Failure-guided deployment of fixed multipoint correlating noise logger network for leakage reduction – a case study in Oslo municipality

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Sammendrag

Bruddbasert utplassering av fastmonterte multipoint korrelerende lydloggernettverk for lekkasjereduksjon - et case-studie fra Oslo kommune. Denne artikkelen presenterer en metode for aktiv lekkasjekontroll, utført i et pilotprosjekt i Oslo kommune. Metoden bruker prognoserte bruddklynger basert på historiske data for å optimalisere plasseringen av et flerpunkts-korrelerende nettverk av lydloggere (FMCNLN), som kontinuerlig overvåker og stedfester lekkasjer. Ved å plassere lydloggere i områder med høy risiko for brudd eller svikt, kan antall enheter reduseres og kostnadene senkes, samtidig som effektiv lekkasjekontroll opprettholdes med en håndterbar teknologipark. Av åtte lekkasjer i pilotperioden oppsto seks i forvendede bruddklynger. Infrastrukturlekkasjeindeksen falt fra 17,89 til 3,57 i pilotperioden, med anslått 67 % større reduksjon i vannlekkasjer sammenlignet med tradisjonelle metoder. Kostnadene er anslått å være 2–3 ganger lavere, hovedsakelig på grunn av reduserte driftsutgifter knyttet til lekkasjetid. Nøyaktigheten til bruddprognosemodellen er avgjørende for suksessen til denne tilnærmingen. Ved å styre utplasseringen av FMCNLN ved hjelp av forventede bruddklynger, kan investeringskostnadene reduseres med opptil 80 % sammenlignet med fullskala utrulling, noe som er essensielt for å skape en håndterbar, kostnadseffektiv metode for lekkasjekontroll.

Summary

This paper introduces a novel approach to active leakage control, piloted in Oslo. It uses predicted failure hotspots from historical data to deploy Fixed Multipoint Correlating Noise Logger Networks (FMCNLN), continuously monitoring and pinpointing leakages. Strategically deploying FMCNLN only in these hotspots minimizes costs by reducing logger units, while ensuring effective leakage control and maintaining manageable technology park related to operations. Of 8 failures during the pilot, 6 were in predicted hotspots. A notable reduction in the infrastructure leakage index (ILI) from 17.89 to 3.57 was observed, with an estimated 67 % greater decrease in water losses compared to traditional methods. Costs are estimated to be 2–3 times lower, attributed to reduced operational and leakage-runtime related costs. Success of this approach depends on the accuracy of the failure prognosis model. FMCNLN's guided deployment can save up to 80 % in initial

investment costs compared to full-scale deployment, vital for a manageable, cost-effective strategy across the water distribution network.

Introduction

Leakage in Water Distribution Networks (WDN) represents challenges to utilities, due to operational inefficiencies, resulting in unsustainable operation with excessive energy and financial expenditure, but more importantly, endangers public health with the risk of ingress of contaminants from the surrounding environment (Fox et al., 2016). Early detection and repair of leakages can prevent the deterioration of small leakages into large bursts, hence preventing significant water loss and the associated risks (Cody et al., 2020). Leakage in WDNs can be caused by poor pipe connections, pipe deterioration and corrosion, or mechanical damage, ground movement and ground conditions, high system pressure, seasonal temperature fluctuations, manufacturing defects and subpar workmanship (Puust et al., 2010). Failures in the context of this paper, are all events leading to subsequent leakages in the WDN, regardless of the initiating cause. Water distribution pipelines can be susceptible to significant losses, typically ranging from 20 % to 30 %, with figures exceeding 50 % in aging systems with inadequate maintenance (El-Zahab and Zayed, 2019). In Oslo's case, Non-Revenue Water (NRW) is approximately 35 % of System Input Volume, of which a significant proportion is estimated as being real losses (Oslo Municipality, 2017). According to Statistics Norway, average water loss is approximately 32 % of produced drinking water in Norwegian municipalities, a statistic significantly surpassing the European average (Kildahl, 2021).

Traditionally the approach to leakage control relied on a passive/reactive approach to reported leakages, as well as time-consuming, manual, and laborious routine walk-throughs, with portable correlators and geophones. Active Leakage Control (ALC), as opposed to passive leakage control, is a proactive strategy to locate unreported leakages, by utilizing specialized equipment and methods (Farley and Trow, 2003), thereby minimizing leakage run-time. Leakage detection systems can also be categorized into static (or stationary) and dynamic (mobile) systems, depending on how they are installed. Static systems are permanently deployed and can alert the utility to the existence of a leakage almost instantaneously, involving minimal manpower. While dynamic systems must be mobilized to survey and pinpoint the exact location of leakages (El-Zahab and Zayed, 2019). Dynamic leakage detection systems involve moving leakage detection devices for leakage investigation and surveying, based on reported leakages or a routine walk-through survey of the WDN.

In Oslo's case, a dynamic system of Portable Correlating Noise Logger (PCNL) are deployed and collected the day after, while logging overnight leakage sounds. It takes two years to complete this routine for the entirety of Oslo's WDN, allowing leakages to persist for an extended time. The leakage noise loggers are placed in utility manholes without any trenching or drilling, connecting to the metallic pipe using a magnet. Positioned in grids, with appropriate distances between each logger, they employ advanced algorithms to distinguish between normal operational sounds and leakage noise, enabling immediate leakage detection upon occurrence. Consequently, according to Negm et al. (2023), these systems can also be classified as hardware-based, non-intrusive, acoustic methods of leakage detection. Combined with correlation principles, i.e. exploiting the time difference in leakage sound reception between sensors, acoustic methods can determine both the presence and the location of the leakage concurrently (Tijani et al., 2022).

With Internet of Things (IoT)-enabled leakage monitoring, sensors can be permanently deployed in static leakage detection systems (El-Zahab and Zayed, 2019), transmitting data to identify, localize, and, in some cases, pinpoint leakages, thus providing a complete Identification, Localization and Pinpointing (ILP) system. An example is Fixed Multipoint Correlating Noise Loggers Networks (FMCNLN) that continuously monitor and automate leakage detection in fixed networks, consequently reducing human error and the need for labour, while also providing multi-point correlation (Ovarro, 2024). As permanent fixtures in often aggressive environments, they require maintenance and battery changes (El-Zahab and Zayed, 2019). This technology has high reliability, with relatively low costs of acoustic sensors (Tijani et al., 2022).

Immediate alarms produced by fixed leakage detection systems, such as FMCNLN, reduce leakage run time to a minimum and, with effective follow-up repair, results in substantial water savings (Hamilton and Charalambous, 2020). The efficacy of acoustic leakage-detection equipment depends on several factors including pipe characteristics, soil conditions, surrounding noise environment, and equipment sensitivity (Hunaidi et al., 2004), alongside installation and maintenance quality. A cost-benefit analysis in Madrid found fixed acoustic leakage detection to be effective under all tested conditions (Sánchez et al., 2005). In Montreal, another cost-benefit study showed that expanding the coverage of noise logger leakage detection systems to be a worthwhile investment, leading to significant temporal and financial savings over the planning horizon (Abu-Samra et al., 2019). Another case study from Anglian water, England, reported a 20 % reduction in leakage from 2010 with fixed network technologies, aiming for a further 25 % reduction by 2025, well below the Economic Level of Leakage (ELL) (Hamilton and Charalambous, 2020). In Hifa, Israel, one of the world's largest fixed monitoring projects with 340 noise logger measurement points, has resulted in an 8 % reduction in Non-Revenue Water (NRW) in one year, with a 320 % return on investment (Hamilton and Charalambous, 2020).

Deployment of fixed networks is based on economic comparisons of labour costs versus capital, initial investment, alongside the added benefits of immediate notification of leakages (Hamilton and Charalambous, 2020). In Oslo's case, transitioning from traditional, passive leakage control to ALC is underway. Yet, a comprehensive deployment of fixed networks across the entire WDN would incur costs of approximately 100 million Norwegian kroner (NOK), making it economically and operationally unfeasible (Oslo Municipality, 2020). Therefore, a strategic approach and prioritization for implementation is necessary, in regard to both cost and operations. For that reason, this paper proposes an implementation approach for Fixed Multipoint Correlating Noise Logger Networks (FMCNLN), using a failure-guided deployment strategy. The aim is to strategically deploy FMCNLN in areas identified as failure hot-spots, in which areas new failures are predicted to occur according to the failure prognosis model. In these areas there is a higher probability for failures, than elsewhere in the WDN. This targeted approach optimizes investment costs, while ensuring effective leakage control and manageable maintenance and operations of the technology park.

The effectiveness of this approach was tested in a case study within Oslo municipality. Also, to evaluate results from the case study, a cost-benefit analysis was performed, comparing failure hot-spot deployed FMCNLN to traditional methods. This analysis was performed for the case-study, but also for a potential, future 10-year scenario.

Material and methods

Study area

Lambertseter, situated in southeast Oslo, covers an area of 4.28 km^2 (Figure 1 (a)). It primarily consists of grey cast iron pipes, with an average age of 61 years, encompassing 41.95 km of mains and 107.8 km of service pipes, serving 2965 connections, primarily residential homes and some commercial units. The District Metered Area of Lambertseter (DMA) includes 842 manholes, mainly serving both drinking water and sewer- and -stormwater infrastructure. As shown in Figure 3, initially, the Minimal Night Flow (MNF) was recorded up to 115 L/s or an ILI (Infrastructure Leakage Index) of 18, indicating a "very inefficient use of water resources" (Leakssuite Library, 2020). Consequently, a FMCNLN was strategically deployed solely in identified failure-hotspots, as shown in Figure 2. Traditional walk-through surveys with PCNL were conducted on the remaining parts of the DMA to validate the accuracy of the failure hotspots. Both FMCNLN and PCNL systems are based on the same underlying technology of correlating leakage noise loggers, with the same sensitivity to leakages. The main difference is that the FMCNLN-system is a fixed, remote system, while the PCNL is aportable and temporary survey tool.

Identification of hotspots

Failure hotspots were created based on Lambertseter's historical failure database with stars representing failures in Figure 1 (b), which dates back to the mid 70's. For Oslo's rehabilitation plan 2010 – 2020, Casses, the freeware for the Linear Extended Yule Process (LEYP)-model developed by Cemagref, was used to perform failure prediction (Riisnes and Ugarelli, 2014). It calculates failure probabilities depending on multiple variables in the model and estimates failure probability over time for each pipe (Reichborn, 2013). LEYP-model results can be geolocationally analyzed in ArcGIS to assess clustering properties using failure probabilities as attributes. Geolocational clustering of historical pipe failures and results from the LEYP-model resulted in eight hotspot areas, shown in Figure 1(c), with hatched polygons. These failure hotspots have higher likelihood of leakage occurrences than elsewhere in the DMA. These hotspots were further prioritized based on the failure prognosis values from the LEYP-model, resulting in four hotspot areas selected for FMCNLN deployment, Figure 1 (d). These four hotspot areas comprised only 8,8 km of mains,

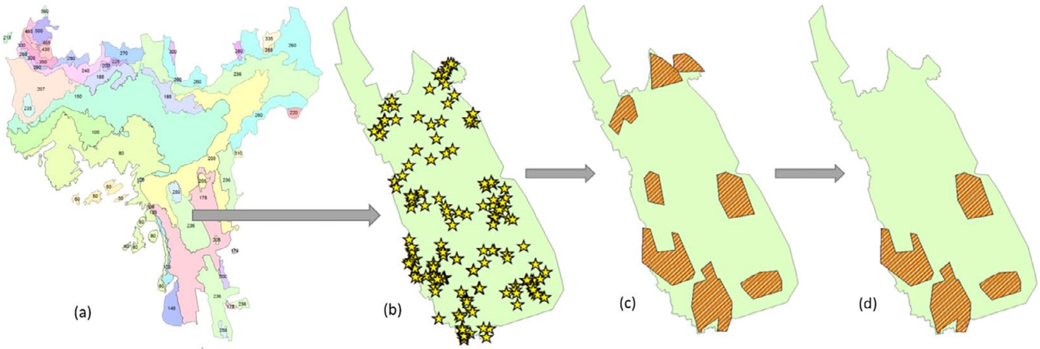

Figure 1. Creation of hotspots: (a) Location of DMA Lambertseter (b) Stars representing historical failures, (c) 8 initial hotspots selected after step (1) and (2), (d) final hotspot selection for FMCNLN deployment after step (3).

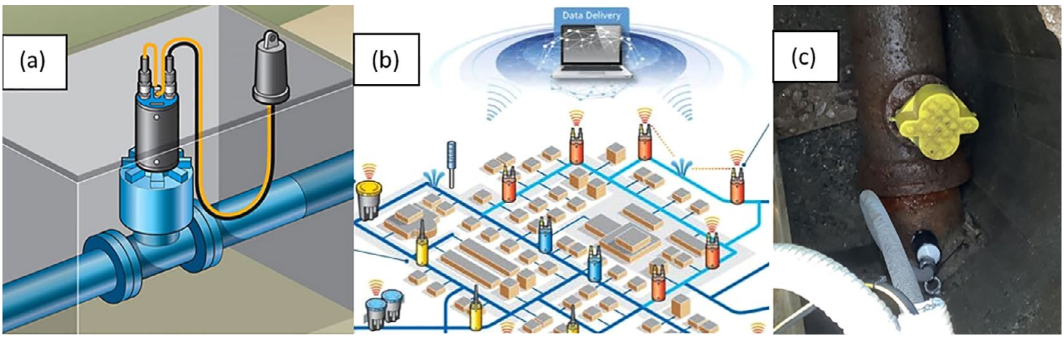

Figure 2. FMCNLN-technology: (a) Device sketch (b) Network sketch, (c) Field photo (Source: Ovarro & Oslo municipality)

from a total of 42 km for the whole DMA, equal to 21 % of the total pipe length. In total, 35 CNLs were deployed in this designated area, in accordance with the manufacturer's guidelines specifying a distance of 250 meters between a set of loggers.

IoT-device configuration

To improve the correlation pinpointing accuracy of the noise loggers, we performed time synchronization over the FM radio band. The need arose due to previous challenges related to signal penetration of cellular frequencies. FM's lower frequency offers wider coverage, particularly beneficial with deep manholes and various local conditions. Therefore, synchronization was done over the FM-band, while correlation results were transferred over 3G cell-phone network.

Assessment of cost-benefits

The cost-benefit analysis has compared two scenarios:

- Scenario PCNL: Manual leakage detection (walk-throughs) with Portable Correlating Noise Loggers (PCNL).
- Scenario FMCNLN: Failure-guided deployment of Fixed Multipoint Correlating Noise Logger Network (FMCNLN). Manual leakage detection (walk-throughs) with PCNL outside hotspot areas.

Both scenarios were cost modelled for:

i. Lambertseter – Pilot project period: 6 months in spring of 2021
ii. Lambertseter – 10-year period

The modelled 10-year period (ii) represents a likely, future scenario, whereas the six-month pilot project-model (i), is based on actual events with real measurements. The cost analysis compared costs incurred during the leakage detection time, i.e. costs related to the process of ILP of leakages. Costs for both scenarios (C_{PCNL} and C_{FMCNLN}) were calculated using relevant costs (Abu-Samra et al., 2019):

$$C = CAPEX + OPEX + LEAK =$$
$$C = (C_{AC} + C_{IC}) + (C_{OP} + C_{OS} + C_{ICT}) + (C_{WP} + C_{WD} + C_{WW}) \quad (1)$$

A. Capital expenditures (CAPEX): Acquiring (C_{AC}) and installing technology (C_{IC}).
B. Operating expenditures (OPEX): Operations (C_{OP}), salaries (C_{OS}) and telecommunications (C_{ICT}).
C. Leakage-related expenditures: Water production (C_{WP}), distribution (C_{WD}), and management of leakage water infiltrating into wastewater pipes (C_{WW}).

For the (ii) 10-year model, all costs except initial investment costs repeat annually, with present worths computed for the N compounding periods, (scenario 10 years), using an annual interest rate of i = 4,1 % (Oslo Municipality, 2023) as shown in equation (2):

$$C^{PV} = CAPEX + \sum_{n=0}^{N} \frac{(OPEX + LEAK)}{(1+i)^n} =$$
$$CAPEX + \left[\frac{(1+i)^N - 1}{i(1+i)^N}\right](OPEX + LEAK) \quad (2)$$

To set up the cost models, the following sources were used:

1. Prices, installation requirements and estimated equipment lifecycles: Equipment manufacturer: Ovarro.
2. Routines and workflow ALC-scenarios: Head of leakage department, Oslo municipality
3. Energy consumption: Oslo municipality energy reporting, 2021
4. Share of water leakages infiltrating sewer pipes: (Ødegaard, 2012)
5. Leakage quantification (size, run-time, distribution): Databases, Oslo Municipality

Table 1 lists variables included in the cost model, which are based on assumptions. A sensitivity analysis was conducted for these parameters, computing costs within the range specified in Table 1 to evaluate the model's sensitivity to changes within this range.

Table 1. Sensitivity analysis parameter overview.

Parameter	Range	Default value	Source	Confidence
Failure rate*	5 – 13 failures/year	9 failures/year	Failure database	High
Leakage distribution*	50 – 90% bursts in hotspot	70% bursts in hotspot	Failure database	High
Leakage size*	5 – 25 L/s	15 L/s	Measurements	Medium
Electricity price*	1 – 3 NOK/kWh	2 NOK/kWh	Price database	Medium
Share of water leakages in sewer**	30 – 70% leakages in sewer	50% leakages in sewer	Literature review	Low
Leakage run time	123 – 607 days	365 days	Time of periodical walk throughs	Low

* For Lambertseter pilot project (1), actual measured parameter values were adopted in the model.
**For Lambertseter pilot project (1), default parameter value was adopted.

The benefits of FMCNLN mainly stem from reduced leakage run-times. To assess real losses, MNF analysis was conducted, examining flow trends during early morning hours when consumption is low. This method requires subdivision of the WDN into DMAs (Candelieri *et al.*, 2013), monitored by permanent flow meters. Flow rate data are analyzed for abnormal increases indicating leakages, and to calculate performance indicators, including the Infrastructure Leakage Index (ILI) (Lambert, 2003; Farley and Trow, 2003; Puust *et al.*, 2010) calculated by equation (3):

$$ILI = \frac{CARL}{UARL} \quad (3)$$

where: CARL = current annual real losses [L/year]
UARL = unavoidable annual real losses [L/year] as shown in equation (4)

$$UARL = (18\text{Lm} + 0{,}8\text{Nc} + 25\text{Lp}) * \text{P} \quad (4)$$

where: Lm = mains length [km]
Nc = Number of service connections (main to property line) [-]
Lp = Total length of underground service pipes, property line to meter [km]
P = Average pressure [mwc]

Results and discussion

Failure hotspots

In the pilot project, eight main breaks were found and fixed, as shown in Table 2. 87.5 % of these leakages were located within hotspots shown in Figure 1 (c), and 75 % were within selected hotspots, covered by the FMCNLN in Figure 1 (d).

Table 2. Table of main bursts in pilot project Lambertseter.

Main leakages		
Adress	**Leakage flow**	**Hot-spot**
Nordseter terrasse	7 l/s	Yes*
Antenneveien	20 l/s	Yes*
Vestbrynet	10 l/s	No
Mellombølgen	10 l/s	Yes*
Nylænde	50 l/s	Yes*
Trygve Ryensvei	10 l/s	Yes**
Gina Krogsvei	1 l/s	Yes*
Nylænde	N/A	Yes*
Total	**108 L/s**	**7/8**

* Selected failure hotspots: Figure 1 (d)
** Failure hotspot: Figure 1 (c)

In 2021, after the pilot project concluded, additionally 4 failures were found, increasing the accuracy of hotspots to 92,3 %. The failure prognosis and results regarding accuracy of hotspots presented, only applies to failures on the water mains, owned by the municipality. In Oslo, it is assumed that approximately 50 % of water losses are related to mains, and 50 % to private service connections (Oslo Municipality, 2020). For the latter, very limited data is available, therefore this is not included in our research.

Leakage reduction

Considering the Lambertseter pilot project (i) with the FMCNLN-scenario, MNF was reduced from approximately 100 L/s to 20 L/s, a decrease from 70 % to 30 % in real losses from project start to end, as depicted in Figure 3. Within this period, the development of bursts pushed the MNF to 115 L/s at its peak. The ILI was accordingly reduced from 18 to 3,6, moving from exceptionally high to moderate (Lambert, 2009). ILI calculations were performed according to equations (3) and (4). Savings in water loss amount to 67 %, compared to the PCNL-scenario. After the pilot project concluded, efforts in reducing water losses continued. In Oslo, the absence of house metering causes leakages in private service pipes, contributing to high NRW levels.

Considering the future 10-year period (ii), with the PCNL-scenario, approximately 42 million m^3 of potable water would be wasted as leakages. In the FMCNLN-scenario, reducing leakage run-times could prevent about 70 % of water losses, saving roughly 30 million m^3 over the 10-year period. It is assumed that another 30 – 70 % of these leakages would infiltrate to the wastewater system, needing additional resources for transport and treatment. It is important to emphasize that the 10-year model is conservative, not factoring in potential higher burst rates due to continuous infrastructure deterioration or increased pressure in the DMA from leakage repairs and other future factors with negative effects on the development of leakages. This emphasizes the urgent need for both targeted rehabilitation of deteriorating pipes, as well as ALC. While costs related to leakage run-time are addressed in the next sub-chapter, the urgent need for leakage reduction far exceeds only the cost aspect from both a sustainability perspective and risk to public health.

Costs

Considering the Lambertseter pilot project (i), the PCNL-scenario costs 0,564 million NOK, while the FMCNLN-scenario costs 0,293 million NOK, as detailed in Table 3, using measured

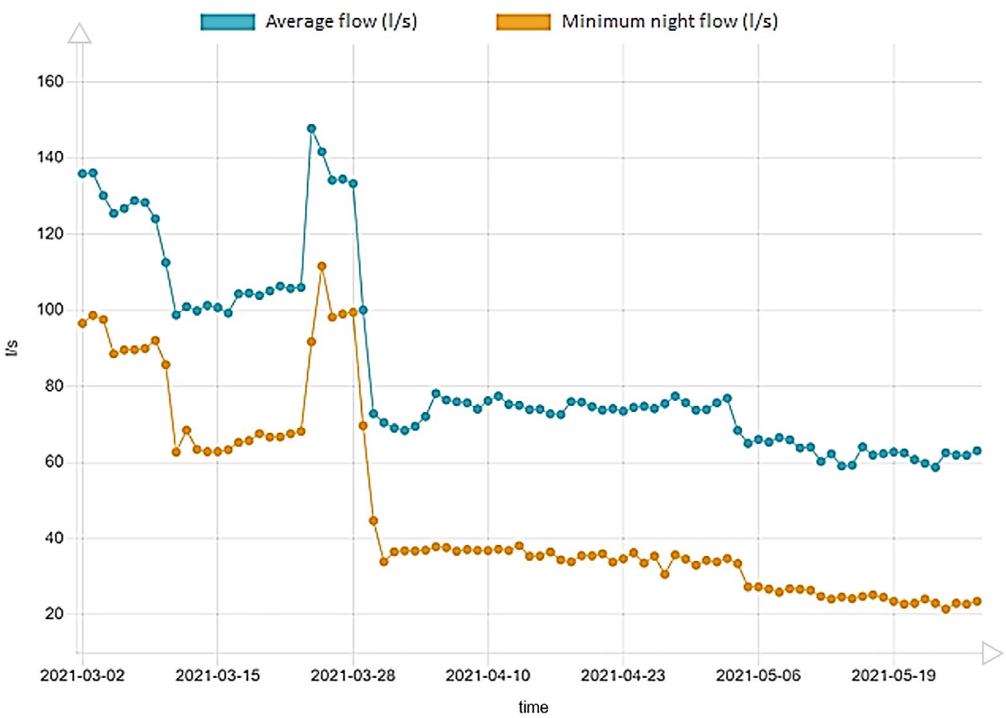

Figure 3. Real losses (orange) and average flow (blue) for DMA Lambertseter.

parameter values. PCNL is therefore approximately two times more expensive than FMCNLN, with the latter reducing operational costs by more than 50 %. It is important to emphasize that, the initial CAPEX of technology acquisition in both scenarios applies to technology life cycles over approximately 10 years, so a 10-year perspective is more suitable when comparing costs. In Norway, high salaries contribute to high OPEX. During episodes with high MNF or burst rushes recorded in the pilot project, the ELL is determined by comparing leakage runtime costs with OPEX and CAPEX. Systems like FMCNLN eliminate a lot of manual labour, which allows for lower ELL, and is of particular interest for countries with relatively high salary costs.

In the future 10-year period (ii) costs for the PCNL-scenario amount to 72 million NOK, and the FMCNLN-scenario is 23 million NOK, using default parameter values, as detailed in Table 4. This makes PCNL 3,1 times more expensive than FMCNLN. Most expenses during this period are attributed to leakage run-time for both scenarios, accounting for over 90 % of costs in both scenarios. With current developments in prices and inflation, this cost is assumed to continuously rise.

The cost ratio PCNL/FMCNLN ranges from 1,93 – 7,87, with a median of 3,21, based on the sensitivity analysis of six parameters given in Table 1. Notably, leakage distribution, i.e. whether leakages occur within hotspots or not, greatly influences our cost model, in contrast with the other parameters, as depicted in Figure 3. Despite variations in other parameters, the consistent PCNL/FMCNLN cost ratio of around 3 emphasizes the critical importance of precise failure predictions for the methodology of failure guided deployment of FMCNLN.

Using the failure-guided deployment, only 35 noise loggers were deployed in the FMCNLN, versus 168 needed to cover the whole DMA, equalling approximately 80 % CAPEX savings compared to full FMCNLN deployment. Our cost model demonstrated that with average leakage runtimes of up to 35 days, the failure-guided deployment of FMCNLN would be the most cost-effective alternative, compared to full-scale deployment of FMCNLN. To con-

Table 3. Costs of PCNL and FMCNLN for project period

	Portable correlating noise loggers (PCNL)		Multipoint fixed correlating noise loggers (FMCNLN)		Difference PCNL - FMCNLN
	Cost [NOK]	Share [%]	Cost [NOK]	Share [%]	Δ [NOK]
Total costs	563 620	100 %	293 558	100 %	270 062
CAPEX	35 650	6 %	73 905	25 %	-38 255
OPEX	478 000	85 %	203 178	69 %	274 822
Leakage costs	49 970	9 %	16 474	6 %	33 496

(1 NOK ≈ 0,11 USD ≈ 0,1 EUR)

Table 4. Present value costs of PCNL and FMCNLN for 10-year period.

	Portable correlating noise loggers (PCNL)		Multipoint fixed correlating noise loggers (FMCNLN)		Difference PCNL - FMCNLN
	Cost [NOK]	Share [%]	Cost [NOK]	Share [%]	Δ [NOK]
Total costs	72 025 207	100 %	23 456 620	100 %	48 568 587
CAPEX	381 000	1 %	1 146 100	5 %	-765 100
OPEX	1 162 176	2 %	1 030 740	4 %	131 436
Leakage costs	70 482 031	97 %	21 279 780	91 %	49 202 251

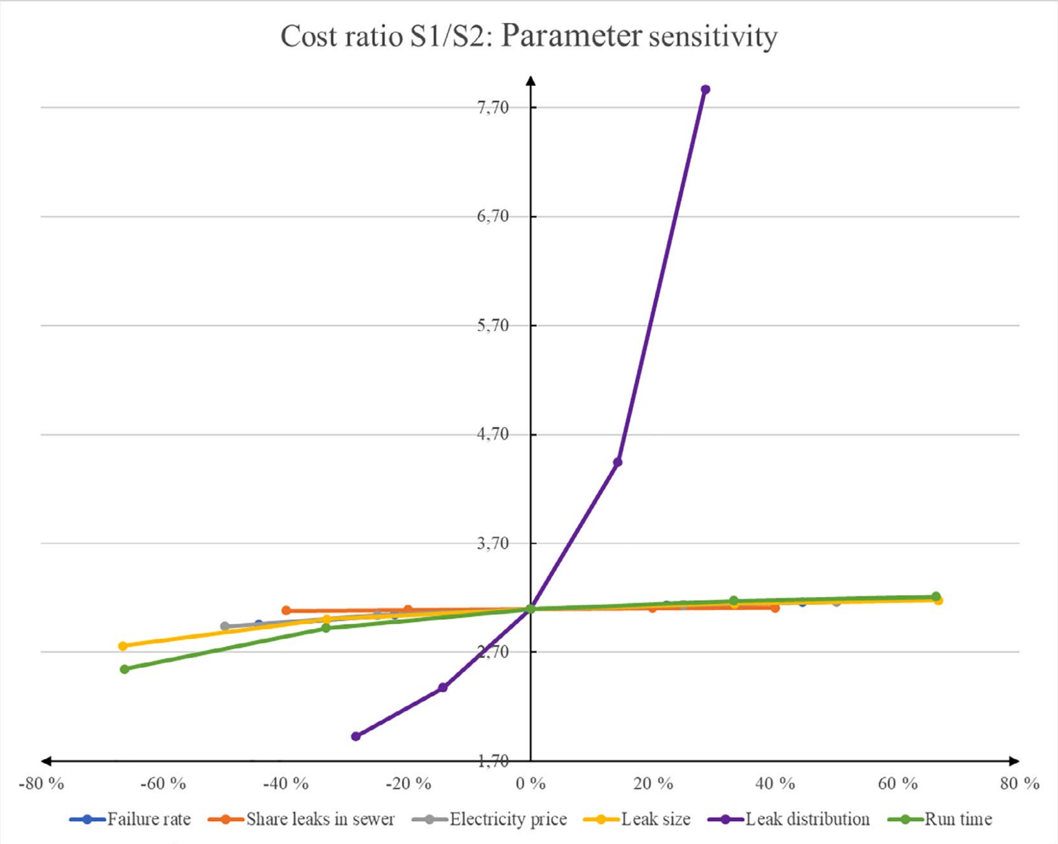

Figure 4. Cost ratio PCNL/FMCNLN as a function of changes in parameter values from default values.

textualize, a full-scale deployment in Oslo's WDN would require approximately 6200 noise loggers for 1550 km water mains, costing approximately 100 million NOK in initial investment costs. Assuming similar failure distributions across the WDN as in Lambertseter, this translates to 80 % savings, or 80 million NOK initial investment costs savings. Besides investment cost, substantial costs and challenges are related to operating a full scale FMCNLN, therefore it is paramount that the technology park is of optimized and manageable size. It is recommended to combine failure-guided deployment of FMCNLN with flow metering in DMAs/MNF, to prompt PCNL only when needed in areas not covered by FMCNLN. This will further reduce the need for manual PCNL-walkthroughs and provide adequate surveillance to the whole DMA.

Conclusions

Key highlights of the FMCNLN approach as applied in the Lambertseter pilot project include:

- 75 % of leakages during the pilot project occurred in the predicted failure hotspots, providing reliable guidance for deployment of FMCNLN.
- There are significant estimated cost-savings for all modelled periods compared to PCNL, with cost ratios (PCNL/FMCNLN) of approximately 2 and 3 during the pilot project period, and modelled 10-year period, respectively. These savings are mostly related to reductions in leakage run-time.
- The cost model indicated that although initial investment costs related to FMCNLN appear significant, they are minor compared to total costs over the 10-year period.

Leakage run-time is the primary cost factor and should be the main target for cost reduction.
- This method provided 80 % CAPEX savings, compared to full-scale deployment, which is crucial in developing an operationally manageable, cost-effective leakage surveillance strategy for the whole WDN.

Future work should test whether the results of this work generalize to other DMAs in Oslo and utilities. The cost modelling could be refined and expanded, and there is probably a potential for optimizing the failure prediction models, by including techniques as Machine Learning. Our results indicate that failure-guided deployment of FMCNLN is a cost-effective alternative which yields satisfactory leakage reduction effects if failure data is available in adequate quality and quantity to provide reliable prognosis of future failures/leakages and their distribution across the WDN.

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Acronym	Meaning
ALC	Active Leakage Control
CAPEX	Capital Expenditure
CIC	Cost of Installation
COP	Cost of Operations
COS	Cost of Salaries
DMA	District Metered Area
ELL	Economic Leakage Level
FMCNLN	Fixed Multipoint Correlating Noise Loggers Network
ILI	Infrastructure Leakage Index
IoT	Internet of Things
LEYP	Linear Extended Yule Process
MNF	Minimum Night Flow
NMBU	Norges miljø- og biovitenskapelige universitet (Norwegian University of Life Sciences)
NRW	Non-Revenue Water
NOK	Norwegian kroner
OPEX	Operating Expenditure
PCNL	Portable Correlating Noise Logger
VAV	Vann- og avløpsetaten, Oslo kommune (Water and Sewage authority in Oslo municipality)
WDN	Water Distribution Network