Report on System Development, Method Applicability and Pipeline Condition Data for Modeling Purposes

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trust

D46.2

TRANSITIONS TO THE URBAN WATER SERVICES OF TOMORROW

Report on System Development, Method Applicability and Pipeline Condition Data for Modeling Purposes

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ABSTRACT

Breivoll Inspection Technologies AS (BIT) is a Norwegian SME and a provider of condition assessment services to water utilities world-wide. BIT's role in the TRUST project is to provide data from inspections of water mains in participating cities to participating researchers. A pipeline condition database has previously been delivered in milestone MS31. This report evaluates the BIT method for condition assessment of water pipes. The inspection system, the client report and the pipeline condition database are presented, and the applicability of the BIT method is analyzed.

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1. INTRODUCTION

Breivoll Inspection Technologies AS (BIT) is a Norwegian SME and provider of condition assessments of water pipes. This report is the deliverable D46.2 of work package WP46.2 in the TRUST project.

The deliverable starts with describing the historical background of the company, the technology and method we use and the report that is delivered to our clients after inspection. Section 2 presents the scientific background, and is a review of related work and literature. Section 2 also discusses the advantages of condition assessment compared to other approaches to asset management. Section 3 presents an overview of the market as seen by BIT.

The database delivered as part of MS31 is presented in Section 4, as well as a case study showing how the TRUST member utility Oslo VAV applies BIT data in their asset management.

Section 5 discusses the applicability of the BIT method of condition assessment, its strengths and weaknesses, as well as its economic aspects.

The report is summarized in Section 6, and references follow directly after.

The deliverable has been subject to the strict review scheme of the TRUST project, with reviewers being Sveinung Sægrov of NTNU/BIT and Sergio T. Coelho of LNEC.

2. SYSTEM DEVELOPMENT

In 1992 Det Norske Veritas (DNV) was commissioned by the Norwegian authorities to develop a method that could detect the amount of residual oil in the sunken German warship Blücher, see Figure 1.1. An acoustic method was used for this project. It became apparent that the resonance technology that was used also revealed the thickness of the hull's steel wall as a by-product.

This has formed the basis for DNVs major emphasis on the development of inspection technology.

The founder of BIT, John D. Breivoll, has been working with DNV since the late 1980s. When he was introduced to the technology he realized, due to his background in water and effluent management, the great potential of using resonance technology on water pipes. In 1998 he founded Breivoll Inspection Technologies AS (BIT) together with Arne Christian Vangdal.

Figure 2.1. The German WW2 warship Blücher

2.1 Background: ART, a Technology Quantum Leap

BIT has developed a PipeScanner for collecting data on the status of drinking water networks from inside the buried pipelines, an operational concept, and data analyzing tools and methods enabling production of detailed reports specifying quality of the pipes analyzed. BIT reports enable water managers to optimize their asset management as, to a large extent, they can base their decisions on hard facts rather than assumptions. The technology also limits the maintenance and repair work in both volume and time needed (users being without water) by a) giving an overview of the need for pipe maintenance, and b) localizing and prioritizing pipes needing maintenance and replacement, and deciding when to perform needed work.

> *"The applied acoustic resonance technology (ART) represents a state-of-the-art totality, when combining the applied electronics, transducers and signal processing. No other commercially available alternative NDT method which is equally viable and suitable for measurements on cast iron water pipes has yet been identified. The versatility embedded in the resonance technology represents a "quantum leap" with respect to inspection performance." (Det Norske Veritas, 2003)*

During three years of pilot testing, BIT has received acclaim from several clients and independent research institutions on the operational quality of BIT technology and services.

The ART technology is based on the transmission of acoustic signals with a broad frequency spectrum from a large number of transducers.[1] The pipe wall is set in motion where it is hit by the signal (the "foot-print area") resulting in natural resonant oscillations in the pipe wall. The oscillations are reflected back to the emitting transducers, now in receive mode, which in turn transmits the resonance data through a fiber-optic leading up to the inspection vehicle. The data is stored here, and after some preliminary processing in the vehicle, the data is forwarded to the BIT data centre where advanced algorithms are applied

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[1] Electro-acoustic transducer - a transducer that converts electrical to acoustic energy or vice versa

to the data by a set of powerful computers. The resulting output creates the foundation for report production. A large amount of data is processed under this procedure; the current PipeScanner produces approximately 100 MB of measurement data per meter.

2.2 Inspection of Water Pipes

BIT inspects water-filled metallic pipes according to a process based on the **Acoustic Resonance Technology (ART).** The technology supports data collection on:

- Remaining wall thickness
    - Reduced thickness caused by corrosion
    - Variations in thickness caused by production methods
- Internal topography
    - Position of pipe, man holes, valves, flanges, branches
    - End control of new or rehabilitated networks
    - Bends and joints
- Metal loss caused by internal and external corrosion
    - To facilitate optimal choice of rehabilitation method, internal and external corrosion must be distinguished.
- Classification of individual pipes in order to enable classification of whole network structures.

The ART technology is limited to water-filled metallic pipes, but has no theoretical limitation for pipe diameter. The technology supports all common pipe thicknesses used in metallic water mains. ART is unaffected by most coatings and linings. Cement mortar lined pipes can in some cases produce less detailed data than pipes without cement mortar.

2.2.1 The Inspection Unit

The inspection unit consists of:

- The inspection vehicle, which is equipped with data collection, control and communication equipment.
- The inspection crew (2 people)
- The PipeScanner

Figure 2.2. The inspection unit and PipeScanner field operation

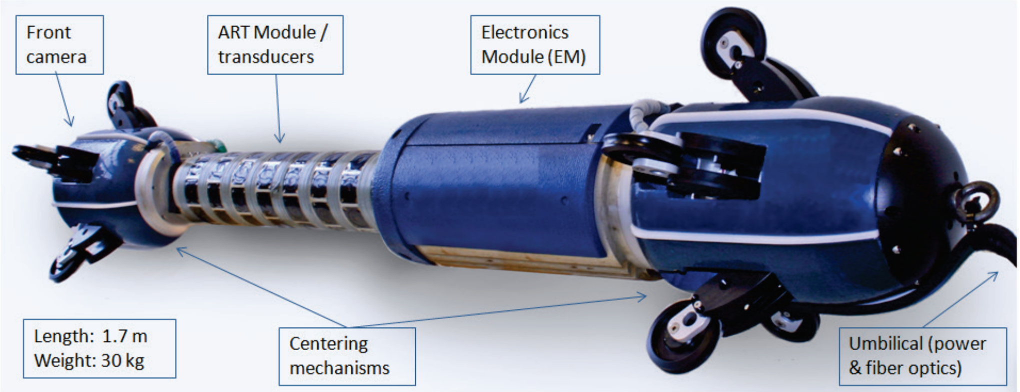


Figure 2.3. The BIT PipeScanner, 2nd generation.

2.2.2 The PipeScanner

The BIT PipeScanner is the result of years of research and development, as well as the experience from scanning thousands of individual water pipes. BIT is continually working to develop the next generation PipeScanner, to add new features and capabilities that allow a larger range of pipes. All BIT PipeScanners contain the ART technology.

The current model, the BIT PipeScanner 2 has the following capacities:

- Scans all types of metallic pipes, i.e. steel, grey cast iron and ductile cast iron.
- Scans pipes with diameters DN 300-400 mm.
- Can scan up to 750 meters in each direction from one access point.

The next generation scanner, BIT PipeScanner 3, will have the following additional capabilities:

- Scans pipes with diameters DN 300-600 mm.
- Detect leakage through on-board hydrophones.

2.2.3 The Company Internal Service Production Chain

The company provides technology-based services for the analysis of the condition of water pipes. At the end of the internal service production chain is a detailed report with recommendations for further actions. The report is a result of a stepwise process:

- Inspection planning, in collaboration between BIT and the client.
- The client prepares the inspection site by uncovering the pipe and installing a special pipe with a custom entrance for the PipeScanner.
- A van containing all necessary tools for field inspection, including a two man specialist crew arrives at the inspection site.
- The inspection unit (“The PipeScanner”) is sent through the water pipe, connected by cable to the field inspection van.
- Measurement data are sent from the PipeScanner to computers in the inspection van.
- Measurement data are transferred to BIT headquarters in Tromsø where they are stored in a database.
- BIT professionals perform software based analysis, summarize the findings and complete a detailed report.
- The final report is presented to the client.

The custom-made entrance pipe facilitating the PipeScanner access to water filled pipes is called the Breivoll Entrance Pipe (BEP). For certain pipe diameters, it is also possible to use standard hatch box units. The PipeScanner is neutrally buoyant in water, and can either be floated with the water current to the starting point for scanning, or propelled by an attached propulsion unit. When the scanning commences, the PipeScanner extends its arms to create and maintain centering, and is then winched back towards the entrance point. During scanning, the operator can assure that data quality is good and also see the inside of the pipe through attached video cameras.

2.3 Report Production

Report production is supported by BIT-developed software.

2.3.1 PARS (PipeScanner Analysis and Reporting System)

The PipeScanner **A**nalysis and **R**eporting **S**ystem, PARS:

- Imports ART raw data from the PipeScanner
- Performs processing of data at the BIT headquarters, through advanced algorithms and data filtering in a high-performance data center.
- Produces plots, statistics, and highlights important findings.
- Produces report templates, ready for analysts to fill summaries of manual analysis.
- Exports data files enabling the use of BIT data in decision support tools such as GIS etc.

The software is developed by BIT. Improvements are being implemented continuously.

2.3.2 The Report

BIT reports may be delivered as the standard version or can be tailor-made should the client have special needs.

The report facilitates a risk and vulnerability analysis when choosing how to rehabilitate the pipe, if deemed necessary. The BIT report identifies errors and weaknesses and quantifies the decay found during inspection.

Collected data from the BIT inspection are visualized in several different ways. Statistical data are presented in tabular form, and highlighted findings are listed both in tabular form as well as graphically on a map of the inspected pipeline. The measurements of thickness, topography and corrosion are presented as graphical plots.

The report focuses on decision support for the “when”, “where” and “how” in the rehabilitation and maintenance of water delivery networks.

The content of the report includes the following background data.

2.3.3 Statistical measurement data

Measurement data are summarized for each named stretch of pipes between two man holes, and listed for each individual pipe. Each pipe can then be given a grade of severity, identified by a color range from green to red.

Table 2.1. Statistical measurement data per LSID

LSID NR	TOTAL LENGTH (M)		NORMAL PIPE LENGTH [M]	THICKNESS (MEDIAN) [MM]	COMPARED TO STANDARD THICKNESS	ASSUMED LOWEST ORIGINAL THICKNESS [MM]	COMPARED TO STANDARD THICKNESS	INTERNAL CORRODED AREA [%]	EXTERNAL CORRODED AREA [%]
TOTAL	74.2	Median	2.3	15.5	107 %	10.9	75 %	8.4	2.2
	# Pipes	Min		12.7	88 %	9.6	66 %	1.6	0.3
	27	Max		17.6	121 %	14.0	97 %	14.1	6.0

2.3.4 Highlighted findings

Highlighted findings are presented in tabular form, as shown above, and in graphical form on a map of the inspected area, as shown in Table 2.2. Findings are graded on a scale from

0-4, where 0 is for technical findings (valves, branches etc), and 4 is for weaknesses and flaws that should be looked into as soon as possible.

Table 2.2. List of highlighted findings

LSID/ PSID	DIRECTION	DISTANCE FROM [M]	DISTANCE TO [M]	RADIAL POS. FROM [DEG]	RADIAL POS TO [DEG]	FIND CODE	GRADE [0-4]	DESCRIPTION	NOTE
109500	SW	6.38	8.98	360	219	TU TV	3	Thickness variance in radial direction, thickness down to 9,2 mm	Upper half
109500	SW	9.08	11.31	360	0	IR	2	Rust nodules up to 3,1 cm	Sparse, largest in bottom
109500	SW	11.65	13.44	186	6	IR UP	2	External pitting, thickness down to 10,4 mm; rust nodules up to 3,0 cm	
109500	SW	11.38	13.56	326	203	IR UP TU	3	Thickness variance in radial direction, thickness down to 9,9 mm; external pitting; rust nodules up to 2,7 cm	

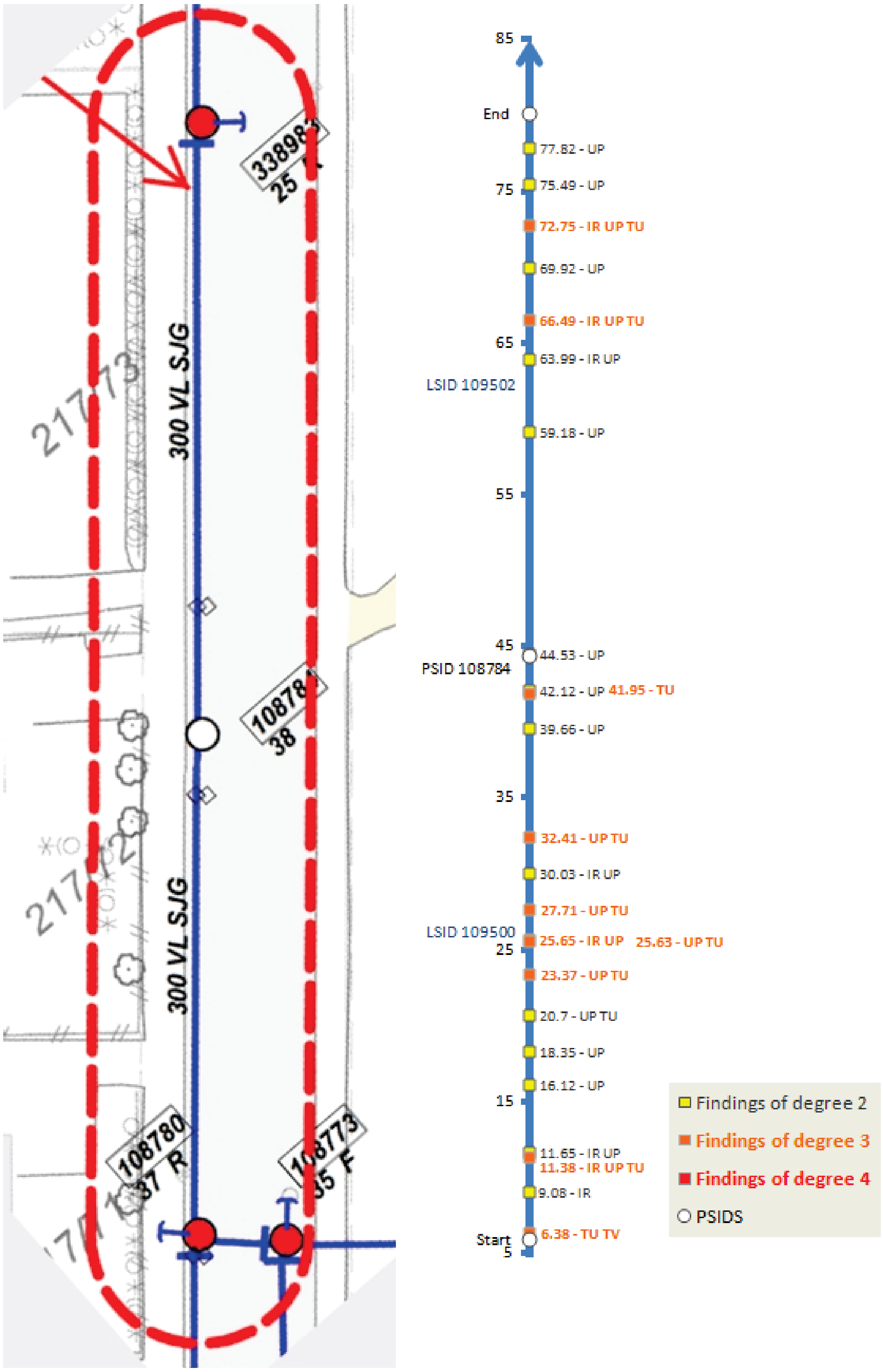
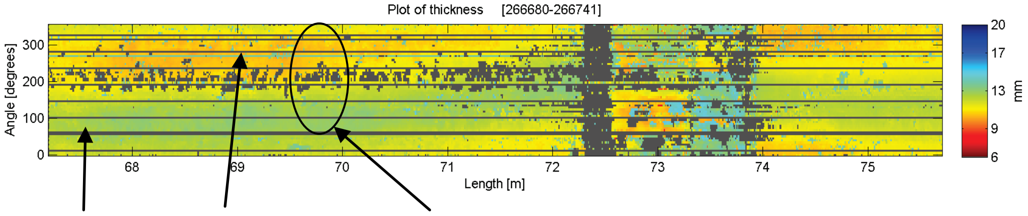


Figure 2.4 Map of inspected area

2.3.5 Thickness plot

Measurements of thickness are plotted in a color-coded plot showing thickness from red (thinnest) to blue (thickest).

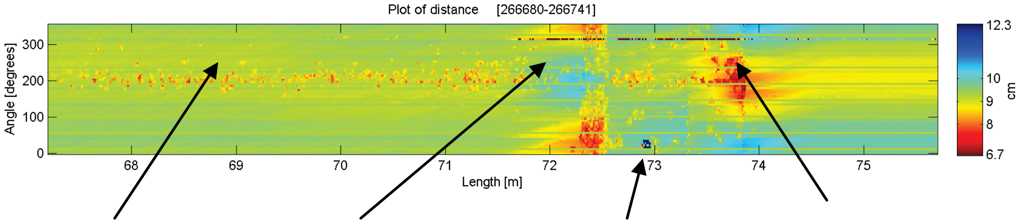


Thick area Thin area Production variance due to horizontal casting.

The black spots are areas that for various reasons are missing thickness measurement data.

2.3.6 Distance plot

Measurements of the internal topography are shown as a colour-coded plot of the distance from the PipeScanner sensors to the pipe wall. Green is normal. Red spots mark protrusions from the surface, such as rust tubercles. Blue areas mark recesses, such as pits, valves or branches.

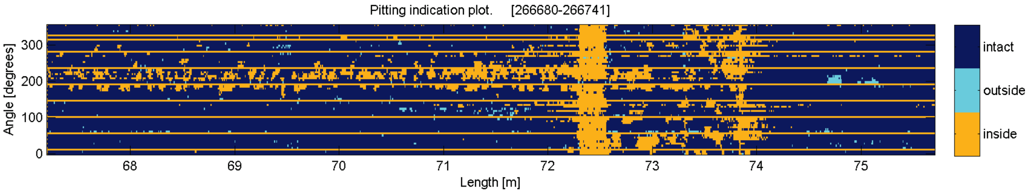


Rust tubercles Joint/bend Branch Angular shift

It is also possible to see features such as joints, bends, angular shifts, valves, branches etc, including displaced joints.

2.3.7 Inner and outer corrosion

The ART method distinguishes internal corrosion from external corrosion. This knowledge is essential to decide the most suitable rehabilitation method. Yellow marks internal corrosion, turquoise marks external corrosion.



2.3.8 Using the report

The data put together gives an overview of the condition of the water pipe in a way no other technology in the world today can match aside from digging up and testing the pipes in a laboratory.

Presented with this report, utility managers can plan and give priority to how and where to rehabilitate. Of additional importance, the information at hand is value-added to other maintenance activity, like planning related to road construction, performing sewage maintenance, connecting power lines, and laying broadband Internet cables. In this way, costs can be cut and time saved, not digging over and over as often seen in city maintenance activities. Clients increasingly appreciate this value-added nature of this approach.

Assessments are made easier by data exports from PARS, where data from BIT inspections can be imported to GIS and other asset management tools.

2.3.9 Summary

BIT delivers information to Global Clients in the drinking water supply industry.

We measure and map:

- Original and remaining wall thickness of metallic pipes.
- Internal and external corrosion.
- Pipe features: Bends, Joints, Branches; Valves

These measurements create the basis for the conclusions and recommendations we report. Based on our recommendations, utilities can rehabilitate the right pipe with the right method – and at the right time.

2.4 ART Potential

The Acoustic Resonance Technology (ART) can be used on all types of materials having a characteristic sound velocity. Consequently, the technology may be utilized for all kinds of steel, iron, concrete, plastic materials, aluminum, copper and asbestos cement, covering all materials today in use in water networks. Up to now, documented and successful tests have been performed on gray cast iron, ductile cast iron and steel. The technology has a huge potential beyond that. Within the focus area commercialized today, BIT will continue to expand the technology to:

2.4.1 Larger diameter pipes

BIT's on-going R&D indicates the ability to inspect up to 600 mm pipes with only minor adjustments to the technology now in use, enabling 300 mm – 600 mm metallic pipe inspection capabilities during 2013. There are no technological constraints to the Acoustic

Resonance Technology with regards to inspecting large diameter pipes. Inspection capabilities for pipes with diameters larger than 600 mm are being considered.

2.4.2 Smaller diameter pipes

An ongoing project partly financed by the EU is looking into the challenges of inspection capabilities for pipes with diameters smaller than 300 mm.

2.4.3 Two-layer inspection capabilities

BIT has initiated testing of two-layer scanning capabilities, e.g. cement-coated metallic pipes. The technology delivers interesting information and is being sold to clients, but further R&D is needed to deliver high quality data.

2.4.4 Leakage detection

BIT has initiated testing of leakage detection equipment that will be carried on-board the BIT PipeScanner. It is expected to be available to the market during 2013.

3. SCIENTIFIC BACKGROUND

This chapter contains a literature review on related research.

3.1 Pipe deterioration

Over the next decades, drinking water pipes and systems will be exposed to colder or warmer climates depending on the region, and to more extreme weather events with high precipitation and storms (Larsen *et al.*, 2009; Holvik, 2010). Additionally, higher corrosiveness of the ground (Vevatne *et al.*, 2007), and fluctuation of the ground water table can lead to settling of the ground and damages to pipes. Surface drinking water sources can experience more turbidity due to higher expected intensity of precipitation events (Bomo *et al.*, 2007; Christensen and Christensen, 2007; Giorgi *et al.*, 2004; Holvik, 2010; Kleidorfer *et al.*, 2009), which can increase the amount of soil sediments that are transported through the runoff process. In surface water sources, particles can be transported to the deep water inlets of the drinking water system due to the expected increase of wind speeds which will facilitate circulation in lakes (Vevatne *et al.*, 2007). If these problems are not solved in the Water Treatment Plants, the increased turbidity will impact the drinking water networks. These conditions will lead to greater strain on the urban drinking water networks, possibly leading to more breaks and corrosion and a higher degree of water leaks which have a large impact on the expenditure of the utilities.

We can expect that corrosion, break rates and water leak rates in the drinking water networks will rise due to the climate change effects listed and described in Table 3.1.

In North America corrosion is the main reason for pipe breaks and leakage (Hollands, 2010). As corrosion will likely be worse due to climate changes, in the future we can expect to see even more severe and widespread problems with pipe breaks and leakage. Reports during the last couple of years already show an increasing trend in pipe breaks in several North American cities (Hollands, 2010). The same trend has been observed during cold winters in Northern European countries.

Table 3.1 Effects of climate change on the drinking water networks.

CLIMATE CHANGE	EFFECT ON DRINKING WATER PIPES
Increased sea level rise.	Raises the corrosiveness of the ground close to the coastline and leads to increased corrosion on metallic pipes.
General increase of the corrosiveness of the ground.	Leads to increased external corrosion on metallic pipes.
Probability for increased turbidity of drinking water, and thus increased sedimentation in the pipes.	Leads to increased internal corrosion on metallic pipes, especially pitting corrosion.
More freeze/thaw cycles. Some areas will experience colder winter periods with colder ground temperatures.	Increased break rates on drinking water pipes. Leakage will increase.
Periods of drought, that can lead to dehydration of ground and soil movement/settling (in hot climates).	Increased break rates on drinking water pipes. Leakage will increase.

The amount of leakage in a water distribution system will depend upon the condition of the pipes and the fittings, the quality and quantity of the leakage reduction work and on the excess pressure in the network. As climate changes can cause reduced lifetime of the pipes and increase the break rates, we can also expect that leakage rates will increase equally. This should raise the awareness of the utilities on how to handle problems of corrosion, breaks, leakage and rehabilitation of the pipes. The pipes represent the largest asset group of a water utility and therefore significantly affect costs for operation and maintenance.

It is estimated that about 17 percent of all water in the United States is lost through leaks in the pipe networks, adding up to a projected 9.84 million cubic meters per year (Hollands, 2010). In parts of Europe, water loss caused by leaks can exceed 40 % of total supplies. In Croatia, for example, water loss of total delivered water has since the late 1990s increased and stabilized at about 40 %. However, other parts of Europe have low leakage rates, like in Denmark where the leakage rates have been reduced from more than 10 % in 1996 to 6-7 % in 2009 (EEA report, 2009; Statistics Denmark, 2008; CROSTAT, 2008).

Physical factors

- Pipe age and material
- Pipe wall thickness
- Pipe vintage
- Pipe diameter
- Type of joints
- Thrust restraint
- Pipe lining and coating
- Dissimilar metals
- Pipe installation
- Pipe manufacture

Environment factors

- Pipe bedding
- Trench backfill
- Soil type
- Goundwater
- Climate
- Pipe location
- Disturbances
- Stray elecrical currents
- Seismic activity

Operational factors

- Internal water pressure, transient pressure
- Leakage
- Water quality
- Flow velocity
- Backflow potential
- Operation and maintenance practices

Figure 3.1 Factors contributing to water pipes deterioration. (Al-Barqawi and Zayed, 2006; EPA, 2012)

3.2 Factors influencing pipe condition

The following is taken from EPA (2012):

Pipe condition is the cumulative effect of many factors acting on the pipe. Al-Barqawi and Zayed (2006) classified these factors into three categories: physical, environmental, and operational, as depicted in Figure 3.1.

The factors in the first two classes can be further divided into static and dynamic (or time-dependent). Static factors include pipe material, pipe geometry and soil type, while dynamic factors include pipe age, climate and seismic activity. Operational factors are inherently dynamic.

Many of the factors listed in Figure 3.1 are not readily measurable or quantifiable. Moreover, the quantitative relationships between these factors and pipe failure are often not completely understood. Consequently, contemporary practices of pipe condition assessment use two types of indicators, namely distress indicators and inferential indicators.

3.3 Distress indicators for cast and ductile iron pipes

The following is taken from EPA (2012):

Rajani et al. (2006) defined distress indicators as the observable/measurable physical manifestations of the ageing and deterioration process. Distress indicators are a result of some or all of the factors listed in Table 3.2. Each distress indicator provides partial evidence for the condition of specific pipe components. It is practical to refer to distress indicators by the respective pipe material as provided for cast and ductile iron pipes in Table 3.2. It is noted that leakage could also be considered as a universal distress indicator regardless of pipe type (although the presence of a leak often indicates that failure has already occurred). Leakage out of pressurized water mains is not an acceptable public health risk and short-term pressure surges may pull contaminants into the pipe.

Cracks and pits are common in CI pipes, while DI pipes usually only have pits. Small diameter CI pipes may also be susceptible to ring fractures in shrink/swell soil conditions.

Table 3.2 Distress Indicators that Influence Pipe Condition for Cast and Ductile Iron pipes (Rajani et al., 2006; EPA, 2012)

Category	Distress Indicator	Comments
External coating (poly wrap/ tar/ zinc)	Crack/tear/holiday	State of external coating will dictate how external corrosion is likely to encourage damage to the pipe.
External pipe barrel/bell	Remaining wall thickness	Remaining pipe wall thickness is usually obtained from NDE tests or from spot exhumations and sand blasting samples. Casting defects (voids or inclusions) can be of significant size in CI pipes.
	Graphitization (pit) areal extent	Areal extent as percentage of pipe diameter times unit length indicates the size of affected area. Severe graphitization may not always mean the pipe should have failed. In practice, graphitized area can still provide some resistance – it acts as a form of sticky plaster. In CI, graphitization is typically in the form of graphite flakes, while in DI it is in the form of nodules.
	Crack (pit)[†] type	A pit is a manifestation of an electro-chemical process, while a crack is a mechanical response to stress. Circumferential cracks indicate some type of longitudinal movement, loss of bedding support, or increase in vertical load (frost) has taken place. Longitudinal cracks occur due to low hoop resistance, typically coupled with high internal pressure.
	Crack (pit)[†] width	Crack width is another indicator of corrosion. A wide crack together with a deep pit will be more detrimental to the pipe than a narrow, but shallow crack.
Inner lining/ surface	Cement lining (epoxy) spalling (blistering)	Inner lining deterioration is often due to incompatible water chemistry or abrasion due to the presence of high water velocities and sediments.
	Remaining wall thickness	Occasionally, closed circuit television (CCTV) scans can give estimates of internal corrosion pits when NDE tests are not done to get an overall picture of the pipe wall status.
	Tuberculation	Heavy tuberculation (blockage) can significantly reduce water delivery and produce red water condition.
Joint	Change in alignment	Changes in joint alignment (rotation) indicate pipe susceptible to ground movement. Large changes can lead to leakage and eventually joint failure.
	Joint displacement	Joints can displace without undergoing joint misalignment and hence is also an indicator of other forces at play.

3.4 Inferential indicators for cast and ductile iron pipes

Inferential indicators point to the potential existence of a pipe deterioration mechanism as it points to the pipe history and external and internal surroundings. These indicators do not directly provide us with the state of a pipe, but do indirectly show us the potential for pipe deterioration. The history of the pipe itself and the construction and laying of the pipeline, and the external and internal physical and chemical strain will affect the condition of a pipe, thus telling us something about the potential for pipe deterioration. Different inferential indicators are listed in Figure 3.1.

Table 3.3 Inferential Indicators for Cast and Ductile Iron Pipes (Kleiner et al., 2005; EPA, 2012)

Category (Level 1)	**Agent (Level 2)**	**Comment**
Pipe vintage	Material type, historic standards, and installation practices	Pipes of specific vintages can experience a higher breakage rate. This can be a manifestation of manufacturing processes and standards (e.g., pit vs. spun cast, pipe wall thickness, etc.), or installation practices (e.g., internal lining, polywrap on DI pipes, etc.). Knowledge of the installer could also help to identify poor vs. adequate installation practices.
Pipe joint	Joint type	Historically, three main joint types: (1) rigid, e.g., bored bell and turned spigot; flanged; (2) semi-rigid, e.g., lead-yarn; and (3) flexible, e.g., rubber-gasket push in joint. Pre-mid 1930s, most joints were semi-rigid type (lead-yarn combination). “Leadite” (brand name for sulfur based compounds - mixture of iron, sulfur, slag, and salt) also was used in North America between early 1900s and late 1940s, however, lead was often the jointing material of choice in North America and in the UK. Rubber gasket push-on or roll-on joints introduced in mid 1950s. Anecdotal reports indicate that leadite joints have performed poorly over the years.
Water quality	Water pH	Water with low pH can leach the internal cement lining or pipe wall itself if lining is absent.
Water pressure	Operating pressure (OP)	High pressure subjects pipe to high stress and hence higher propensity to failure.
	Pressure change amplitude (% OP)	Large pressure changes (% of OP) can induce higher stresses than expected by design.
	Pressure change frequency	Either slow or fast fatigue mechanism can induce early failure.
Location	Pipe embedment	Pipes exposed to wet/dry conditions have higher failure rate than pipes totally below water table or pipes totally exposed to atmosphere.
	Surface loads - traffic type	Heavy surface loads will subject the pipe to high stresses and hence faster deterioration in the long term.
	Wet/dry cycle(s)	Changing environment can promote corrosion.
	Water table level	Water table position will indicate if wet/dry cycle is likely to occur.
Soil	Soil type / backfill	Non-draining backfill leads to moisture retention and promotes corrosion; also, poor backfill can lead to development of out-of-roundness condition as soil side (springline) support is not available as required by design of DI pipes.
	Soil resistivity	Low resistivity soil leads to higher corrosion rates. Soil chlorides (e.g., from de-icing salts) reduce soil resistivity.
	Soil pH	Low pH (< 4) means soil is acidic and likely to promote corrosion; high alkaline conditions (pH > 8) can also lead to high corrosion.
	Redox potential	High availability of oxygen promotes microbial induced corrosion (MIC) in the presence of sulfates and sulfides.
	Soil chloride	Low chloride levels in high pH (> 11.5) environments can lead to serious corrosion.
	Soil sulfate	Accounts for MIC and possible food source for sulfate reducing bacteria in anaerobic conditions under loose coatings.
	Soil sulfide	Sulfate reducing bacteria give off sulfides that are excellent electrolytes.

	Frost susceptibility (load)	CI and DI pipes are not designed for frost loads. If conditions exist to develop significant frost loads, then pipe will be subjected to additional stresses (annual) and lead to pipe failure if already significantly corroded. These conditions are: high water table; thermal gradient; right soil type to develop suction (i.e., silt or clayey silt).
Corrosion	Cathodic protection	Cathodic protection (galvanic as well as impressed current) is likely to reduce corrosion.
	Stray current	Stray current is known to accelerate corrosion unless adequate measures have been taken.

Table 3.4 Pit depth measurement definitions (EPA, 2012)

Name	Pit depth measurement
Purpose/Scope	Measure the pit depth of ferrous pipes due to corrosion. Can help to evaluate historical pipe corrosion rate (subject to some fundamental assumptions that often cannot be verified). This rate, in conjunction with deterioration modeling, can be used to assess pipe remaining life.
Status	Various pit depth measurement devices are commercially available. Some devices (e.g., laser range finder) have been developed for research purposes only.
Source of information	SwRI, 2002; Marlow et al., 2007; many others available
Advantages	• Direct measurement, no need for interpretation • Provides good indication of sample condition. • Does not require special skills, easy to train personnel. • For external corrosion, exposed pipe does not need to be taken out of service.
Limitations	• Can be practically applied only to samples, therefore requires some sophisticated statistical analysis to infer general condition of the entire pipe (or pipe segment). • Need to expose the pipe or to cut coupon (destructive testing). When exposing a pipe, care needs to be taken to adequately protect the exposed pipe segments from future corrosion. • Existing coating needs to be removed. • Original pipe wall thickness must be available for corrosion rate estimation. • For internal corrosion, pipe needs to be taken out of service.
Performance	Manual measurement does not need highly-skilled operators. Simple to implement. Only provides information that is specific to the sample. No issue with false positives, false negatives, etc.
Breadth of use	No direct information about breadth of use, but because of its simplicity, it is likely used by many to varying degrees.
Other information	Pit depth measurement of samples along the pipe can be used in a statistical analysis to infer pipe condition. Also, can be used as an input to pipe deterioration models to estimate time to failure.

Table 3.4 states that the pit depth measurement methodology can only be applied to samples (a limitation of the technology) and therefore requires some sophisticated statistical analysis to infer general condition of the entire pipe or pipe segment. This is however not the case for the PipeScanner where real measurement data are provided for the whole pipe segment and statistical analysis and prognosis are no longer needed. All the pit depth data can now be measured on site. In addition, the PipeScanner provides the user with the remaining wall thickness along the whole pipe segment as additional information.

3.5 Condition assessment with the BIT Pipe Scanner

The PipeScanner is a tool used in condition assessment of drinking water pipes to obtain information about internal and external corrosion and remaining wall thickness. The scanner can be sent inside of water-filled, metallic drinking water pipes with diameters of 300 to 400 mm, and uses acoustic resonance technology to obtain information about the extent of corrosion pits and the remaining thickness of pipe walls. The scanner distinguishes internal from external corrosion of the pipe walls and thus gives a thorough analysis of the current state of the entire pipe wall.

The BIT Pipe Scanner is a direct technique of condition assessment, where shutdown of pipe and/or excavation is required, as illustrated in Figure 3.2.

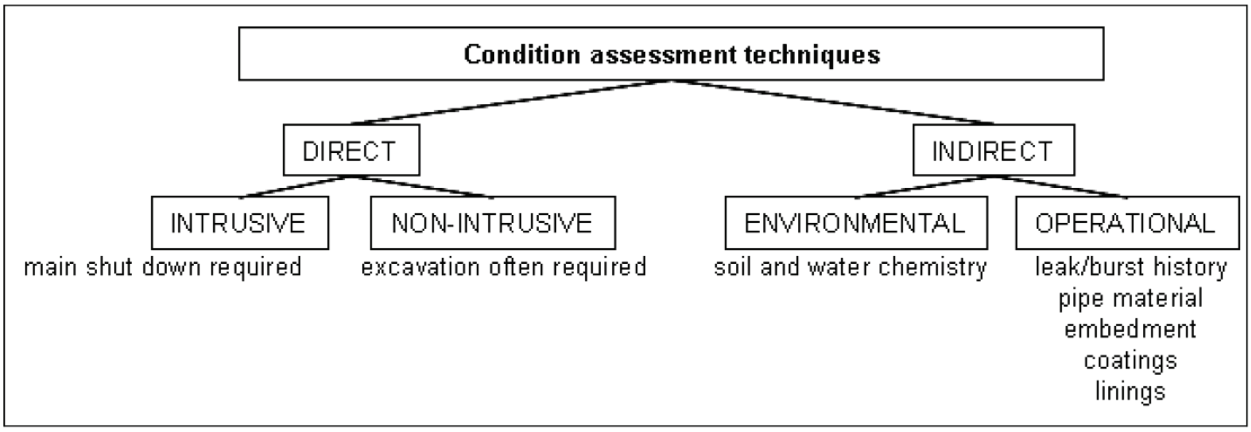


Figure 3.2 Categories of condition assessment techniques (Ugarelli, 2009)

During use, a portion of the pipe to be inspected must be dug up and the top of it must be cut out so that the Pipe Scanner can be sent inside it. The water supply must be shut off during inspection.

The BIT technology can be used for selective rehabilitation of entire pipe lengths by defining the specific pipe quality along its entire length and also pinpointing the weakest links. The results of the PipeScanner can be used to define which parts of a pipe length should be renewed by changing of the pipe or no-dig techniques, which parts should be coated and which parts should be repaired. Such a procedure will optimize rehabilitation strategies and may reduce costs significantly as long as the investment costs in the pipe scanning are not too high.

3.6 Rehabilitate or repair the pipes?

Since the PipeScanner can distinguish internal and external corrosion, it can be used to decide whether to rehabilitate, renovate pipes with coating or to repair the pipes. In order to use coating, the existing pipe should not have external corrosion and one of the few ways to find this out is to apply PipeScanner. Also, the PipeScanner can identify exactly where in a pipe stretch (from manhole to manhole) problems with corrosion and pitting occur, so that problem sections along the entire stretch can be identified. When planning rehabilitation, this information can therefore be used to decide what part of the pipe stretch that will be rehabilitated (with no-dig or changing the pipe) and what part will be renovated with lining or coating. This way the PipeScanner is used to optimize rehabilitation decisions.

One of the main points of uncertainty for decision-makers is related to doubts of what will be the better solution between rehabilitating or repairing the system, and when is the optimal moment for intervention. However, first of all, the decision-maker should be certain about the need for intervention.

Deciding whether to replace or maintain an asset is extremely difficult. It is commonly stated that good asset management is rehabilitating the right pipe, at the right time and with the right technique. Finding the right pipe may be manageable, but finding the right time and technique is regarded as a science by many. Obviously rehabilitating an asset too early is unwise; rehabilitating it too late can lead to large consequential damages. The task is finding the balance point between a reactive and a proactive approach. Asset Management can make it possible to predict a reasonable balance point based on the condition of the asset.

The decision whether to replace or repair a pipe should take into account the balance between three interlink levers: expected level of service, costs and budget over the asset's life. If maintaining the pipe is less expensive than replacing the pipe, in terms of direct costs, the utility can decide whether to maintain it to extend the life of the pipe. However, this can decrease the level of service or the quality of the service due to frequent leaks, odors, or repetitive service interruptions to perform the maintenance.

A point of consensus in the discussion is that all water utilities should put in place a process which minimizes whole life cycle costs for their main assets while achieving community expectations for customer service standards. The life-cycle cost (LCC) is the total cost of owning, operating, maintaining, and (eventually) disposing of an asset over a given period of time (usually related to the life of the project) with all costs adjusted (discounted) to reflect the value of money. But the LCC of one asset has little value by itself. It is most useful when it can be compared to the LCC of other design alternatives which can perform the same function, in order to determine which alternative is the most cost effective for this purpose

In later years the focus in rehabilitation planning has shifted from focusing on stretches of pipes (from manhole to manhole) to focusing on single pipe lengths. With the use of the PipeScanner, the focus on each single pipe can be made easier in that it gives meter by meter information of the pipe underground, from both the inside and the outside of the pipe wall. Detailed information can thus be gained at the single pipe level and rehabilitation and maintenance decisions can therefore be made on the single pipe level instead of on the level of longer pipe stretches. Rehabilitation decision will then be based on more detailed information with the effect that results are more accurate.

Hathi (2012) states that the unit cost (in Oslo, Norway) for using the PipeScanner is thirteen times cheaper than replacing a pipe and 10 times cheaper than fully structural No-dig methods. Costs for coating the inside of the pipe are about 2-3 times lower than replacing it or doing No-dig, but in order to use inside coating one needs to know whether the pipe has external corrosion or not. This can be solved by using the PipeScanner. If the pipe is found to be suitable for applying a coating, the cost savings can be extensive. The total unit cost for PipeScanner and coating is about 45 % cheaper than No-dig and about 60 % cheaper than replacing the pipe (These are general numbers for Oslo, but are also site-specific for different areas within Oslo).

It is in the optimization of rehabilitation and maintenance actions that the PipeScanner is a good tool, in that it gives detailed external and internal condition of inspected pipes. Under given circumstances (as in Oslo), the PipeScanner can be applied and also lead to cost savings in the rehabilitation process, as described above.

4. WATER INFRASTRUCTURE CHALLENGE OBSERVED BY BIT

An enormous investment lag in the water sector has been building up for years. Siemens AG and the Fraunhofer Institute have estimated the global need for maintenance and replacements of drinking water pipe infrastructure to be 6 500 B€ over the next 20 years. European figures show water sector investment needs reaching 1 600 B€ (Siemens AG) while comparable USA numbers show investment needs of approximately 780 B€ (Green Chip Review). Comparing today's investments with what is needed over the next 20 years, today's investment level in the water industry will have to be multiplied 43 times, a number much higher than in comparable industry segments. This investment picture underscores the urgency of action and the business opportunities involved (Schmidt 2009). Market evaluations made by BIT shows value of the initial inspection of water pipes in a confined part of the European market together with North-America reaching 10-15 B€, or 0,4-0,6 % of the estimated maintenance and replacement total made by Fraunhofer and Siemens. The figures are staggering, but show with all clarity that initial planning of the type delivered by BIT will enable resource allocation in a cost-saving manner as the basis for concrete planning and intervention.

There is only one way to distribute water efficiently in urban areas – through pipes, and metallic pipes have been installed since the 1850's. A crucial question now is how to address critical performance challenges for water pipes being laid up to 160 years ago, knowing that replacement of water pipes introduces huge costs, especially so in big cities. At the same time it is realized that low quality water pipes means low quality water and loss of water through leaking pipes.

Water pipes are made of metallic materials (grey cast iron, ductile iron, steel), asbestos/concrete, plastic (PE/PCV) and other materials. In big European cities most pipes are metallic. Statistics show German, English and Swiss cities to have some 60-80 % metallic water pipes, Lisbon 50 %, Norwegian cities 85 – 90 %. Water pipe failure rates vary highly, normally between 0.1 and 0.9 breaks pr km and year. Research reports shows that iron based pipes have the highest failure rate (Sægrov 2008).

In Norway there are about 48 000 km of water pipes, amounting to a replacement cost of some 400 000 MNOK (50 000 M€). A third of this length is of poor quality and will need replacement during the next couple of decades. If every Norwegian local council invests 2 000 MNOK (260 M€) each year replacing water pipes, it will take some 70 years to replace low quality water pipes needing replacement. A comparison study of 25 European cities from 2001 revealed that the combined average rehabilitation and replacement need for water pipes represents 0.9 % of the total length of water pipes in these 25 cities (Sægrov 2008). So, what is then the needed amount of rehabilitation and replacement to avoid a major failure of water supply in these cities? The answer: No one knows! And the reason for not knowing: No knowledge of internal and external water pipe condition resulting in rehabilitating and replacing pipes in the wrong places and at the wrong time with possibly the wrong method. The efficiency in water pipe infrastructure maintenance is poor, and the reason for this is, to a large degree, lack of technology giving pipe condition. This is a real challenge. Supply of healthy water without too big losses during transport is critical and the price of water is on a steep rising curve. Technology has driven market development since the 18th century, and now the water distribution market segment needs new technology to solve their imminent challenges.

Breivoll Inspection Technologies AS is in the market to meet these challenges' which for the company constitutes a business opportunity.

5. PIPELINE CONDITION DATA FOR MODELING PURPOSES

This section describes the design and proposed schema of the database deliverable connected to milestone MS32 in the TRUST WP46.2. The delivered database comes with example data.

5.1 Database design

The pipeline condition database is based on the data model used internally in BIT, and modified with input from Oslo VAV (also a TRUST partner). The over-arching idea is that each individual pipe should be identified and diagnosed. To secure historic data for analysis purposes, it is possible to keep data about pipes that have been replaced during rehabilitation operation. This makes it possible to recreate the entire history for one specific site, of what pipes have been in place and why they have been replaced.

The pipeline condition data can also easily be exported to GIS systems.

5.1.1 Description of database entities

The following entities will be stored in the database:

5.1.2 E1: Inspections

Description: All top-level information that relates to all pipes scanned in one inspection. Address/location has been withheld.
Columns: Unique inspection id, date of inspection, inspected length, year of laying, recommendation ID, severity level ID.

E1.1: Recommendations

Description: BITs recommended action for each inspection.
Columns: Unique recommendation ID, description

E1.2: Severity levels

Description: BITs assessment of time to action or next inspection.
Columns: Unique severity level ID, description

E1.3: Issue types

Description: Generalization/summary of the factors found in an inspection.
Columns: Unique issue type ID, description

5.1.3 E2: Pipes

Description: Top-level information related to individual pipes and their properties, and whether it is a regular pipe or a pipeline component (PSID) with features such as valves or branches.
Columns: Unique pipe ID, pipe thickness ID, pipe lining ID, start position, end position, sid, is_psid, inspection ID

E2.1: Standard pipe thicknesses

Description: The list of pipe types is a hierarchy with the thickness and material on top. This is because these are the two things we usually know about the pipes beforehand.
Columns: Unique pipe thickness ID, pipe type ID, pressure group ID, pipe class name, thickness, outer diameter

E2.2: Pipe materials

Description: Pipe materials and their properties.
Columns: Unique pipe material ID, short name, description, sound speed, critical thickness

E2.3: Pipe types

Description: Pipe types, extracted from manufacturing standard, material and diameter.
Columns: Unique pipe type ID, pipe material ID, manufacturing standard ID, inner diameter

E2.4: Pipe linings

Description: Pipe linings, name and description.
Columns: Unique pipe lining ID, short name, description

E2.5: Manufacturing standards

Description: Manufacturing standards, their name and start date for production.
Columns: Unique manufacturing standard ID, short name, description, production start date

E2.6: Pressure groups

Description: Pressure groups, list of operating pressure limits.
Columns: Unique pressure group ID, description, maximum operating pressure

5.1.4 E3: Findings

Description: Findings as declared by the BIT analysis. Contains statistical and automatically computed data as well as manually detected flaws or points of interest.
Columns: Unique finding ID, inspection ID, pipe ID, grade ID, description, memo, internal corrosion height, internal corrosion area, external corrosion area, maximum thickness, median thickness, minimum thickness

E3.1: Finding types

Description: The types of findings BIT reports.
Columns: Unique finding type ID, finding type code, finding text ID

E3.2: Finding grades

Description: Condition assessment; from critical to good.
Columns: Unique finding grade ID, description, finding grade

E3.3: Finding texts

Description: Standard texts automatically entered into reports based on type of finding
Columns: Finding text ID, description, finding text, unit of measurement

5.2 Description of many-to-many relationships

The following many-to-many relations will be stored in the database:

5.2.1 R1: Issue types per inspection

Description: All possible issues per inspection.
Columns: Inspection ID, issue type ID

5.2.2 R2: Finding types per finding

Description: Each finding can have several finding types (overlapping/adjoined findings). There will only be one finding per pipe.
Columns: Finding id ID finding type ID

5.3 Scanned Pipes: Oslo VAV

No pipes have been scanned in the context of the TRUST project. BIT is therefore including sample data collected by Oslo VAV in its database delivery that will allow TRUST researchers to evaluate the database and its structure.

5.3.1 Data Quality

The BIT PipeScanner version 2 delivers 6400 measurements of thickness, internal topography and corrosion for every meter of pipe. On a DN300 pipe, this is equivalent to approximately 21 300 measurements per square meter of the pipe surface.

As detailed in section 5.1, the delivered data consist of both automatic measurements and semi-automatic annotations and findings. Data quality is assured by adding human judgment into the loop, and all reports are reviewed by at least four analysts before it is handed over to the client.

5.3.2 Oslo VAV Applicability of BIT Services

Oslo VAV uses data from inspections to plan and prioritize tasks in their rehabilitation program (Hathi, Ugarelli 2011). For efficiency, the data from the inspections are exported to a GIS system, where Oslo VAV engineers can work with the data in combination with all other GIS information. The following screen shots from their application show how our data can be visualized in their GIS database.

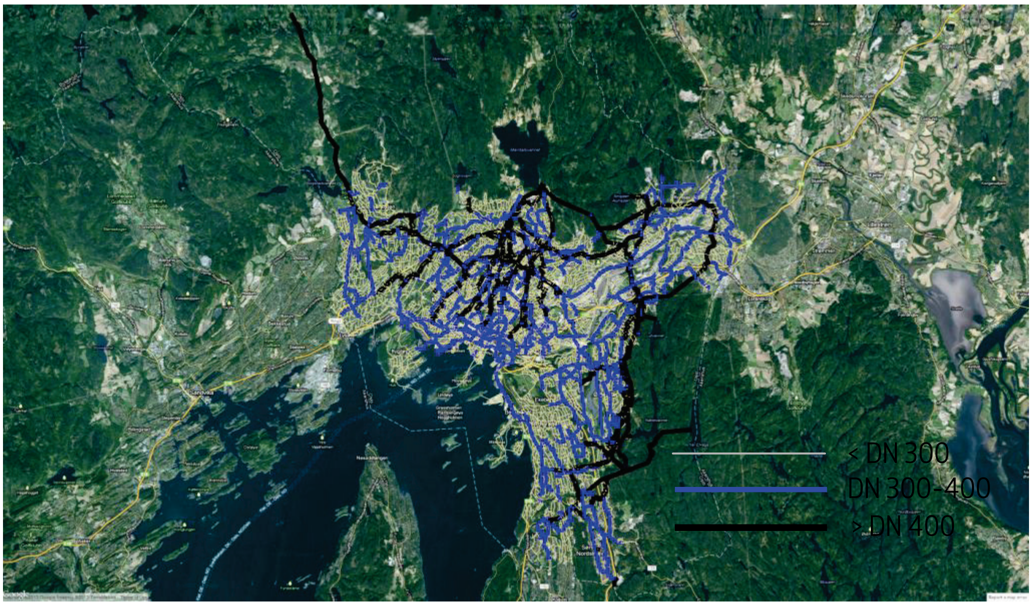


Figure 5.1 Oslo VAV water distribution network, by dimension.

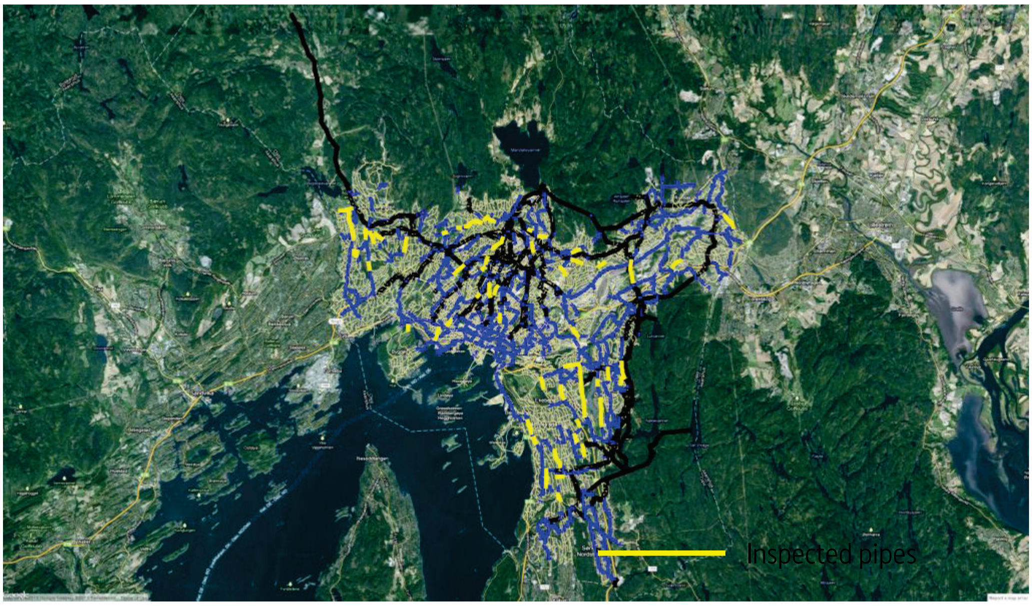
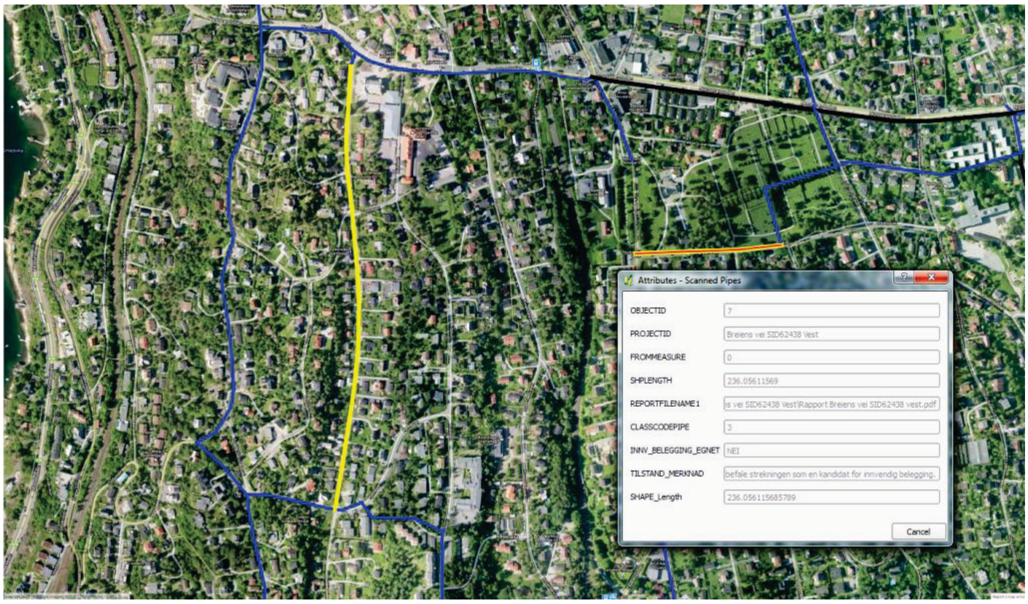
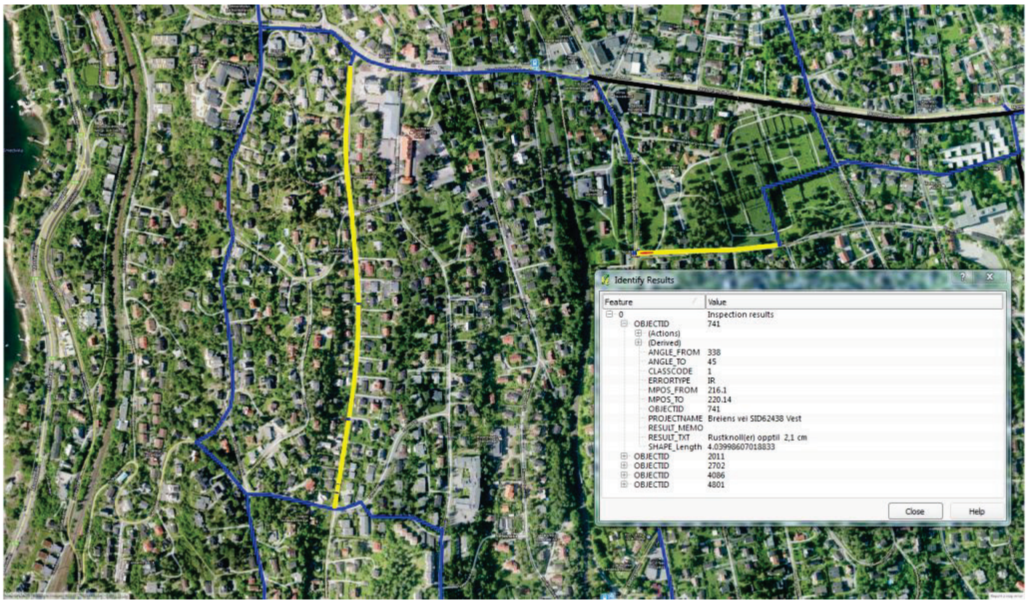


Figure 5.2 Oslo VAV inspected pipes overlaid on network map



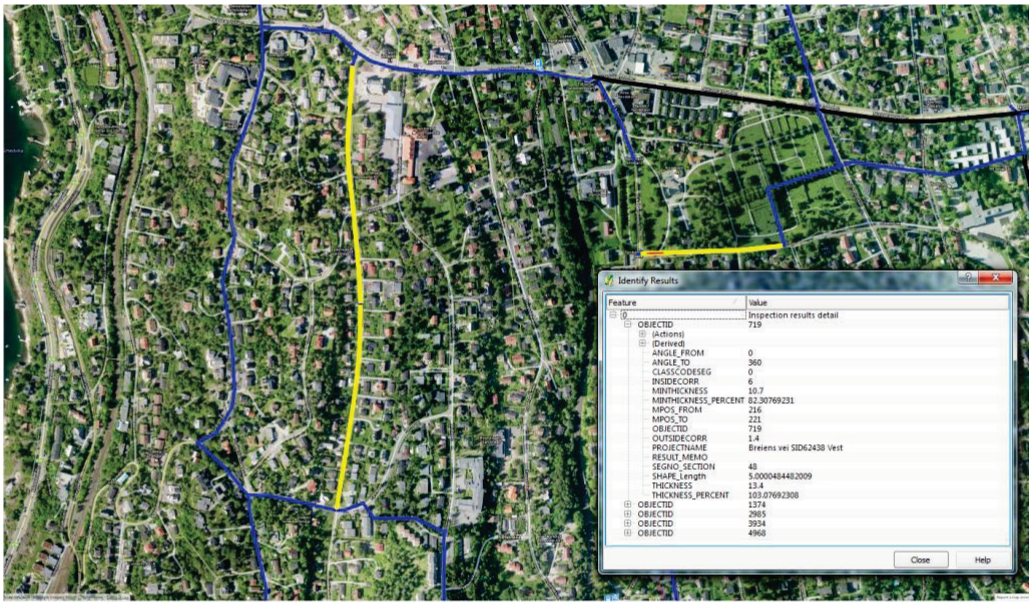
OBJECTID	7
PROJECTID	Breiens vei SID62438 Vest
FROMMEASURE	0
SHPLENGTH	236.05611569
REPORTFILENAME1	is vei SID62438 Vest\Rapport Breiens vei SID62438 vest.pdf
CLASSCODEPIPE	3
INNV_BELEGGING_EGNET	NEI
TILSTAND_MERKNAD	befale strekningen som en kandidat for innvendig belegging.
SHAPE_Length	236.056115685789

Figure 5.3 Oslo VAV detail on inspected section



```
Feature              Value
⊟ 0                  Inspection results
  ⊟ OBJECTID         741
    ⊞ (Actions)
    ⊞ (Derived)
      ANGLE_FROM     338
      ANGLE_TO       45
      CLASSCODE      1
      ERRORTYPE      IR
      MPOS_FROM      216.1
      MPOS_TO        220.14
      OBJECTID       741
      PROJECTNAME    Breiens vei SID62438 Vest
      RESULT_MEMO
      RESULT_TXT     Rustknoll(er) opptil  2,1 cm
      SHAPE_Length   4.03998607018833
  ⊞ OBJECTID         2011
  ⊞ OBJECTID         2702
  ⊞ OBJECTID         4086
  ⊞ OBJECTID         4801
```

Figure 5.4 Oslo VAV inspection results summary



Feature	Value
0	Inspection results detail
OBJECTID	719
(Actions)	
(Derived)	
ANGLE_FROM	0
ANGLE_TO	360
CLASSCODESEG	0
INSIDECORR	6
MINTHICKNESS	10.7
MINTHICKNESS_PERCENT	82.30769231
MPOS_FROM	216
MPOS_TO	221
OBJECTID	719
OUTSIDECORR	1.4
PROJECTNAME	Breiens vei SID62438 Vest
RESULT_MEMO	
SEGNO_SECTION	48
SHAPE_Length	5.0000484482009
THICKNESS	13.4
THICKNESS_PERCENT	103.07692308
OBJECTID	1374
OBJECTID	2985
OBJECTID	3934
OBJECTID	4968

Figure 5.5 Oslo VAV inspection results

Figure 5.6 Oslo VAV with soil map overlay and maintenance events

In the case of Oslo VAV, over 70 inspection sites are now displayed on the GIS involving over 5000 individual pipe segments. Their work with combining BIT data into GIS was presented in an award-winning poster at LESAM 2011 (Hathi, Ugarelli 2011).

5.4 Economic model for condition assessment

Being a relatively new technology, there are so far no economic models that take into account the economic benefits of condition assessment of water pipes. As discussed in section 3.6, there are intuitively significant savings to be had if only the right pipes are rehabilitated, and if they can be rehabilitated at a time that maximises their service life. However, to quantify these savings, it should be a goal for future research to derive a cost model that is capable of quantifying the economic benefits of inspecting a pipe now rather than either leaving it until it breaks or replacing it at a particular age or at a time determined in a more subjective manner. Such a model needs to be transparent and geared towards the decision makers in a utility. In asset management, a model for whole life cost of water pipes needs to be adopted and both environmental and social (indirect) costs taken into consideration.

The following factors should be considered in an economic model:

- **Direct replacement costs** – these need to be based on a variety of no-dig and conventional technologies that might be considered were the pipe to be replaced in its entirety without prior inspection.
- **Social or indirect costs** – these include disruption to water supply, traffic and businesses, increased insurance premiums and costs relating to burst damages. Estimations on social costs from various case studies vary considerably from around 25% of direct costs for certain no-dig techniques, to around 400% of direct costs (NRC, 2005).
- **Environmental costs –** these are of increasing importance as stricter regulations are introduced (e.g. CO_2 emissions).
- **Failure-related costs** – The consequences of a large diameter pipe failure can be very significant and need to be factored into any calculations (Gaewski et al, 2007). The purpose of inspection should be to maximise the life of good assets whilst singling out weaker segments and reducing the number of such incidents.
- **In-ground cost** – the value of ageing, yet structurally sound, buried infrastructure is underestimated (indeed for assets over 40 years, utilities currently consider the book value as zero). Based on the residual life (determined by inspection rather than using an average value for the particular cohort), the in-ground cost will be between zero and the full “as new” value of a replacement pipe.

However, if saving can be shown based on direct costs only then this is an even more persuasive argument, as none of the assumptions required to calculate the social and environmental costs need be contested.

6. METHOD APPLICABILITY

The BIT method and the capabilities of the BIT PipeScanner have been discussed in sections 2, 3.5 and 3.6. A brief overview of the amounts of water pipes suitable for the BIT method has been discussed in section 4, and a case study of how BIT data can be combined with other, legacy data was shown in section 5.3.

This section contains a discussion of the BIT method's strengths and weaknesses. A case study showing the economic aspects of the BIT is also shown.

A detailed comparison with other methods for condition assessment of water pipes is outside the scope of this report.

6.1 BIT Method Strengths

- **Scans water-filled pipes.** The ART technology employed by BIT actually requires that the pipes are filled with water. This reduces the time a pipe has to be taken out of service for inspection.
- **Robust to sediments and corrosion products.** The BIT PipeScanner will measure the thickness in most areas covered by sediments or corrosion products.
- **360 degree scans of every pipe.** A full-circumference scan of every pipe yields a complete picture of the condition of every pipe. The importance of knowing the full condition of every pipe is underlined by the often dramatic production variance found among cast iron pipes.
- **Distinguishing internal and external corrosion.** This distinction is absolutely necessary to forecast the most suitable and cost-effective rehabilitation strategy, as discussed in section 3.6.
- **Exact positioning of findings.** All reported findings are marked with high precision from a reference man-hole. This enables confident decisions on point-rehabilitation.

6.2 BIT Method Weaknesses

- **Pipe access.** If a hatch box unit is not present, a custom entry pipe (the Breivoll Entry Pipe (BEP)), must be installed. This requires cutting out 90-140 cm of the pipe and installing a BEP or hatch box in its place. The incurred service interruption is limited by a well-trained and efficient crew. This requirement is a purely mechanical limitation, and BIT is working to alleviate this issue in future PipeScanner models.
- **Water evacuation.** If the target pipeline has a high operating pressure or if the entry point is lower than other sections of the pipeline, large amounts of water may have to be evacuated. This is a waste of potable water, but can usually be minimized with careful planning.
- **Limited range of pipes diameters.** The current BIT PipeScanner (version 2) is the first commercial model of the BIT PipeScanner range. The pipe diameter range is a purely mechanical limit. The pipe diameter range on PipeScanner version 2 was decided to be

DN 250-400 based on a business perspective. However, the design struggles to inspect heavily corroded pipes smaller than DN 300. BIT is currently designing the PipeScanner version 3, which will increase the diameter range upwards to DN 600. It is likely that a version 4 will lower the range down to DN 100.

- **Limited range of pipe materials.** BIT is focusing its efforts on metallic pipes, which includes pipes made from grey cast iron, ductile cast iron and steel. The ART technology can, in theory, be applied to all objects which exhibit a resonance frequency. This includes concrete, asbestos cement, PCV and HDPE. Extending the ART technology to these materials is likely to require significant research.

6.3 Market reception

BIT has received international acclaim for its method of condition assessment of water pipes. The TRUST member utility Oslo VAV has declared that “all pipes in Oslo that are being considered for rehabilitation, should be scanned first, if possible” (Hathi 2012).

Other TRUST member cities have been hesitant to apply BIT services in their rehabilitation strategies – some citing price concerns and other citing that “urgent cases to decide on pipe renewal do not exist yet”.

6.4 Applicability of BIT data in GIS modelling

A comprehensive GIS database for a water utility should already include information relating to the pipes and fittings, maintenance events (such as breaks) and environmental information (e.g. a soil map or traffic data). Separate layers relating to pipes that are to be inspected or have already been inspected can be added, together with any associated condition assessment data. The additional information can be used in several ways:

- **Planning which pipes to inspect next** – Decisions might be based on environmental data (e.g. deciding to inspect in an area of corrosive soil) or operational data (e.g. number of customers affected by temporary water outage).
- **Strategic rehabilitation planning based on previous inspection results** – Several pipes in poor condition in one area might prompt a more thorough rehabilitation programme in that area.

Additional layers can be added to the GIS as they become available (e.g. leakage detection results or video inspections). The ability to visualise all this information is important in order to achieve efficient asset management.

Based on the case study from Oslo VAV in section 5.3, we can conclude that BIT data are well suited for modelling purposes.

6.5 Case study: cost/savings analysis Oslo VAV

As discussed in section 3.6, condition assessment of water pipes is especially useful if it can help decide on which pipe to rehabilitate with which method, and at what time. The BIT method for condition assessment has the technological means to decide what condition a pipe is in, and, if necessary, whether it should be rehabilitated, repaired or replaced. The economic argument for using condition assessment methods before deciding on which method to use, is that there are significant cost differences between the different methods. Arguably, cheaper methods may not give the same extension of service life as more expensive methods, but it may well be worthwhile to apply coating to a pipe if that means you can wait another few decades before it must be replaced completely.

To support these claims, BIT has collaborated with Oslo VAV to create a simplified economic schema that compares the costs of BIT inspection with the savings that are enabled. The schema only accounts for direct costs, and does not take into account any effects on expected life span, real current value and depreciation. Also, the internal costs of the utility associated with digging and preparations are not included, nor are indirect costs potentially incurred by third parties or climate costs (CO2 emissions).

Table 6.1 Comparison of total cost of recommended actions and cost of BIT inspection

Recommended action	***Number***	***Meter***	***Of total***	***Cost / m***	***Total cost of action***		
Structural rehabilitation (No-Dig)	33	7 995,6	**35%**	€ 1 300	€ 10 394 280		
Point rehab./repair	13	3 298,0	14%	€ 154	€ 507 000	€ 39 000	pr m w/2 rep pr insp
Internal lining or coating	23	6 069,1	27%	€ 520	€ 3 155 932		
No actions in short or middle term	23	4 617,0	**20%**	€ -	€ -		
No recommendations in database	8	800,2	4%				
TOTAL cost of BIT inspection				€ 65	€ 1 480 696	10%	of tot. direct cost.
TOTAL cost of recommendations	**100**	**22 779,9**	**100%**	-	**€ 15 537 908**	***40%***	***of cost of new pipes w/dig***

BIT has conducted around 100 inspections for Oslo VAV, for which we have provided clear recommendations for further actions for 92. This is a total of almost 23 km. Table 6.1 shows that BIT recommends structural rehabilitation of 35% of all inspected pipes (7 995,6 m) and internal lining or coating on 27% (6 069,1 m). This differentiation is made on the basis of the amount of internal versus external corrosion BIT has found. The table also shows that 20% of all pipes (4 617 meters) could safely be left in the ground without any actions in the short or middle term[2]. 14% of all pipes (3 298 meters) are declared healthy in the long term[3] if the weakest points of a pipeline are improved through targeted point rehabilitation.

Table 6.1 also includes the direct costs for the recommended actions, should they be executed today. Oslo VAV calculates € 1 300-1 700 per meter for NoDig structural

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[2] We define short term as five years, and middle term as 10 years. Unless there are no serious issues, we recommend a new inspection after 10 years to be able to say more about the rate of corrosion and thus the expected remaining service life time.

[3] We define long term as 10 to 20 years.

replacement, and € 520-590 per meter for internal coating[4]. Point rehabilitations where an individual pipe or a section of a pipe is replaced is calculated at around €39 000 per repair[5]. BIT is charging € 65 per meter to Oslo VAV. Adding up these costs we see that the total cost of action is € 15 million, of which the cost of BIT inspections is 10%.

Now, the most interesting part is comparing the total cost of a BIT-advised rehabilitation strategy with a strategy that does not include such detailed advice. The most straight-forward comparison is to calculate the costs of using the different rehabilitation methods on the entire 22.8 km. These costs are shown in Table 6.2. The numbers are calculating by multiplying the costs per meter given by Oslo VAV by the number of meters inspected by BIT.

Table 6.2 Total cost if same given method used on all pipes:

STRUCTURAL REHABILITATION (NO-DIG)	€ 29 613 922		
Internal lining or coating	€ 11 845 569		
No actions in short or middle term	€ -		
New pipes laid by traditional digging	€ 38 498 099		€ 1 690/m

We see here that the costs of the BIT-advised scenario from Table 6.1 are just 40% of the cost of complete replacement with digging, and 52 % with NoDig. Applying a coating is a cheaper method, but since we could not advise this for more than 27% of the pipes, the BIT-advised scenario is more expensive.

It is also worth noting that even though repairing or replacing one individual pipes costs as much as € 39 000, BIT advised this strategy for 14 % of the pipes. The number of actual recommended point rehabilitations is not recorded in our data, so for the sake of comparison we have assumed an average of two point repairs per inspection. Table 6.3 shows the costs associated with applying a coating or replacing all pipes in the areas where BIT advised point repairs. In Table 6.1 the cost of all point repairs are calculated at € 507 000, which is only around 10 % of the cost of structural rehabilitation of these 3 298 m.

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[4] Oslo VAV uses NOK as currency, this case study uses an exchange rate of 0.13 EUR/NOK.

[5] In this case study, we have calculated with 2 point repairs per inspection.

Table 6.3 Costs of using other methods in stead of point rehabilitation:

STRUCTURAL REHABILITATION (NO-DIG)	€ 4 287 400
Internal lining or coating	€ 1 714 960
New pipes laid by traditional digging	€ 5 573 620

Besides being able to advise the most suitable rehabilitation method, condition assessment with BIT may also show that no action is necessary in the short or middle term. Table 6.1 shows that BIT could do this in 20 % of the inspections. The direct savings associated with this advice is given by calculating the costs of using other methods on the same amount of pipes, and shown in Table 6.4.

Table 6.4 Costs of using other methods in stead of no action:

STRUCTURAL REHABILITATION (NO-DIG)	€ 6 002 100
Internal lining or coating	€ 2 400 840
New pipes laid by traditional digging	€ 7 802 730

Compared to a scenario in which these pipes had been selected for replacement by traditional digging, this represents a direct current saving of 7.8 million Euros. The direct cost of BIT inspection of these 4 617 m is approximately € 214 000, or just 2.75% of the replacement costs.

All in all, the savings that can potentially be achieved in Oslo VAV by following BIT's recommendations compared to open-cut traditional pipe replacement by digging are as high as 60 %. The costs of BIT inspection in this case study are as little as 10% of the direct costs of the recommended actions, and as low as 4 % of the cost of replacing all pipes using an open-cut method.

7. SUMMARY

During the TRUST project period, BIT has started the development of a more solid inspection system, capable for a broader range of dimensions. Capabilities for extending the pipe diameter range up to DN 600 are underway, and will likely be on the market by the end of 2013. A parallel project has been started to extend the pipe diameter range down to DN 100, possibly through the use of a “hot tapping technique” to access the pipe without causing service disruption.

The Pipeline Analysis and Reporting System (PARS) has been improved during the TRUST project period. Analysis is now automated to a higher extent than previously, which shortens the time needed for data analysis. Extensions to export data to GIS databases have been developed and demonstrated.

The applicability of the BIT method for condition assessment of metallic water pipes has been assessed. Strengths and limitations have been discussed. An economic case study has been presented, which exposes significant direct cost reductions.

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