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# Statistical process control based system for approximate location of pipe bursts and leaks in water distribution systems

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**Abstract**

This paper presents a novel data analysis methodology for determining the approximate location of a leak/burst within a District Metered Area (DMA). This methodology is based on Statistical Process Control (SPC) and it is encapsulated in a Leakage Location System (LLS) that automatically processes the night-time data recorded, with a one minute frequency, by the DMA's pressure loggers. The LLS was field tested and verified on a large number of real-life DMAs with both real and engineered leak/burst events (i.e., simulated by opening fire hydrants). The selected DMAs have varying sizes and different characteristics (e.g., industrial/urban/rural, pressure-managed/gravity-fed, etc.). These DMAs were monitored for a period of approximately 4 months and 132 engineered events simulating leaks/bursts ranging between 1% and 40% of the average DMAs' inflow were carried out. The results obtained illustrate that the LLS enables obtaining substantially reduced operational costs by significantly reducing the leaks/bursts search area and reducing the number of unnecessary leak/burst repairs. The results obtained also illustrate that the LLS has the potential to enable water companies to: (a) improve customer service through more proactive and informed communications and reduction of the number/duration of supply interruptions and poor pressure situations, (b) realise a wide range of sustainability and environmental type benefits by saving large amounts of water, reducing energy requirements for pumping, consumption of chemicals for water treatment and hence the carbon footprint and (c) reduce the social costs associated with the disruption of traffic and business, the reduced fire-fighting capabilities and the potential of pollutant ingress through cracks.


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## 1. Introduction

Smarter and more sustainable management of Water Distribution Systems (WDSs) is needed to achieve improved operational efficiency and customer service despite tightening budgetary constraints. The use of advanced data analytics has the major potential of enabling a shift toward the smart WDS management paradigm. The WDS data analysed is normally comprised of the data already generated by and stored into the Information and Communication Technology (ICT) systems utilised by modern water companies, such as Supervisory Control and Data Acquisition (SCADA) systems. Having said this, additional data is becoming available lately following the increase in density of coverage of pressure/flow monitoring devices.

Novel techniques utilising machine learning and advanced statistical methods have been recently developed to manage and analyse increasing numbers of data-streams aiming at enabling the detection and approximate location of leaks, bursts and other similar events [1-10]. These techniques automate mundane tasks involved in the data analysis process and enable efficiently extracting useful information that aids decision making. These techniques have several advantages over other numerical techniques such as the steady state hydraulic analysis-based [11, 12], transient analysis-based [13, 14] and negative pressure wave-based [15, 16] techniques: (a) they do not require physically based WDS models to be built, calibrated and maintained; (b) they rely on the empirical observation of the behaviour of a WDS hence do not require precise knowledge of the WDS and instrumentation parameters; (c) require pressure and/or flow measurements to be sampled much less frequently than those required for transient analysis thus saving data logger's battery life. In addition to this, it is worth mentioning that the analysis of multiple pressure/flow signals can also provide useful information about the leak/burst location. In this regard, methodologies are also been recently developed to identify the optimal sensor placement to capture the leak/burst effect no matter where in a DMA the leak/burst occurs [17-19]. These methodologies have the potential to aid other techniques to not only enable performing approximate leak/burst location within a DMA but also to allow obtaining more reliable detection results.

In this paper a novel Statistical Process Control (SPC) [20, 21] based methodology for determining the approximate location of a leak/burst within a DMA is presented, together with the results of its real-life testing and verification in a large UK water company. The novel methodology presented here is encapsulated in a Leakage Location System (LLS) that automatically processes the night-time pressure data (e.g., data recorded between 03:00 a.m. and 04:00 a.m. - while the network is "calmer") by the sensors deployed in oversampled DMAs. The methodology testing involved deploying 75 extra pressure sensors (i.e., in addition to the existing sensors measuring pressure at the various DMAs' Critical Monitoring Points – CMPs) in 17 DMAs (i.e., 5 extra sensors per DMA, on average) and carrying out 132 Engineered Events (EEs) whereby leaks/bursts were simulated by opening fire hydrants.

## 2. Methodology

Nowadays, the UK DMAs are usually observed by using: (i) flow and (in some cases) pressure sensors located at the DMA entry and any water import/export point and (ii) a pressure sensor located at the CMP in the DMA. The methodology described here assumes the increased availability of distributed sensors in a DMA. It synergistically analyses the one minute nigh-time data coming from all the pressure sensors installed in a DMA and makes use of the SPC Control Charts [20, 21]. A Control Chart is a graphical representation of certain descriptive statistics used for specific quantitative measurements of a process.

In the LLS's methodology, Control Charts are used for comparing, on a daily basis, several descriptive statistics computed by using the pressure readings for the current night with the corresponding descriptive statistics computed for the previous $n$ nights (note that n = 14 nights is used in the case study here) aiming at identifying unexpected variations that can be occurring due to the presence of a leak/bust. More specifically, for each sensor deployed in a particular DMA, data for the current night (recorded during a user-specified time window; e.g., between 03:00 a.m. and 04:00 a.m.) together with relevant data for the previous $n$ nights are retrieved first from the database containing the historical pressure time-series. Three individual scores (i.e., values between 0 and 100), which indicate how different the current night-time data are from the data observed during the previous $n$ nights, are then computed using