SMART GAS NETWORK
for Preemptive Leak Detection

Urban Infrastructure Institute

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I PROBLEM DEFINITON

The unprecedented increase in urbanization, especially in large cities, such as NYC has led to a growing demand for natural gas, thus giving rise to a dense urban natural gas pipeline network system. The expansion of NYC's gas network system from 1940 to 2012 has risen from approximately 1 500 to over 6 000 miles of gas pipelines [1].

Public safety and security, cost-efficiency, and optimal performance of gas distribution systems crucially depend on the early and reliable detection of leaks and their immediate localization. The time elapsed until the detection of a leak is critical for the prevention of potential subsequent damages that may lead to disasters. Recent disasters and their associated fatalities include: Rio Piedras, PR (1996) 33 lives; Carlsbad, NM 12 lives; Sabine Pass, Texas (1989) 8 lives; San Bruno, Ca. (2010) 8 lives; Crystal Springs, MS (1986) 8 lives, and East Harlem, NYC (2014) 8 lives (investigation pending) [2].

The East Harlem gas explosion has highlighted the vulnerabilities in the NYC subsurface infrastructure system. To address these vulnerabilities, Mayor De Blasio's Administration convened the New York City Underground Infrastructure Working Group (2014), which released an interim report that highlighted the risk associated with the multiplicity and complexity of NYC's subsurface stakeholders and their infrastructures. The New York City Underground Infrastructure Working Group is composed of: Department of Transportation (DOT), Department of Environmental Protection (DEP), Department of Design and Construction (DDC), Department of Buildings (DOB), Fire Department (FDNYC), Economic Development Corporation (EDC) and the Mayor's Office of Long-term Planning and Sustainability (OLTPS) [3].

In May 2014 Bill No.: S7430A: Title: An Act to amend the public service law in reporting of natural gas leaks by gas corporation; was established. It requires: (a) classification by gas companies of all reported leaks of natural gas; (b) annual report of each gas company to the Department of Public Service (the "department") including location, classification, date, date of repair of each reported leak; (c) access to information provided by the department to any municipal or state public safety official and to members of the legislature [4].

In compliance with the above mentioned Bill, Con Edison has made publicly available a map of reported gas leaks within its service area. Leakages are classified as either blue dots (Type I leaks) or green dots (Type II and Type III leaks). This classification as either TYPE I, II or III are based on guidelines set by the Pipeline and Hazardous Materials Safety Administration (PHMSA), a subset of the US Department of Transportation. Con Edison conducts a yearly federal government mandated gas inspection, as well as 12 additionally surveys instituted by Con Edison to cover all 4,300 miles of distribution mains.

The current leak detection methods have been primarily developed for linear transmission pipelines. Their deployment for leak detection and geo-localization in the gas distribution systems raise reliability concerns as they do not provide a continuous real time monitoring throughout the entire gas network. Therefore, in order to upgrade the public safety and security it is proposed to assess the technical and economic feasibility of real time smart gas network monitoring for continuous leak detection throughout the entire gas distribution network. More specifically the purpose of this project is to assess the technical and economic feasibility of the adaptation of artificial intelligence based Command and Control System of Systems (C2SOS) [5] for early leak detection in the gas distribution system.

The proposed development of the C2SOS system for early leak detection in gas distribution system is based on the adaptation of the INCOM™ System developed by CALM Water and the French Commission of Atomic Energy, CEA-LIST Research Institute, for preemptive leak detection in water distribution systems. The INCOM™ system was developed with the water company of the city of Paris (Eau de Paris - EdP) using specific artificial intelligence based control algorithms to automate the leak detection methodology and sensor health verification currently used by the Eau De Paris operators. It is presently demonstrated through the European Research and Development (R&D) Project Smart Water for Europe (SW4EU).The purpose of this project is to assess the adaptation and integration of the INCOM™ System for upgrading reliability and efficiency of leak detection in gas distribution systems and support the system operator(s) through "intelligent" near real-time system monitoring and leak detection in preventive and proactive rather than reactive gas distribution system management.

II ASSESSMENT OF CURRENT GAS LEAK DETECTION METHODS

Considerable effort has been devoted to the development of reliable techniques for detecting natural gas leakage. The most common way of classifying leak detection methods is based on their technical nature[6]. Currently three main categories of methods are used:

- Hardware Based Methods (Scott &Barrufet, 2003)
- Non-TechnicalMethods(Geiger et al., 2003)
- Software Based Methods(Zhanget al., 1997)

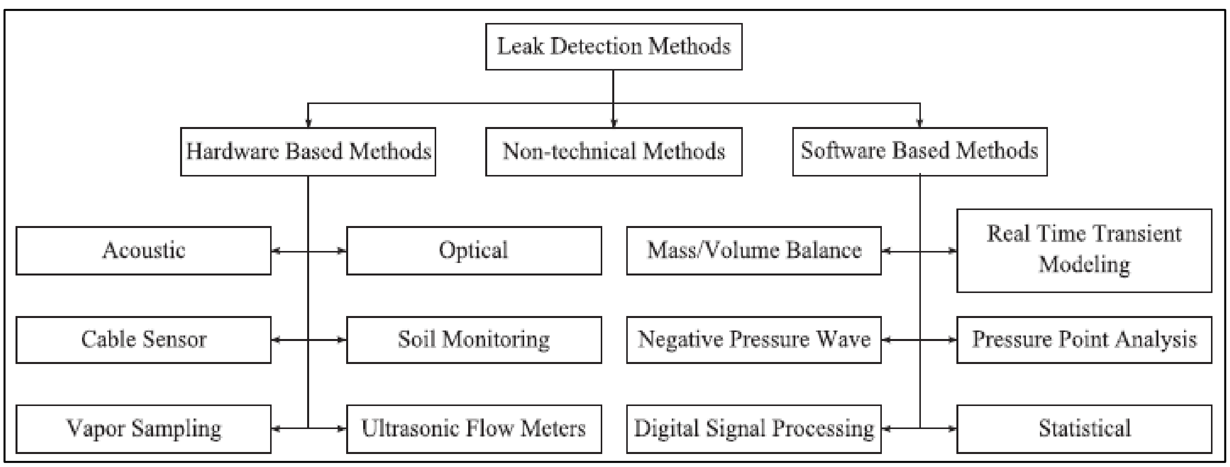


Figure 1: Classification of gas leak detection techniques based on their technical nature.[6]

<u>Hardware Based Methods</u> rely mainly on the usage of special sensing devices in the detection of gas leaks. Depending on the type of sensors and equipment used for detection, these hardware methods can be further classified as:

- Acoustic (Loth et al., 2003)
- Soil monitoring (Thompson et al., 1993)
- Vapor sampling (Sperlet al., 1991)
- Ultrasonic flow meters ((Bloom, 2004)
- Cable sensor (Sandberg, Holmes, McCoy, &Koppitsch, 1989)
- Optical methods (Reichardt, Devdas, Kulp, &Einfeld, 2002)

Acoustic leak detection method techniques have been studied since the 1930s, and are typically used by the gas and water distribution systems. Escaping gas generates an acoustic signal as it flows through a breach in the pipe. Thus, this signal could be used to determine that a leak has occurred. To record the internal pipeline noise, acoustic sensors have to be used. They can be integrated in handheld detection devices employed by personnel patrolling the pipeline or in "intelligent pigs" that travel through the pipeline inspecting it [7]. Continuous monitoring is also done by installing acoustic sensors outside the pipeline at certain distance from one another [8]. The distance between two acoustical sensors has to be adapted based on the sensitivity of the acoustic sensor and allocated budget. Placing sensors too far from each other will increase the risk of undetected leaks while installing them too close will lead to an increased system cost. Several types of sensors were used to detect sounds produced by gas leaking out. They range from acoustic sensors and accelerometers to microphones and dynamic pressure transducers all of which are detailed by Loth, et al. [9].

Rocha[10] used pressure sensors to record the appearance of acoustic pressure waves caused by leaks, while Brodetsky and Savic(1993)developed a system that requires permanent monitoring units along the pipeline using a *k* nearest neighbor classifier to distinguish leaks from background noise[11].Some methods involve the measurement of two acoustic signals on each end of a pipe segment. Based on these measurements, the leak can be detected using a time-frequency technique [12] or the low frequency impulse method [13]. A more recent experimental study focused on distinguishing between signals made by leaks and background noises using time-frequency analysis and adapted the leak location formula to increase accuracy [14].

Applying the acoustic technique throughout a continuous operation model is feasible and the system can be automated. Acoustic methods can also help in determining the location of the leak and estimating its size. When in continuous monitoring mode the system can respond in real-time. The disadvantage is that the background noise conditions may mask the actual leak signal (e.g. noise from vehicles passing by, valve or pump noise).

Figure 2: Acoustic leak detection technique equipment.[29]

Soil monitoring and vapor sampling leak detection methods rely on empirical correlations with the test output. Soil monitoring involves inoculating the gas pipeline with an amount of tracer compound [15]. This tracer chemical, a non-hazardous and highly volatile gas, will exit the pipe in the exact place of the leak. To detect a leak, instrumentation has to be used to monitor the surface above the pipeline by dragging devices along it [16] or through probes installed in the soil near to the pipelines. The samples collected are then analyzed using a gas chromatograph [17].Leaks can be detected also by sampling hydrocarbon vapors in the vicinity of the pipeline. This can be done either through a vapor monitoring system which involves a sensor tube buried along the pipeline, or by using mobile detectors carried by personnel or mounted on ROVs (remotely operated vehicles) [18].

Figure 3: Soil monitoring and Vapor sampling. [18]

Cable sensors are built using materials that react when in contact to certain substances. This reaction changes cable properties such as resistance or capacitance which can be monitored to sense the appearance of a leak [19]. Cables contain two circuit loops [20]. One circuit will be connected to a power supply and the other one to an alarm. When the two circuits come into contact the alarm will be signaled.

Ultrasonic flow meters: Testing data analysis assumes that the pipeline is comprised of a series of segments [21-22]. Each segment is bounded by two so-called Site Stations which consist of a clamp-on flow meter, a temperature sensor, and a processing unit. Each Site Station will measure or compute volumetric flow rates, gas and ambient air temperature, sonic propagation velocity and site diagnostic conditions. All data obtained on Site Stations are collected by a Master Station which computes the volume balance by comparing the difference in the gas volume entering and leaving each pipeline segment and compares the measured consumption rate.

Optical methods used for leak detection can be divided in two categories [23]: passive and active. Active methods require illuminating the scanned area using a radiation source while passive methods do not require a source and rely only on background radiation or the radiation emitted by the gas.

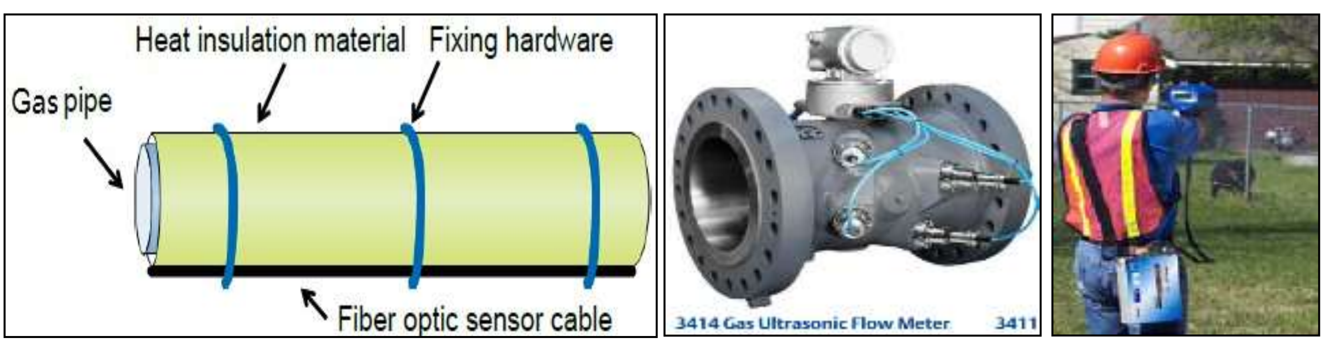


Figure 4: Cable sensors, ultrasonic flow meters and optical methods.[19-23]

Limitations of hard ware based methods: The performance level of a leak detection system can be assessed taking into account a series of factors. Some of the criteria that are used to evaluate the performance of leak detection systems are: the ability to determine the location of the leak, the detection speed and the ability to estimate the size of the leak. Today, the gas leak detection industry tends to develop the real-time data monitoring and acquisition systems, which include sensors, data transmission devices, and data analysis software. The development in the software area is highly sophisticated and practical.

Non-Technical Leak Detection Methods involve personnel patrolling along the pipelines looking for visual effects of a gas leak[24], smelling substances that might be released through a leak or listening to specific sounds that can be made by gas as it leaks out (i.e. trained dog, soap bubble screening [25]).

Figure 5: Trained dog, soap bubble screening. [26]

Software Based Methods:The identifiedalgorithms continuously monitor the state of pressure, temperature, flow rate or other pipeline parameters and can infer, based on the evolution of these quantities, if a leak has occurred. The software methods can use different approaches to detect leaks:

- Mass/Volume Balance (Liou, 1996; Parry, Mactaggart, &Toerper, 1992)
- Real Time Transient Modeling (Billman&Isermann, 1987)
- Negative Pressure Wave (Silva, Buiatti, Cruz, & Pereira, 1996)
- Pressure Point Analysis (Farmeret al., 1989)
- Statistics (Zhanget al., 1993)
- Digital Signal Processing (Golby&Woodward, 1999)

MassPack™[27]is software offered by EFA Technologies Inc. as part of the LEAKNET™ package for leak detection and relies on accumulating differences between inflow and outflow measurements. LEAKNET™ seamlessly incorporates two independent pipeline leak detection methods, Pressure Point Analysis (PPA) [28-30]and MassPack™ into a single off-the-shelf package. Each method is based on completely different technologies. Together they provide a tight web of coverage which ensures high sensitivity and rapid detection. LEAKNET™ also includes a way to provide tight monitoring and false alarm-free operations called SmartPoint.

A mass balance system, incorporating dynamic corrections for changes which are integrated in the LEAKNET™ system [31] monitors all flow into and out of a pipeline segment. It automatically calculates optimal threshold settings and warns when a leak condition is developing. It is defined under API 1130 as a modified volume balance methodology that is highly configurable. Integrating both PPA and MassPack™ systems provides the highest level of reliability and leak detection capability known to the market. A unique feature of MassPack™ is its SmartPoint™ PPT standard intelligent alarm processing that provides 100 percent alarm-free operation. It conducts logical analysis of the PPA inputs from a pipeline section to determine whether a statistically significant event is a leak or a normal transient condition.

Figure 6: MassPack™& LEAKNET™ leak detection and analysis system interface. [32]

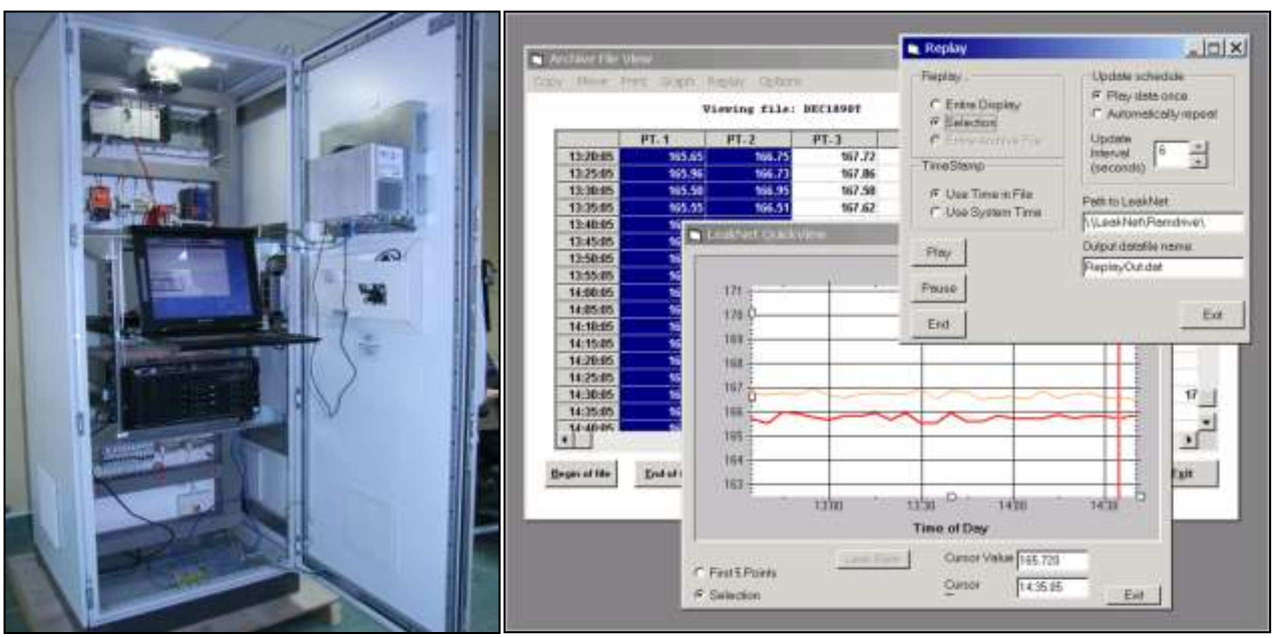


Figure 7: MassPack™& LEAKNET™ system data output and save program. [33]

Figure 8 illustrates that the pressure and flow are sensitive to pipeline leak. A leak in the pipeline can be detected through the monitoring of flowrate and pressure provided by LEAKNET™. The leak can be observed on the graph on the right; at time 14:05:24 to 14:05:30 as flow increases from approximately 480 gpm (gallons per minute) to 490 gpm and pressure decreases from approximately 400 psig (pound per square inch) to 390 psig.

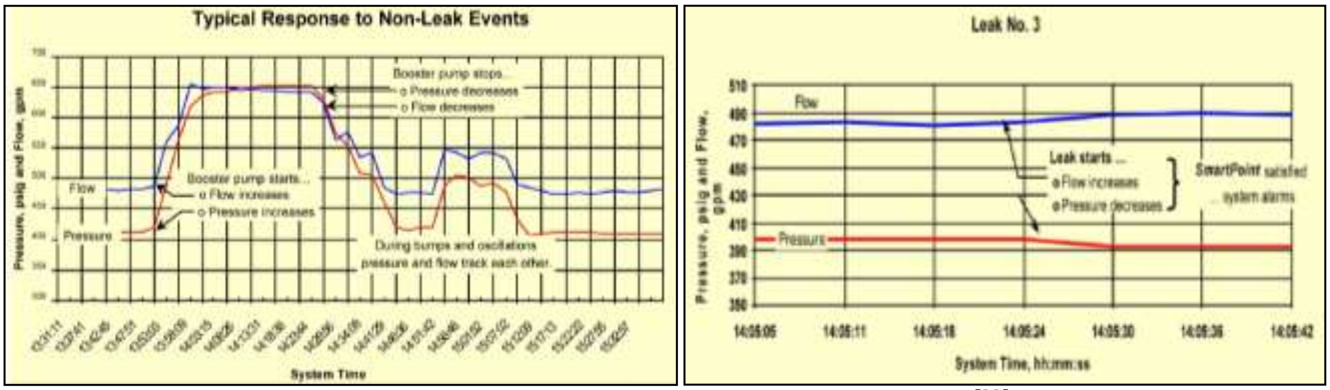


Figure 8: LEAKNET™ system analysis interface. [33]

MassPack™& LEAKNET™ have been adapted for risk assessment of long distance gas and crude oil transmission systems. However these leak detection systems have not been adapted or tested for leak detection in the urban natural gas distribution system. The lack of practical application for reliability verification raises a significant limitation with regard to their deployment for leak detection in the distribution system.

AtmosWave[34] is based on the detection of the negative pressure (Buiatti et al., 1996) associated with a leak generated either by the onset of the leak or by the pressure instability at the leak position.

Figure 9 summarizes the three step process used in ATMOSWave. The data acquisition unit (AWAS-3) collects all the analogue pressure data locally and sends them to the central location for processing. In the first step the pressure signals are filtered to remove noise. In the second step a dynamic 3-dimensional picture of the moving pressure wave is generated. In the third step the algorithms identify and differentiate the leaks taking into consideration the entire pressure distribution along the pipeline and its dynamic evolution in time.

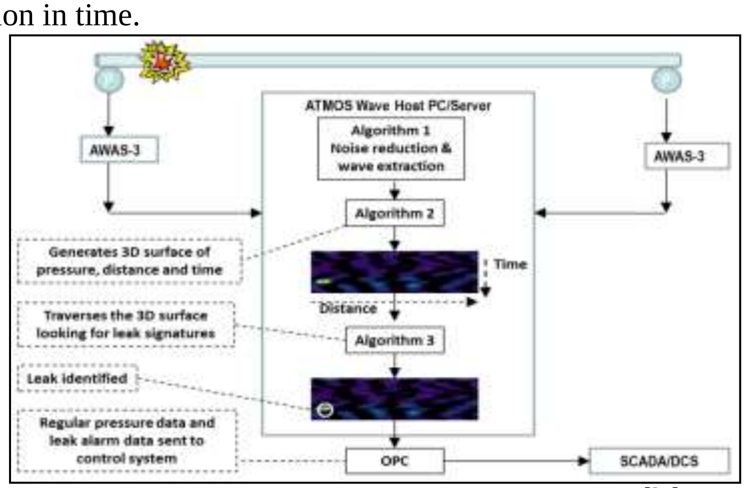


Figure 9: Atmos Wave system step process. [35]

ATMOS Wave uses “off-the-shelf “sensors, which are wrapped around the wall of a natural gas pipeline, and the pressure meters are installed to the pipelines in conventional way and connected directly to theAWAS-3.The AWAS-3 units are connected to the available communication system but the meters can also be used to relay manometric pressure directly to the RTUs (remote terminal unit) for process control and monitoring.Figure10 illustrates a basic set-up for installation in one gas pipeline with one intermediary outlet/inlet.

Figure 10: Basic set-up at each inlet/outlet in a gas pipeline.[35]

Atmos Wave identifies the pressure changes due to the onset of a leak (rarefaction wave) and the opening or closing of theft events. When a leak or theft occurs, rarefaction waves propagate from the event site in both pipeline directions that are detected by the pressure sensors. Atmos Wave uses wave rarefaction to accurately pinpoint the leak and estimate how much fluid is being lost. As Figure 11shows gas pipeline leakage generates an alarm on the system interface, and leak detection system can estimate accurately the location of the leak, leakage time and leakage rate when gas pipeline leakage occurs.

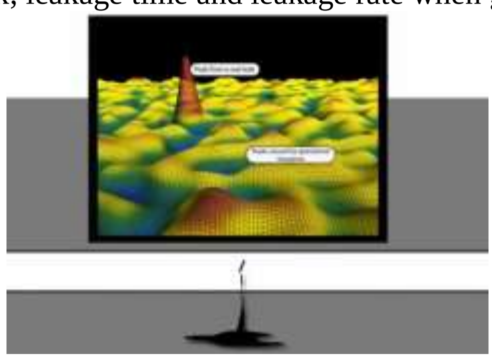


Figure 11: A wave peak appears when the detected gas pipeline leaks. [36]

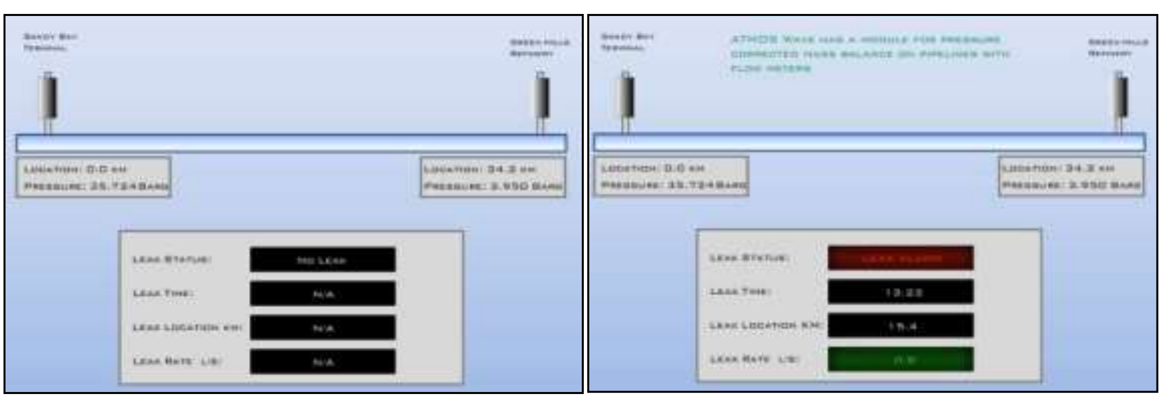


Figure 12: Gas pipeline normal situation and leak alarm.[36]

Atmos Wave has been rigorously tested on operational transmission pipelines with great success. Extensive performance evaluation and field trials have proven that Atmos Wave consistently differentiates leak/theft signals from transients. According to Atmos experts as demonstrated on a crude oil pipeline, Atmos Wave has detected more leaks than the competitive systems and generated zero false alarms, while the competitive system produced false alarms during the evaluations conducted by PRCI (Pipeline Research Council International).

Table1summarizes the main features of the MassPack™ &LEAKNET™ and Atmos Wave leak detection Systems.

The current gas leak detection systems, benefiting from real-time data monitoring and transmission capability of the software based methods, along with specific advantages such as continuous data acquisition and analysis, seem to be the future trend in gas leak detection. While such methods have been extensively tested and growingly used for leak detection in gas transmission lines they have been adapted or validated for leak detection in the gas distribution networks. With the expansion of urban natural gas distribution networks, there is a growing need for development/adaptation of leak detection techniques for preemptive asset management of gas distribution networks.

In order to upgrade the public safety and security it is proposed to assess the technical and economic feasibility of real time smart gas network monitoring for continuous leak detection throughout the entire gas distribution network. More specifically the purpose of this project is to assess the technical and economic feasibility of the adaptation of artificial intelligence based Command and Control System of Systems (C2SOS) for early leak detection in the gas distribution system.

Table1a: MassPack™ &LEAKNET™ System function. [27]

System	Source	Input	Monitor	Output	Reliability	Sensitivity	Accuracy	Robustness
MassPack™ & LEAKNET™ System	SCADA	Gas Composition	All liquids, gasses and most multiphase flow	False alarm free with SmartPoint Leak alarm		18 mm (0.75 inch) of leak size within 5 minutes	18mm (0.75 inch) leak size with +/- 200 meters (657 ft) from actual leak location	No performance degradation due to loss of field sensors/communication link
	PLCs	Flow rate	Risky lines, such as H_2S, chlorine, anhydrous ammonia	Leak location	ONE or NONE false alarms per year			
	Direct from field instruments	Inflow/Outflow pressure	Short lines (hundreds of feet) to longer than 1,000 miles	Leak rate Volume lost	Leak sizes of less than 18mm (0.75 inch			
	Any combination of the above	Inflow/Outflow temperature	Offshore platforms, terminal facilities and cross country pipelines	Leak time Watchdogs via OPC				

Table1b: AtmosWave leak detection System function.[34]

System	Source	Input	Sensors used	output	Solutions	Main features
Atmos Wave	4-20mA instrument input data is acquired at high resolution and high sample rate by the Atmos Wave Acquisition System (AWAS)	Gas composition Flowrate Inflow/Outflow pressure	Primary sensors are pressure meters positioned 0.3-240km apart Flow and pressure can be used as secondary inputs for full section coverage	Leak alarm Leak location Leak time Leak rate and volume lost	1. Detect leak onsets, opening and closing of illicit connections quickly 2. Locate leaks accurately 3. Maintain a low false alarm rate 4. Easy to retro fit 5. Work under all operating conditions	1.Detection time within minutes-fixed by the section under monitoring 2. Performance proven on pipeline sections up to 240km with no intermediate pressure sensors 3. Proven to detect a leak orifice down to 1mm diameter 4. Typical achievable sensitivity (with no false alarms) is below 0.5% of the pipeline's nominal flow rate 5. Proven location accuracy within 10m 6. Typical location accuracy below 0.25% of monitored section length 7. Dedicated algorithms to identify the closure of illicit connections 8. Uses 'off-the-shelf' pressure sensors from top approved manufacturers 9. No flow meters required, but can be utilized if available as secondary system inputs 10. High Spec Data Acquisition Unit designed to gather high fidelity data as required for outstanding performance 11. Atmos Wave Acquisition System (AWAS) has local data storage to mitigate short-term communication failures, ensuring no leak is missed 12. Complies with API 1130, 1149, and 1155

III PROPOSED METHODOLOGY FOR PREEMPTIVE LEAK DETECTION IN GAS DISTRIBUTION SYSTEMS

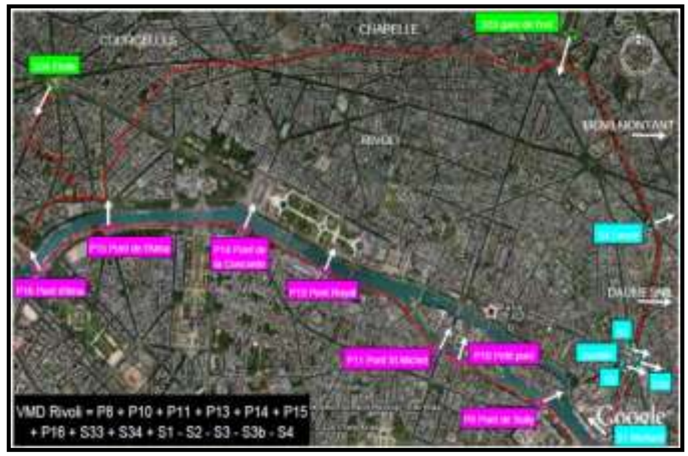
III.1 Introduction

The purpose of this project is to assess the technical and economic feasibility of the adaptation of artificial intelligence based Command and Control System of Systems (C2SOS) for early leak detection in the gas distribution systems. More specifically, the proposed development of the C2SOS system for early leak detection in gas distribution systems is based on the adaptation of the INCOM™ System developed by CALM Water and the French Commission of Atomic Energy, CEA-LIST Research Institute, for preemptive leak detection in water distribution systems. The INCOM™ (Intelligent Network Control and On-site Monitoring) System[5] has been recently developed and demonstrated on a pilot scale, through off-line data processing for automated leak detection in simulating the current practice of Eau de Paris (EdP) operators. It integrates specific artificial intelligence based control algorithms identified by the CEA-LIST Institute, CALM's Enterprise System and its Human-Machine Interface (HMI) to automate the leak detection process and sensor health verification tools currently used by the EdP operators.

III.2 Smart Leak Detection in Water Distribution Systems

The methods and tools for leak detection currently used by the water utilities are based on the analysis of near real-time flow-meter data of in-flow distributed volume change variations and AMR (Automated Meter Reading) consumption data (F. Montiel, B. Nguyen - 2011). These tools require data fusion from different data acquisition systems (Real-time Information, AMR, and "intelligent" sensors), combined with the expertise of the operators for the identification and diagnostics of the system anomalies.

For the purpose of leak detection, the network is naturally or artificially separated into topographically based sub-networks, which are isolated from each other by valves and are controlled by flow-meters. Each sub-network is artificially divided with flow-meters into District Metering Areas (DMA). In figure 13, the Paris distribution network DMAs are represented by different colors.



Note: 30 sub areas have been defined for the city. 180 flow-meters used (real time and differed time). All the water transfers between areas are counted and manual valves are closed if necessary.

Figure 13: The district metering areas in Paris **Figure 14:** Example of metering DMA

To allow for the analysis of the distributed water in each area, the DMAs have been artificially isolated from each other by metering the water flow at the DMAs inlets and outlets with flow meters.

The anomaly detection analysis is based upon:

- ➢ Brutal pressure change measurement - The pressure regulation enables a leak detection (pipe break) when a brutal change in the pressure is observed. For the case where the hydraulic network is regulated in pressure, the pressure level has to be stable. A brutal drop of pressure on the network is the indication of an incident. This incident could be due to different causes as, for example, a pipe break or sensor defaults. The information delivered has to be correlated to other information to confirm the origin of the drop. While a leak due to pipe burst can be detected by the brutal drop of pressure in the area considered, a progressive leak cannot be observed by this method due to the pressure regulation.

Figure 15: Brutal Pressure Change Measurement

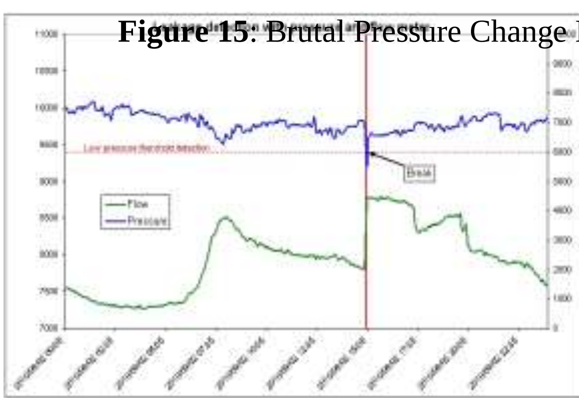


Figure 15: Brutal Pressure Change Measurement

➢ <u>Flow-meter data: In-flow distributed volume and AMR consumption data</u> – for this purpose, the real-time inflow volume distributed in a specific DMA is systematically compared with historical volume record in this area, using indicators such as:

- Variation of the daily water distributed in the DMA, sub-network and network, which are compared for a specific DMA with historical volume record of daily consumption curves in this area obtained for defined reference dates.

- Average night area volume – which is a sensitive indicator, independent of the day of the week with a relatively high leak signal to “normal” level ratio.

Paris is a densely populated city, built on a lightly hilly zone. To ensure the security and the reliability of water distribution in Paris, the pipe network is highly gridded. The city covers an area of 100 km^2 and is equipped with an 1800 km long drinking water pipe network.

Historically Paris follows a specific 'Haussmann’s' urbanism rules with no more than 7 floors.A specific water distribution regulation is defined for Paris, which implies that pressure regulation is used to maintain a constant network pressure. In order to maintain the pressure constant for a flow which depends on the human consumption it is necessary to permanently regulate the network pressure using remote control valves at the outlet of the reservoir and in the network. The regulation is manually made by operators working twenty four hours a day. This pressure regulation cannot be automated because of continuous changes in the network (renewal of pipe, maintenance of the network, etc.).

This pressure regulation mode leads to a characteristic consumption curve that is typical for the entire network, sub-networks and areas of the distribution network. As for a specific sub-network the pressure is maintained constant the flow follows the consumption. The inflow water in the distribution network follows typical time dependent variation according to the day, the week, the month and the year and particular events.

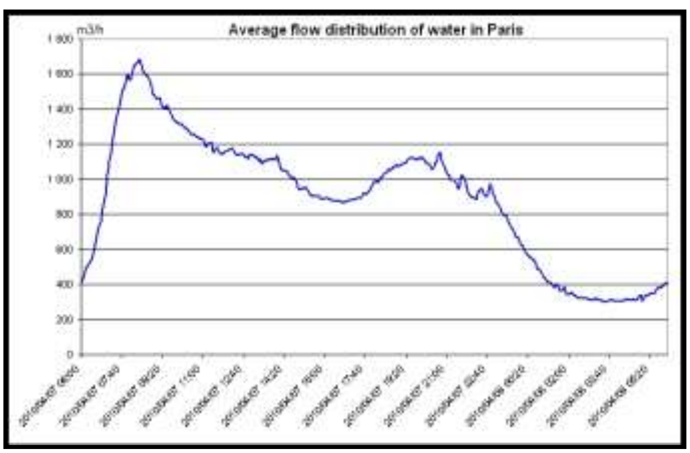


Figure 16: Typical trend of a daily consumption

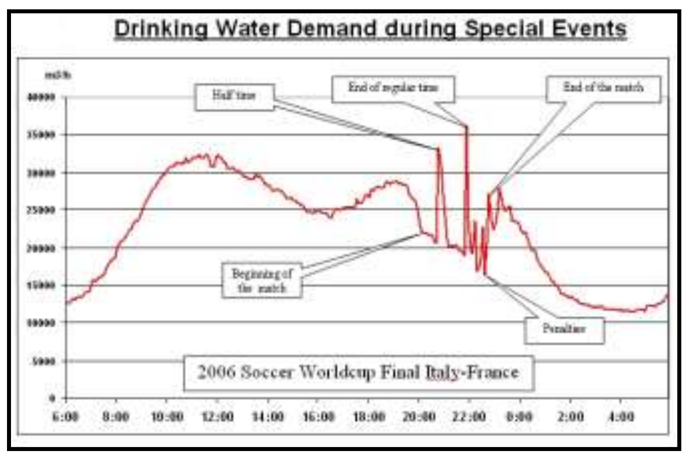


Figure 17: Consumption’s impact of a particular event

Given the topography of the city, the water distribution network has been divided into sub-networks depending on the ground elevation, and for each sub-network the pressure is maintained constant.

The comparative analysis of the trends of both the daily variation curve of the distributed water volume in each DMA and the nightly average volume for all the DMA's belonging to a specific sub-network provides the operator with a near real-time situation picture of the similarity and differences between the trends observed in these DMA's. Generally, all the DMAs of a specific subnetwork present similar consumption trends. Dissimilarity or increasing difference indicates an anomaly which may result from either leakage or abnormal consumption like water supply for municipal swimming pool refilling.

The following example, shown in Figure 18, illustrates a progressive leakage. Figure 18a illustrates the real time measured volume distributed in a DMA, Figure 18b shows the variation of the average night volume of this DMA.Figure 19 shows an abnormal average night volume in a DMA, while the average night volume of the other DMAs of the same sub-network remains quite constant. The increased volume that appears in the sub-network average night volume indicates leak detection.

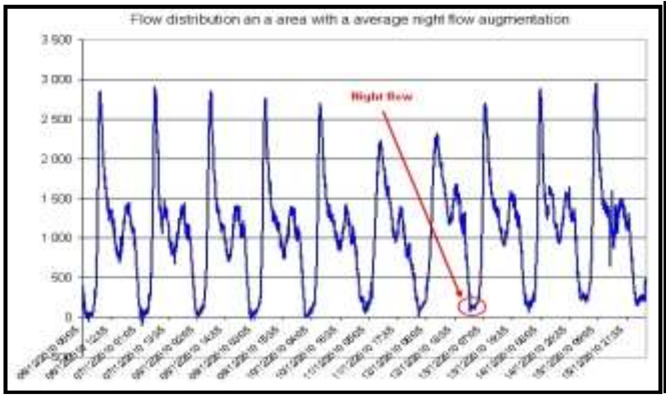


Figure 18a: Average night flow augmentation

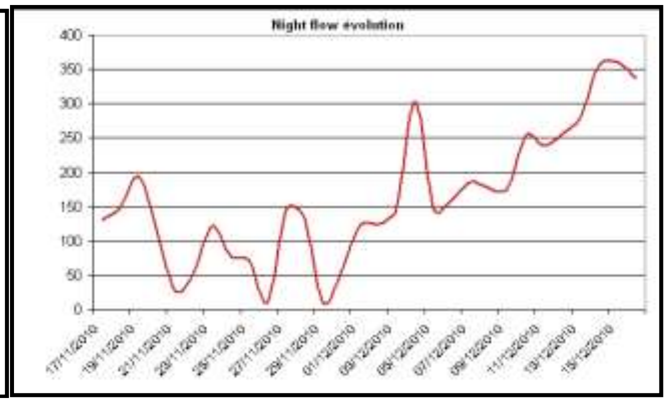


Figure 18b: Variation of the average night volume DMA

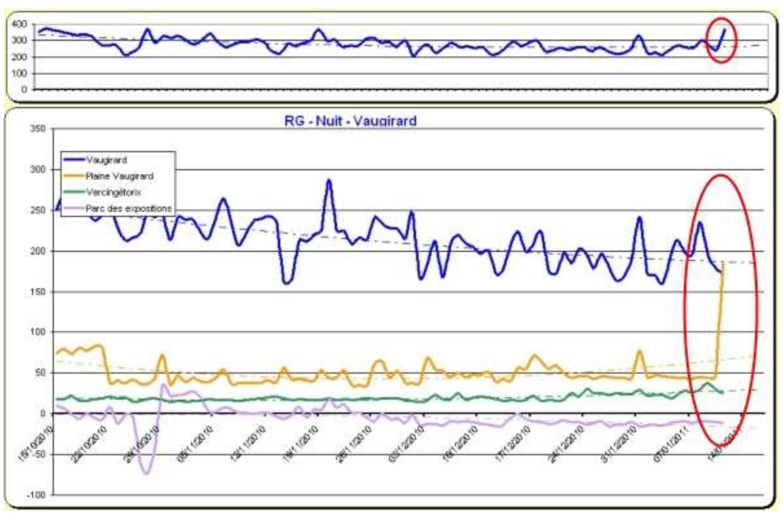


Figure 19: Leakage detection in a sub-network

At this stage the comparison of the daily distributed water volume and the daily consumption measured with AMR allows for reliable leak detection in the water distribution network. As illustrated in figure 20 a rate increase of daily distributed water volume which does not affect the consumption recorded by the AMR system indicates a leak in the distribution network.

Alternatively if the AMR recorded daily consumption volumes are greater than the measured daily distributed water volume it indicates that there is a leak on the building / consumer's property.

Data management and quality control are critical elements in the reliable deployment of smart monitoring systems for leak detection. EdP operators have developed specific diagnostic tools to identify and detect sensor flows in the monitoring system. As illustrated in figure 21 when a flow-meter between two adjacent DMAs is deficient, the volume of transferred water between the two areas cannot be measured which results in a "mirror effect" while the sub network curve of distributed water is not affected.

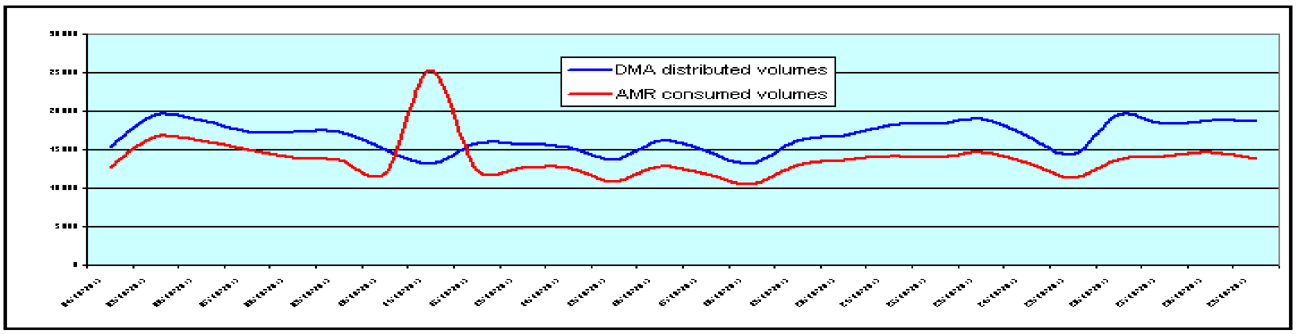


Figure 20: distributed volume comparison between DMA and AMR.

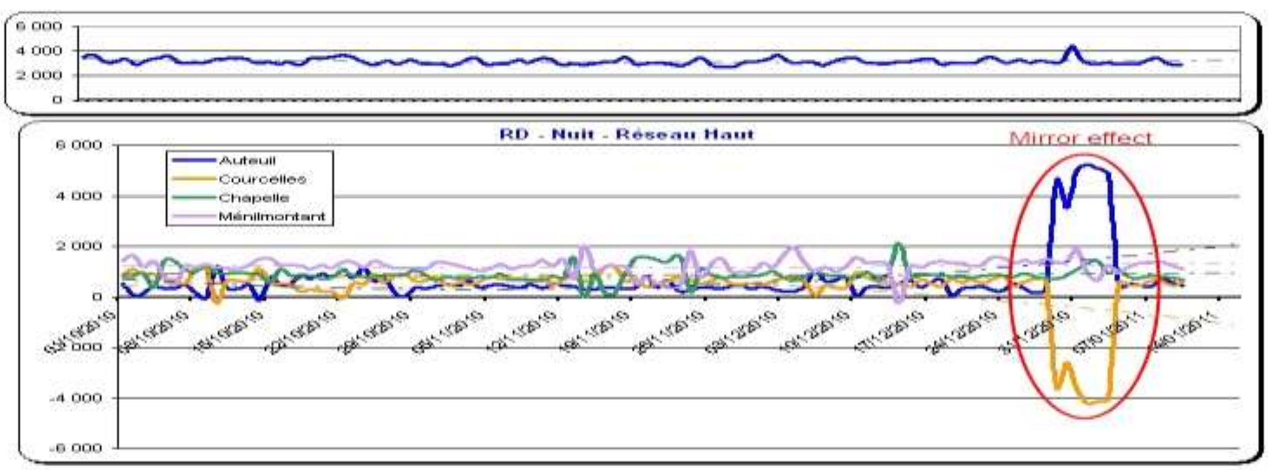


Figure 21: Mirror effect of an area flow-meter default.

This point is particularly important because most of the errors in the analysis of the daily distributed volume data for leak detection are due to a default in the human identification of the mirror effect.

Figure 22 illustrates the leak detection based upon systematic comparison of the real-time measured sub-network distributed flow rate and the reference historical flow rate recorded for similar periods (e.g. day in the week, season, etc.) in the sub-network or DMA. A low and high threshold based alarm system is established to detect abnormal variation of the sub-network water distributed flow rate which indicates leakage and to monitor the leak elimination due to the repair operation.

The INCOM™ leak detection system enables integration of the artificial intelligence based control algorithms identified by the CEA-LIST Institute, CALM's Enterprise System and its Human-Machine Interface (HMI) to automate the leak detection process and sensor health verification tools currently used by the EdP operators.

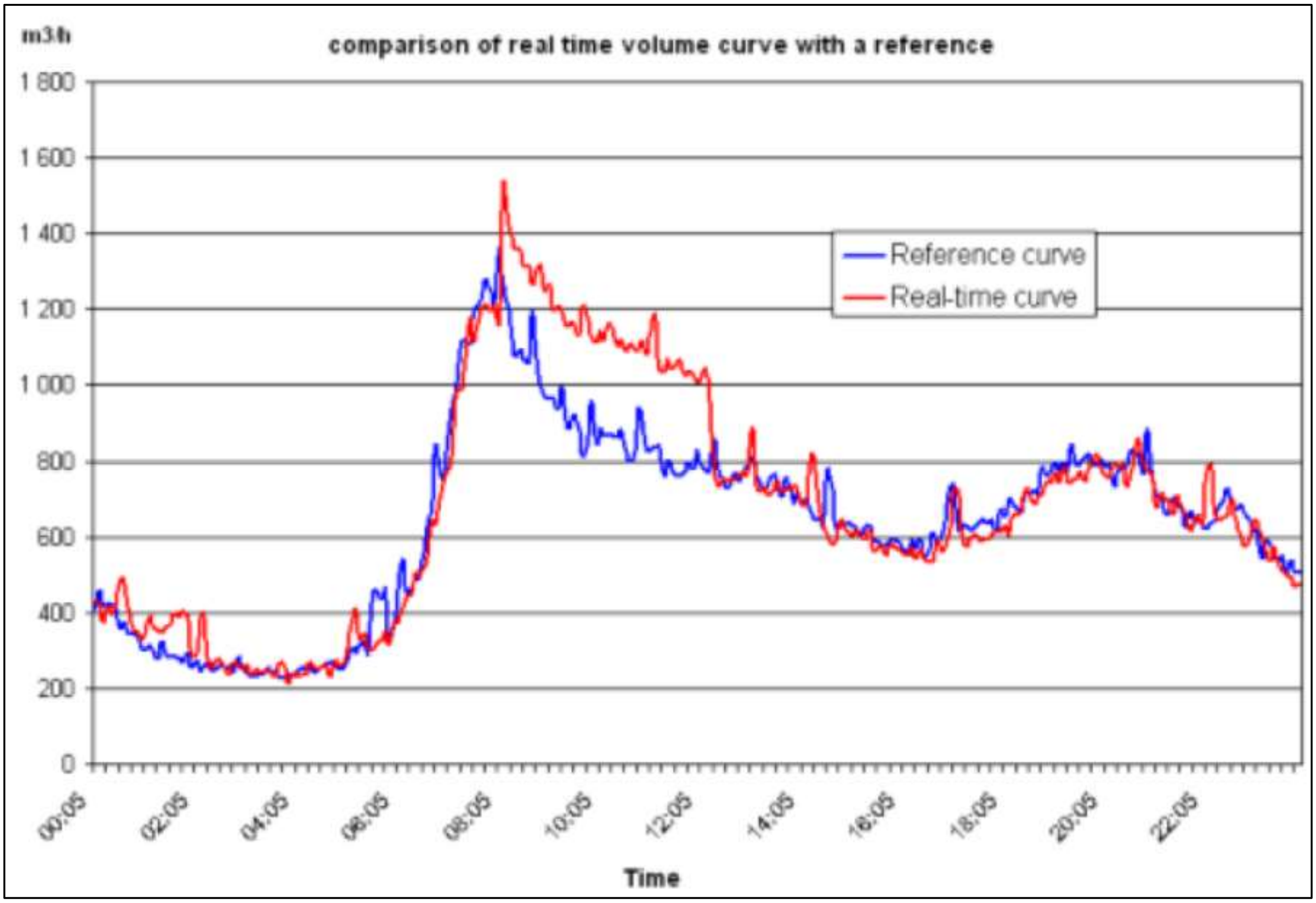


Figure 22: Comparison of real time volume curve with a reference curve

The purpose of the INCOM™ Leak Detection system is to provide utility managers a systemic enterprise platform for near real-time anomaly diagnostics and leak detection. It has been assessed by EdP operators through off-line data processing for automated leak detection in simulating the current practice of EdP operators and has been selected by the European Community experts for pilot scale field demonstration.

The CALM Human-Machine Interface (HMI) used in the INCOM™ system displays the detected anomalies. Leakages are displayed in "ALARM PANEL" interface, along with anomalies, the time stamp, geo-location (location where the anomaly occurred), confidence level, severity and flag detection as well as detected sensor flows in the monitoring system. In visualization module, an operator can view the anomaly graphical representation, which is displayed on the Graphical User interface (GUI) along with severity/confidence level and geo-location.

The purpose of this project is to assess the adaptation and integration of the INCOM™ System for upgrading reliability and efficiency of the current leak detection in gas distribution system and support the system operator(s) through “intelligent” near real-time system monitoring and leak detection for preventive and proactive rather than reactive gas distribution system management.

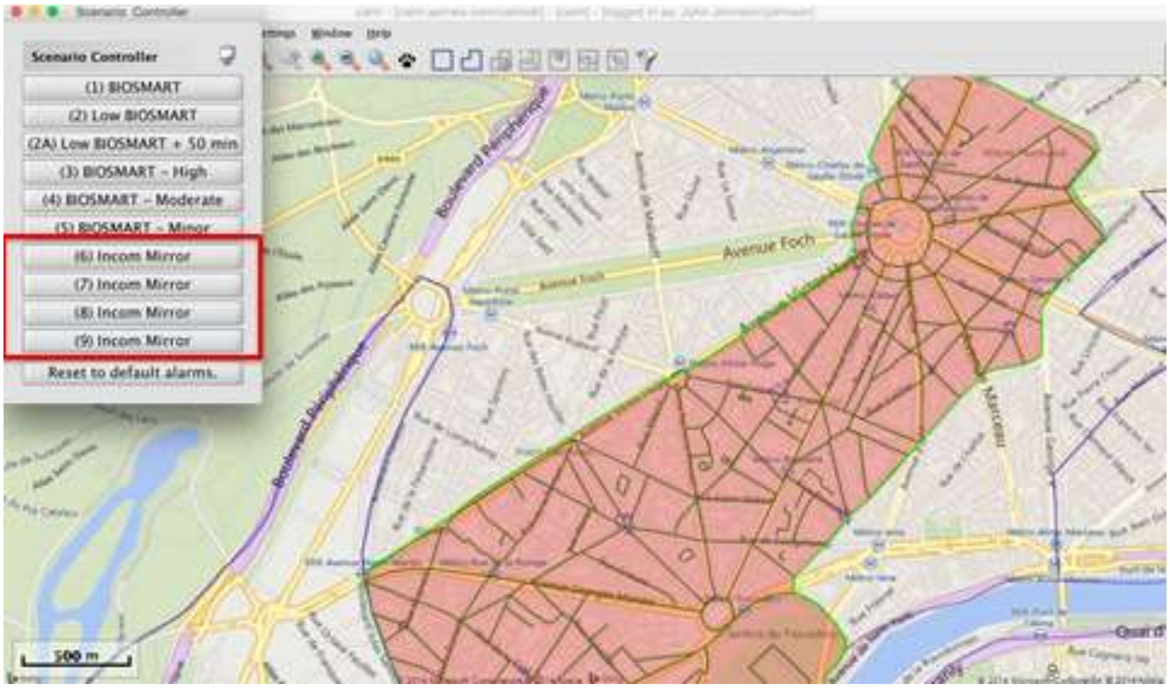


Figure23: INCOM™ Output of detected leakages and sensor flows (mirror effects) in the monitoring system

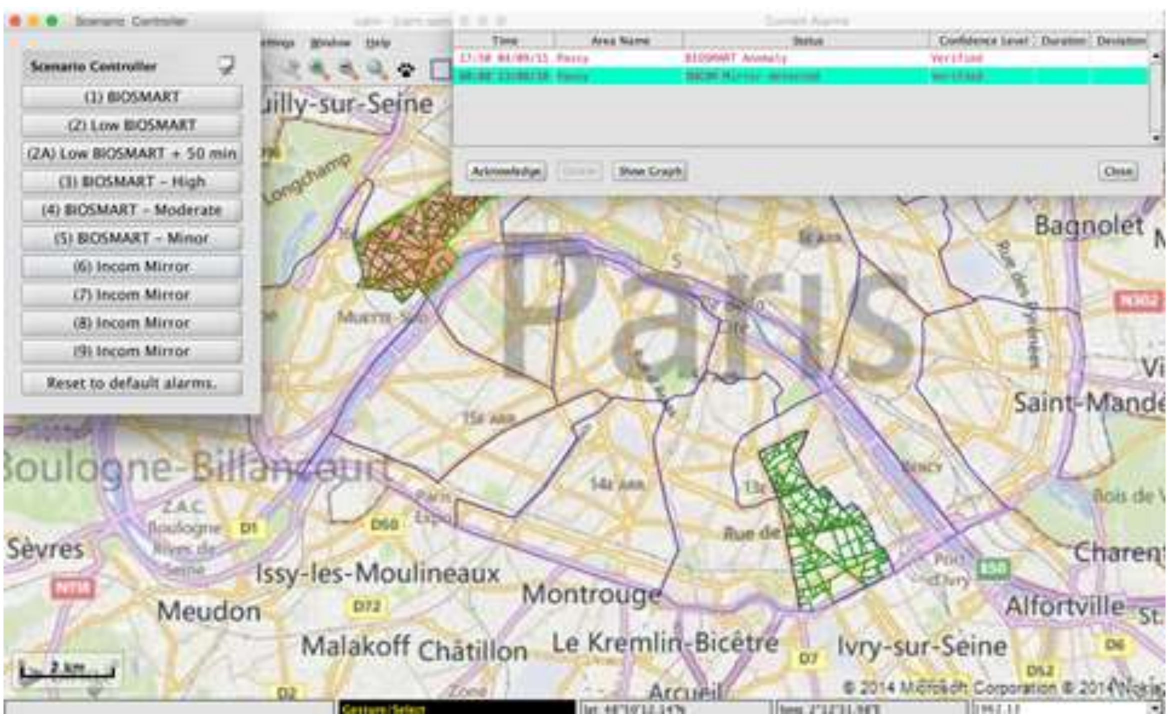


Figure 24: Alarm Panel to Demonstrate Anomaly Detection

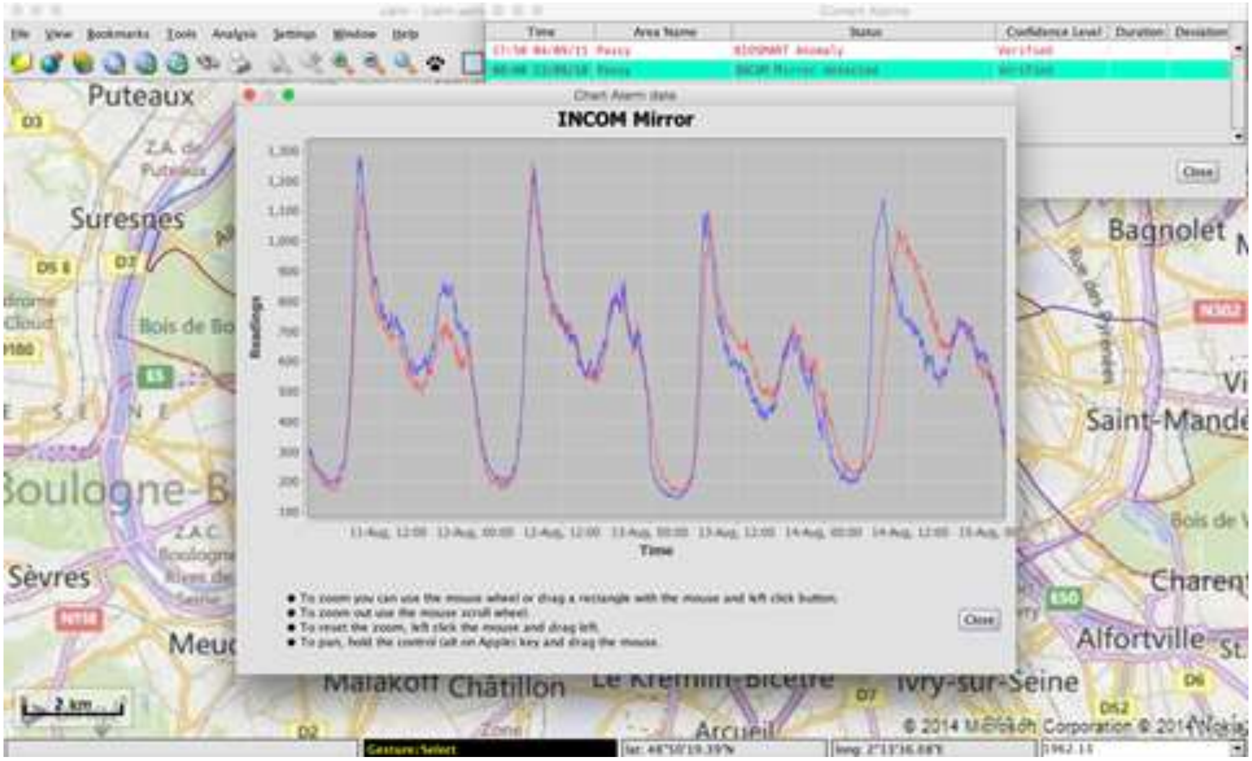


Figure 25: Visualization of the data from Detected Anomaly

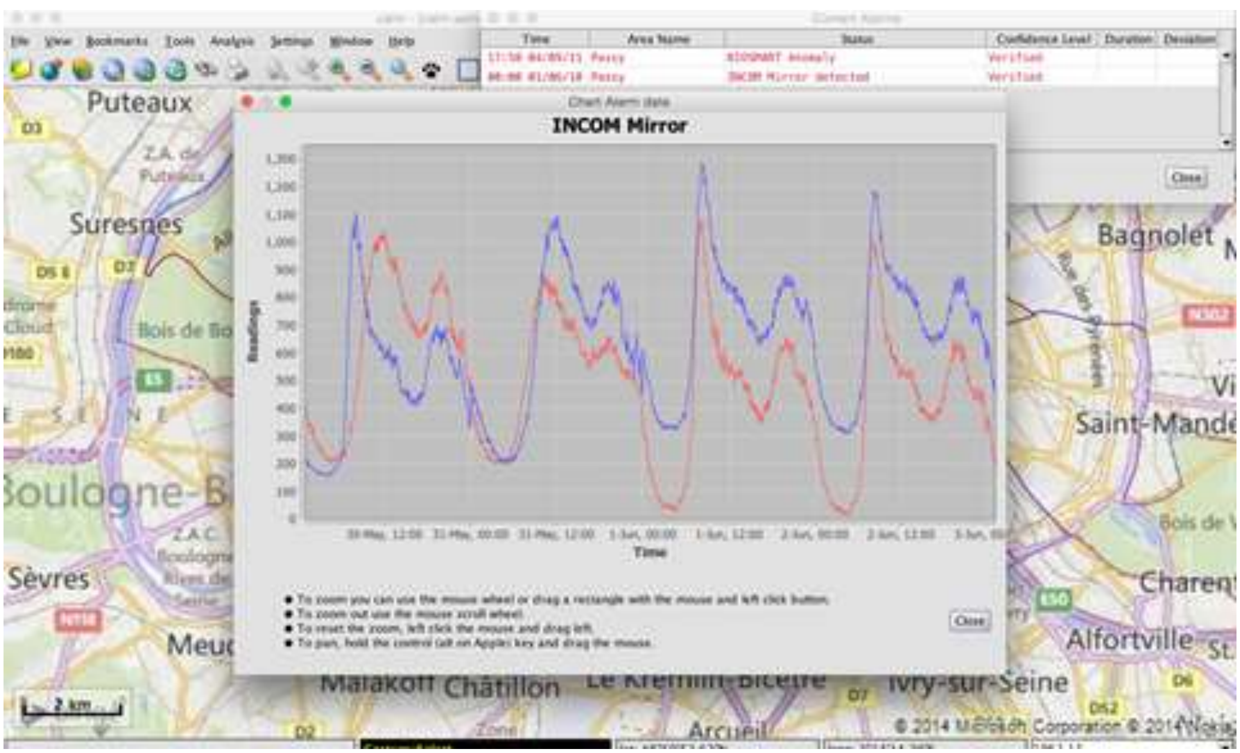


Figure 26: Visualization of the data from Detected Anomaly

III.3 Adaptation of the INCOM™ System to Preemptive Leak Detection in Gas Distribution Systems

The purpose of this project is to assess the adaptation and integration of the INCOM™ System for upgrading reliability and efficiency of the current leak detection in gas distribution system and support the system operator(s) through "intelligent" near real-time system monitoring and leak detection for preventive and proactive rather than reactive gas distribution system management.

The proposed project is focused on the technical and economic feasibility assessment of the adaptation of the INCOM™ system to the user requirements of Con Edison gas operators for preemptive leak detection in the gas distribution system. The INCOM™ control algorithms will be adapted for real time automated leak detection using system parameters monitored by Con Edison. The specifications of the system parameters monitored and Con Edison users' requirements are the critical elements for the feasibility assessment of the adaptation of the INCOM™ system to meet these requirements. They will be thoroughly discussed and identified in Phase Zero of the project with Con Edison experts along with technical and economic feasibility assessment and will provide the basis for detailed planning of the project tasks outlined below.

Scope of Project (SoP) - The project will involve the following tasks:

Task 1 – Phase Zero–Definition of Con Edison system parameters, attributes specifications, protocols, and users' requirements and feasibility assessment of the adaptation of the INCOM™ prototype system for reliable early leak detection in Gas Distribution Systems (GDS).

Task 2 – Demo-illustration of the INCOM™-GDS through offline data processing and leak anomalies detection using data provided by Con Edison to assess system performance in responding to user requirements specified by Con Edison experts.

Task 3- User assessment of INCOM™-GDS Prototype System–user assessment of the prototype system performance will be based upon the Con Edison experts' review of the outcome of task 2 and will reconfigure users' requirements for the INCOM™-GDS enterprise system integration and β prototype system development with a detailed plan for pilot deployment.

Task 4 – Phase One - INCOM™-GDS Prototype System Integration–Phase One will consist of the integration of the artificial intelligence based control algorithms identified by the team experts, the CALM's Enterprise Command and Control System of Systems (C2SOS) and its Human-Machine Interface (HMI) to automate the leak detection process and sensor health verification tools. The purpose of the INCOM™-GDS Leak Detection system is to provide utility managers a systemic enterprise platform for near real-time anomaly diagnostics and leak detection.

Task 5 – Phase Two - Pilot deployment of the INCOM™-GDS Prototype System in a selected Con Edison site. Detailed pilot deployment plan including site attributes, data management system, site specific user requirements and other operational issues will be configured with Con Edison experts at the conclusion of Phase One. This task will also involve business model for the deployment of the INCOM™-GDS in Con Edison sites, professional training and IP agreements.

III.4 Time Line and Estimated Cost – Table 2 show the timeline and estimated cost of each task.

Table 2: Timeline and Cost Estimate

Timeline and Cost Estimate																										
OBJECTIVES	**Duration (MS)**	**YEAR 1**												**YEAR 2**												**Budget ($)**
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Task 1	4																									$50K
Feasibility assessment of the prototype system for reliable early leak detection in Gas Distribution Systems																										
Task 2	8																									$200K
Demo illustration of the INCOM™ - GDS capabilities though offline data processing and leak anomalies detection using data provided by Con Edison																										
Task 3	2																									$100
User assessment of INCOM™ - GDS Prototype System and user requirements for enterprise system integration and β prototype system development with a detailed plan for pilot deployment																										
Task 4	4																									$650
INCOM™- GDS Prototype integration																										
Task 5	6																									$1M
INCOM™ - GDS pilot deployment in a selected Con Edison site																										
Total	**24**																									**$2M**

III.5 Research Team

Under the direction of Professor Ilan Juran the Research Team of the Urban Infrastructure Institute will be supported by CALM-Water Experts and the Scientists of the CEA-LIST Institute who developed, tested and implemented on a pilot-scale demonstration the INCOM™ System for leak detection in the water distribution system. The development of the INCOM™-GDS System will require effective participation of Con Edison experts in configuring the user requirements for the system, its performance measures, and, more specifically, in providing accessibility to off-line and on-line site specific data, sharing SoPs and other relevant information, sharing user assessment of the system performance, providing recommendations for the β prototype development and guidelines for planning and execution of each step including the pilot scale demonstration.

Notes:

The tasks outlined above are consecutive phases of the INCOM™-GDS β prototype development and at the completion of each task Con Edison's decision will be required for undertaking the consecutive task.

IP – NDA agreements will need to be established between the parties to further explore the adaptation of the INCOM™ System for leak detection in gas distribution system

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