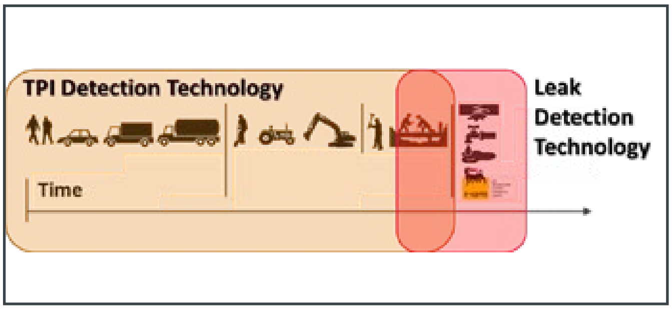

Figure 2: The typical timeline of the illegal operations before the spillage

The TPI technology is able to detect the preparation activities to the illegal tapping, whereas the LD intervene during the spillage itself. Impacts can be considered as and area of overlap between the two technologies.

The second is called LD+TPI (Third Party Interferences) and includes all the characteristics of the previous system, but it is also able to detect manual digging. In this case the distance between stations is about 5km. LD and LD+TPI can live on the same pipeline raising distinct alarms, so the pipeline operator can cope with all the differences between alarms and how and when to intervene.

SYSTEM SPECIFICATIONS

The e-vpms® system works by means of dedicated sensors positioned tens of kilometers apart and typically mounted on already existing hydraulic derivations.

All the sensors are ATEX certified areas 0/1/2, ensuring maximum operational safety and capability to work also on pipelines transporting multi-phase with H2S content (sour gases), and CO2 transporting pipelines. On the field, the e-vpms® sensor and acquisition system needs power, direct, solar panels or fuel cell, requiring less than 20W. Moreover, a portable version is available; this can run for days on battery and is typically used for demonstration or pilot projects.

The e-vpms® sensors are ideal for retrofitting existing transport lines, in fact they can be are mounted on the pipeline using the existing derivations, without the need of ad-hoc tapping.

Figure 3: The e-vpms® sensor block mounted on an existing derivation.

The field system communicates with a central processing server with a very low bandwidth consumption (about 20 kbit/s) by means of any kind of telecommunication system and protocol (LAN, wifi, UMTS, ADSL, satellite, etc.). The central processing server is responsible for the execution of the monitoring processes and the alarm notifications.

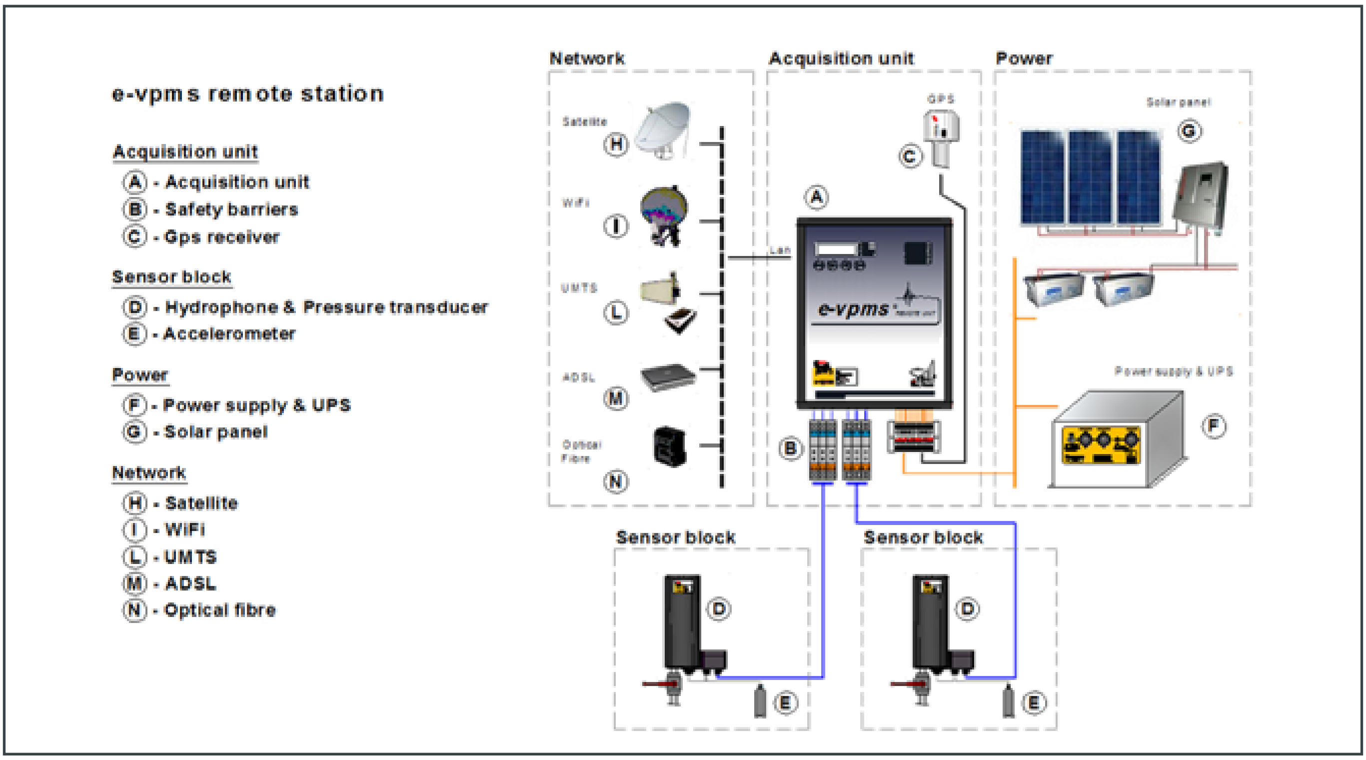

Figure 4: Schematic of the acquisition unit and its interfaces. The acquisition unit can be powered by different types of energy supplies and synchronized by a GPS device; external communications can be performed by using any kind of networking system and protocol.

Figure 5: The manual digging operation, a typical preparatory activity anticipating the illegal tapping. This kind of events are detectable by the TPI system by exploiting the high sensitivity of the e-vpms® vibro-acoustic sensors.

TPI: FROM DIGGING TO ILLEGAL TAPPING

The illegal tapping event does not follow a universal rule, but typically is preceded by the approach to the pipeline, the digging operations, and the tapping preparation. The leak detection system intervenes from the tapping preparation to the taking place of the leakage, while the TPI technology can detect also digging activities, which is crucial for an effective prevention.

It is important to emphasise that the time-domain and spectral signatures of this kind of signals are very different with respect to any event caused by trains, cars or anything passing by and these features are used to discriminate false from real alarms. For instance, an event referred to a digging activity can be classified as real TPI alarm only if a series of recurring events persists for an appropriate and

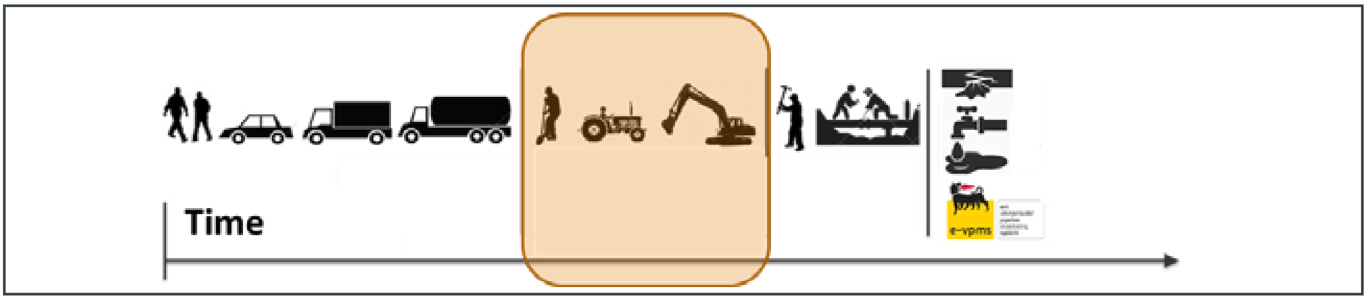

Figure 6: The specific domain of TPI technology, namely the illegal digging detection, crucial for a quick and effective prevention

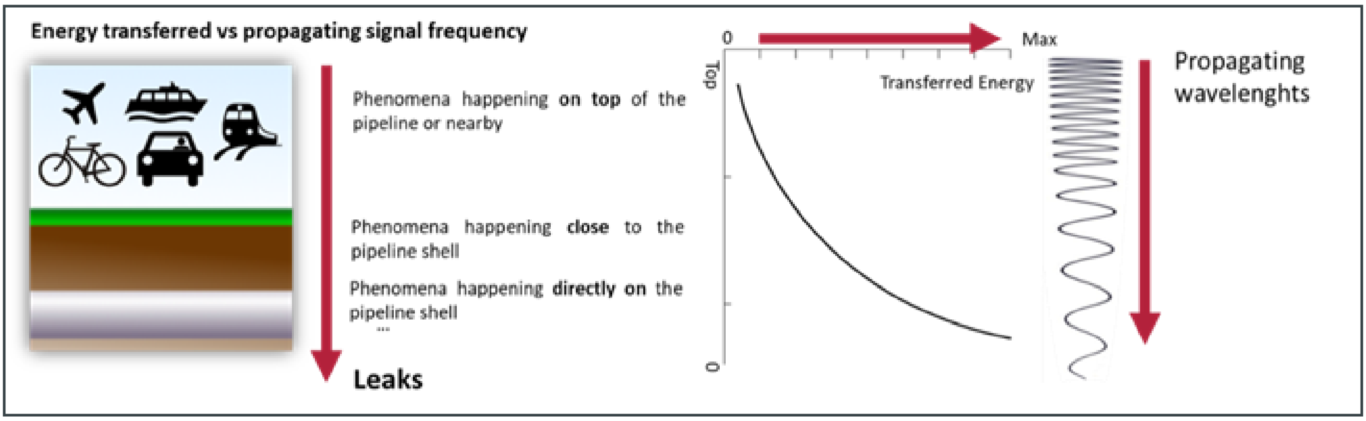

Figure 7: The transferring of the mechanical energy to the pipe follows an exponential decay with respect to distance. For this reason, events occurring on the top of the pipeline are detectable with high reliability.

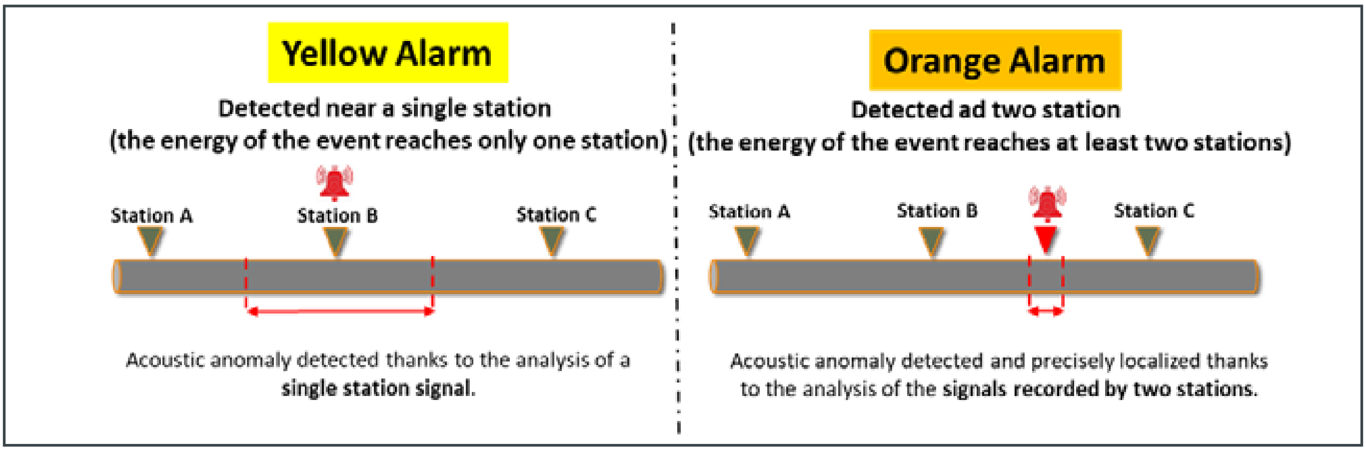

Figure 8: TPI alarms when the illegal event is registered by one station or at least two stations. In the first case, the yellow alarm is raised and only the detection can be performed. In the second case, the orange alarm is raised and an accurate and precise localization of the source of vibration can be provided.

user-defined time span and the frequency is compatible The exceptional low FAR of e-vpms® is also due to the physics of the problem, in fact the relationship between the distance to the fluid from the noise source and the transferred quantity of energy is exponential. If people are digging, the mechanical energy of the operation is transferred to the soil, towards the pipe shell and finally to the fluid; according to the exponential model. This energy transferring is effective if the digging activity is performed on the top of pipeline.

In particular, if the energy of the TPI event is strong enough to reach at least two stations, the source of vibration is localized with high accuracy (less than 25m). In case of the vibro-acoustic field reaches only one station the localization cannot be provided; anyway, an alarm is raised to inform the pipeline operator that something anomalous is happing nearby the e-vpms® station.

To calibrate the TPI system, our field engineers emulate the manual digging activities on the soil above the pipelines by means of use shovels and pickaxes and simulate the illegal tapping preparation with hammer strikes on the pipeline itself. Moreover, a fast, portable, non-invasive e repeatable calibration method is performed by means of a specific device, which impresses a definite amount of energy to the soil by a calibrated falling mass

Figure 9: The falling mass calibration device

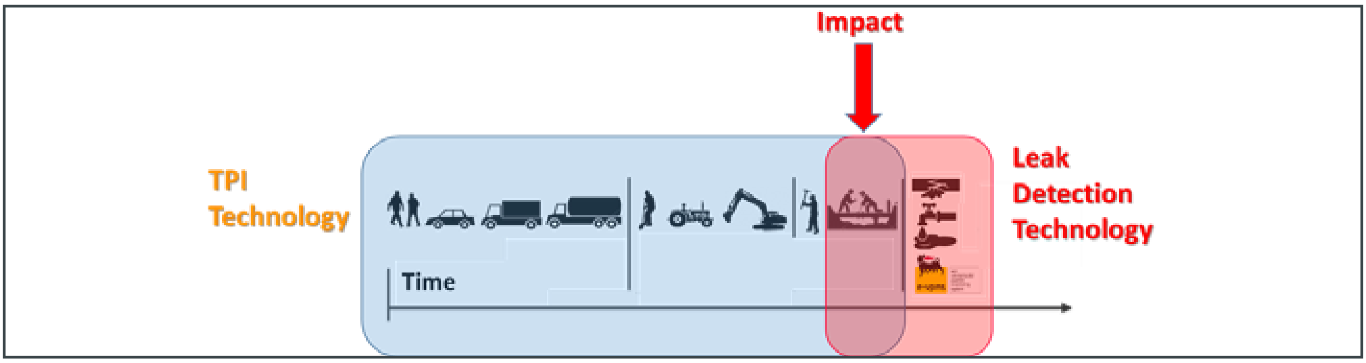

Figure 10: Impacts are detectable both by LD and by LD+TPI

EXAMPLES AND APPLICATIONS

From a general point of view, the e-vpms® can be considered as multi-purpose asset integrity platform. In fact, in addition to the LD and LD+TPI monitoring systems, the e-vpms® is able to cope with many additional issues, such as the impact detection, the real-time PIG tracking, the failure detection during hydraulic tests and so on.

IMPACTS

As previously explained, impacts are detectable both by LD and by LD+TPI.

In this section, an on-site test is shown; a real impact experiment is performed on the pipeline monitored by the e-vpms®. The test consists in performing a series of strikes on the pipeline with a hammer and registering the vibro-acoustic field; the amount of energy transferred to the pipeline is very low and this makes difficult to detect this kind of events with technologies different from the e-vpms®. The e-vpms® vibro-acoustic sensors are capable to register the propagation of impacts for tenth of kilometer, since the pipeline acts as a very effective wave-guide for signal transmission. In Figure 11, the effects of the hammering on the e-vpms® sensors is evident; three series of hitting are performed on the pipeline and the propagation of signals to sensors follows the law of attenuation, that depends on the relative distance from the source of noise.

Figure 11: The impact test consists in performing a series of strikes on the pipeline with a hammer and registering the vibro-acoustic field

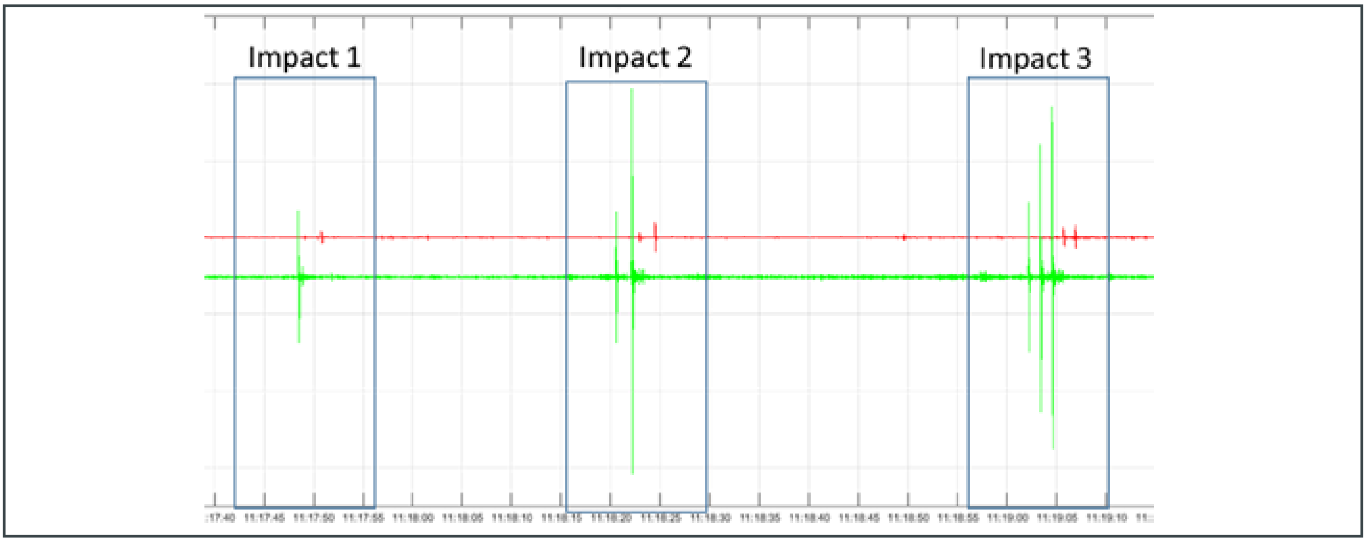

Figure 12: The experiment performed by hitting a pipeline with a hammer (green time series) and registering such signals to a remote e-vpms® station (red time series) at a distance of about 20km

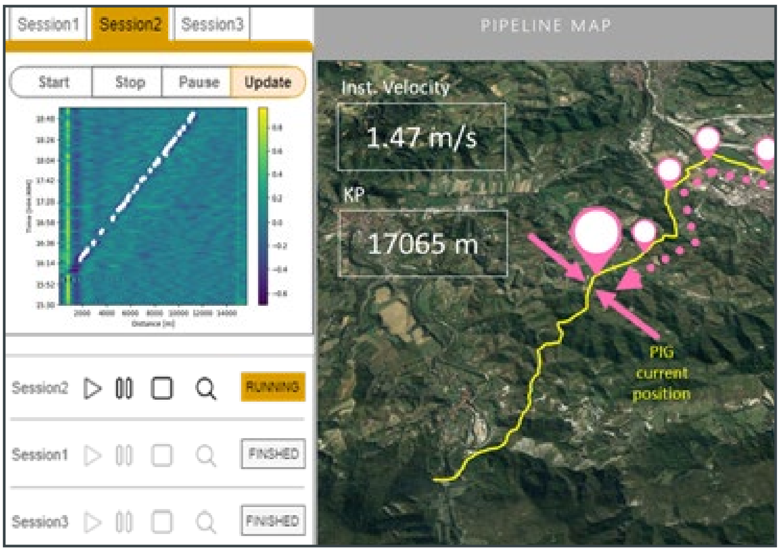

Figure 13: The PIG tracking application. Exploiting the noise produced by the PIG moving into the pipeline, the e-vpms® is able to track in real-time the moving device.

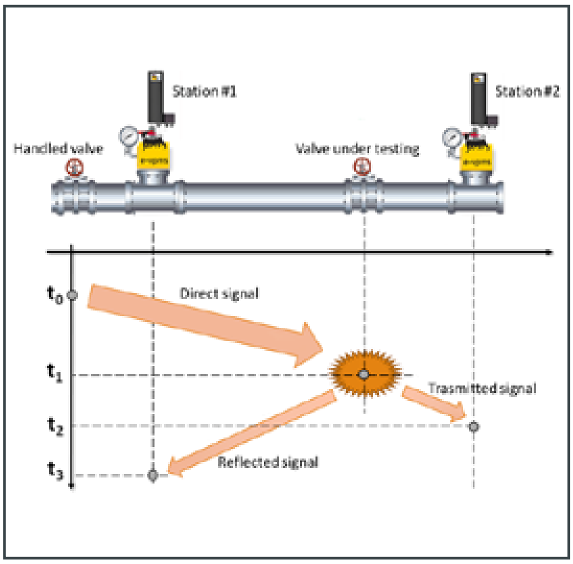

Figure: X

PIG TRACKING

The PIG generates sounds while moves inside the pipeline and by means of the e-vpms® sensing it can be continuously localized and tracked in real-time. Even if the PIG is not moving, e-vpms® is still able to locate it by using reflection-based analyses exploiting the pump noise as source of sounds. The PIG position and the instantaneous speed are continuously estimated with high accuracy. More-in-depth e-vpms® analysis can even provide the location of impact points with unexpected obstacles. Additional details on the specific functions of PIG Tracking can be found on [11] and [13].

VALVE STATUS ASSESSMENT

The e-vpms® can be efficiently used to assess the valve sealing grade; this application is especially helpful to investigate, in an easy and cost-effective way, the effects of aging on any specific valve. The principle is the joint exploitation of vibro-acoustic sources (e.g. handling a valve, or even just pump noise) and their reflections and transmissions (Figure: X): the incident acoustic direct signal (e.g. the source) is recorded by the station #1. A comparison between signal transmitted to the station #2 and reflected to the station #1 allows to compute the ratio between the transmitted versus reflected energy. The calculated ratio is dependent on the valve sealing grade at the moment of the test. By means of the status assessment application, the e-vpms® is able to tell if the valve under testing is properly closed or is leaking product, namely "leaking" sounds.

FAILURE DETECTION

By Failure Detection we mean the capability to detect even very small leaks (e.g. from pinhole corrosion) not detectable during normal operations, typically as a support activity during hydraulic or pneumatic tests.

EARTHQUAKES DETECTION

e-vpms® is also able to detect earthquakes and SolAres team is trained to perform quick assessments of potential damage occurred to the pipeline, in real time. The alarm trigger sensitivity can be adjusted according to customer's request to trigger alarms or not: earthquakes have their own distinctive signature with respect to other phenomena. For example, in FIGURE 16 is the shown an earthquake occurred in Albania and sensed by an e-vpms® system located in the northern Italy.

CONCLUSIONS

The vibro-acoustic technology has unique properties with respect to other technologies, as it is not flow or product-based, but relies on the effects of interactions with the product, detected by the different technologies. The high sensitivity of the multi-sensor blocks is a characteristic that makes the e-vpms® a general-purpose system, able to cope with the challenges of the modern pipeline asset integrity, from the detection of illegal activities to the assistance to the pipeline operator during the pigging campaign or hydraulic test. Leaks and impacts, TPI recognition, PIG tracking, failure detection and valve status assessment are just a few capabilities that the e-vpms® can successfully express. Moreover, the system is a real asset for all the pipeline operators thanks to its scalability and adaptability to any kind of operational conditions. In fact, the e-vpms® can work with any pipeline diameter, single-phase fluids, and multi-product batches. It keeps similar performance both during pumping and sealed conditions without limitation of the minimum leak quantity. It is non-invasive,

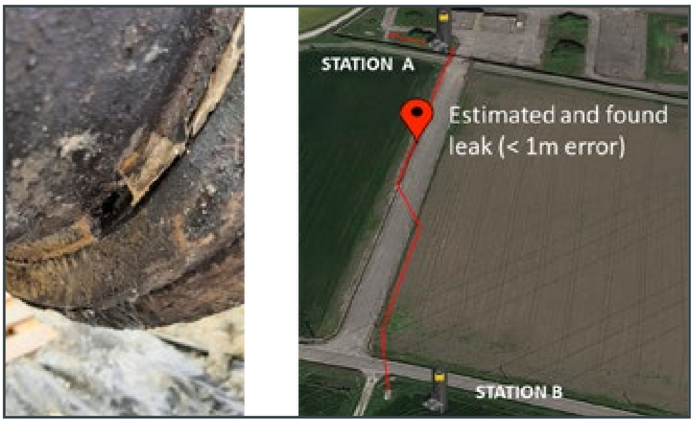

Figure 14: A small pin-hole leakage due to corrosion (left) and the experimental setup to monitor a segment of the pipeline during the hydraulic test.
Even very small leaks still create a distinguishable source of vibro-acoustic noise, which can be detected and localized.

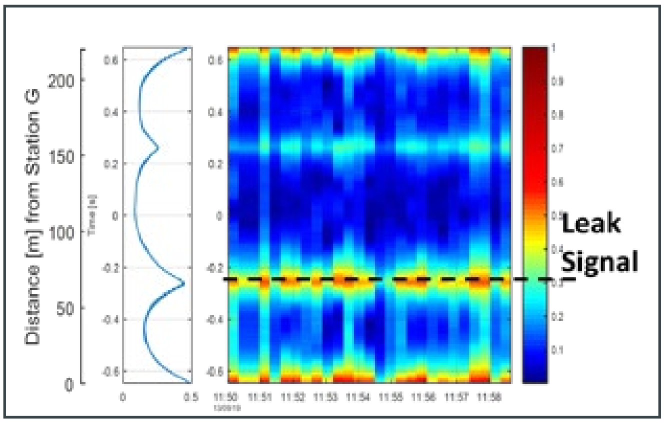

Figure 15: Correlation processing to localize the point of leakage
Such capability has been proved to work effectively both in liquids and gases, saving considerable effort to locate the leak location.

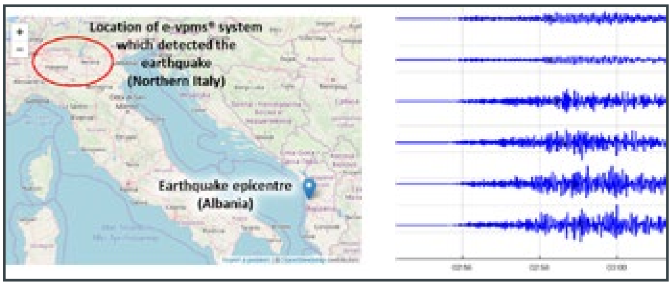

Figure 16: An earthquake occurred in 2019 in Albania was sensed by the six e-vpms® sensors installed on pipeline in the northern Italy

cost-effective, fully integrated with the existing equipment and therefore ideal for retrofitting existing transport lines both onshore and offshore. The recent evolutions of the system, as described in [12], allow to follow a data-driven approach to the solution of many problems related to pipeline transportation, maintenance, and operational issues. The e-vpms® system and its technology family, can thus be used not just for intervention after threat detection, but also for prevention, up to predictive maintenance capabilities.

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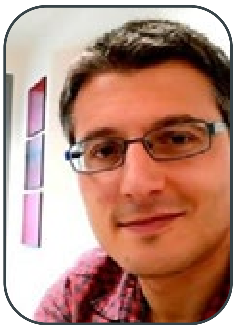

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Association

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