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A Response Methodology for Reducing Impacts of Failure Events in Water Distribution Networks

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Abstract

This paper presents a methodology for developing efficient and effective operational, short time response to a water distribution system (WDS) pipe failure event (e.g. pipe burst). In general, management and response to failures in WDS are performed by isolating the failure, estimating the impacts of isolation on the customers and recovering the affected part of the system by restoring the flows and pressures to normal conditions. The isolation is typically achieved by manipulating the nearby on/off valves whilst a hydraulic simulator (such one used in EPANET2.0) is used for estimating impacts. The recovery, which is the focus of this work, involves selecting a combination of suitable operational interventions from a number of possible choices to bring the water into the isolated area and restore normal flow conditions. The options considered here include valve manipulations, changing the pressure reducing valve's (PRV) outlet pressure and installation and use of a temporary overland bypasses from a nearby hydrant(s). The optimal mix of interventions is identified by using a multi-objective optimization algorithm integrated with the pressure driven hydraulic solver. The optimization is driven by the minimization of the negative impact on the customers and minimization of the corresponding number of operational intervention activities (which acts as a surrogate for operational costs). The above methodology has been applied to a real world water distribution network of C-Town. The results obtained demonstrate the effectiveness of the proposed methodology in identifying the Pareto optimal intervention strategies that could be ultimately presented to the control room operator for making a suitable decision.

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Keywords: Water distribution network; pipe failure; response; isolation; intervention; recovery; multi-objective optimization; hydraulic solver

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1. Introduction

Water distribution networks (WDNs) are considered as one of the essential urban infrastructures. The primary function of any WDN is to supply water to consumers with sufficient pressure, quantity and quality [1, 2, 3]. Even though WDNs tend to perform satisfactorily most of the time (i.e., under the normal operating conditions), interruptions to water service and pressure-deficient condition are not uncommon events [4, 5, 6]. These failure conditions could arise as a result of either planned interruptions, such as periodical maintenance and system rehabilitation, or due to unexpected events, such as pipe bursts, pump failure condition and equipment failures [7, 8, 9]. Such abnormal occurrences can cause inconvenient disruptions to consumers and utilities [10, 11]. When the pressure is lower than the minimum operating requirement, the required demand to the nearby properties cannot be delivered. This in turn can trigger a partial reduction in water delivered to the customers who live in a wider area [1, 12].

For all types of failure (especially unplanned one), effective management and short-time response are required to prevent or alleviate the negative impacts on customers and environment. In nowadays water systems (e.g., smart water system), good failure management comprises three main stages [13, 9]: (1) a detection system, where data are collected from monitoring equipment (i.e., sensors, SCADA) and historical flow and pressure data analysed with to visualize and detect the source of failure; (2) a real time alarm system; and (3) the intervention and decision support system, which involves estimating negative impacts and introducing intervention plans to restore service to normal conditions.

Even with the recent progress in monitoring and communication technologies, the management of WDN under failure condition is still a difficult task in terms of finding the exact location of the failure and dealing in near real-time with their negative impacts on the system. Most research in this field thus far, has been limited mainly to strategic reliability and risk analysis [1, 11, 14]. However, no studies have yet focused on the elaboration of a short-time response strategy defining the field operations after a failure event has been detected and isolated aimed at protecting consumers from the supply interruption and low-pressure consequences. Hence, in this work, a new effective response methodology for reducing impacts under failure conditions in near-real-time is presented. The main elements of the methodology are described with a focus on the recovery and intervention management stages that form the core of the new framework.

2. Methodology

A response to a failure event, (e.g., pipe burst or equipment failure) can be conducted through three basic intervention stages, once the failure is detected and located. In the first stage, the damaged pipe (or equipment) should be isolated from the rest of the network by closing nearby valves. In the second stage, the consequences of a failure event (e.g., water supply interruption, low pressure, water discoloration, etc.) are identified and estimated. This could be conducted by using hydraulic solvers. In the final stage, recovery is introduced through minimizing or preventing the failure impacts. This may require changing the original topology of the WDN by finding new temporary routes to supply water to the isolated area and/or by modifying the settings of relevant devices (e.g., settings of pressure reducing valves) to increase the pressure in the area surrounding the isolated part of the network.

2.1 Failure isolation

In this stage, the potential failure event (FL_j, where j is the index of failure element) is isolated from the network by closing nearby valves, i.e., to perform maintenance process later. Jun & Loganathan [15] defined isolating part(s) of the network as a segment. A segment often contains more elements (e.g., nodes and pipes), not only the damaged one. For example, a single segment needs to have two valves at both upstream and downstream ends of the failed element, which rarely exists in real WDNs. As a result of segment isolation, other portions of the network may get disconnected unintentionally (unintended segment) from the water sources. The methodology developed by [8] is applied to identify isolated segments for a potential pipe failure in the isolation stage. At the same time, the identification of unintentional segment(s) is performed automatically by Giustolisi & Savic [8] method with some